School of Physiotherapy and Exercise Science

Mobile Touch Screen Device Use and Musculoskeletal Symptoms in Adolescents

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics: The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research studies received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RDHS-77-15 and RDHS-100-15.

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Abstract

Introduction

The use of mobile touch screen devices (MTSDs), which are typically smartphones and tablets, has increased rapidly in recent years and is especially high among adolescents today. This has raised concerns about the associations of MTSD use with musculoskeletal and visual health outcomes. Such outcomes could adversely affect adolescents' growth, development and health. However, research examining the impact of MTSD use on musculoskeletal and visual health is currently limited, especially among adolescents. Existing studies on MTSD use and musculoskeletal symptoms are mostly of cross-sectional design, using convenience sampling and conducted with adults. The temporal associations of MTSD use and musculoskeletal and visual health in adolescents are thus still largely unknown. Moreover, the majority of studies to date on MTSD use have focused on only duration of use, with simple exposure measures. Therefore, the current understanding of the exposures and patterns of use by adolescents is limited, as well as a lack of understanding of how adolescents and their parents perceive adolescents' MTSD use.

Aims

The aims of this thesis were to:

1) systematically review current literature on musculoskeletal symptoms and exposures associated with the use of MTSDs

2) explore perspectives from adolescents and parents on:
   i. patterns of MTSD use by adolescents including routines, bout length, types of activities and multitasking
   ii. rules, restrictions and concerns from parents/caregivers on adolescents' MTSD use
   iii. discomfort and postures associated with MTSD use

3) examine among a representative sample of adolescents the:
   i. amount and patterns of contemporary technology use (i.e. bout length, types of activities, multitasking), particularly of MTSDs
   ii. cross-sectional associations of MTSD use with musculoskeletal symptoms and visual health outcomes (i.e. visual symptoms, myopia)
   iii. prospective longitudinal associations of:
      - MTSD use, including patterns of use, with musculoskeletal symptoms
      - MTSD use with visual health outcomes

Methods

For the systematic review, electronic databases were searched for articles using keywords describing MTSDs, musculoskeletal symptoms and musculoskeletal exposures (e.g. postures, discomfort). Articles were screened, relevant data extracted and methodological quality of included studies was assessed. Due to heterogeneity in the studies, a structured narrative synthesis of the findings was undertaken.

In a qualitative study, semi-structured interviews were conducted with adolescents (n=36; 11-18 years) and their parents/caregivers (n=28) in Singapore to gain their perspectives on adolescents' MTSD use. Question prompts covered MTSD use amount and patterns of use, control measures and concerns. Interviews were recorded and transcribed. Coding of transcripts and thematic analysis were carried out using NVivo 11.

The third study was a prospective quantitative study consisting of a survey at baseline and at one-year follow-up. At baseline, a representative sample of 1884 adolescents (50% girls) from four school grade levels - primary 5, secondary 1, secondary 3 and junior college 1 (10-19 years) were recruited from 13 schools in Singapore, via stratified sampling based on socioeconomic and academic indicators. At follow-up, there was a high retention rate (89.8%) with a total sample of 1691 adolescents (51% girls). The same questionnaire was completed online in class at both baseline and follow-up, and contained questions relating to demographics of participants, use exposures including patterns of use for MTSDs as well as other screen devices, musculoskeletal symptoms at various body regions, visual symptoms, myopia, and covariates of mental health and physical activity.

The sample and technology use exposures and patterns of use, especially of MTSDs, were described, stratified by gender and school levels. Multivariable logistic regressions were carried out to examine the cross-sectional and longitudinal relationships between variables (MTSD use and patterns of use and musculoskeletal symptoms and visual health outcomes). These regressions were adjusted for potential confounders of gender, school level, mental health, physical activity and total technology use of the other devices using STATA 14.

Results

The systematic review found limited evidence for associations between MTSD use, and various aspects of its use (i.e. amount of usage, features, tasks and positions), with musculoskeletal symptoms and exposures. This was considered to be at least partly due to mainly low quality experimental and case-control laboratory studies, with few cross-sectional and no longitudinal epidemiological studies.

The qualitative study provided useful insights and rich information on the patterns and influences of adolescents' MTSD use, as well as discomfort experienced and postures adopted by adolescents during use. Almost all the adolescents reported using and/or owning a smartphone, while only some used a tablet. Many adolescents and their parents perceived adolescents' MTSD use to be high, frequent and ubiquitous. Use was integrated into their daily routines, with frequent checking of device and multitasking with multiple devices, especially while doing homework. Several functional, personal and external influences of MTSD use were reported which either facilitated or limited their use. Discomfort, most commonly at neck/shoulder, was often reported by adolescents after or whilst using MTSDs, though it was generally perceived as of only mild intensity and non-disruptive to other activities of daily living. A variety of mostly non-neutral postures adopted during MTSD use at various settings at home were demonstrated.

The quantitative survey provided detailed information on MTSD use exposures by adolescents, including patterns of use and associations with musculoskeletal symptoms and visual health outcomes. At baseline, high prevalence and amount of technology and MTSD use were reported by adolescents. Smartphone use dominated among the devices, with the highest mean (SD) daily use (264 (243) mins/day), as well as longest bout length of use and highest daily use for each type of activity (i.e. homework, social activities, games, watching shows/videos and general use). Multitasking with multiple devices was common, with smartphone having the highest percentage of frequent multitasking.

Gender and school level differences were observed in adolescents' MTSD use. Girls had significantly higher smartphone ownership and daily use duration than boys. Girls also had greater use of smartphones for homework, social activities and videos than boys across all the school levels, while boys had greater use across the devices for games. Smartphone use and ownership increased with increasing school levels (school levels used as a proxy for ages). However, smartphone daily use was the highest at around mid-adolescence (secondary 3), while tablet daily use was fairly similar among the school levels, with a reduction of both smartphone and tablet use at late adolescence (junior college 1).

Musculoskeletal symptoms were commonly reported, with the highest prevalence of musculoskeletal symptoms in the last month at neck/shoulder (42%). Regarding their cross-sectional associations with MTSD use at baseline, greater hours/day of smartphone use, but not tablet use, was significantly associated with higher prevalence of musculoskeletal symptoms after adjusting for confounders. At one-year follow-up, prospective associations were found between baseline use of smartphone/tablet and follow-up neck/shoulder, low back and/or arms symptoms (OR 1.33, 95%CI 1.04;1.71 to OR 1.86, 1.10;3.14). Baseline patterns of smartphone/tablet use (bout length of ≥1 hour, participating in certain types of activities and/or use of multitasking) were also associated with follow-up musculoskeletal symptoms. However, there were no dose-response relationships between the amount of MTSD use duration and musculoskeletal symptoms.

Regarding visual health, cross-sectionally, greater hours/day of smartphone use was significantly associated with higher number of visual symptoms, but lower prevalence of myopia after adjusting for confounders. However, at follow-up, no prospective associations were found between smartphone or tablet use and visual outcomes.

Conclusion

In conclusion, findings from this thesis have provided a better understanding of MTSD use exposures including patterns of use by adolescents, and their associations with musculoskeletal symptoms and visual health. MTSD use is high among adolescents and has become an integral part of adolescents' everyday lives. Smartphone use was the most prevalent with its use dominating among all the devices. Musculoskeletal symptoms were also commonly reported among adolescents. Moreover, longitudinal analysis revealed that MTSD use, though not the amount of use, and certain patterns of use appear to pose a prospective risk for musculoskeletal symptoms. MTSD exposure is therefore a cause for concern and wise use of MTSDs by adolescents is warranted. Information gained in this thesis will inform guidelines and interventions for wise use of MTSDs to assist researchers, policy makers, educators, parents and adolescents themselves. This will also help to maximize benefits of adolescents' use for learning and education while minimizing any potential adverse impact on their health and development.

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When I started this PhD journey, it was a leap of faith; I did not foresee the immensity of the obstacles and challenges that I would face, as well as the commitment and sacrifices required. Looking back, it felt like I was on a roller coaster ride – experiencing thrills of several ups and downs and being unsure of when the ride will end.

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List of Publications and Presentations

Aspects of this thesis have been published in journal articles and presented at international conferences:

Toh SH, Coenen P, Howie EK, Straker LM (2017) The associations of mobile touch screen device use with musculoskeletal symptoms and exposures: A systematic review. *PloS One* 12: e0181220.

Toh SH, Howie EK, Coenen P, Straker LM (2019) "From the moment I wake up I will use it...every day, very hour": A qualitative study on the patterns of adolescents' mobile touch screen device use from adolescent and parent perspectives. *BMC Pediatrics* 19: 30.

Toh SH, Coenen P, Howie EK, Mukherjee S, Mackey DA, Straker LM (2019) Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents. *Ergonomics* 62: 778-793.

Toh SH, Howie EK, Coenen P, Straker LM. What do teenagers and their parents think about mobile touch screen device use? 20th Congress International Ergonomics Association (IEA) Symposium - Ergonomics challenges in the rapidly evolving digital world of children internationally. August 2018. Florence, Italy

Toh SH, Coenen P, Howie EK, Mukherjee S, Straker LM. The associations between mobile touch screen device use and musculoskeletal and visual symptoms: A cross-sectional study of adolescents. 20th Congress International Ergonomics Association (IEA). August 2018. Florence, Italy

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List of Abbreviations

MTSD	mobile touch screen device
PAQ-A	Physical Activity Questionnaire for Adolescents
DASS	Depression, Anxiety and Stress Scale
OR	odds ratio
SD	standard deviation

Chapter 1 Introduction

1.1 Background to the study

Technology use has increased rapidly among children and adolescents recently, especially the use of mobile touch screen devices (MTSDs), such that children of the early 21st century have been described as the “touch screen generation” (Rosin 2013). MTSDs refer to electronic devices that are portable and allow interaction with the user via a touch screen interface, which are typically smartphones and tablet computers. Recent studies have shown high overall electronic screen technology use (which encompasses various electronic screen devices such as television, laptop or desktop computers, game consoles and MTSDs) by adolescents. In this thesis, the period of adolescence refers to between 10 and 19 years old, as according to World Health Organization (Goodburn EA and Ross DA 1995), while early adolescence refers to between 10 and 14 years and late adolescence to between 15 and 19 years.

Large-scale surveys in USA have shown that adolescents aged 13 to 18 years old had an average of 7 hours per day of total screen technology use (not including use for school and homework) (Rideout 2015), while adolescents in UK aged 12 to 15 years old spent close to 21 hours per week in total on the internet (Ofcom 2017). In particular, the use of MTSDs is especially high among adolescents today (Australian Communications and Media Authority 2016, Ofcom 2017, Rideout 2015), which has raised concerns about the negative impact this may have on adolescents’ growth, development and health (George and Odgers 2015, Kwok et al 2017, Yang et al 2017).

Several nationwide surveys have reported a high prevalence of MTSD use and ownership, for example over 80% of adolescents aged over 12 years old or more in USA, UK and Australia used and/or owned a smartphone (Australian Communications and Media Authority 2016, Ofcom 2017, Rideout 2015). Use of tablets has also risen considerably, from 42% in 2013 to 78% in 2017 among children aged 5-15 years old in UK (Ofcom 2017). The use of MTSDs appears to have become an integral part of their everyday lives, whether for school, leisure or personal daily functions. Reasons reported for the high MTSD use by adolescents have included increased ownership and accessibility in households (Australian Communications and Media Authority 2010, Ofcom 2014), the multiple functions and activities offered (e.g. social networking, games, video watching and internet browsing), portability of MTSDs, as well as increased availability in schools and use in education to aid students in their learning (Clayton and Murphy 2016, Norris et al 2011, Pegrum et al 2013).

Physical, mental, social and educational benefits of MTSD use have been articulated, such as increasing physical activity or weight loss through use of MTSDs to deliver health information or interventions (Fanning et al 2012, Khokhar et al 2014), reducing depression and anxiety via self-therapy through applications or messaging (George et al 2017), building family time and connectedness (Livingstone et al 2018, Sarah et al 2014), as well as improving ease of communication, motivations in learning and learning outcomes (Haßler et al 2016, Hwang and Wu 2014). However, on the other hand, several studies have also demonstrated associations with adverse outcomes. Inappropriate use of these devices had been associated with negative physical outcomes, such as increased sedentary time and reduced physical activity which may in turn pose a risk for obesity, poorer cardiovascular fitness (Chahal et al 2013, Kenney and Gortmaker 2017) and poor quality of sleep (Carter et al 2016). Negative mental health outcomes such as depression or suicidal risk (Jean et al 2017), social outcomes such as poor communication skills or antisocial behaviour, and cognitive outcomes such as reduced attention span or poorer cognitive performance have been found to be associated with MTSD use (George and Odgers 2015, Lissak 2018). There are also growing concerns that MTSD use can pose a risk for musculoskeletal symptoms, and poor visual health outcomes such as visual symptoms and myopia; yet research examining the impact of MTSD use on musculoskeletal and visual health is currently limited (Binboğa and Korhan 2014, Ramamurthy et al 2015a, Toh et al 2017, Xie et al 2017).

An extensive body of research has been conducted on the use of traditional electronic devices, such as desktop/laptop computers or electronic games in both adults and adolescents, suggesting associations with musculoskeletal symptoms (Green 2008, Korpinen and Paakkonen 2011, Straker et al 2010). Systematic reviews conducted have found evidence for prolonged hours of computer work in adults posing a risk for musculoskeletal symptoms and disorders (Griffiths et al 2007, Village et al 2005). Several survey studies have also demonstrated increased prevalence of musculoskeletal symptoms in college students and young adults associated with computer use (Dockrell et al 2015, Ekşioğlu 2017, Korpinen and Paakkonen 2011). Among adolescents, higher computer use and electronic game use were also found to be associated with musculoskeletal symptoms (Silva et al 2016, Zapata et al 2006). These associations may be explained by the increased biomechanical strain due to repetitive movements and non-neutral postures sustained during computer use (Binboğa and Korhan 2014, Brink et al 2014), thus providing support for concerns about potential risk of symptoms from MTSD use.

However, prior laboratory studies have demonstrated that MTSDs present different musculoskeletal exposures than the traditional devices. For example, greater non-neutral postures and different muscle activity levels at head/neck (Straker et al 2008c, Yu et al 2018), neck/shoulder and distal upper extremities (e.g. wrist or hand/fingers) (Hong et al 2013, Kargar et al 2018, Kietrys et al 2015, Xie et al 2016) were observed during use of MTSDs compared to desktop/laptop, physical keypad phones or keyboards. These differences in exposures might be due to portability of MTSDs, different device placement, and the use of a touch screen interface when using MTSDs. MTSDs may thus be associated with different risks for musculoskeletal symptoms than traditional screen devices.

Despite high use and concerns on musculoskeletal outcomes, evidence based detailed guidelines on wise use of MTSDs in adolescents, especially on musculoskeletal health, are lacking (Binboğa and Korhan 2014, Yang et al. 2017). For instance, current guidelines on screen technology use by the American Academy of Pediatrics have mainly focused on the impact of MTSD use on social, mental, cognitive development, sleep and obesity, while sufficient attention was not given to the potential impact on musculoskeletal health (Straker et al 2016, Straker et al 2018b). Given that musculoskeletal symptoms can lead to undesirable consequences in adolescents, such as school absenteeism, activity limitations, reduced physical activity (Kamper and Williams 2017, O'Sullivan et al 2012) or development of chronic pain (El-Metwally et al 2004), it is important to provide guidance on appropriate use of MTSDs to minimize any potential negative impact on their musculoskeletal health (Kwok et al. 2017).

Additionally, there is a lack of evidence to inform guidelines for wise MTSD use; research examining associations between MTSD use and musculoskeletal symptoms, especially among adolescents, is limited. There is no systematic review to date on MTSDs and musculoskeletal symptoms. In order to appraise the evidence available on MTSD use and musculoskeletal symptoms and identify areas for further research, there is a need to systematically review information on musculoskeletal symptoms and exposures associated with the use of MTSDs in the current literature. Moreover, current research on MTSD use and musculoskeletal symptoms consists mostly of cross-sectional epidemiological studies and laboratory studies investigating musculoskeletal exposures of MTSD use. In cross-sectional studies, it is difficult to determine the cause and effect as exposure to the risk factor and outcome variables are simultaneously evaluated (Sedgwick 2014). There are no longitudinal studies known to date on this issue, hence the temporal and causal relationships between MTSD use and musculoskeletal symptoms are not known.

In addition, most of the studies on MTSD use and musculoskeletal symptoms and exposures have been conducted with adults (Xie et al. 2017), which may not apply to adolescents who may have different physical responses to MTSD use. The greater flexibility and different muscle, bone and ligamentous strengths in children than adults (Huelke 1998), may elicit different biomechanical responses during MTSD use. Additionally, adolescents may also have different use and preferences of activity on MTSDs. For example, recent consumer studies found that adolescents spent more time online on smartphones (Verto Watch 2018) and used more text messaging compared to adults (Pew Research Center 2010).

Other limitations of current research on MTSD use and musculoskeletal symptoms also include convenience sampling and a focus on Western populations. Many of the reported studies adopted convenience sampling, which can introduce a selection bias and recruited participants may not have been representative of the respective population (Tyrer and Heyman 2016). Moreover, the majority of epidemiological studies to date have been conducted in Western countries, such as Australia, Europe and USA (Haug et al 2015, Houghton et al 2015, Mascheroni and Cuman 2014, Ofcom 2017, Pew Research Center 2018, Rideout 2015, Torsheim et al 2010), while studies in Asian countries have only evolved recently (Kwok et al. 2017, Shan et al 2013, Woo et al 2016). MTSD use patterns by adolescents in Asian countries may be different due to cultural or societal differences (Jackson et al 2008, Li and Kirkup 2007). In a global survey of multiple nations, the extent of societal technology use in some of the more developed Asian countries was even greater than some Western countries (World Economic Forum 2016). Different cultures may thus result in different exposures and patterns of MTSD use.

In order to understand the associations of MTSD use with outcomes including musculoskeletal and visual symptoms, there is a need for good evidence of MTSD use exposures and patterns of use. However, current understanding of MTSD exposures and patterns of use by adolescents is limited. Studies to date on MTSD use measurement have mostly focused on duration of use, with simple exposure measures. Prior studies generally measured self-reported use by collapsing hours of use together in a few broad categories and/or did not capture short duration of less than an hour of use. For example, in some of the studies, the questionnaire answer options for MTSD daily use duration only had "more than three or four hours" listed as their maximum or "less than one hour" listed as their minimum (Kim and Kim 2015, Shan et al. 2013, Yang et al. 2017). Given that MTSD use per day by adolescents can be much longer or shorter than one and three hours (Rideout 2015), results of MTSD use duration might therefore have been inaccurate using these methods.

There are also limited studies to date examining patterns of MTSD use. Patterns of computer use, such as bout use duration (Menéndez et al 2008) and types of activities (Straker et al 2013, Torsheim et al. 2010) have been found to pose different risks for musculoskeletal symptoms. A recent review has also found that the purpose of use may be important, with gaming and texting on mobile handheld devices identified as risk factors for musculoskeletal symptoms (Xie et al. 2017). Additionally, the prevalence of multitasking during use of MTSDs has increased among adolescents, especially with the portability of MTSDs (Cain et al 2016). Multitasking refers to engaging with multiple devices at the same time or quickly alternating between them, e.g. texting on a smartphone while surfing the internet on a computer (Rideout et al 2010). However, the nature of multitasking by adolescents and how it may impact on musculoskeletal symptoms are unknown. Existing findings suggest that patterns of MTSD use, such as bout length, types of activities and multitasking may influence the risk for musculoskeletal symptoms, but the nature of such use patterns and their impact on musculoskeletal health are still not exactly known.

With the high portability of MTSDs and use in non-desk settings, unlike desktop computers, a variety of postures may be adopted by adolescents when using MTSDs. However, the types and influences of postures adopted during MTSD use by adolescents are still not well understood. Some epidemiological and laboratory studies have suggested non-neutral postures during MTSD use to pose a risk for musculoskeletal symptoms (Chiang and Liu 2016, Lee et al 2018b, Straker et al 2009, Werth and Babski-Reeves 2014, Yu et al. 2018). However, these studies mostly involved adults and tended to focus on traditional workstations or constrained postures during MTSD use (e.g. standing, sitting with or without back support), and ignored that the mobility of MTSD allows use in varied settings (e.g. sofa, bed) and postures (e.g. side-lying, prone, supine, reclined lying). The musculoskeletal implications of MTSD use in varied postures are thus potentially different from desktop computer use, which is in more constrained postures and can pose different risks for musculoskeletal symptoms.

Moreover, there is also a lack of qualitative information on adolescents' MTSD use as current research consists mostly of quantitative studies (e.g. epidemiological or laboratory studies) (Rideout 2016). Qualitative studies are valuable as they allow deeper probing into relevant topics and provide rich data that are not able to be captured via quantitative methods (Rich and Ginsburg 1999). Adolescents' and parents' perspectives on the patterns of use, rules or restrictions implemented, concerns of use, as well as discomfort experienced (if any) and the common postures adopted, would thus be useful in providing insights on adolescents' MTSD use, which quantitative survey research is not able to provide (Rideout 2016). Perspectives from parents on adolescents' MTSD use can also help to triangulate data obtained from adolescents (Carter et al 2014).

Lastly, there is also a lack of consideration in current research of the potential impact of MTSD use on adolescents' visual health and the interaction of visual and musculoskeletal symptoms. Although the main focus of this thesis is on the impact of MTSD use on musculoskeletal health, it is also important to examine visual health outcomes. For example, visual symptoms and myopia among adolescents, as they might be associated with musculoskeletal symptoms. This is suggested by previous studies showing increased visual stress or demands during computer use being related to increased risk for musculoskeletal symptoms (Wiholm et al 2007, Zetterberg et al 2017). The potential negative impact of increasing MTSD use on adolescents' visual health is also an area of concern for many parents, especially in the Asian countries where there is a high prevalence of myopia (Ramamurthy et al. 2015a). Prior studies have shown that computer use posed a risk for visual symptoms e.g. eye strain, dry eyes or watering of eyes (Gowrisankaran et al 2015), and near-work activities posed a risk for myopia (Huang et al 2015), suggesting that MTSD use may also pose a risk for visual outcomes as it also involves screen use and near-work activities. However, current research on MTSD use and such visual health outcomes among adolescents is limited. There is also a lack of longitudinal studies which are important for determining the temporal relationships between visual health outcomes and MTSD use in adolescents.

There is therefore a need to address these limitations of current research on MTSD use and musculoskeletal symptoms in adolescents, to inform guidelines for wise use and other strategies to maximize the benefits from MTSD use while minimizing potential negative impacts on adolescents' health.

1.2 Objectives of Thesis

Given the increasing prevalence of MTSD use among adolescents, and aforementioned gaps in the current literature on MTSD use and musculoskeletal symptoms, the objectives of this thesis were therefore to:

1) systematically review current literature on musculoskeletal symptoms and exposures associated with the use of MTSDs

2) explore perspectives from adolescents and parents on:

    i. patterns of MTSD use by adolescents including routines, breaks or bout length, types of activities and multitasking
    ii. rules, restrictions and concerns from parents/caregivers on adolescents' MTSD use
    iii. postures and discomfort associated with MTSD use

3) examine among a nationally representative group of adolescents in Singapore the:

    i. amount and patterns of contemporary technology use (i.e. bout length, types of activities, multitasking), particularly MTSDs

    ii. cross-sectional associations of MTSD use with musculoskeletal symptoms and visual health outcomes (i.e. visual symptoms, myopia)

    iii. prospective longitudinal associations of:

        - MTSD use, including patterns of use (i.e. bout length, types of activities, multitasking) with musculoskeletal symptoms
        - MTSD use with visual health outcomes (i.e. visual symptoms, myopia).

1.3 Thesis organization and structure

To address the objectives listed, systematic review, qualitative and prospective quantitative studies were conducted to examine mobile touch screen device (MTSD) use and musculoskeletal symptoms and visual health outcomes in adolescents. These studies will be elaborated in the following chapters in this thesis.

A review of relevant current literature is discussed in Chapter 2 which is divided into two sections, with section 2.1 covering a systematic review of the literature on musculoskeletal symptoms and exposures associated with the use of MTSDs (inclusive of adults), and section 2.2 covering the use of MTSDs and their associations with musculoskeletal symptoms and visual health outcomes, specifically in adolescents. The systematic review in Section 2.1 has been published and is presented verbatim.

Chapter 3 describes a qualitative study on the patterns of MTSD use by adolescents, including routines, bout length of use, types of activities and multitasking, as well as the rules, restrictions and concerns from parents/caregivers, as perceived by adolescents and parents. Semi-structured interviews were conducted with adolescents and their parents in this study. The methods, results (consisting of rich descriptions of adolescents' MTSD use) and discussion of results are covered in this chapter. Findings of this study have also been published and are presented verbatim in this chapter.

Chapter 4 describes additional investigation in the qualitative study mentioned in Chapter 3; however, this chapter presents and discusses findings concerning discomfort experienced (if any) and postures adopted during MTSD use by adolescents, as perceived by adolescents and their parents. The semi-structured interviews as well as photographs of postures adopted during MTSD use are reported in this chapter.

Chapters 5 and 6 report a prospective quantitative study comprising of surveys conducted at baseline and at one-year follow-up, with a nationally representative sample of adolescents (aged 10 to 19 years old) recruited via stratified sampling. Chapter 5 describes and discusses the baseline cross-sectional study data and its findings on contemporary technology and MTSD use by adolescents, including patterns of use (i.e. bout length, types of activities, multitasking), and their cross-sectional associations with musculoskeletal symptoms and visual health outcomes (i.e. visual symptoms, myopia). Descriptive statistics of musculoskeletal symptoms and visual outcomes among the adolescents are also provided. In addition, gender and school level differences in MTSD use exposures and musculoskeletal and visual outcomes are also presented. This cross-sectional baseline study has also been published and is presented verbatim in this chapter.

Chapter 6 describes the follow-up study, where the prospective associations between MTSD use and musculoskeletal symptoms and visual health outcomes are reported and discussed. Prospective associations between patterns of MTSD use and musculoskeletal symptoms are also presented in this chapter. This prospective study has been submitted to a journal and is currently under review.

Chapter 7 provides an overall discussion of the findings from these studies. Findings are summarised and discussed in relation to other existing studies. The significance of the findings on prevalence and amount of MTSD use, patterns of MTSD use and associations between MTSD use and musculoskeletal symptoms and visual health outcomes in adolescents are discussed. Additionally, the strengths and limitations of these studies, implications for wise use of MTSDs by adolescents, and future research directions on MTSD use exposures and associated musculoskeletal and visual outcomes in adolescents are also discussed.

Lastly, Chapter 8 provides a concise conclusion to the thesis.

Chapter 2 Literature review

This Chapter is presented in two parts, with section 2.1 covering a systematic review of the literature on musculoskeletal symptoms and exposures associated with the use of MTSDs inclusive of adults, and section 2.2 covering the use of MTSDs and their associations with musculoskeletal symptoms and visual health outcomes in adolescents. Section 2.1 has been published and is presented verbatim as below. Full reference of paper:

Toh SH, Coenen P, Howie EK, Straker LM (2017) The associations of mobile touch screen device use with musculoskeletal symptoms and exposures: A systematic review. *PloS One* 12: e0181220

2.1 Mobile touch screen device (MTSD) use and musculoskeletal symptoms and exposures - systematic review

2.1.1 Introduction

Mobile touch screen devices (MTSDs) are portable devices with a touch screen interface that can be used with stylus or finger touch, such as smartphones and tablet computers. There has been an increase in ownership and usage of MTSDs among adults and children over the last decade (Pew Research Center 2016b, Rideout et al. 2010). Recent figures from 2016 showed that the majority of teenagers aged 14 to 18 years in the USA (87%) (eMarketer 2016) and 12 to 15 years in the UK (79%) reported owning a smartphone (Ofcom 2016). Smartphone ownership is even higher among adults, with 92% and 95% of the adults aged 18 to 34 years in the USA and Australia respectively reported to own a smartphone (Pew Research Center 2016b). Another recent survey in the USA showed that in 2015 adult users spent approximately three hours daily (excluding voice activities) on their mobile devices, which was double the duration spent in 2012 (eMarketer 2015). The substantial ownership and usage of MTSDs is expected to continue to increase in the years ahead (eMarketer 2015), and is therefore an important societal change.

Apart from potential social, mental and behavioural effects such as negative impacts on social relationships, depression and sleep quality (Demirci et al 2015, Seo et al 2016), the increased MTSD use has also raised concerns for potential physical health effects including musculoskeletal symptoms (Berolo et al 2011, Sharan et al 2014). The use of more traditional electronic devices, i.e. desktop and laptop computers, has been associated with musculoskeletal symptoms in several epidemiological studies (Hakala et al 2006, Harris et al 2015b, Siu et al 2009, Torsheim et al. 2010). Laboratory research has demonstrated that musculoskeletal exposures including awkward postures, lack of posture variation, and altered muscle activity are associated with computer use and these may explain the development of musculoskeletal symptoms due to the use of traditional devices (Straker et al 2008a, Straker et al. 2010). These indications of changes in postures and muscle activity thus provide support for concerns about the potential risk of symptoms from MTSD use.

However, the use of MTSDs is different from traditional electronic devices such as desktop or laptop computers or physical keypad phones, due to their portability and control interaction via a touch screen interface rather than via a keyboard and/or mouse. MTSDs may therefore be associated with different musculoskeletal exposures (e.g. postures or muscle activity), which may create different risks for musculoskeletal symptoms than traditional devices. Due to their portability, MTSDs may be used in various non-traditional workstations and postures (e.g. on a sofa or while using public transport), which may be associated with different musculoskeletal exposures than while using a device whilst seated at a desk (Werth and Babski-Reeves 2014). Due to their designs that do not allow wrist and fingers to rest on the screen surface, the use of a touch screen may incur further exposures to awkward neck/shoulder postures and distal upper extremity muscles (Kim et al 2014a, Shin and Zhu 2011). As a result of this, it has been reported that tablet use may cause higher musculoskeletal stresses on the neck compared to desktop computer use (Straker et al. 2008c), and higher stress on the wrist during smartphone use compared to when using a keypad phone (Kietrys et al. 2015). Moreover, higher activity in the neck/shoulder muscles (Straker et al. 2008c, Xie et al. 2016), and lower activity of the wrist extensor muscles (Hong et al. 2013, Kietrys et al. 2015) have been reported during MTSD use compared to when using traditional electronic devices. The different musculoskeletal implications from the use of MTSDs versus traditional devices were also reinforced by the few cross-sectional studies that have found evidence for an association between MTSD use and musculoskeletal symptoms (Kim and Kim 2015, Shan et al. 2013, Sommerich et al 2007).

These findings support concerns about MTSD use posing a risk for musculoskeletal symptoms. Information on the associations between musculoskeletal symptoms, musculoskeletal exposures and MTSD use is therefore important in understanding the potential musculoskeletal implications associated with the use of these devices. Such evidence is currently dispersed. Although there are reports of studies investigating different aspects of MTSD use, to the best of our knowledge, a systematic review of the current evidence on musculoskeletal symptoms and exposures associated with MTSD use is not yet available. Therefore, the aim of this study was to systematically review available literature on musculoskeletal symptoms and exposures associated with the use of MTSDs. The synthesised information may inform guidelines for wise use of MTSDs and identify areas in need of further research.

2.1.2 Methods

2.1.2.1 Search strategy

The protocol for this systematic review was registered in PROSPERO (Toh et al 2015). Systematic searches of the literature were conducted in five electronic databases (EMBASE, Medline, Scopus, PsycINFO and Proquest) up to June 2016. The first touch screen phone (Simon; IBM) and the first personal digital assistant (Newton; Apple) were made available in 1993 (Ion 2013), hence the search was conducted for relevant studies published from 1993 onwards. Keywords describing MTSD (e.g. smart phone, tablet computer, touch screen, mobile device), musculoskeletal symptoms (e.g. pain, musculoskeletal pain, discomfort) and musculoskeletal exposures (e.g. posture, muscle activity, electromyography) were used (Appendix A).

Two reviewers (SHT and PC) independently screened all potential titles, abstracts, and if needed, full-texts for eligibility. Disagreement for inclusion was resolved through a consensus meeting or consulting a third reviewer (EKH). Studies were included if: (1) the study examined the use of MTSD and associated musculoskeletal outcomes (i.e., musculoskeletal symptoms such as discomfort or pain, and/or musculoskeletal exposures such as postures or muscle activity); (2) the study described original research from laboratory or field studies or cross-sectional or longitudinal epidemiological studies (i.e., excluding case reports, reviews, conference proceedings, editorials and letters) written in English. Studies that described the use of MTSD as interventions for managing health conditions (e.g. text message or mobile applications for telemedicine) or examined outcomes of gait or balance parameters were excluded. Reference lists of all included full-text articles were screened for additional papers. Authors of articles were contacted to seek clarification where insufficient information was provided.

2.1.2.2 Data extraction and methodological quality assessment

In line with the PROSPERO registration, due to the heterogeneity in study designs, methods, outcomes and data presented in the included articles, a structured narrative synthesis was undertaken as the planned meta-analysis was not able to be carried out. For the narrative synthesis, relevant data from all included articles were extracted and methodological quality was assessed by two reviewers (SH and PC) independently. Disagreement between the two reviewers was resolved through a consensus meeting or consulting a third reviewer (EKH). Findings of the articles were described and synthesized in a narrative format.

Data for the following categories were extracted from the included studies: study purpose, study design, study population, musculoskeletal symptoms (if applicable), musculoskeletal exposures and/or physiological responses (if applicable), statistical analyses and results. Other musculoskeletal outcomes which did not fall under musculoskeletal symptoms or exposures, such as pressure pain threshold or median nerve size, were identified in some of the studies and were extracted separately as physiological responses may provide further insights on musculoskeletal outcomes of MTSD use. As various terminologies of head, neck and gaze angles were present among the studies, terminologies defined by Straker and colleagues (Straker et al 2008b) were used to enable consistent comparison between studies.

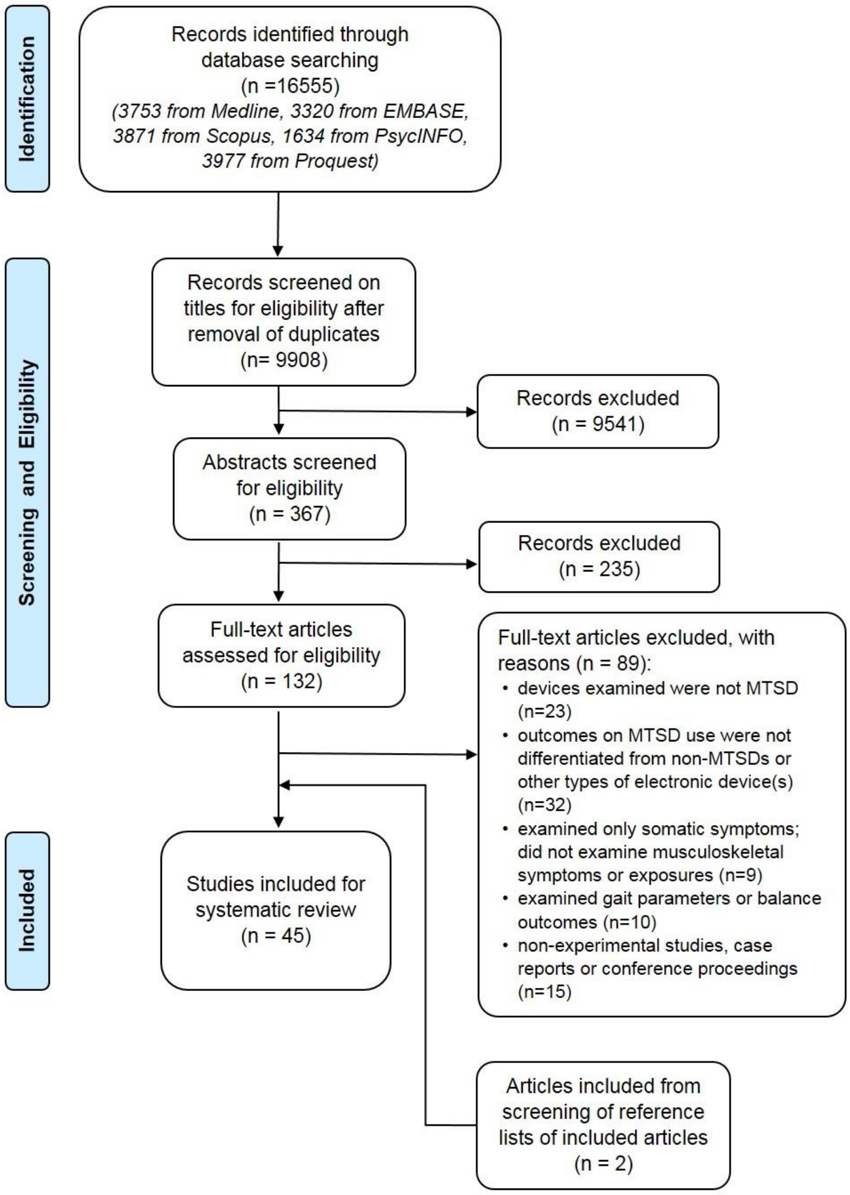
A criteria list adapted from existing methodological quality assessment scales (Coenen et al 2014, Kmet et al 2004, von Elm et al 2007, Waersted et al 2010) was used (Appendix B), with criteria on study purpose, study design, study population, musculoskeletal symptoms, musculoskeletal exposures and/or physiological responses, statistical analyses and results. Each of these categories were scored positive (+), negative (-), unclear (?, i.e. insufficient information available) or not applicable (NA). For each study, the percentage of positive categories scored was tabulated.

2.1.3 Results

2.1.3.1 Search results

From the database search, after removing duplicates, 9,908 references were retrieved and screened for eligibility based on their titles (Figure 2.1). Following that, 367 abstracts and 132 full-text articles were assessed for eligibility. Articles were excluded due to: the device(s) being examined was not a MTSD, the outcomes associated with MTSDs were not being differentiated from non-MTSDs or other types of devices; or only somatic symptoms (e.g. headache, dizziness), gait or balance parameters were examined (not addressing musculoskeletal outcomes). Two additional articles were included after screening reference lists of the included articles. A total of 45 articles were included in this review.

Figure 2.1 PRISMA flow chart for selecting relevant articles



2.1.3.2 Participants and study designs

Included articles were published from 2007 to 2016 and described assessments of participants with reported mean ages ranging from 5.8 to 67.5 years old. Forty articles reported studies conducted with adults, mostly young adults, four with young children or adolescents, while three articles did not report the age of participants. Included articles described six cross-sectional studies (Appendix C and D), nine case-control laboratory studies (Appendix D, G and I) and 32 experimental laboratory studies (Appendix E, H and J), with two articles describing more than one type of study design (Chiang and Liu 2016, Guan et al 2016). No longitudinal studies were identified.

Cross-sectional studies examined aspects of smartphone and tablet use e.g. duration and/or postures of use, with musculoskeletal symptoms and exposures using surveys or observational measurement methods. Experimental and case-control laboratory studies investigated: amount of usage, features (e.g. tilt angle, touch screen size, keyboard design, surface curvature), tasks (e.g. typing, gaming, internet browsing, reading, watching videos) and positions (e.g. handhold position, workstations such as desk, lap or sofa, and gross postures such as sitting or standing) of MTSD use with musculoskeletal symptoms, musculoskeletal exposures and physiological responses. For case-control laboratory studies, participants were categorised with respect to their symptoms (i.e., symptomatic or asymptomatic), amount of smartphone usage (i.e. more or less than four hours per day), and extent of "addiction" to smartphones (via questionnaires). Individual differences in participants, i.e. between symptomatic and asymptomatic, males and females or among different hand sizes and shapes, were also examined in a few of the studies.

2.1.3.3 Methodological quality

Included studies scored on average 55.7% on the methodological quality scale, ranging from 14.3% to 85.7% (Table 2.1). Slightly less than one third (n=13/45) of all the included studies scored 50% and above. All the studies except one study (Chiu et al 2015) scored negative (-) or unclear (?) for musculoskeletal symptoms, musculoskeletal exposures and/or physiological responses as no standardized measures of acceptable quality were used or no clear information on reliability and/or validity was provided.

Table 2.1 Methodological quality assessment results

Author	Study purpose	Study design	Study population	Musculoskeletal exposures and/or physiological responses	Musculoskeletal symptoms	Statistical analyses	Results	No. of positive categories	% of positive categories
(Ahn et al 2016)	+	+	?	-	?	-	+	3/7	42.9%
(Albin and McLoone 2014)	-	+	?	?	?	?	-	1/7	14.3%
Billinghurst and Vu (2015)	+	+	+	?	NA	?	?	3/6	50.0%
Chiang and Liu (2016)	+	?	+	?	?	?	?	2/7	28.6%
Chiu et al. (2015)	+	+	+	?	+	+	+	6/7	85.7%
(Choi et al 2016)	?	+	+	-	NA	+	-	3/6	50.0%
(Guan et al 2015)	-	+	+	?	NA	?	+	3/6	50.0%
(Guan et al. 2016)	+	+	?	?	NA	+	?	3/6	50.0%
(Hong et al. 2013)	?	-	+	?	NA	?	?	1/6	16.7%
(Inal et al 2015)	+	+	+	?	?	?	+	4/7	57.1%
(Jacquier-Bret et al 2014)	?	?	-	?	NA	+	+	2/6	33.3%
(Jung et al 2016)	-	+	?	?	NA	?	+	2/6	33.3%
(Kee et al 2016)	+	+	+	?	?	+	+	5/7	71.4%
(Kietrys et al. 2015)	+	+	+	?	NA	+	+	5/6	83.3%
(Kim 2015)	+	-	+	?	?	+	+	4/7	57.1%
(Kim and Kim 2015)	-	+	?	-	-	-	+	2/7	28.6%
(Kim et al 2012)	-	?	+	?	NA	-	-	1/6	16.7%
(Kim et al. 2014a)	+	+	+	?	?	+	+	5/7	71.4%

Author	Study purpose	Study design	Study population	Musculoskeletal exposures and/or physiological responses	Musculoskeletal symptoms	Statistical analyses	Results	No. of positive categories	% of positive categories
(Kim et al 2014b)	+	+	+	?	?	+	+	5/7	71.4%
(Kingston et al 2016)	+	+	+	?	NA	+	+	5/6	83.3%
(Ko et al 2015)	+	+	+	?	NA	+	+	5/6	83.3%
(Lee and Seo 2014)	+	+	?	?	NA	+	+	4/6	66.7%
(Lee et al 2012)	-	+	+	?	?	?	-	2/7	28.6%
(Lee et al 2015)	+	+	+	?	NA	+	-	4/6	66.7%
(Liang and Hwang 2016)	+	?	+	?	NA	+	+	4/6	66.7%
(Lin et al 2015)	+	+	+	?	?	+	+	5/7	71.4%
(Ning et al 2015)	+	+	?	?	NA	?	+	3/6	50.0%
(Park et al 2015)	+	+	?	-	NA	+	?	3/6	50.0%
(Pereira et al 2013)	+	+	+	?	NA	+	+	5/6	83.3%
(Shan et al. 2013)	+	+	+	?	?	+	+	5/7	71.4%
(Shim 2012)	?	?	+	?	NA	+	+	3/6	50.0%
(Shin and Kim 2014)	-	?	+	?	?	-	-	1/7	14.3%
(Sommerich et al. 2007)	?	+	?	?	?	?	?	1/7	14.3%
(Stoffregen et al 2014)	?	+	+	?	NA	+	-	3/6	50.0%
(Straker et al. 2008c)	+	+	+	?	NA	+	+	5/6	83.3%
(Trudeau et al 2012)	+	+	?	?	NA	+	+	4/6	66.7%
(Trudeau et al 2013)	+	+	+	?	?	+	+	5/7	71.4%
(Trudeau et al 2016)	+	+	+	?	NA	+	+	5/6	83.3%

Author	Study purpose	Study design	Study population	Musculoskeletal exposures and/or physiological responses	Musculoskeletal symptoms	Statistical analyses	Results	No. of positive categories	% of positive categories
(Vasavada et al 2015)	+	+	+	?	NA	+	+	5/6	83.3%
Werth and Babski-Reeves (2014)	?	+	+	?	NA	?	-	2/6	33.3%
(Xie et al. 2016)	-	+	+	?	?	+	+	4/7	57.1%
(Xiong and Muraki 2014)	+	+	+	?	NA	?	?	3/6	50.0%
(Xiong and Muraki 2016)	+	+	?	?	NA	+	+	4/6	66.7%
(Young et al 2012)	+	+	+	?	NA	+	+	5/6	83.3%
(Young et al 2013)	+	?	+	?	NA	+	+	4/6	66.7%

(+): positive, (-): negative, (?): unclear (i.e. insufficient information available), NA: not applicable

2.1.3.4 Main findings

Musculoskeletal symptoms associated with MTSD use were reported in 17 studies (Appendix C, D and E), and included self-reported pain, discomfort or perceived comfort at the neck/shoulder, back and upper extremities (e.g. upper arm, forearm, wrist, fingers and thumb). Symptoms were measured either using a visual analogue scale, numeric or 100-point rating scale, Likert scale, Borg's category ratio scale, body map or questions on symptom presence. Hypesthesia or dysesthesia in areas controlled by the median nerve, and temporomandibular disorders were examined via clinical tests in two of the studies (Kee et al. 2016, Lee et al. 2012).

Musculoskeletal exposures (postures and muscle activity) associated with MTSD use were assessed in 38 studies (Appendix F, G and H). Posture variables examined included angles of head, neck, cranio-cervical, shoulder, distal upper extremity (e.g. elbow, wrist, fingers and thumb) flexion/extension, head and neck gravitational demand as well as posture and movement variability. These variables were measured using motion analysis systems, video or photograph analyses, range of motion meters or electrogoniometers. Muscle activity variables included electromyography (EMG) measurements of upper trapezius, cervical extensors and distal upper extremity muscles (e.g. wrist, finger or thumb flexors/extensors).

Physiological responses associated with MTSD use were examined in 11 studies and included measurements of pressure pain threshold, muscle fatigue, perceived exertion, cervical repositioning error, pinch strength, hand function and median nerve size (Appendix I and J).

Musculoskeletal symptoms associated with MTSD use

Musculoskeletal symptoms have been examined in four cross-sectional (Chiang and Liu 2016, Kim and Kim 2015, Shan et al. 2013, Sommerich et al. 2007), four case-control (Inal et al. 2015, Kee et al. 2016, Lee et al. 2012, Xie et al. 2016) and eight experimental laboratory studies (Ahn et al. 2016, Albin and McLoone 2014, Chiu et al. 2015, Kim et al. 2014a, Kim et al. 2014b, Lin et al. 2015, Shin and Kim 2014, Trudeau et al. 2013). In the cross-sectional studies, neck and/or shoulder symptoms had the highest prevalence rates reported among MTSD users, ranging from 26.3% to 60% (Chiang and Liu 2016, Kim and Kim 2015, Sommerich et al. 2007). One study had 37.5% and 30% of college students reporting symptoms related to tablet use at neck and shoulder respectively (Chiang and Liu 2016). In another study, in a group of high school students, 50% or more of the students reported discomfort in the neck, and upper and lower back with tablet use (Sommerich et al. 2007). In another large survey among high school students in China (n=3,016), neck/shoulder pain was significantly associated with tablet use (OR 1.311, 95% CI 1.117-1.538), but not with the amount of daily tablet usage after controlling for confounding factors (Shan et al. 2013). Another study (n=80) did not find any statistically significant relationship of discomfort with tablet daily usage (Chiang and Liu 2016). In another survey, higher (but not significant) prevalence of pain in various body regions was reported for participants who used a smartphone for more than two hours daily compared to those who used for less than two hours daily (Kim and Kim 2015).

Three cross-sectional studies (Chiang and Liu 2016, Kim and Kim 2015, Sommerich et al. 2007) have also reported associations of musculoskeletal symptoms with various aspects of MTSD use, i.e. gross postures, screen size and gaming task. One study reported higher prevalence of pain in those who used a smartphone whilst sitting and lying on their back compared to those who used a smartphone in other postures (Kim and Kim 2015). In another study, the frequency of awkward postures when using a tablet was significantly correlated with discomfort (Sommerich et al. 2007). Smartphone screen size was also significantly but weakly correlated with pain in the waist. Another study found that participants who tended to play games on a tablet reported a higher prevalence of discomfort after using a tablet (Chiang and Liu 2016).

The case-control laboratory study by Xie and colleagues (Xie et al. 2016) showed that participants with and without neck symptoms developed discomfort after using a smartphone for ten minutes while sitting; however, the symptomatic group developed significantly more discomfort than the asymptomatic group.

Symptoms of the neck and/or shoulder were also shown to be associated with MTSD use in experimental laboratory studies. Pain in the neck increased over time after using a smartphone on a desk and on the lap (Shin and Kim 2014). Discomfort of the neck and shoulder were found to be significantly associated with different workstations; with the highest discomfort during tablet use on the lap, followed by during inclined sitting on a bed (with the tablet on lap) and on a desk (Lin et al. 2015). Tablet tilt angles also had a significant effect on comfort of the neck; with decreasing comfort with decreasing (more horizontal) tilt angles (Chiu et al. 2015). During gaming, there was lower perceived comfort of the shoulder but not the neck when compared to watching movies (Chiu et al. 2015).

Discomfort or pain in the distal upper extremities were also reported to be associated with MTSD use, including with workstations, features (e.g. tilt angles, key size) and tasks in one case-control and several experimental studies. In a case-control study conducted with university students (n=102), self-reported pain of the hand was significantly higher in the high smartphone “addiction” group compared to the low “addiction” group (Inal et al. 2015). Experimental laboratory studies showed significantly lower comfort at distal upper extremities when typing on a virtual compared to a physical keyboard on a laptop (Kim et al. 2014a). Discomfort of the wrists and arms were generally higher with tablet use on the lap or during inclined sitting on a bed compared to when sitting at a desk (Lin et al. 2015). Comfort of the hands and arms was reported to be lower at 60° compared to at 34° tablet tilt angles (Albin and McLoone 2014). There was also lower distal upper extremity comfort with small compared to large key sizes (Kim et al. 2014b), and during gaming compared to movie watching (Chiu et al. 2015).

Upper and lower back, and buttock discomfort were also reported in experimental laboratory studies, with one study showing higher discomfort when using a tablet on the lap compared to when sitting inclined on a bed or at a desk; while no significant differences in discomfort among different keyboard designs were shown (Lin et al. 2015). Higher overall discomfort (without specifying the body region) during tablet use in landscape compared to portrait orientation, and standard compared to split keyboard design (tablet in landscape orientation) were found in the study by Trudeau and colleagues (Trudeau et al. 2013).

Other musculoskeletal symptoms were found to be associated with smartphone use in two other case-control laboratory studies (Kee et al. 2016, Lee et al. 2012). There was more frequent presentation of temporomandibular problems (Kee et al. 2016) and increased wrist/forearm sensitivity (Lee et al. 2012) in smartphone “addicted” compared to “non-addicted” participants.

Musculoskeletal exposures associated with usage of MTSD

Musculoskeletal exposures have been reported for the amount of MTSD use and in comparisons with other device use in one cross-sectional and several laboratory studies. In a cross-sectional study among university students (n=426), of which more than 90% used a mobile phone (97.7% of which were a smartphone) for more than one hour per day (Guan et al. 2016), no significant association between head and neck postures (both during usual standing posture and while looking at a smartphone in standing) and frequency of mobile phone usage were found.

Two case-control laboratory studies revealed associations of higher smartphone usage and smartphone “addiction” with greater neck flexion (Jung et al. 2016, Park et al. 2015) and rounded shoulders during habitual standing (Jung et al. 2016). In addition, two other case-control laboratory studies found greater upper and lower cervical flexion (Kim 2015), and greater muscle activity in cervical erector spinae and upper trapezius muscles in a group with neck/shoulder symptoms compared to an asymptomatic group (Xie et al. 2016).

The experimental laboratory studies generally showed higher head and neck flexion and muscle activity during MTSD use. In two experimental laboratory studies by Guan and colleagues (Guan et al. 2016, Guan et al. 2015) with a large number of participants (n=186 and 429), significantly greater extents of static flexed head and neck and forward head posture were found during standing while looking at a smartphone (handholding smartphone) compared to normal standing (without holding smartphone); head and neck flexion were also greater in males compared to females during both standing while looking at a smartphone and normal standing.

In other experimental laboratory studies, MTSD use was compared with the use of traditional electronic devices. In a study by Straker and colleagues (Straker et al. 2008c) among young children, there were significantly higher head and neck flexion, higher shoulder flexion and elevation, and lower cranio-cervical and cervico-thoracic angles when using a tablet with a stylus compared to when using a desktop computer. The use of a tablet also induced greater variability of neck posture and muscle activity than when using a desktop computer. Higher neck flexion when using a tablet compared to a laptop or netbook has also been reported, but not when compared to a physical keypad phone (Kietrys et al. 2015).

Muscle activity of the upper trapezius and/or cervical erector spinae were also found to be higher while using a tablet compared to a desktop computer (Straker et al. 2008c), or when using a virtual compared to a physical keyboard on a laptop (Kim et al. 2014a). However, trapezius muscle activity was lower during the use of a smartphone when compared to a desktop computer (Xie et al. 2016), while no significant differences were found when smartphone use was compared to physical keypad phone use (Kietrys et al. 2015).

Postures and muscle activity of the distal upper extremities were also dependent on the types of devices, with generally greater non-neutral postures, but lower muscle activity at the level of the wrist, elbow, fingers and/or thumb found during use of MTSD compared to traditional electronic devices. There was more wrist extension (Kietrys et al. 2015, Werth and Babski-Reeves 2014), wrist pronation and elbow flexion (Kingston et al. 2016) during the use of a smartphone or tablet compared to a laptop or physical keypad phone. Several studies reported similar findings of lower muscle activities at wrist and finger flexors and extensors (Hong et al. 2013, Kietrys et al. 2015, Werth and Babski-Reeves 2014, Xie et al. 2016) and thumb abductors (Hong et al. 2013, Kietrys et al. 2015) when using a smartphone or tablet compared to a laptop, netbook or physical keypad phone, and when using a virtual compared to physical keyboard (Kim et al. 2014a).

Musculoskeletal exposures associated with features of MTSD

Musculoskeletal exposures associated with different features of MTSD (e.g. screen size or tilt angles) were examined in several experimental and case-control laboratory studies. Greater non-neutral postures and higher muscle activity were generally found with larger tablet screen size. A significant trend for increasing head/neck flexion with increasing screen size (3.5 inch smartphone, 7 and 9.5 inch tablet) (Kietrys et al. 2015), and generally greater amount of wrist extension and ulnar deviation as well as muscle activity of upper trapezius, wrist and finger flexors and extensors during the use of a larger compared to a smaller tablet screen size (Kietrys et al. 2015, Pereira et al. 2013) were reported. Additionally, it was noted that placing MTSD on one’s lap was most adopted when using a device with a larger screen (9.5 inch tablet), while handholding and texting with both thumbs was most preferred when using a device with a smaller screen (3.5 inch smartphone) (Kietrys et al. 2015).

Tilt angles of tablet supported in cases on a desk also had an effect on musculoskeletal exposures associated with MTSD use, and were investigated in some relatively small studies (n=10 to n=33) conducted with young to middle-aged adults. Four studies showed, in general, increasing head and neck flexion with decreasing tablet tilt angles ranging from 73° tilt (almost vertical) to 0° tilt (horizontal on desk) (Albin and McLoone 2014, Chiang and Liu

2016, Vasavada et al. 2015, Young et al. 2012). The gravitational demand on head and neck, trunk flexion angles (Vasavada et al. 2015) and activity of the upper trapezius were higher, but anterior deltoid muscle activity was lower (Chiu et al. 2015), while using a tablet at lower compared to higher tilt angles. No differences were found for finger flexors muscle activity (Chiu et al. 2015) and hand gestures (Billinghurst and Vu 2015) among different tilt angles. Other features of MTSD use, e.g. key sizes, keyboard design and location, were also found to affect musculoskeletal exposures (Kim et al. 2014b, Lin et al. 2015, Trudeau et al. 2013).

Musculoskeletal exposures associated with tasks on MTSD use

Various tasks that could be performed on a MTSD (e.g. typing, gaming, internet browsing, reading, watching videos) have been investigated in some experimental laboratory studies, with task duration ranging from 90 seconds to 15 minutes. No case-control or cross-sectional studies examining the effect of different tasks on a MTSD were found. The tasks on MTSDs can be considered as active tasks, when frequent finger activity is required (e.g. typing, gaming), or passive tasks, which consist mainly of visual interaction with minimal or no finger activity (e.g. internet browsing, reading, watching videos). Active tasks were generally associated with greater non-neutral postures and muscle activity of the head, neck and distal upper extremities compared to passive tasks. For example, typing or gaming was associated with significantly higher head and neck flexion (Chiang and Liu 2016, Lee et al. 2015, Ning et al. 2015), and higher muscle activity of upper trapezius, anterior deltoid (Chiu et al. 2015, Young et al. 2013) and cervical extensors (Ning et al. 2015) compared to passive tasks. Another study however did not find any significant differences in postures and gravitational demand at the head and neck between typing and reading tasks (Vasavada et al. 2015). The authors of the latter study did not standardize duration for each of the tasks, which may have affected the accuracy of findings. At the distal upper extremities, greater wrist pronation and ulnar deviation (Kingston et al. 2016, Young et al. 2013), as well as greater muscle activity of finger flexors (Chiu et al. 2015, Ning et al. 2015) and wrist extensors and flexors (Young et al. 2013), were found during active tasks compared to passive tasks.

Musculoskeletal exposures associated with positions of MTSD use

Different positions of MTSD use, affected by the gross body postures (such as sitting, standing), handhold positions (such as MTSD handheld at different levels, one/two-handed hold or handheld in portrait/landscape orientation) and workstations (such as MTSD on desk, lap or sofa), were examined in one cross-sectional study (Liang and Hwang 2016), one case-control (Xie et al. 2016) and several experimental laboratory studies. The cross-sectional study observed handhold positions and general postures of passengers using smartphones while commuting in metro trains in Taiwan (Liang and Hwang 2016). They found that the use of two hands, with one hand holding and the other hand operating the smartphone, was most commonly observed in sitting postures (45.5%). Operating the smartphone with only one hand, with the other hand holding a train pole or hand strap, was most commonly observed in standing commuters (45.8%).

Two experimental laboratory studies compared exposures during smartphone use in different gross body postures. One study reported significantly higher head flexion while using a smartphone in sitting compared to use in standing (Lee et al. 2015). The other study found no significant differences in muscle activity of splenius capitis and upper trapezius, among sitting postures with neutral, “middle” or “maximum neck bending” with five minutes of smartphone use (Choi et al. 2016).

Different MTSD handhold positions were examined in one case-control and some experimental laboratory studies. One experimental laboratory study found significantly higher neck and elbow flexion while handholding a smartphone at chest level, compared to at eye or knee level (with the trunk bent forward and elbows resting on the thighs) (Ko et al. 2015). Muscle activity of the upper trapezius muscle was, however, significantly higher at eye level than at knee and chest level. There was a small but significantly lower head/neck flexion of 2° during one-handed compared to two-handed texting on a smartphone (Kietrys et al. 2015). Upper trapezius muscle activity was however, significantly higher during one-handed compared to two-handed hold of a tablet (Young et al. 2013), with comparable (but non-significant) findings in another study (Xie et al. 2016). Similarly, muscle activity was higher for wrist extensors (Hong et al. 2013, Kietrys et al. 2015, Xie et al. 2016, Young et al. 2013), wrist flexors (Hong et al. 2013, Kietrys et al. 2015), fingers and thumb muscles (Hong et al. 2013, Ko et al. 2015, Xie et al. 2016) during one-handed compared to two-handed hold. The different handholds caused no significant differences in distal upper extremity postures (Kietrys et al. 2015, Young et al. 2013). Postures at wrist and thumb during the different handholds were influenced instead by MTSD orientation, with higher wrist extension and thumb movements during two-handed hold in landscape than one-handed hold in portrait orientation (Trudeau et al. 2016). During the use of a tablet in portrait compared to landscape orientation, there were significantly lower wrist, fingers and thumb joint postural angles (Pereira et al. 2013, Trudeau et al. 2013).

Different workstations for MTSD use, i.e. a desk or use of non-traditional workstations (such as bed, sofa or lap), were compared in some experimental and case-control laboratory studies. It was generally found that neck flexion was significantly greater during tablet use in non-traditional workstations (i.e., sofa (Werth and Babski-Reeves 2014) or lap (Vasavada et al. 2015, Young et al. 2012)) compared to when sitting at a desk. Gravitational demand on the head and neck were also significantly higher while using a tablet on the lap compared to on a desk (Vasavada et al. 2015). Muscle activity of the upper trapezius, however, was lower during tablet use on the lap compared to on a desk, which corresponded to lower shoulder flexion and elevation (Young et al. 2013). Another study showed no differences in flexion relaxation ratio of cervical erector spinae muscle activity between smartphone use on a desk and the lap (Shin and Kim 2014). For distal upper extremities postures, there was generally higher elbow flexion (Lin et al. 2015, Werth and Babski-Reeves 2014), wrist extension (Lin et al. 2015, Young et al. 2013) and ulnar/radial deviation acceleration (Young et al. 2013) but no differences in wrist muscle activity (Young et al. 2013) while using a tablet on non-traditional workstations (sofa, lap or bed) compared to on a desk.

Physiological responses associated with MTSD use

Physiological responses (e.g. pressure pain threshold, muscle fatigue, perceived exertion, cervical repositioning error, pinch strength, hand function, median nerve size), were investigated in experimental and case-control laboratory studies, and were found to be associated with MTSD use. These studies generally showed increased physiological responses with MTSD use, suggesting an increased risk for musculoskeletal symptoms. Pressure pain threshold in the upper trapezius muscle was significantly lower in a group with heavy smartphone “addiction” compared to a control group with low “addiction” (Park et al. 2015), and after using a smartphone compared to before (Kim et al. 2012). Muscle fatigue (measured by EMG) of upper trapezius, elbow and wrist flexors, and thumb abductors were higher after using a smartphone compared to before (Kim et al. 2012), while that of upper trapezius and splenius capitis muscles also increased during smartphone use in sitting with “maximum” compared to “middle neck bending” (Choi et al. 2016). Self-reported fatigue in neck, shoulder, forearm and wrist were also affected by features of a tablet, i.e. screen size, grip and stylus shape (Pereira et al. 2013).

Perceived exertion was higher in symptomatic participants (with neck/shoulder discomfort) compared to those who were asymptomatic after using a smartphone (Xie et al. 2016). In other case-control studies, high smartphone “addiction” or usage was found to be associated with greater cervical repositioning errors (Lee and Seo 2014), reduced pinch strength and hand function (Inal et al. 2015). In an experimental laboratory study, median nerve circumference and area (examined via ultrasonography) decreased significantly after using a smartphone compared to before (Shim 2012). Two case-control laboratory studies showed significantly higher median nerve cross-sectional area in the dominant arm side compared to non-dominant side in the high smartphone “addiction” group (Inal et al. 2015), while no significant differences in median nerve thickness among groups with different degrees of smartphone “addiction” were found (Lee et al. 2012).

2.1.4 Discussion

2.1.4.1 Discussion of main findings

This is the first review, to our knowledge, to systematically describe the available evidence on musculoskeletal symptoms and musculoskeletal exposures associated with MTSD use. Findings from this review, based on evidence mainly from experimental and case-control laboratory studies with only a few cross-sectional studies, suggest that aspects of MTSD use (i.e. usage, features, tasks and positions) can create various musculoskeletal exposures, possibly leading to physiological responses and musculoskeletal symptoms. However, current evidence is limited with many studies of low methodological quality with limitations in measurement methods, study design and/or presentation of the results. Moreover, a wide variation in measures and conditions of MTSD use evaluated across the studies makes it hard to make valid comparisons and to draw firm conclusions on certain aspects of MTSD use. No longitudinal studies were identified, and thus the direction of the associations as well as the long-term musculoskeletal impact of MTSD use were also not able to be determined.

Musculoskeletal symptoms associated with MTSD use

Current evidence on musculoskeletal symptoms associated with MTSD use from cross-sectional studies is limited with mainly low quality studies. However, available evidence does suggest that MTSD use and aspects of its use, i.e. long duration, awkward postures, larger screen size and gaming task, may be associated with musculoskeletal symptoms

(Chiang and Liu 2016, Kim and Kim 2015, Shan et al. 2013), most commonly in the neck/shoulder region (Kim and Kim 2015, Shan et al. 2013, Sommerich et al. 2007). Limitations of the available studies include the use of measures of the amount and aspects of MTSD use, and musculoskeletal symptoms, with no reliability and/or validity of the measurement methods specified by the authors. Confounding factors were often not considered, and representative samples were not obtained in many of the studies. These limitations may have affected the accuracy of findings in the studies and potentially biased the true associations between musculoskeletal symptoms and MTSD use.

From case-control and experimental laboratory studies, there was consistent evidence that musculoskeletal symptoms are associated with MTSD use, and different positions, features and tasks of its use can have an impact on the symptoms experienced (Albin and McLoone 2014, Chiu et al. 2015, Kim et al. 2014b, Lin et al. 2015). Other musculoskeletal symptoms in areas controlled by the median nerve may also be associated with greater usage of MTSD or smartphone "addiction" (Lee et al. 2012), suggesting risk for 'repetitive strain injuries' or 'carpal tunnel syndrome' reported with traditional desktop computer use (Keller et al 1998, van Tulder et al) may also be a risk with MTSD use. Nonetheless, such evidence is still limited with only a small number of studies examining symptoms associated with MTSD use, and measures with unspecified reliability and validity, which may have biased the findings.

Musculoskeletal exposures associated with usage of MTSD

Evidence from the few experimental laboratory studies showed that musculoskeletal exposures of greater non-neutral postures (Guan et al. 2016, Guan et al. 2015) and gravitational demand (Vasavada et al. 2015) at the head and neck/shoulder were associated with MTSD use when compared to not using any device. When compared to the more traditional electronic devices (e.g. physical keypad phone, desktop/laptop computers), exposures at head and neck during MTSD use may differ which may be due to the different device placement and the use of a touch screen interface. For example, greater non-neutral postures and muscle activity at the head and neck were found with tablet (placed flat on a desk) compared to desktop computer use (supported upright on a desk) (Straker et al. 2008c), while no significant differences were found between smartphone and physical keypad phone, which were both used handheld (Kietrys et al. 2015). The different placements and viewing angles with tablet and desktop computer use is likely to have affected the amount of neck bending. Moreover, the use of a touch screen has been shown to be associated with increased upper trapezius muscle activity, which may be due to wrists and fingers not being able to fully rest on the screen (Kim et al. 2014a, Shin and Zhu 2011). Therefore, current evidence indicates that different device placement and the use of a touch screen interface can influence musculoskeletal exposures, and cause greater non-neutral postures at head/neck (Straker et al. 2008c) and distal upper extremities during MTSD use (Hong et al. 2013, Kietrys et al. 2015, Werth and Babski-Reeves 2014, Xie et al. 2016), which may lead to increased risk of symptoms.

Musculoskeletal exposures associated with features, tasks and positions of MTSD

Current evidence showed that screen size had an effect on musculoskeletal exposures, potentially through an influence on weight and placement position of the device. MTSD with a larger screen may pose greater stress at the neck/shoulder and distal upper extremities (Kietrys et al. 2015, Pereira et al. 2013), possibly due to heavier weight of the larger screen, and a preference to place it on the lap (which tended to induce greater head/neck flexion and muscle activity). Handholding a larger screen could also create greater shoulder and arm fatigue (Kietrys et al. 2015). Hence, it may be more advisable to support a larger screen MTSD on a desk rather than handholding it, especially for prolonged periods of use.

There was also consistent evidence from experimental laboratory studies that lower tablet tilt angle (with tablet supported flat on a surface) generally cause greater gravitational demand (Vasavada et al. 2015), muscle activity (Chiu et al. 2015) and non-neutral postures at the head/neck (Albin and McLoone 2014, Chiang and Liu 2016, Vasavada et al. 2015, Young et al. 2012) than higher tablet tilt angles, with the greatest exposures at 0° tilt (placed flat on surface). At lower tilt angles, the head and neck need to bend forward more to look at the screen which poses more biomechanical stresses at the head and neck/shoulder. However, exposures on upper extremities during different MTSD tasks should also be considered when choosing an optimal MTSD tilt angle (Chiang and Liu 2016). Although there is less non-neutral head and neck/shoulder postures at higher tilt angles of e.g. 60° or 70° (which might be appropriate during passive tasks), such high tilt angles may not be conducive for tasks that require frequent finger input (e.g. typing) and may induce greater non-neutral postures and muscle activity at shoulder, wrist and/or fingers. Tilt angles ranging from 33° to 37° were preferred during various tasks on a tablet (Albin and McLoone 2014, Chiang and Liu 2016, Young et al. 2012), which may be the angle range that is more comfortable for wrists and fingers during active tasks. Therefore, higher tablet tilt angles (with tablet supported on a surface) may tend to result in lesser biomechanical stresses at the head and neck than lower tilt angles but may not be as ideal for exposures at distal upper extremities, especially during active tasks.

Current evidence also showed that active MTSD tasks generally caused greater non-neutral postures and higher muscle activity around the head, neck, wrist and finger areas, which pose more risk for biomechanical stresses compared to passive tasks (Chiang and Liu 2016, Chiu et al. 2015, Lee et al. 2015, Young et al. 2013). However, active tasks may provide movement variation. It has been suggested that variation may be a strategy to reduce the risk for musculoskeletal symptoms from increased exposures (Mathiassen 2006, Srinivasan and Mathiassen 2012). However, it is still unknown if active MTSD tasks can provide sufficient movement variation to offset the increased risk for symptoms from non-neutral postures and higher muscle activities.

Different handhold positions during MTSD use also had an effect on musculoskeletal exposures. One-handed hold tended to pose more strain with higher muscle activity on wrists, fingers and thumbs compared to two-handed hold (Hong et al. 2013, Kietrys et al. 2015, Ko et al. 2015, Xie et al. 2016, Young et al. 2013). However, handhold positions also varied with device placement, so there is a need to consider this interaction and balance of exposures at the head/neck versus upper extremities in reducing musculoskeletal strain during use of MTSDs.

Evidence on workstations of MTSD use suggests that use in a sitting position in non-traditional workstations (i.e. on a sofa, bed or lap) may pose more musculoskeletal stress on the head and neck compared to supported use on a desk (Lin et al. 2015, Vasavada et al. 2015, Werth and Babski-Reeves 2014, Young et al. 2012). Lower muscle activity at upper trapezius was however reported during the use of a tablet placed on the lap compared to on a desk, possibly due to the more pronounced arm and shoulder postures at the desk versus on the lap (Young et al. 2013). Nonetheless, these studies have only looked at a limited number of sitting positions in non-traditional workstations (i.e., bed, sofa or lap) whereas other workstations (e.g. on the floor) and a variety of postures at those workstations (e.g. side lying, prone lying, cross-legged sitting) (Ciccarelli et al 2015, Werth and Babski-Reeves 2014), along with the resulting musculoskeletal consequences, are yet to be studied.

Overall, current evidence from case-control and experimental laboratory studies suggests that features, tasks and positions of MTSD use significantly affect musculoskeletal exposures associated with MTSD use, and can interact with each other to influence the exposures. However, some studies had more than one independent variable in each condition of MTSD use, which makes comparisons among studies and drawing strong conclusions difficult.

Physiological responses associated with MTSD use

Evidence from case-control and experimental laboratory studies also suggests that MTSD use (and aspects of MTSD use such as different MTSD features, the amount of usage and extent of MTSD “addiction”) can cause physiological responses (such as median nerve changes, lower pressure pain threshold or greater muscle fatigue) which suggest potentially increased susceptibility to musculoskeletal symptoms (Inal et al. 2015, Park et al. 2015, Pereira et al. 2013, Shim 2012). For example, the median nerve changes reported with MTSD use (Inal et al. 2015, Shim 2012) suggest that MTSD use may have the potential to lead to narrowing of (Bower et al 2006, Skie et al 1990), and increased pressure in the carpal tunnel (Keir et al 1997), and thus pose a risk for carpal tunnel syndrome (Harris-Adamson et al 2015).

Association between musculoskeletal symptoms and exposures in MTSD use

As summarised above, there is some evidence from cross-sectional, case-control and experimental laboratory studies that musculoskeletal symptoms, musculoskeletal exposures and physiological responses are each related to MTSD use. The findings on musculoskeletal exposures and physiological responses associated with MTSD use are also consistent with current understanding of increased risk and susceptibility for musculoskeletal symptoms. Indeed, some of the included studies suggested increased non-neutral postures, and/or increased muscle activity were potential mechanisms for the increased discomfort or pain reported from MTSD use (Albin and McLoone 2014, Chiu et al. 2015, Kee et al. 2016, Lin et al. 2015, Trudeau et al. 2013, Xie et al. 2016). Nonetheless, evidence on what exposure aspects are the critical mechanisms for the observed associations between musculoskeletal symptoms and MTSD use is still limited.

Influence of individual differences on musculoskeletal symptoms and exposures

Individual differences in musculoskeletal symptoms and exposures associated with MTSD use between symptomatic and asymptomatic participants, between participants with different hand sizes and shapes, and between males and females were also examined in a few of the studies. Musculoskeletal symptoms and exposures (cervical flexion and neck/shoulder muscle activity) were greater in participants with neck/shoulder symptoms compared to those who were asymptomatic (Kim 2015, Xie et al. 2016). MTSD use may hence pose even greater risk for biomechanical stress and load on individuals who are symptomatic, inducing a vicious cycle of musculoskeletal symptoms. This has been reported before in studies showing altered motor control and muscle activation (during non-MTSD tasks) among people with neck pain (Johnston et al 2008, Sterling et al 2001, Szeto et al 2009). Different hand sizes and shapes may also influence musculoskeletal symptoms or exposures at the distal upper extremity, as one study indicated their significant effect on muscle activity of the fingers and thumb during MTSD use (Ahn et al. 2016).

Gender differences were also noted with higher head and neck flexion found in males compared to females during smartphone use (Guan et al. 2016, Guan et al. 2015), as previously noted during computer use (Straker et al 2007). This may be due to taller statures of males than females (Briggs et al 2004). However, the risk of neck/shoulder (Shan et al. 2013, Straker et al 2011) and low back pain (Shan et al. 2013) have been shown to be higher instead in females compared to males, possibly due to higher pain sensitivity in females (Fillingim et al 2009) or their different nature of computer use (e.g. type of activities, duration) (Rideout et al. 2010, Straker et al. 2011). These findings suggest different musculoskeletal risks involved with MTSD use between males and females, and a potential modifying effect of gender on associations between symptoms and MTSD use.

2.1.4.2 Quality of evidence

The quality of the included studies was generally low, with less than one third of the studies scoring 50% or above on the methodological quality assessment, mainly due to insufficient or unclear information provided on measurement methods of musculoskeletal symptoms and/or exposures in many of the studies. Although some methods for the assessment of musculoskeletal exposures were sometimes thoroughly described (e.g. EMG or motion analysis), reliability and validity of the measures were often not specified. In addition, anatomical points for measuring postures and muscle activity were not always clearly indicated and various terminologies for postural angles were used, making it hard to consolidate findings from the studies. Some of the studies were also unclear in reporting of the results. Moreover, as a number of studies did not report on symptoms for each specific body region (by only providing an average or overall score), it was difficult to determine the impact of MTSD use on specific body regions.

2.1.4.3 Further research

Findings from the current review need to be interpreted with caution as current evidence is limited and mainly from cross-sectional, case-control and experimental laboratory study designs with poor methodological quality. High quality epidemiological studies, including longitudinal studies, examining MTSD use in natural settings (e.g. in the home or school environment) are therefore needed to strengthen the body of evidence. To date however, no low burden but accurate methods for measuring the amount and nature of MTSD usage in daily life are available and there is a need to develop reliable and valid methods to capture MTSD usage accurately. Laboratory studies should use accurate measurement methods for musculoskeletal symptoms and exposures (with established validity and reliability), and anatomical angle definitions should be clearly specified and preferably be harmonized across studies. MTSD use in other possible positions and non-traditional workstations and prolonged duration of MTSD use should also be investigated. It will also be important to examine variability of musculoskeletal exposures during MTSD use and gender differences.

This review is the first, to our knowledge, to systematically describe the current evidence on musculoskeletal symptoms and exposures associated with MTSD use. The systematic approach used to screen articles, extract data and assess methodological quality of the included studies helped to minimise biases which may be introduced in unstructured narrative reviews where findings from one study may be given inappropriate emphasis. A further limitation was that the methodological quality assessment tool used may not have captured all the possible issues that may be present across the broad range of study designs in the included studies; nonetheless, the tool used was the most appropriate available for the purposes and nature of studies in this review.

This review has excluded studies that examined gait and balance parameters during MTSD use. It will be important to review this evidence, considering the portability of MTSDs and their use during walking and multitasking (Lim et al 2015, Schabrun et al 2014). Findings from the included studies on performance, task efficiency or typing speed during MTSD use were also not reported in this review. These outcomes should be considered as they provide useful information on productivity associated with MTSD use.

2.1.4.4 Implications for wise use of MTSDs

Based on currently limited available evidence on MTSD use, and other research on risk factors for musculoskeletal symptoms, some tentative suggestions for wise use of MTSD to help reduce musculoskeletal exposures and associated risks for musculoskeletal symptoms from MTSD use are proposed (Table 2.2).

Table 2.2 Tentative suggestions for wise use of MTSD

- Avoid excessive total usage
- Avoid prolonged static postures
- Use opportunities to vary whole body, head/neck and upper extremity postures during MTSD use
- Avoid awkward postures during prolonged or repetitive use
- Position MTSD at a height to balance head/neck and upper extremity stress – holding a MTSD at around eye level encourages neutral head/neck posture but increases upper extremity loading; holding a MTSD at around waist/lap level increases head/neck flexion but reduces upper extremity loading
- For longer durations of use, support MTSD at a tilt angle (e.g. with the use of device accessories) to balance head/neck and upper extremity stress – a higher tilt encourages neutral head/neck posture and is good for viewing only tasks; a lower tilt allows lower wrist and finger stresses and is good for tasks requiring finger or thumb input
- Avoid high repetition of movements such as prolonged typing or swiping on MTSD
- Avoid forceful exertions such as holding larger or heavy MTSD in one hand for long durations

2.1.5 Conclusion

There is limited evidence that MTSD use, and various aspects of its use (i.e. amount of usage, features, tasks and positions), are associated with musculoskeletal symptoms and exposures. This is due to mainly low quality experimental and case-control laboratory studies, with few cross-sectional and no longitudinal studies. Further research with higher quality studies which examine: MTSD dose-response relationship, associations of specific aspects of MTSD use (e.g. features, tasks and positions) with musculoskeletal symptoms, as well as the mechanisms, direction and long-term effects of the associations are required. This enhanced evidence is needed to provide evidence-based guidelines for wise use of MTSDs.

2.2 MTSD use and musculoskeletal symptoms and visual health outcomes – focus on adolescents

2.2.1 MTSD use in adolescents

Although the majority of studies to date on MTSD use have been conducted on adults, as seen in the earlier systematic review in section 2.1, studies on adolescents' MTSD use have started to evolve over the recent few years. This section will thus provide a brief further review on the use of MTSDs and their associations with musculoskeletal symptoms and visual health outcomes, specifically in adolescents and in relation to the objectives of this thesis (as outlined in Chapter 1.2).

2.2.1.1 Prevalence and amount of MTSD use in adolescents

Several surveys across various countries, mostly in Western countries, have reported high and increasing prevalence and ownership of MTSD use by adolescents. A recent nationwide survey in the USA reported that 95% of adolescents aged 13 to 17 years old used a smartphone in 2018, an increase from 73% as compared to in 2015 (Pew Research Center 2018). Among adolescents aged 12 to 15 years old in UK, 93% used a smartphone in 2017 which was also an increase from 89% in 2013 (Ofcom 2017). Although the prevalence of tablet use by adolescents is generally lower than that of smartphone, tablet usage is also considerably high. In UK, 78% of adolescents used a tablet (Ofcom 2017). In Europe, more than 80% of Swedish adolescents aged 12-15 years old used a smartphone while more than 67% used a tablet daily or sometimes (vom Orde and Durner 2017). Similarly, 72% of 9 to 16 year-olds in Denmark used a smartphone daily while 37% used a tablet daily (Mascheroni and Cuman 2014).

This high MTSD usage could be attributed to the high and increased smartphone and tablet ownership among adolescents today. For example, 83% of adolescents (12-15 years old) in UK owned a smartphone while 55% owned a tablet in 2017, compared to only 62% and 26% respectively in 2013 (Ofcom 2017). In Australia, 94% of adolescents (14-17 years old) owned a smartphone in 2016 (Roy Morgan Research 2016) compared to 80% in 2015 (Australian Communications and Media Authority 2016). Among French adolescents, 68% of 13 to 19 year-olds owned a smartphone while 29% owned a tablet (vom Orde and Durner 2017). Additionally, more pre and early adolescents have also started to own a MTSD. For example, among 8 to 11 year-olds UK adolescents, smartphone ownership increased from 50% in 2013 to 62% in 2017; tablet ownership also increased from 44% in 2013 to 80% in 2017 (Ofcom 2017). These studies have thus shown high and increased MTSD ownership by adolescents.

In addition, studies have also reported a relatively high amount and prevalence of daily use of MTSDs by adolescents. A survey in Switzerland found 51% of young people (n=1519; 15-21 years) used a smartphone for more than 2 hours per day (Haug et al. 2015). In USA, a consumer survey by Common Sense Media reported smartphone use of close to 3 hours per day by adolescents (n=1399; 13-18 years), while tablet use was lower at 45 minutes per day (which included adolescents who did not use a smartphone or tablet at all) (Rideout 2015). The amount of smartphone use per day was also similar for UK adolescents (n=500; 12-15 years) with approximately 18 hours per week (2 hours 24 minutes/day during weekdays, 3 hours 12 minutes/day during weekends) (Ofcom 2017). High tablet use of approximately 2 hours 20 minutes per day was noted in another recent study conducted with Australian adolescents (n=924; 10-19 years), while their smartphone use was lower at 1 hour 40 minutes per day (Straker et al 2018a). The higher tablet use was possibly due to tablet being used regularly as part of their school curriculum and by the use of a non-representative sample from only one school.

MTSD use in Asian countries (and even other Western countries) has not been as extensively studied as that in some Western countries, despite high technology penetration in some of the more developed Asian countries (We Are Social 2017, World Economic Forum 2016). Use of MTSDs by adolescents in Asian countries may differ due to different cultural and societal influences and values (Kang and Jung 2014, Recabarren et al 2008), but the amount and patterns of their MTSD use are still not exactly known. Studies on adolescents' MTSD use have only recently evolved in a few Asian countries, which have showed a considerably high prevalence of MTSD use. One of the studies showed smartphone ownership among adolescents (12-18 years) was approximately 85% in South Korea, 65% in Philippines and Japan and more than 55% in Hong Kong and Malaysia (Mak et al 2014). Among 12-year-olds in Singapore, 62% owned a smartphone while 26% owned a tablet (DQ Institute 2016). Regarding the amount of MTSD use, most studies reported on prevalence of hours of use per day instead of mean use duration. For example, in China, 51.7% of adolescents (n=3016; 15-19 years) used a tablet for more than 2 hours per day, while 48.2% used a mobile phone for more than 2 hours per day (Shan et al. 2013). Another survey with Hong Kong adolescents recruited via convenience sampling (n=960; 10-19 years) reported 85.9% used a MTSD daily and 65% used it for more than 2 hours per day (Kwok et al. 2017). A smaller study with Taiwanese adolescents from one junior college (n=315; 16-19 years) reported 56.6% used a smartphone for more than 3 hours per day (Yang et al. 2017). Only a recent study of South Korean adolescents (n=1824; 13-15 years) reported mean daily smartphone use (5 hours) (Cha and Seo 2018), which was substantially higher than that reported in the previously mentioned studies. These studies have shown considerably high prevalence of MTSD use among adolescents in Asian countries, though their average daily usage and patterns of use are still not exactly known.

Accurate measurement of technology use exposures is challenging, which is even more so for MTSDs considering its portability and prevalent use for multitasking (Rideout 2016). The majority of studies to date on MTSD use in adolescents have employed self-reports methods with questionnaires to measure use exposures. Some studies have established reasonable test-retest reliability of self-report used in their studies (Houghton et al. 2015, Queiroz et al 2017, Straker et al. 2018a). However, some studies did not establish any reliability and/or validity (Kwok et al. 2017, Shan et al. 2013, Sommerich et al. 2007); their findings on the prevalence and amount of MTSD use and/or outcomes of use may thus be questionable. A few recent studies have attempted to use software applications in MTSDs to track the amount of usage (Christensen et al 2016), or adopt field observation methods (Liang and Hwang 2016, Szeto et al 2019) to determine MTSD use in adults, but these methods are likely to be too costly or not feasible to conduct with a large sample. Self-report remains the most feasible method to use currently in measuring use exposures, and it is important to establish reliability and validity to ensure that findings are sound.

However, many of the studies to date (conducted with either adolescents or adults) have adopted simple measures of MTSD use exposures, which might have affected the accuracy of reported use duration. Firstly, existing studies tend to provide questionnaire options for use duration as categories of per hour or collapsing several hours of use together, with maximum usage often defined as more than 4 hours and minimum usage as 1 hour. For example, in the study by Kwok et al. (2017), questionnaire options for adolescents' MTSD use duration was <1 hour, 1 - 2 hours, 2 - 3 hours, 3 - 4 hours and >4 hours. As shown by recent studies and anecdotal evidence, MTSD use can be of sporadic short periods of less than an hour or prolonged periods of more than 4 hours (Rideout 2015, Rideout 2016). Hence, many studies might not have captured accurately the whole range of use exposures. In addition, some studies only captured use duration per day or week but not the frequency of use, e.g. number of days used per week (Cha and Seo 2018, Shan et al. 2013, Yang et al. 2017), nor considered weekday and weekend usage (Cha and Seo 2018, Kwok et al. 2017, Shan et al. 2013). Previous studies on computer use have showed that it is important to obtain the frequency of use in addition to use duration, for a more accurate measurement of use exposures (Harris et al 2013). Moreover, differences in MTSD use between weekdays and weekends have been reported (Straker et al. 2018a, Yang et al. 2017), which can affect the mean daily usage across the whole week.

In addition, the majority of studies to date examining adolescents' MTSD use have focused on a single type of MTSD (smartphone and/or tablet) (Cha and Seo 2018, Kwok et al. 2017, Yang et al. 2017) or total screen technology use (encompassing MTSD and other electronic screen technology), instead of a range of devices or a breakdown of use by each device type (Houghton et al. 2015, Rosenberg et al 2018). There is hence limited information on their MTSD use relative to other types of device use. Given that adolescents are prevalent users of multiple devices (Cain et al. 2016, Rideout 2015), examining multiple device use (including MTSDs) is also important since different device use has shown differential impacts on health outcomes and well-being (Mathers et al 2009, Straker et al. 2018a). Only a few recent studies have examined the different types of devices including MTSDs by adolescents, and demonstrated high use of MTSDs, especially smartphone, over the other devices (Ofcom 2017, Pew Research Center 2018, Straker et al. 2018a). Nonetheless, there is still a lack of information on adolescents' contemporary technology use, and more studies on the relative use of MTSDs with other screen technology use are needed.

Overall, it is common for adolescents to use and/or own a MTSD today, but several limitations still exist in the current literature on adolescents' contemporary screen technology use including MTSD use. Detailed information on MTSD use would help to inform strategies for wise use and future studies examining outcomes of use. This thesis will therefore aim to provide information on contemporary screen technology use, especially of MTSDs, by adolescents and address above-mentioned limitations by measuring MTSD use exposures with a wide range of use duration, frequency of use, and separate measurement of weekday and weekend use with adolescents in Singapore.

2.2.1.2 Patterns of MTSD use in adolescents

To date, the majority of studies have focused on prevalence and amount of MTSD use, while patterns of use such as routines, bout length, types of activities and multitasking during MTSD use have not been that well examined, neither in adolescents nor in adults. Prior studies have shown that continuous computer use with reduced breaks (Galinsky et al 2007, Henning et al 1997, Menéndez et al. 2008), and certain types of activities such as gaming on computers (Straker et al. 2013, Torsheim et al. 2010) can pose a risk for musculoskeletal symptoms. Longer bout length or continuous use of computers and television have also shown association with visual symptoms including eye strain (Gowrisankaran et al. 2015). However, research on the impact of such patterns of MTSD use on musculoskeletal and visual outcomes is still limited. The nature of multitasking by adolescents and how it may impact on musculoskeletal symptoms are also relatively unknown.

These patterns of use have also shown to pose differential risks for other outcomes such as poor sleep quality (Brambilla et al 2017, Jiang et al 2015), depression (Hellström et al 2015) or reduced cognitive performance and distractibility (Moisala et al 2016, Uncapher et al 2017). Patterns of use are therefore important aspects of MTSD use exposures that should be closely examined (Rideout 2015, Rosenberg et al. 2018), which can help to provide a better understanding of how adolescents use MTSDs and inform strategies for wise use. Updated guidelines on technology use by American Academy of Pediatrics (AAP Council on Communications and Media 2016) also recognised the importance of adolescents engaging in appropriate types of activities on MTSDs. However, there are limited studies and no specific recommendations on what the appropriate types of activities are. This thesis will thus examine the following patterns of use: routines, bout length, types of activities and multitasking during MTSD use. This section provides an overview of existing research and its limitations.

Routines of MTSD use

Studies on MTSD use have generally indicated that adolescents use MTSDs as an integral part of their everyday life routines, but descriptive information on how they use MTSDs throughout the day and integrate this into their routines is still not exactly known. A few quantitative studies have examined timings of MTSD use in adolescents, and found that they used MTSDs almost throughout the whole day, with most common usage generally after school hours in mid or late afternoon and/or evening and night time. For example, a consumer study of Australian adolescents (n=1000, 14-17 years old) showed that smartphone and tablet use were reported across all the timings from early morning till night time, even in the middle of the night during supposedly sleeping hours (midnight to 6.59am) (Australian Communications and Media Authority 2016). The most common timing of smartphone and tablet use by adolescents was from evening till night time, i.e. 5pm to 9.59pm, for both smartphone and tablet; 45% and 23% of adolescents respectively reported using MTSDs at this time. Up to 19% also reported using MTSD from 10pm to midnight. Another large study with adolescents in South Korea (n=1824) also reported common use of smartphones in late afternoon/evening and night time, where 28.8% used it from 4pm to 8pm and 39.6% used it from 8pm to midnight (Cha and Seo 2018).

MTSD use by adolescents in school and while on the move, such as when commuting, waiting for transportation or when dining outside, were also reported by a few studies. In the above-mentioned study of Australian adolescents, 28% reported using smartphone/tablet from early morning till afternoon (7am to 4.59am), which likely overlapped with schooling hours (Australian Communications and Media Authority 2016). Another study conducted with Taiwanese adolescents (n=302) reported 15.6% using smartphone in class and 73.8% using them during recess time in school (Yang et al. 2017). The authors also found a high percentage of adolescents using smartphone while taking or waiting for transportation. A field study also observed adolescents engaging with their smartphones while eating in fast food restaurants (Radesky et al 2014). These studies have thus shown that adolescents commonly used MTSDs in school as well as whilst commuting or when outdoors.

In addition, studies on screen use in general have reported higher use during weekends than weekdays by adolescents (Devís-Devís et al 2009), and this is also similarly reported by a few studies that examined adolescents' MTSD weekday and weekend usage separately. For example, UK adolescents (12-15 years old) reported using smartphones for longer duration of 3 hours 12 minutes on a weekend day compared to 2 hours 24 minutes on a weekday (Ofcom 2017). Similarly, among Australian adolescents (10-19 years old), smartphone use was 114.6 minutes on a weekend day compared to 95.3 minutes on a weekday (Straker et al. 2018a). However, this group of Australian adolescents reported longer tablet use on a weekday (144.5 minutes) instead of on a weekend day (124.5 minutes), possibly due to tablet use during school lessons on weekdays. These findings have highlighted the difference in MTSD usage between weekdays and weekends and also possibly among device type. Weekend usage also may not be necessarily higher than weekdays, although weekends seem to offer more leisure time available for use.

Nonetheless, despite the above-mentioned findings, much is still not understood about how adolescents use MTSDs throughout the day and integrate into their daily routines. Studies on their routines of use throughout the day, including use at home, in school or outdoors, and weekday and weekend use of MTSDs are still quite limited. There is a lack of descriptive and qualitative information on routines of use. Gaining the perspectives of adolescents and their parents would help to provide a better understanding of the patterns of use by adolescents.

Bout length of MTSD use

Studies on the bout length of MTSD use, the typical duration of MTSD use each time, are scarce, especially in adolescents. Prior studies on computer use exposures suggest that it is important to consider the bout length of technology use as prolonged and continuous computer use has been shown to pose risks for musculoskeletal outcomes including pain, discomfort and musculoskeletal conditions (Galinsky et al. 2007, Henning et al. 1997, Menéndez et al. 2008).

Nonetheless, current research on MTSD use has focused mostly on the total amount of use per day or per week, instead of the typical duration of use before one stops using MTSDs or takes a break from using. Very few known studies to date have examined bout length of smartphone or tablet use. A survey of 77 adolescents (grade 11 or 12) who participated in a school tablet programme examined discomfort associated with continuous tablet use duration in sitting (bout length of 30, 60, 90 or 120 minutes), but no data on the percentage of use for each bout length duration were provided by the authors (Sommerich et al. 2007).

Another survey which was conducted with university students (n=2353, mean (SD) age=23.2 (4.5) years), examined bout length of smartphone use and found that it was significantly correlated with neck pain intensity and Neck Disability Index (Lee and Song 2014). Their findings also showed that most of the students used a smartphone for a bout length of 10 to 30 minutes each time (48.2%), while only 4.5% reported using their device for more than one hour each time. This study provided a glimpse of possible bout length use patterns among adolescents. However, patterns and preferences of MTSD use of adolescents are different from adults (Pew Research Center 2010, Verto Watch 2018). Bout length of MTSD use can have important implications on physical demands on adolescents, yet studies investigating bout length are still quite limited despite the high use of MTSDs among adolescents.

Types of activities on MTSDs

Most identified studies examined types of activities on overall screen technology use in general (Houghton et al. 2015, Mascheroni and Cuman 2014, Ofcom 2017), while only a few studies have examined the proportion or actual time spent on different types of activities by device type including smartphone and/or tablet use (Cha and Seo 2018, Kwok et al. 2017, Rideout 2015, Straker et al. 2018a). Current literature has showed that adolescents carried out a variety of activities on MTSDs, such as social networking, messaging/texting, playing games, watching shows/videos, browsing websites, or other general use such as taking photographs, checking directions on map or listening to music. Use of MTSDs for homework or school work was also commonly reported (Kwok et al. 2017, Rideout 2015, Straker et al. 2018a), with MTSDs increasingly being used in schools as part of the school curriculum to facilitate lessons (Clayton and Murphy 2016, Haßler et al. 2016).

Reported percentage and the amount of time spent were different among various types of activities, but social use including messaging/texting, gaming, watching shows/videos and browsing websites seemed to be generally more commonly used than other activities on MTSDs (Australian Communications and Media Authority 2016, Cha and Seo 2018, Kwok et al. 2017, Rideout 2015). For example, among Australian adolescents, use on MTSDs was highest for social networking (60%), followed by research browsing (55%), emails (52%), streaming videos (52%) and streaming music or radio (32%) among a list of several activities (Australian Communications and Media Authority 2016). Among adolescents in USA, social media (40%) and listening to music (40%) were the most common activity types on smartphone, followed by playing games (23%), watching videos (22%) and browsing websites (22%) (Rideout 2015). Another study with adolescents in South Korea reported highest mean (SD) daily use for internet (excluding for learning) (92 (66) mins/day), followed by messaging (86 (47) mins/day), gaming (85 (48) mins/day) and social networking (23 (16) mins/day). These studies have thus shown that adolescents commonly used MTSDs for social purposes, gaming, watching shows/videos and browsing websites, though various activities were performed on MTSDs.

A recent Australian study also showed that time spent on MTSD activities differed between weekdays and weekend. Tablet use duration for homework was higher while watching videos was lower on a weekday compared to a weekend day (Straker et al. 2018a). However, this usage data may not be representative of the population at large; this study was conducted with adolescents recruited from only one school where tablets were used as part of school lessons, hence possibly resulting in higher usage for schoolwork on weekdays.

From the review presented above, it is evident that the prevalence and amount of use for each type of activities on MTSDs are variable across studies. This might be due to use of different measurement methods of exposures for activities, types of activities being examined and population samples, making it hard to compare studies. Further research is still required on MTSD use exposures of various types of activities, including their separate use during weekdays and weekend, in adolescents.

Multitasking during MTSD use

The use of multitasking with multiple screen devices simultaneously, for example using a smartphone to message while in the midst of watching shows on the television at the same time, has become increasingly prevalent among adolescents (Cain et al. 2016, Rideout et al. 2010). Among 8 to 18 years old adolescents in USA, in 2009 29% of their technology use was spent multitasking with multiple devices, an increase from 16% in 1999 (Rideout et al. 2010). Prior studies have also shown that adolescents have a higher prevalence of multitasking with multiple devices than adults (Cain et al. 2016, Voorveld and van der Goot 2013), and they alternated between devices more frequently and more quickly than adults (Brasel and Gips 2011). However, the majority of current research on multitasking during technology use are focused on adults or university students, while studies examining the use patterns and nature of multitasking with multiple devices in adolescents are still limited (Cain et al. 2016, Carrier et al 2009). A prior study has also shown that adolescents who were users of high technology use and ownership were more likely to multitask with multiple devices (Rideout et al. 2010).

Among the limited studies examining multitasking in adolescents, one aspect of multitasking that has been commonly reported is the concurrent use of another device or non-device (e.g. paper) whilst doing homework or studying (Carrier et al 2015, Rideout 2015). This has gained attention as studies have shown potential negative associations with learning outcomes, academic performance and cognitive function as a result of this multitasking (Cain et al. 2016, van der Schuur et al 2015). A survey among adolescents in USA (n=2002, 8-18 years old) reported that 31% of adolescents multitasked "most of the time" with screen use (general use, non-specific of any device type) while doing homework or studying (Rideout 2015). Among these adolescents, common multitasking activities reported were listening to music (76%), messaging/texting (60%), watching television (51%) and social networking (50%).

However, most studies, including the Rideout (2015) study among USA adolescents, examined use of devices in general, instead of multitasking specific to device type. It may be likely that MTSDs are included in the more recent studies, but the extent and frequency of smartphone and tablet usage in multitasking by adolescents are still not known.

Given that MTSD use is high among adolescents today (Kwok et al. 2017, Pew Research Center 2018, Straker et al. 2018a) and the portability of MTSDs makes multitasking easy (Carrier et al. 2015), MTSD multitasking by adolescents would be expected to be considerable. It would therefore be useful to examine multitasking and activities during multitasking by device type, especially of MTSDs, to provide a better understanding of this pattern of use among adolescents. More qualitative information from adolescents' perspectives are also needed to provide rich information on the nature and preferences of their multitasking with MTSDs.

2.2.1.3 Age and gender differences in MTSD use among adolescents

Current evidence has demonstrated some age and gender differences in MTSD use among adolescents. Various studies have showed higher prevalence, amount of use and ownership of smartphone in older adolescents compared to younger adolescents (Kwok et al. 2017, Lauricella et al 2014, Ofcom 2017, Rideout 2015). For example, in UK adolescents, mobile phone use was higher among those 12 to 15 years old (approximately 18 hours/week) compared to those 8 to 11 years old (10 hours/week) (Ofcom 2017). Some studies have also showed increasing smartphone ownership with age in adolescents (Lauricella et al 2016, Ofcom 2017, Rideout 2015). For early adolescents, TV still occupied a major proportion of technology use. The higher smartphone ownership in older adolescents may have thus contributed to higher smartphone usage than the younger adolescents.

However, a few recent studies have suggested that MTSD use may vary across the ages or school grades of adolescents, and that it does not necessarily increase with increasing age (Coyne et al 2017, Straker et al. 2018a). A recent study of adolescents (n=924, 10-19 years old, grades 5 to 12) in Australia showed that the highest daily use of smartphone was at grade 11 instead of grade 12, and highest daily use of tablet was at around grade 6 to 8, suggesting that MTSD use may be different for each age group or grade (Straker et al. 2018a). Another 6-year prospective study of USA adolescents (n=425, 13 years old at baseline to 18 years old at end of follow-up) observed that mid adolescence (around 16 years old) was the period where their texting and social media use on mobile phones were the highest instead of during late adolescence (Coyne et al. 2017). As most studies to date tend to examine adolescents of a single age group or specific grades, such as early or late adolescents or primary or lower/upper secondary school level, current research on potential differences of MTSD use exposures across the age range of adolescents is limited.

There are also gender differences reported on the amount of use and types of activities on MTSDs by adolescents. Studies have generally found that smartphone use was significantly higher among girls than boys (Kwok et al. 2017, Rideout 2015, Straker et al. 2018a). For example, among adolescents aged 12 to 15 years old in UK, girls spent approximately 22 hours/week using their mobile phone, which is almost 50% higher than that by boys (15 hours/week) (Ofcom 2017). Many studies on general screen technology use have also reported that girls engaged more in social activities, while boys engaged more in playing games (Houghton et al. 2015, Lenhart 2015, Ofcom 2017, Pew Research Center 2018, Rosenberg et al. 2018). Only a few studies have, however, investigated gender differences in types of activities carried out on MTSDs by adolescents; these studies have similarly found greater use of social activities or texting and lower use of games on smartphone and/or tablet in girls than boys (Rideout 2015, Straker et al. 2018a). Girls were also found to use tablets more for homework than boys (Straker et al. 2018a).

Additionally, a recent study has also showed that gender differences also exist in types of activities on MTSDs across school grades (Straker et al. 2018a). This study analysed interactions amongst gender, grades and types of activities, and reported that girls had higher use of smartphones for social activities in grade 10 and 11, but not in grade 12, as well as higher use of tablet for watching videos in earlier grades but lesser in senior grades when compared to boys. From anecdotal evidence, the authors suggested that this might be due to girls reducing their MTSD use in senior grades so as to focus on academic studies and their major school leaving examinations in grade 12. The results suggest that there is a need to target guidelines for wise MTSD use specific to the types of activities that girls and boys may use at each school level. However, current evidence is limited and more studies are needed to find out the possible interactions between these variables.

Overall, current evidence shows that there are age and gender differences in MTSD use by adolescents, which could confound associations between MTSD use and outcomes. However, despite this, some studies to date did not adjust for age and/or gender when examining these associations; future studies on MTSD use and associated outcomes should thus consider age and gender as potential confounders.

2.2.2 Musculoskeletal symptoms in adolescents

The following section discusses literature relating to musculoskeletal symptoms among adolescents, i.e. bodily or physical pain or discomfort that may be experienced for example in the neck/shoulder, arms or back. A review of this literature will assist in understanding the issues and impact associated with musculoskeletal symptoms in adolescents, and the importance of identifying risk factors to mitigate the risk of having these symptoms. The prevalence, impact and age and gender differences of musculoskeletal symptoms in adolescents are reviewed below.

2.2.2.1 Prevalence of musculoskeletal symptoms in adolescents

Musculoskeletal symptoms are a major public health concern among adolescents, as they occur during a critical period of physical development (Feldman et al 2001, Jeffries et al 2007), and can result in increased risk for pain during adulthood (Brattberg 2004), or other negative outcomes such as limitations in daily activities, school absenteeism, reduced physical activity and increased financial costs (Kamper et al 2016).

There is a substantial proportion of adolescents who experience musculoskeletal symptoms or pain. This is well documented by in various general studies examining the prevalence of musculoskeletal symptoms in adolescents. Musculoskeletal symptoms in adolescents have been reported in general or by specific body regions, such as spinal regions and/or upper and lower extremities. For example, general musculoskeletal pain was reported by 32% of Finnish adolescents aged 9 to 12 years (El-Metwally et al. 2004). A literature review by Kamper et al. (2016) also found a similar prevalence of up to one third of adolescents reporting general musculoskeletal symptoms at least monthly.

For spinal or neck and back pain, some cross-sectional and prospective studies, as well as reviews, have been conducted in adolescents with variable prevalence rates reported. A small cross-sectional study of Malaysian adolescents (n=100; 8 and 11 years old) reported neck pain to have the highest lifetime prevalence of 37.3%, followed by upper back and low back pain (22.7% and 13.3% respectively) (Mohd Azuan et al 2010). Other larger cross-sectional studies have also found a high prevalence. In Poland, 67% of adolescents (n=986; 13 to 20 years old) reported having had back or neck pain at least once in their lives (Drozda et al 2011). In China, 29.1% of adolescents (n=2083; 10 to 18 years old) reported having had low back pain in the past 3 months (Yao et al 2011). Prospective studies by Dissing et al (2017) and Stahl et al (2008) showed baseline prevalence of 29% for spinal pain in the last 3 months in Danish children (n=1400; 8 to 15 years old), which was higher (71%) for neck pain. A comprehensive review of 56 epidemiological studies showed a wide range of spinal pain lifetime prevalence, ranging from 4.7% to 74.4% in adolescents (Jeffries et al. 2007).

Musculoskeletal symptoms in the upper and lower extremities have also been reported in adolescents, though they appeared to be less frequently documented than spinal pain. A 3-year prospective study found approximately 50% of Danish adolescents had lower extremity pain, and 25% had upper extremity pain for each of the study years (Fuglkjaer et al 2017b). A recent systematic review by Fuglkjaer et al (2017a) showed up to 32% point prevalence of upper and lower extremity symptoms among adolescents 10 to 19 years old. This review also found that lower extremity symptoms were more commonly reported than upper extremity symptoms.

Musculoskeletal symptoms in multiple locations, and not just in one body site have also been reported for a considerable proportion of adolescents. This was highlighted by a large cohort study of 15 to 16 years old adolescents (n=6986) in Finland, which found 23% of boys and 40% of girls reported musculoskeletal pain in at least three locations over the past 6 months (Paananen et al 2010). Another large cohort study in Norway also found pain at multiple locations to be fairly common among adolescents; 25.5% of adolescents aged 13 to 18 years (n=7373) reported pain weekly in the past 3 months in at least two locations (Hoftun et al 2011).

From the above-mentioned studies, it can be seen that there is variability in reported musculoskeletal symptom prevalence estimates. This could be due to various reasons, including different demographics, geographical locations and/or age groups of the participants, sampling methods, outcome measures used, prevalence period, case definitions and/or locations of reported symptoms (Kamper et al. 2016).

2.2.2.2 Impact of musculoskeletal symptoms in adolescents

Research on the impact of musculoskeletal symptoms in adolescents is limited when compared to research in adults (Fuglkjaer et al. 2017a, Kamper et al. 2016). This is likely due to the perception of musculoskeletal symptoms in adolescents being trivial - low intensity, self-limiting, short lasting and without as much detrimental impact as in adults (Drozda et al. 2011, Kamper et al. 2016, MacDonald et al 2017). However, existing studies, though limited, have revealed that musculoskeletal symptoms in adolescents can be debilitating and impact negatively on adolescents' daily activities and health. The Global Burden of Disease Study by World Health Organization (WHO) has revealed that musculoskeletal symptoms in adolescents are a global burden; low back and neck pain were ranked the 5th highest for Years Lived with Disability (YLDs) in adolescents aged 10 to 19 years, which was even higher than other well-recognised health issues in adolescents such as anxiety disorders and asthma (Global Burden of Disease Pediatrics Collaboration 2016).

In addition, some studies have also shown that musculoskeletal symptoms in adolescents can become persistent or chronic during adolescence and also even into adulthood (Kamper and Williams 2017). Holley et al (2017) reported that 35% of adolescents (n=88; 10 to 17 years) continued to have persistent pain 4 months after baseline measurement. Two other larger prospective studies by El-Metwally et al. (2004) and Stahl et al. (2008), also found a significant proportion of early adolescents (40% (n=403), 76% (n=1756) respectively) having persistent musculoskeletal pain at 4-year follow-up, with neck pain having the highest prevalence for persistent pain (El-Metwally et al. 2004). An even longer prospective study conducted by Brattberg (2004) followed pre and early adolescents (n=335; 8, 11 and 14 years old) for 13 years (from 1989 to 2002), and found that a substantial minority of them continued to have pain even during adulthood. Their analysis also demonstrated that back pain during childhood and adolescence was a significant predictor of pain during young adulthood.

Several surveys have also shown that a substantial proportion of adolescents with musculoskeletal symptoms experienced negative impact on their daily activities, including school, sporting and physical activities (Bejia et al 2005, O'Sullivan et al. 2012, Roth-Isigkeit et al 2005, Stommen et al 2012). A recent literature review has indicated that up to 51% of children with musculoskeletal symptoms (including adolescents) were absent from school, and up to 72% were limited in their participation in school or sporting activities (Kamper et al. 2016). Drozda and colleagues surveyed adolescents in Poland (n=1475) and found that physical activity (36%), learning/concentration (24%) and lifting of objects (30%) were the daily activities that were most impaired by back or neck pain (Drozda et al. 2011). Another survey of Norwegian adolescents (n=7373) also reported difficulties with daily activities during leisure time (60%) and sitting during school lessons (50%) (Hoftun et al. 2011). Impairments in daily activities were reported to be even greater for those with persistent chronic pain and/or higher pain intensity (Roth-Isigkeit et al. 2005). Consequently, these impairments on daily and physical activities could also pose increased risk for poorer quality of life and health problems such as obesity or other cardiovascular conditions (O'Sullivan et al. 2012, Paananen et al. 2010).

Other adverse outcomes reported to be associated with musculoskeletal symptoms in adolescents include psychological outcomes of such as anxiety or depression (Paananen et al. 2010, Palermo 2000), social outcomes such as limited social functioning and interaction with peers (Paananen et al. 2010, Palermo 2000, Roth-Isigkeit et al. 2005), or somatic outcomes such as eating or sleeping problems (Konijnenberg et al 2005, Roth-Isigkeit et al. 2005). Poorer family functioning was also implicated with studies reporting ongoing family difficulties and parents facing emotional distress from dealing with their child's chronic pain (Palermo 2000). Musculoskeletal symptoms have also resulted in adolescents needing to utilize health services and medication (Bejia et al. 2005, O'Sullivan et al. 2012), and creating a financial burden on the family and society at large (Ciccarelli et al 2016, Groenewald et al 2014).

As seen from the above-mentioned studies, a substantial proportion of adolescents experienced a range of adverse impacts associated with musculoskeletal symptoms. These impacts include restrictions on various aspects of their daily living, including school and physical activity, and their emotional, social and family functioning, as well as the need to seek medical care. Greater attention should therefore be given to musculoskeletal symptoms in adolescents, and further research be conducted on their associated risk factors.

2.2.2.3 Age and gender differences in musculoskeletal symptoms among adolescents

Besides being associated with MTSD use as aforementioned in section 2.2.1.3, age and gender differences have also been reported in musculoskeletal symptoms among adolescents. The prevalence of musculoskeletal neck/shoulder and back pain symptoms have been reported by several studies to increase with age in adolescents. Among surveys conducted with Australian (Straker et al. 2018a) and Danish adolescents (Aartun et al 2014), prevalence of neck/shoulder and back pain were found to increase with age during adolescence. Yang et al. (2017) reported that upper back and low back pain prevalence increased significantly with school levels among adolescents in Taiwan (n=302, 16 to >19 years old). Another large study of adolescents in China (n=2083) also reported higher prevalence of low back pain in the older age group of 15 to 18 years (38.2%) compared to younger ages of 10 to 14 years (21.5%) (Yao et al. 2011). Moreover, systematic reviews conducted have also found lifetime prevalence of spinal pain to increase steadily with age (Jeffries et al. 2007), and significant positive associations with the age of adolescents (Calvo-Munoz et al 2013).

However, a few studies have found no significant differences in the prevalence of musculoskeletal symptoms at distal upper extremity areas with increasing age in adolescents (Dissing et al. 2017, Yang et al. 2017). No significant differences were found in the prevalence of arms, wrist and fingers symptoms with increasing age among Danish adolescents (Dissing et al. 2017), as well as in the prevalence of elbow and wrist/hand symptoms with increasing school levels among Taiwanese adolescents (Yang et al. 2017).

Regarding gender differences, several studies have demonstrated a higher prevalence of musculoskeletal symptoms in girls than boys (Fuglkjaer et al. 2017b, O'Sullivan et al. 2012, Queiroz et al. 2017, Shan et al. 2013, Yang et al. 2017). However, a few other studies have indicated that the prevalence was higher in boys than girls (Mohseni-Bandpei et al 2007) or found no significant differences between the genders (Calvo-Munoz et al. 2013, Yao et al. 2011), so findings on gender differences in prevalence of musculoskeletal symptoms in adolescents are not entirely conclusive.

Some studies which examined musculoskeletal symptoms in general (without specifying by body regions) found that more girls than boys reported general musculoskeletal symptoms (59% versus 47%) (Queiroz et al. 2017) and chronic musculoskeletal pain (54% versus 34%) (Hoftun et al 2012). Prevalence of spinal pain was also found to be higher in girls than boys by several studies. Shan et al. (2013) conducted a large study of adolescents in China (n=3016, 15 to 19 years old) and reported that girls had significantly higher odds of having neck/shoulder and low back pain compared to boys (OR 1.29, 95% CI 1.11;1.51, OR 1.30, 1.10;1.52 respectively). Moreover, higher prevalence of low back pain in girls than boys (26% versus 13%) was reported in a large study of Australian adolescents (n=1288, 17 years old) (O'Sullivan et al. 2012). A similar pattern of higher prevalence in girls than boys for upper back pain was also reported in another study of Taiwanese adolescents (n=315, 16 to >19 years old) (Yang et al. 2017), as well as for upper extremity pain (shoulder, elbow, arms, wrist/hand/fingers) among Danish adolescents (n=1917, 8 to 14 years old) (Fuglkjaer et al. 2017b).

Conversely, a survey of Iranian adolescents (n=5000, 11 to 14 years old) reported that the prevalence of low back pain in the past 6 months and one year were higher in boys than in girls (Mohseni-Bandpei et al. 2007). No gender differences in the prevalence of low back pain in the past 3 months between girls and boys were found among adolescents in China (n=2083, 10 to 18 years old) (Yao et al. 2011). A meta-analysis of studies in children (≤18 years old) also found no significant gender differences in their low back pain lifetime prevalence (Calvo-Munoz et al. 2013).

Overall, current evidence shows that there are age and gender differences in musculoskeletal symptoms among adolescents, although some of the findings on these differences are mixed. The mixed findings may be due to different outcome measures, study designs, prevalence period of symptoms or age group of participants. It is therefore important to consider age and gender as potential confounders when examining associations between musculoskeletal symptoms and MTSD use.

2.2.3 Associations of MTSD use and patterns of use with musculoskeletal symptoms in adolescents

Emerging studies have showed that MTSD use is associated with musculoskeletal symptoms in adolescents (Queiroz et al. 2017, Straker et al. 2018a, Yang et al. 2017). This is also suggested by prior studies indicating associations between the use of desktop/laptop computer and/or electronic game consoles, and musculoskeletal symptoms in adolescents (Hakala et al. 2006, Silva et al. 2016). Given the high prevalence of MTSD use and the undesirable consequences of musculoskeletal symptoms in adolescents, an understanding of the relationships between their use and musculoskeletal symptoms is important. However, musculoskeletal outcomes of MTSD use have not been examined much as compared to other outcomes such as psychosocial or somatic outcomes (Yang et al. 2017).

The earlier section 2.1 has provided a systematic review on MTSD use and musculoskeletal exposures and symptoms across all ages. To date, only a few studies, including a few recently published epidemiological studies, have examined MTSD use and musculoskeletal symptoms specifically in adolescents. This section will evaluate these studies and provide an overview of the associations of MTSD use and patterns of use with musculoskeletal symptoms in adolescents below.

2.2.3.1 Associations of MTSD use with musculoskeletal symptoms in adolescents

Smartphone and/or tablet use had been found to be significantly associated with musculoskeletal symptoms in adolescents by a few studies (Kwok et al. 2017, Queiroz et al. 2017, Shan et al. 2013, Straker et al. 2018a). A study by Straker et al. (2018a) of Australian adolescents (n=924, grade 5 to 12, 10-19 years old) found higher smartphone use (hours/day) to be significantly related with increased odds of neck/shoulder and low back symptoms (OR=1.13, 1.09 respectively), and higher tablet use (hours/day) to be significantly related with neck/shoulder symptoms (OR=1.07), after adjusting for age and gender. In this study, approximately 50% of adolescents reported symptoms at neck/shoulder, 35% at low back and 30% at upper limb. The frequency and duration of MTSD use exposures, along with other devices, were measured with a questionnaire that had good test retest reliability and face validity. However, their sample consisted of adolescents from only one school, hence sample and thereby results might not be representative of the broader adolescent population. The overall percentage of device use was the highest for TV (97.6%), followed by tablet (95.4%), smartphone (91.3%), laptop (81.7%), desktop (77.5%) and game consoles (<62.6%). Nevertheless, daily use of MTSDs dominated against the other devices, with the highest mean use (SD) of 139.0 (147.0) mins/day for tablet and 100.2 (141.3) mins/day for smartphone.

Another study by Kwok et al. (2017), which recruited 960 adolescents (primary and secondary students from grade 5 to 12, 10-19 years old) from several schools in Hong Kong via convenience sampling, also found that higher MTSD use duration (smartphone and/or tablet combined) was associated with similar higher odds of having musculoskeletal discomfort (among secondary but not primary students) (OR=1.15 (0.99-1.34)). The majority of participants (85.9%) were daily MTSD users, with approximately 65% using MTSD in the last week for >2hours/day. A relatively high prevalence of general musculoskeletal discomfort (specific body regions not measured) was also reported, with over 37% reporting discomfort on at least one day in the last week. This study however, did not adjust for important confounders such as age and gender, but conducted regression analysis separately for primary and secondary students. They also did not indicate the reliability and validity of the questionnaire used which could affect the accuracy of outcomes measured and in turn the results obtained. Additionally, they measured MTSD use duration as a whole in the questionnaire, hence associations specifically with smartphone or tablet use alone are unknown.

A few other studies also found the use of MTSDs to be significantly associated with musculoskeletal symptoms in adolescents, but in contrast to results from the above-mentioned studies, studies did not show any associations between use duration with symptoms (Queiroz et al. 2017, Shan et al. 2013). Shan and colleagues conducted a large survey in China (n=3016, 15 to 19 years old) with adolescents recruited via convenience sampling from several schools, and found significant associations between the use of a tablet (OR=1.31 (1.12-1.54)), but not tablet use duration, with neck/shoulder pain after regression analysis controlling for age and gender. The authors measured use exposures with limited categories of use duration in the questionnaire - maximum usage of >2 hours/day when MTSD use per day had been reported to be much longer than 2 hours (Ofcom 2017, Rideout 2015). This would have thus limited the range of use duration measured and affected detection of possible associations of use duration with symptoms. A smaller survey by Queiroz et al. (2017) conducted with adolescents from a school in Brazil (n=299), found that the percentage who used a mobile phone was significantly higher in participants with musculoskeletal pain in the last 3 months (93%) than those without musculoskeletal pain (81%). Despite this no differences in the median use duration (hours/day) was found between the two groups. However, their findings only suggest possible associations between mobile phone use and musculoskeletal symptoms as regression analysis was not carried out. These two studies also have other limitations including convenience sampling. Their results thus may not represent the adolescent population at large, even if the sample size is large (Tyrer and Heyman 2016). Use exposures were also measured with limited categories of use duration, without obtaining frequency of use and/or separate weekday and weekend usage, hence actual daily use across the week may not have been accurately portrayed.

On the other hand, results from a few other cross-sectional studies suggest no significant associations between MTSD use and musculoskeletal symptoms (Cha and Seo 2018, Yang 2016). For example, a study of 302 students from a junior college school in Taiwan (16 to >19 years old) found that weekend smartphone use duration (hours/day) was not significantly related to musculoskeletal discomfort at any of the body regions in the last 6 months (Yang 2016). No important confounders such as age and gender were adjusted for despite their known associations with musculoskeletal symptoms (Harris et al 2015a, Jeffries et al. 2007). Another larger study by Cha and Seo (2018) of 1824 middle school students in South Korea (13-15 years old) examined several outcomes including musculoskeletal symptoms between smartphone 'addicted' and 'non-addicted' adolescents instead. High overall mean use (SD) of smartphone (290 (107) mins/day) was reported among the students. No differences in the percentage of adolescents with pain at neck/wrist/back were found between adolescents who were at high risk of addiction and those who were not. There were also limitations in these studies such as convenience sampling, reliability and validity of questionnaires not indicated, limited categories of use duration, and frequency of use not being captured.

Overall, current evidence on associations between MTSD use and musculoskeletal symptoms in adolescents is still limited, with a few studies suggesting MTSD use poses a risk for musculoskeletal symptoms while a few other studies have shown otherwise. There are also various limitations, as mentioned above, that limit the quality of existing studies and generalizability of their results. The varied study objectives, measurement of MTSD use exposures and musculoskeletal symptoms with different prevalence periods, and analysis methods may have also contributed to the inconsistency of results. Most importantly, existing studies were cross-sectional in design, which are unable to determine the temporal associations between MTSD use and musculoskeletal symptoms in adolescents. It is therefore important to address these limitations by research which endeavours to: obtain a representative sample, ensure reliability and validity of measures used, adjust for important confounders and conduct longitudinal studies. Such research will enable a more thorough understanding of the relationship between MTSD use and musculoskeletal symptoms.

2.2.3.2 Associations of patterns of MTSD use with musculoskeletal symptoms in adolescents

Associations between musculoskeletal symptoms from patterns of MTSD, in addition to the duration of MTSDs use, are also important areas that should be examined. This would allow a greater understanding on the relationships between various aspects of MTSD use exposures (bout length of use, types of activities, multitasking) and musculoskeletal symptoms. However, the majority of the studies have tended to focus on examining outcomes associated with MTSD use/non-use or use duration. Studies to date on the associations between patterns of MTSD use and musculoskeletal symptoms are scarce. Only a few recent studies have attempted to examine patterns of MTSD use in relation to musculoskeletal symptoms in adolescents.

Associations between MTSD bout length of use (the typical amount of usage each time) and musculoskeletal symptoms were examined in an older study of adolescents (n=77) who participated in a tablet programme in school (Sommerich et al. 2007). The amount of time (i.e. 30, 60, 90 or 120 minutes) that they sat continuously using a tablet was not significantly correlated with musculoskeletal neck, upper lower back or hand/wrist discomfort. This is in contrast to findings from a survey conducted with young adults (n=2353) in South Korea, where significant positive correlations were found between bout length of smartphone use (not limited to any posture) and neck pain intensity (Lee and Song 2014). The study by Sommerich et al. (2007) examined bout length limited to sitting posture instead, which might have contributed to differences in the findings between these studies. MTSD use postures are likely much more variable considering its portability (Liang and Hwang 2016, Werth and Babski-Reeves 2014). More studies with a larger sample size and bout length in relation to musculoskeletal symptoms, with consideration that use may be in varied postures, are needed.

With regards to types of activities on MTSDs, two recent studies found differential risks of certain types of activities for musculoskeletal symptoms in adolescents (Kwok et al. 2017, Yang et al. 2017). The study by Kwok et al. (2017) of 960 students (10-19 years old) recruited from schools in Hong Kong examined use of MTSD as a whole (smartphone and/or tablet combined) for leisure, study, messaging, posting, gaming, watching

TV/movies and browsing and their relationships with general musculoskeletal discomfort. Their findings revealed that greater time spent on watching TV/movies and browsing were significantly associated with higher odds of general musculoskeletal discomfort in the last week among secondary students (OR=1.29 (1.17-1.41) and 1.36 (1.12-1.64) respectively). However, greater time on gaming was associated with *lower* odds of musculoskeletal discomfort in the last week instead (OR=0.65 (0.48-0.88) among primary students, 0.83 (0.73-0.94) among secondary students). No significant associations were found for the other activities with discomfort.

Differential risks for musculoskeletal symptoms from types of activities on smartphone were also shown in another study by Yang et al. (2017) of 302 adolescents (16 to >19 years old) in Taiwan. The study found that the subgroup of adolescents who made phone calls for >3 hours/day on a smartphone had significantly higher odds of upper back discomfort (OR=4.34 (1.10-17.11)), but *lower* odds of wrist/hands discomfort (OR=0.27 (0.08-0.90)) than those who did this for <1 hour/day. Adolescents who used ancillary functions longer for 1-3 hours/day also had lower odds of lower back discomfort than those who used <1 hour/day (OR=0.31 (0.12-0.83)). It was not clearly stated what activities “ancillary functions” referred to, only that they may include games, photography or music. This study also examined texting but found no significant associations with discomfort at any of the body regions.

Therefore, though very limited, current evidence suggests that types of activities on MTSDs may pose different risks for musculoskeletal symptoms, even at different body regions in adolescents. This might be due to different behaviours of use and/or biomechanical demands (Kwok et al. 2017, Xie et al. 2017, Yang et al. 2017). Again, these studies are limited with the use of convenience sampling, limited categories of use duration for activities on MTSDs and lack of adjustment for important confounders. Much remains unknown and further research is required to elucidate the relationships between different types of activities and musculoskeletal symptoms.

Current research on the relationships between multitasking during MTSD use and musculoskeletal symptoms is scarce. A recent survey examined simultaneous use of at least two electronic devices - computer, electronic game (on mobile handheld devices including MTSDs), mobile phone and/or TV, and their associations with musculoskeletal pain in the last 3 months in a sample of 299 adolescents (10-19 years old) in Brazil (Queiroz et al. 2017). The percentage of adolescents who had simultaneous use of at least two devices was significantly higher in those with musculoskeletal pain than those without pain. This finding suggests that the use of multitasking with multiple devices including MTSDs may pose risks for musculoskeletal symptoms. However, the mechanisms behind the associations are still unknown; further research with higher quality studies is needed to better understand the nature of multitasking and possible associations with symptoms.

In summary, these findings suggest that patterns of MTSD use, i.e. bout length, types of activities and multitasking may influence the risk for musculoskeletal symptoms. However, there is still a paucity of research on the associations of such patterns of use with musculoskeletal symptoms in adolescents. The nature of patterns of MTSD use and their impact on musculoskeletal health are still not exactly known.

2.2.4 Associations of MTSD use with visual health in adolescents

With the increasing use of MTSDs among adolescents, concerns of visual symptoms and myopia from inappropriate or excessive MTSD use have been raised. Prior studies have reported relatively high prevalence of visual symptoms, which commonly include dry eyes, eye strain, double vision, redness of eyes and eye fatigue (Kim et al 2016, Sheppard and Wolffsohn 2018, Vilela et al 2015a). A systematic review of available studies found prevalence of eye strain ranging from 12.4% to 32.2% among children aged 5 to 19 years old (Vilela et al 2015b). Myopia is also a common visual problem among adolescents; a systematic review has reported an increase in myopia prevalence over time in children, and a high prevalence of up to over 80% in urbanized Asian countries such as China and Singapore (Rudnicka et al 2016). These visual health outcomes can cause discomfort and potentially impact on learning and school performance (Sheppard and Wolffsohn 2018, Vilela et al. 2015b), as well as pose risk for eye-related developmental problems (Akinbinu and Mashalla 2014) and age-related macular degeneration in adolescents (Tosini et al 2016). In this section, an overview of current research on the associations of MTSD use with visual symptoms and myopia in adolescents will therefore be provided below.

Regarding *visual symptoms*, extensive research has been conducted on computer use, with studies showing associations between computer use and visual symptoms (Akinbinu and Mashalla 2014, Sheppard and Wolffsohn 2018). Visual symptoms related to computer use or other electronic devices are also collectively referred to as computer vision syndrome or digital eye strain (Gowrisankaran et al. 2015, Sheppard and Wolffsohn 2018). Despite pervasive use of MTSDs among adolescents, however, research on MTSD use and visual symptoms are limited and mostly conducted with adults or college students (Sheppard and Wolffsohn 2018, Vilela et al. 2015b).

Although limited, the few studies conducted with adolescents have generally showed that smartphone or tablet use were associated with visual symptoms (Kim et al. 2016, Kwok et al. 2017, Straker et al. 2018a). Kim et al. (2016) carried out a survey with adolescents in South Korea (n=715, mean age 15 years) to examine the associations between various exposures of smartphone use (i.e. daily use duration, intermittent (≤2hours bout length) or continuous use (>2 hours bout length), and lifetime use) and visual symptoms (i.e. total of seven symptoms comprising blurring, redness, visual disturbances, secretion, inflammation, lacrimation and dryness). Their study showed that adolescents who used a smartphone daily for longer duration either intermittently (>2 hours/day and ≤2hours bout length) or continuously (>2 hours/day and >2 hours bout length), had more than two times higher odds of having multiple visual symptoms compared to those who used for shorter duration (<2 hours/day). Moreover, lifetime smartphone use (>12 lifetime hours, obtained by multiplying daily use hours by years of smartphone use) were also found to be associated with higher odds of having multiple visual symptoms (OR=3.05 (1.51-6.19)).

Another cross-sectional survey of Australian adolescents (n=924, mean age 14.7 (SD=2.7) years) has also similarly showed associations between MTSD use and visual symptoms (Straker et al. 2018a). In this study, a total of nine visual symptoms were examined which comprised of eye dryness, eye irritation and other symptoms of computer vision syndrome (not specified). Results from the study showed that more hours/day of smartphone or tablet use significantly increased the odds of having higher number of visual symptoms (OR=1.07 and 1.10 respectively (95%CI not specified), $p<.05$), after adjusting for gender and school grade. Such associations between MTSD use and visual symptoms could be due to reduced amount of blinking during screen viewing (Sheppard and Wolffsohn 2018), eye muscles working harder to focus on near distance use of MTSDs (Akinbinu and Mashalla 2014) or electromagnetic fields and radiation emitted from MTSDs causing oxidative stress in corneal and lens tissues (Balci et al 2007, Choi et al 2018), thereby leading to visual symptoms such as dry eyes and eye strain.

Moreover, findings from a recent study also suggest that types of activities on MTSDs may pose differential risks for visual symptoms in adolescents (Kwok et al. 2017). This study examined the relationships between MTSD use (smartphone/tablet combined) and eye discomfort (no specific visual symptom examined) among adolescents in Hong Kong (n=960, mean age 13.8 (SD=1.9) years). Among secondary students, greater time spent on browsing internet and watching TV/movies were found to be associated with higher odds of having eye discomfort (OR=1.20 (1.04-1.38) and 1.09 (1.01-1.18) respectively). On the other hand, greater time spent on messaging was associated with lower odds for eye discomfort (OR=0.88 (0.80-0.97)), possibly due to intermittent use of MTSDs during messaging which reduced the strain on eyes. Nonetheless, further studies are needed to elucidate the relationships between more detailed exposures of MTSD use and visual symptoms in adolescents. There is also a need for longitudinal studies to determine the temporal relationships between them.

Regarding *myopia*, several factors including genetic and environmental factors have been suggested to play a role in its development. Near work activities, including use of devices such as TV and/or computers, and reading and writing on print, have been identified as an environmental risk factor for the development and progression of myopia (Cooper and Tkatchenko 2018, French et al 2013, Huang et al. 2015). This suggests that MTSD use, which is also a near work activity, may pose a risk for myopia. For example, a 5-6-year longitudinal study (n=2103, two cohorts of 6 and 12 years old at baseline) of Australian adolescents reported near work activities of TV, computer use and reading were significant risk factors for incident myopia, though only in the younger cohort but not in the older cohort (French et al. 2013). Time spent outdoors was also examined and found to be negatively associated with incident myopia in both cohorts. Moreover, a meta-analysis of available studies reported greater time spent on near work activities (comprising mostly of TV, computer and/or video game use, reading and/or studying on print) was associated with having higher odds of myopia (OR=1.14 (1.08-1.20)); greater time spent on near work might therefore increase the prevalence of myopia (Huang et al. 2015). As found from animal studies, this association might be due to the visual lag of accommodative response to near distance viewing, which produces optical blur that may have in turn driven excessive eye growth to cause myopia (Cooper and Tkatchenko 2018, Ramamurthy et al. 2015a).

Conversely, some studies have showed no significant effect of near work activities on myopia in adolescents. A cross-sectional study of 2353 12-year-old adolescents in Australia found no significant associations between near-work activities and myopia (Ip et al 2008). Similarly, in another one-year prospective study of adolescents in the USA (n=835, 6 to 14 years old), near work activities (studying, reading, computer and video game use) and the amount of time spent on them were not associated with myopia progression (Jones-Jordan et al 2012). Among adolescents living in city (n=386, 6 to 17 years old) (Lin et al 2014) and rural areas (n=878, 6 to 18 years old) (Lin et al 2017) in China, near work activities were also found not to be associated with myopia. Near work activities examined in these studies also comprised mostly reading, studying, computer and/or video game use, with handheld computers included only in the recent study (Lin et al. 2017). There are therefore some inconsistencies on the relationships between near work activities and myopia in current research. Recent evidence has, however, consistently showed that less outdoor time spent is a significant environmental risk factor for myopia (Sherwin et al 2012, Xiong et al 2017). Outdoor time may also be inversely related to near work activities and have a direct protective effect on the risk of having myopia (Lin et al. 2014, Ramamurthy et al. 2015a, Xiong et al. 2017), though further research is still required on the interplay between outdoor time and near work activities.

Another limitation of current research on myopia is that most studies examined near work activities which comprised use of traditional electronic devices such as TV and computers, and/or reading and studying on print (Huang et al. 2015). Studies examining the link between myopia and MTSD use (either solely or included their use as part of near work activities being examined) are limited, and therefore associations between MTSD use and myopia are still not exactly known in adolescents. With MTSD use occupying a large proportion of electronic device use and near work activities for adolescents today, more studies on the relationships between MTSD use and myopia are needed.

2.2.5 Summary of literature review on adolescents

In summary, this section of the literature review focused on evidence of associations between MTSD use and musculoskeletal and visual health outcomes in adolescents. Whilst there is evidence generally showing a high prevalence of MTSD use, as well as a high prevalence of musculoskeletal symptoms and visual health outcomes among adolescents, there is limited evidence (including a lack of longitudinal studies) that MTSD use, and various aspects of its use such as patterns of use, are associated with symptoms. There is also a lack of research from the perspectives of adolescents and parents of adolescents on these issues.

Chapter 3 Study A1: Qualitative study on the patterns of MTSD use by adolescents

This Chapter presents results from the qualitative study on patterns of MTSD use by adolescents, including routines, types of activities and multitasking, as well as the rules, restrictions and concerns from parents/caregivers. Semi-structured interviews were conducted with adolescents and their parents to obtain their perspectives on adolescents' MTSD use. Findings from this study have been published and are presented verbatim in this chapter. Full reference of the paper:

> Toh SH, Howie EK, Coenen P, Straker LM (2019) "From the moment I wake up I will use it...every day, very hour": A qualitative study on the patterns of adolescents' mobile touch screen device use from adolescent and parent perspectives. *BMC Pediatrics* 19: 30.

Ethics approval for this study has been obtained from Curtin University Human Research Ethics Office (RDHS-77-15) (Appendix L). Information sheet and informed consent/assent forms were given and obtained from the participants (Appendix M and N). A recruitment flyer was used to recruit participants (Appendix O). As a token of appreciation for participating in the study, a handout on tips and advice for wise use of technology, such as on appropriate sitting postures and avoiding sustained postures, was given to all the participants (Appendix P).

3.1 Introduction

In the past few years, there has been a surge in the ownership and usage of mobile touch screen devices (MTSD) among adolescents (Australian Communications and Media Authority 2016, Ofcom 2017, Rideout 2015). MTSDs refer to portable electronic devices in which users interact with a touch sensitive screen interface using their digits or a stylus pen, specifically smartphones and tablet computers (Toh et al. 2017). Several recent large surveys have reported higher prevalence and amount of MTSD use among adolescents compared to traditional electronic devices such as television, desktop or laptop computers (Lauricella et al. 2014, Ofcom 2017, Rideout 2015, Robb et al 2017). This prevalence of use may be due to increased ownership, portability, ease of accessing the internet, and a variety of other functions such as social networking, gaming and shows/videos offered by MTSDs (Australian Communications and Media Authority 2016, Lauricella et al. 2016, Rideout 2015). Furthermore, MTSDs can also offer other benefits such as delivering health information or interventions (telehealth) (Lee et al 2018a), building family time and connectedness (Sarah et al. 2014), or improving ease of communication and motivation in learning (Hwang and Wu 2014), which may further facilitate increased use. However, this increased use has also raised concerns among parents, researchers and educators about its potential negative impact on adolescents' mental, social and physical well-being and development, such as depression (Jean et al. 2017), adverse family relationships (Kwok et al. 2017), cyberbullying (Vaillancourt et al 2017), poor sleep quality (Fossum et al 2014, Hale and Guan 2014), sedentariness (Straker et al. 2016), musculoskeletal symptoms (Shan et al. 2013, Straker et al. 2018a) and visual symptoms (Straker et al. 2018a).

To date, research on adolescents' MTSD usage has mostly focused on the prevalence and/or duration of use, with a lack of in-depth reporting on the patterns of MTSD use, including routines, types of activities, breaks taken and nature of multitasking. Although several studies have reported that many adolescents use MTSDs frequently (Lauricella et al. 2014, Ofcom 2017, Rideout 2015, Robb et al. 2017), and commonly at night or before sleeping (Brambilla et al. 2017, Carter et al. 2016), little is known about adolescents' daily routines of using these devices, which can be affected by different types of day (e.g. weekdays versus weekend, school days versus holidays) or settings (e.g. home versus school). Another not well understood pattern of use is the nature and extent of multitasking during MTSD use. Adolescents use MTSDs for a variety of activities such as social media, messaging, gaming or video watching (Australian Communications and Media Authority 2016, Lenhart 2015), but research on how they perform and/or switch between these activities is limited. Different patterns of MTSD use, such as the type of activities or nature of multitasking, may also vary risks for various negative outcomes. For example, some studies found associated adverse outcomes of eye discomfort with video watching (Kwok et al. 2017), and disrupted learning, sleep and reduced productivity with multitasking (Cardoso-Leite et al 2015). Therefore, it is important to examine in-depth the various patterns of use, to allow a better understanding of adolescents' use of MTSDs.

Rules or restrictions from parents have been shown to help mediate adolescents' technology use (Pew Research Center 2016a, Ramirez et al 2011, Vaala and Bleakley 2015).

Most of the research, from quantitative and/or qualitative studies, has examined parental rules or restrictions for television (Nathanson 2001, Warren 2001), internet use (Martínez de Morentin et al 2014, Symons et al 2017, Vaala and Bleakley 2015) or technology use in general (Kostyrka-Allchorne et al 2017, Pew Research Center 2016a, Shin and Li 2017). Parental rules and restrictions for MTSDs may, however, be different from the traditional devices. There may be different challenges posed in view of greater portability and pervasive use of MTSDs (Robb et al. 2017), and possibly different parental concerns on adolescents' use of MTSDs (Ofcom 2017, Pew Research Center 2016a). Hence, it is important to examine parental rules or restrictions and concerns to understand the family context.

Moreover, there is limited qualitative research on adolescents' MTSD use. Qualitative studies are important as they can provide rich detailed information on adolescents' use of MTSDs, which survey research is not able to provide (Rideout 2016). Therefore, this study will adopt qualitative methods to explore perspectives from adolescents and parents in Singapore on (i) the patterns of MTSD use by adolescents including routines, type of activities, breaks and multitasking and (ii) the rules, restrictions and concerns from parents/caregivers on adolescents' MTSDs use. Whilst the focus of this study was the perspectives from adolescents on their MTSD use, perspectives from their parents were also sought in order to provide triangulation and to give greater context to data obtained from adolescents (Carter et al. 2014). Any agreement or disagreement on perspectives between adolescent and his/her parent were also identified. Information gained from this study will allow a better understanding and deeper insights into adolescents' MTSD use, which can help parents, educators, policy makers and researchers to develop strategies to support wise use of MTSDs by adolescents.

3.2 Methods

3.2.1 Recruitment and participants

Adolescents and their parents/caregivers (from the same families) were recruited together, via convenience sampling through personal contacts and advertisements on social media and forums in Singapore. Inclusion criteria for adolescents were: aged 11 to 18 (inclusive) years old, used any type of MTSDs, and could speak English. Recruitment was also carried out to ensure adolescents from both genders and across age groups of 11 to 12, 13 to 15 and 16 to 18 years old were represented. Participation of parents/caregivers was not a prerequisite for participation by the adolescents. Ethics approval for this study had been obtained from Curtin University Human Research Ethics Committee (RDHS-77-15). For adolescents aged 11 to 17 years, written informed parental consent and written youth assent were obtained. For adolescents aged 18 years, youth consent was obtained. Written consent was also obtained from the parents/caregivers. Recruitment continued until data saturation occurred, when no new information was being obtained across three consecutive interviews (Francis et al 2010, Greg et al 2006).

3.2.2 Interviews

Semi-structured interviews were conducted during June to September 2016, with both adolescents and their parents/caregivers by one of the authors (SHT) who had received training on interviews for qualitative research prior to the study. Interviews were conducted based on an interview guide with question prompts (see Appendix L). For adolescents, questions covered types and ownership of MTSDs used, types of activities carried out, routines of use on weekdays and weekends, breaks taken, multitasking, perception of amount of usage and parental rules or restrictions. For parents/caregivers, questions covered amount of usage, rules or restrictions and concerns about their adolescent's MTSD use. Demographics such as race, type of housing and parents' education level (as proxy socioeconomic statuses) were also obtained. The semi-structured format was adopted as it allowed for discussion of new topics raised by participants and for any nuances to be pursued (Cohen and Crabtree 2006).

Interviews were conducted individually with each adolescent and his or her parent/caregiver in English. Attention was given to ensure that adolescents and parents were not in the same room during each other's interviews. The majority of the interviews were carried out in participants' homes with another location (e.g. restaurant, café or parent's workplace) used if it was not convenient to conduct the interviews at the participant's home. Most of the interviews lasted approximately 30 minutes (range: 20 to 55 minutes) with each adolescent and 15 minutes (range: 10 to 35 minutes) with each parent/caregiver.

3.2.3 Data analysis

With permission from participants, each interview was audio-recorded and transcribed verbatim by the first author. Transcripts were coded independently by one of the authors

(SHT) and reviewed by another author (EKH), using NVivo 11 software based on areas of research questions, i.e. patterns, routines, rules and restrictions and concerns of adolescents' MTSD use. Coding for each adolescent's transcript was done first, followed by his or her own parent/caregiver's transcript. Adolescent and his or her parent/caregiver's transcripts were then compared for triangulation of data (Carter et al. 2014), and separate codes on any agreement and/or disagreement between adolescents and their parent/caregiver were generated. Thematic analysis was carried out with themes generated from the codes using an inductive approach. The research questions set the broad areas for analysis, and coding and theme generation were refined throughout the analysis period (Braun and Clarke 2006, Vaismoradi et al 2013). All themes were reviewed and discussed by all the authors, and differences in interpretation were resolved.

3.3 Results

3.3.1 Participant demographics

In total, 36 adolescents and 28 parents/caregivers (n=27 parents, n=1 caregiver) (from the same families) were recruited and interviewed. The mean age of adolescents was 14.2 (2.3) years. The number of parents/caregivers were less than the number of adolescents as four pairs of adolescents were siblings with another participant and their parents were interviewed once regarding both siblings. Four of the parents were not interviewed as they did not speak English. Demographics of adolescents are presented in Table 3.1.

Table 3.1 Adolescent participant demographics (n=36)

Characteristic		Participants n, (%)
Age range		
	11 to 12 years	11 (31)
	13 to 15 years	14 (39)
	16 to 18 years	11 (31)
Schooling level		
	Primary school	11 (31)
	Lower secondary school	11 (31)
	Upper secondary school	6 (17)
	Post-secondary school	8 (22)
Gender		
	Male	16 (44)
	Female	20 (56)
Race		
	Chinese	27 (75)
	Malay	5 (14)
	Indian	3 (8)
	Others	1 (3)
Type of housing		
	2/ 3 room HDB[1] flat	4 (11)
	4 room HDB[1] flat	8 (22)
	5 room HDB[1]/ executive HDB[1] flat	13 (36)
	Private housing	11 (31)
Father's highest education level	Primary	0 (0)
	Secondary	8 (22)
	Post-secondary	25 (69)
	Don't know	3 (8)
Mother's highest education level	Primary	2 (6)
	Secondary	10 (28)
	Post-secondary	22 (61)
	Don't know	2 (6)

[1]HDB: Housing Development Board (public housing), with increasing size related to ascending socioeconomic status, and private housing being higher status than HDB housing

3.3.2 Themes

The analysis yielded several themes which were organized by the research questions into four overall themes, with the first theme being the types of MTSDs used and owned. The second theme explored patterns of how adolescents use MTSDs and incorporate use into their daily routines. The third theme explored functional, personal and external factors that influence adolescents' use of MTSDs. The last theme was about concerns on MTSD use.

Themes and their sub-themes are presented in detail and supported with quotes from adolescents (A) and parents (P) below. Adolescents and their parents agreed on most aspects of MTSD use, except on certain influences and concerns of use where quotes from parents were also presented.

3.3.2.1 Types of MTSDs used and owned

Smartphones were the most frequently used MTSD and were used by all adolescents. Tablet computers were used by some, and a touch screen iPod was used by one adolescent. Some used multiple MTSDs - both smartphone and tablet or more than one smartphone. Almost all adolescents owned a smartphone and used it daily, except a few younger adolescents (in primary school; 11-12 years old) who did not have their own as their parents did not allow them to have one. They usually sought permission from their parents and borrowed their smartphones to use instead.

For most adolescents, a tablet computer was used much less frequently than a smartphone, usually once or a few times per week or month. Most did not have their own tablet and used a tablet that was shared with either parents or siblings. Some adolescents did not use a tablet as much as a smartphone as they felt that a tablet had fewer functions, was harder to use for messaging and social media and also less portable than a smartphone. They usually used a tablet as a replacement when their smartphone was out of battery or malfunctioned, or to watch shows/videos or browse for information when they wanted to use a larger screen.

3.3.2.2 Patterns of MTSD use

High and frequent use, integrated into daily routines with "frequent checking" of device

Many of the adolescents, especially those who owned a MTSD, used MTSDs frequently throughout the whole day during weekdays and weekends, whenever possible. They used them from morning until night time, often interspersed with their daily activities and with frequent "checking" of the device. Upon waking up in the morning, they started using their smartphones to turn off the alarm, check the time and/or social media and messages, and used them again after washing up and/or during breakfast. They used them again when commuting to and from school and during school hours, usually before the start of lessons, during recess and/or lessons (if allowed by teacher). After returning home from school, they used MTSDs again, after or during lunch and/or dinner, and continued to use them during or after finishing homework. They also often reported using them again at night before bedtime, usually in their bedrooms, as these were the times that they were usually free and able to have uninterrupted use and privacy. During weekends many adolescents similarly used MTSDs throughout the whole day whenever possible, even when outdoors for school extra-curricular activities, tuition (supplementary lessons), outings with family and friends or while commuting. Examples of how they used MTSD frequently throughout the day are:

> "In the morning when I eat breakfast, I use my phone, then after that [when] go[ing] [to] school [I] also use… after school [when I] come back [I] also use. Technically I every moment also use…" (A24)

> "For weekends… I use [a] handphone [a] lot of time… and social media and the usual… then after that, probably would freshen up and head out to meet friends outside. Yeah throughout the whole day when I [I'm] doing activities and stuff outside, I will definitely still be using my phone." (A23)

Throughout the day there was also frequent "checking" of smartphones for messages, updates from social media, games and/or other applications. This "checking" was reported by many adolescents and it could occur sporadically, ranging from small bursts of time for a few minutes to longer periods, for example:

> "It's more of an interval thing… open [phone] check then close, open check close… [almost] every other minute, each time less than even three minutes. Just a simple check then close." (A23)

Many parents also agreed with their adolescents in their adolescents' frequent use of MTSDs; they reported that their adolescents seemed to always have their MTSDs with them, using them almost the whole time whenever possible:

> "She is using her mobile most of the time. So, [whenever] I see her, the mobile phone usually will not leave her… just like [it is] attached to her every time [I see her]." (P15-16)

Ubiquitous use

The use of MTSDs by adolescents was ubiquitous; at various locations at home, in school and in the community when outdoors, bringing them almost wherever they were and having them often within reach. At home, adolescents used MTSDs at various places, such as on the sofa or dining table, in the living room or kitchen, on the study table or in bed in the bedroom, and even in the toilet, which were similarly noted by their parents too:

> "Every other minute they will not go anywhere without the phone, even from the room to the hall to the kitchen… anywhere in the house he moves, the phone moves with him." (P28)

In school, whether in the assembly hall before school starts, the classroom during or in between lessons, or in the canteen during recess or lunch time, they also used MTSDs. When outdoors in the community, for example when commuting in public transport, in cars or when walking to and from school or other places, and when out with family and friends (e.g. shopping centres or restaurants), they also often used MTSDs. At home, many adolescents tended to use MTSDs for longer periods as they had more free time available and were not occupied with school lessons or other activities. In school and in the community, use tended to be intermittent in shorter bouts, during breaks or any free time that was available when they go about their activities; for example, before start of morning school assembly, when commuting or whilst waiting (e.g. for food to arrive when dining out or parents to finish their shopping errands).

Multitasking

Many adolescents reported multitasking with other tasks, e.g. homework, eating, and even during washing up or dressing, at the same time when using MTSDs. They also used MTSDs with other devices, e.g. television (often during advertisements), desktop or laptop computers. When they were multitasking, they often checked their smartphones for messages or social media updates. They also engaged in online browsing, games, video watching or listening to music, for example:

> "…I will watch [TV] and at the same time I will look at my phone to check the messages. Sometimes I listen to music on my phone, then I read the subtitles on TV… I use the phone during advertisements and if like the show is boring right, halfway [through the show] I just get the main idea, then I [start to] use my phone." (A17)

Some adolescents generally felt that multitasking MTSD use with other tasks or devices did not require "much effort" and that it was "natural" for them to do so:

> "Usually when you eat out nowadays, you either watch television or YouTube on the internet. It's actually natural, [be]cause when you eat you don't really use your eyes. You can actually eat and look at the phone… just look once [at the phone] and then you eat, so it doesn't really take much effort to do that." (A35)

Use of MTSDs while doing homework was commonly reported by many adolescents. They used them for personal activities (e.g. messaging, games or music) and for schoolwork (e.g. Google translate or dictionary, searching information for projects, messaging with schoolmates to consult each other on homework).

In addition, some adolescents also reported that they often multitasked among different types of activities, by switching and alternating repeatedly among them, with short periods of use for each activity. They might switch to and from different activities due to notifications or updates received from messages, social media or other applications prompting them to switch, boredom with a particular activity or their mood (what they felt like doing at that time). For example, they might be playing games, but when they received notifications, become bored with playing games or feel like checking messages or social media, they would switch to messaging or social media and then back to games again. This process of switching was then repeated again:

> "…when no new feeds or updates on the social media, then I will switch to game. Then after that, when I'm done with the game, I'll switch back to social media, and [when] there's incoming WhatsApp and so on, I'll switch to that. Yeah so it's just a constant switch around." (A23)

Table 3.2 provides other example of quotes supporting the themes of high and frequent use, integrated into daily routines with frequent "checking" of device, ubiquitous use and multitasking.

Table 3.2 Findings on patterns of use

Patterns of MTSD use	
High and frequent use, integrated into daily routines with frequent "checking" of device	"From the moment I wake up I will use it to check my messages, and then also [to] check the time, like before I go school, I check how much time [is] left and all. Then I will use my phone in school to check when the next period is, cause I saved my timetable in my phone. Then I use iPhone to communicate with my friends, if I need to find them I will then text them. Then maybe like on the way to school, I will listen to music using my phone, even during my Chinese orchestra practices [school extra-curricular activity]… so basically there's like a lot of functions for me to use. It's like every day, every hour [I] definitely will be using it." (A17) "Saturday and Sunday I got [have] tuition… I wake up in the morning then after that I use, eat breakfast and use my phone also. Then [when] go tuition, I'll also use the phone on the bus … After I come back from tuition, I just start doing my homework. Sometimes [when] I'm bored during the middle [of homework], I will also use [phone]." (A24) "If it's a weekend, then normally I [will] have time to use [phone]. I'll probably use my phone before I sleep at maybe like 10 o'clock." (A25) "Yeah, just before I sleep I use [phone] in my room because I want to check my WhatsApp. Then after that I sleep." (A26) "After school, I go back [home] and open Wi-Fi. Check [if] got any messages, sure [to have] got [messages] after so long. Surely got twitter messages coming. If no messages, I'll just watch some videos." (A11) "After waking up, I'll check the time again. Then check social media, watch some YouTube videos, [and] read a bit more." (A25) "When they come into the house…the first step is they [will] go and on the Wi-Fi. So that means that they want to use it [phone] all the time. And then they will see messages from friends or whatsoever. So this is their lives, part of their lives." (P18)
Ubiquitous use	"Use it [phone] anywhere, just bring my cup and use my phone at the same time" (A7) "…once I reach school, the next time I will be using it [phone] will be [during] lunch...then I will check messages or any others…should be around 5 to 10 minutes only because the rest of the time I would be talking to my friends and eating." (A12) "Wherever she walk her phone must be with her, even [when] go[ing] [to] toilet, [she] also must bring [phone]." (P2)

Multitasking	"[When] I brush my teeth, the video [on phone] is playing... when I put on the buttons on my school uniform, I will also watch videos [on phone]. Then sometimes when I do homework I also use [phone]." (A30) "Sometimes I listen to song [on phone] when doing work [homework]. Sometimes if I am not listening to song, I [will] just watch video, put the video [phone] over here…and do work [homework]." (A11) "...we use Google document to do our project on the computer, but then we [also] use WhatsApp to talk. I don't know why, WhatsApp is the easiest… For Google document, we just type out whatever we need, but then we [also] use WhatsApp to communicate..." (A17) "…use my phone and do my homework at the same time…to check for some word meaning that I don't understand, like go [to] Google and search for the definition of the word." (A11)

3.3.2.3 Reported influences of MTSD use

Several influences of MTSD use were reported by adolescents and parents, which could be categorized into functional, personal and external influences.

Functional influences

Device performance and internet availability

Poor device performance and lack of internet access or mobile data can limit the amount of time spent and activities available to use on MTSDs. A few of the adolescents mentioned that they seldom used their older models of tablet or smartphones as they were slow in loading applications and websites, or they might malfunction halfway when using. Moreover, some adolescents had no internet/Wi-Fi access at home, outdoors, in school or public places and/or limited or no mobile data plan on their MTSDs. They were thus limited in their use of social media, messaging, online games or browsing on their MTSDs, and were only able to make phone calls, play games or watch videos that they had already downloaded on their MTSDs. Adolescents who lacked a data plan on their MTSDs often tried to access the internet at places that had Wi-Fi access, such as in school, public areas or areas in the house where Wi-Fi connection was available or stronger.

Portability of device could also affect the types of MTSD used at various locations. Both smartphones and tablet computers were often used at home by the adolescents; but in school or in the community, a smartphone was often brought and used outdoors instead, as it was more portable than a tablet. A tablet was usually brought to school only if it was needed for school lessons.

Multiple functions and activities

Many adolescents reported using MTSDs for a wide variety of functions and activities, ranging from personal and schoolwork to daily life functions. Personal activities commonly included social activities such as messaging using WhatsApp, social media on Facebook, Instagram, Snapchat or Twitter, and making phone calls. They also used MTSDs to browse the internet on areas of interest e.g. entertainment idols or strategies for computer games, read online fiction or shop online. Other common activities included watching shows/videos ranging from a few minutes to a few hours on YouTube, video streaming websites or downloaded videos, playing games and listening to music. They also used them for school related matters, e.g. during school lessons, searching information for projects and communication with classmates and teachers to consult on homework. MTSDs were also frequently used for daily functions, e.g. checking time, setting a wake-up alarm, checking directions on map or transport arrival time and taking photographs.

Entertainment or relaxation

Some of the adolescents used MTSD during any available leisure or free time, either as a form of entertainment or relaxation to reduce boredom or to kill time. Some of the instances mentioned were free time before or after lessons, during recess, after finishing homework, before sleeping or whilst waiting e.g. for meals when dining out or for transport to arrive. They used MTSDs to keep themselves entertained or occupied, as they had "nothing else to do", or were generally "bored" with the tasks that they were doing, such as homework:

> "Because when I'm eating, there's nothing [else] to do. So I will be quite bored, so I will just like watch videos or read… if you just sit down and eat [also] very boring, so I [will] also use my phone." (A24)

> "I do my work, and then after a while, I use my phone. Then I will do my work again, then I use my phone and I do my work again… When I don't know how to do the question or [when] I'm like bored, I will quickly use it, [be]cause [I] lose interest in the work. Then what else can you do? You [I] just use the phone." (A21)

Homework was one of the common tasks where adolescents reported using MTSDs intermittently. MTSD use was often perceived as a form of break or relaxation from homework. A few even mentioned that they were in fact able to concentrate better on their homework after or while using MTSDs. Interestingly, a few adolescents also mentioned that they eventually ended up getting bored with using MTSDs after some time, although they were kept occupied and entertained by them initially, for example:

> "You know on that weekend where you got absolutely nothing to do, it's boring. Because you are not going to school, you're not doing anything, you're not going out… you're just staying at home and doing absolutely nothing but using the phone. It's very boring. Sooner or later you will become bored [with the phone] and it is obvious." (A13)

Personal influences

Irresistibility of MTSDs

To many of the adolescents, MTSDs seemed irresistible such that they often felt an inclination to use MTSDs, even more so when MTSDs were within their sight and reach. This appeared consistently and is a strong theme that emerged from the data. There was also a sense of attachment and dependency on MTSDs, especially smartphones, to the extent that they were always with them or within their reach, and "one day without phone [I] cannot survive" (A36). For example:

> "...it's quite tempting because you are always using it, then you suddenly don't use it for several hours, you will tend to want to pick it up and look. For me I'll just look through [phone], then after [when] I'm done with the things, I'll put [phone] down." (A8)

In addition, it appeared that many adolescents also had a strong inclination to check their smartphones. They reported frequent checking of their smartphones throughout the day, and often receiving beeping from notifications or updates from messages, social media or other applications, which prompted them to check and use their smartphones. There was also regular influx of notifications of new messages, especially those from group chats. These notifications were at times distracting but the adolescents were still inclined to check them as they wanted to keep updated with their peers and of events happening around them, and "not want to be left out" (A28). Otherwise, they might feel uncomfortable or not able to concentrate on the tasks that they were doing:

> "I don't know, I feel uncomfortable if I don't look at my phone, there will be lots of messages going out to me. I can't just ignore it. I feel uncomfortable [if] I don't look at it before I fall asleep, so I reply a bit on whatever that [messages] is happening, then I go to sleep." (A28)

Adolescents' inclination to use MTSDs was also evident when some of them attempted to plead or ask for permission from their parents, despite parental rules or restrictions on duration or periods of use:

> "Sometimes [when] I finish halfway I [will] want to continue, but the time limit is running out, so I have to [switch] off. Sometimes I will ask my parents [I want to] play a little bit more please. Sometimes they will say yes, but sometimes no." (A18)

Lack of self-control

Many adolescents appeared to have a lack of self-control over their use whereby they found it hard to resist or stop using MTSDs. They expressed that they tended to get carried away when using MTSDs and lose track of time. For example, when they are watching shows, they are often inclined to continue watching another episode to the extent that their homework or sleeping time was delayed:

> "When you watch shows, these shows actually have series and so after you watch one episode, you will just want to watch the rest. So that part is quite hard to overcome, so that's why I become addictive." (A8)

> "…bad to the extent that I would not sleep on time…I only sleep at 3 or 4 am and then after that the next day, I have to wake up at 7 o'clock [for school]." (A10)

Some adolescents reported that they attempted to implement self-control measures and exercise self-discipline on their MTSD use, as they felt that they were overusing them. Self-control measures mentioned included putting MTSDs out of reach, setting a timer or alarm to use for limited durations, using applications with reminders to discourage unlocking devices, ignoring messages or notifications that were unimportant, and avoiding certain activities (e.g. shows/videos that they tend to get carried away with). However, some of these adolescents reported difficulties with adhering to the measures, as they sometimes also became carried away with what they were doing on their MTSDs and ended up overusing them:

> "I put it [phone] outside if not I will keep on using. Cause once you start using, it can go on for like 3 hours just sitting there and using…then after another 2 hours I will come out and use my phone again. Sometimes it depends, sometimes I get carried away with my phone, end up using phone for like half an hour then never go back and do work [homework]." (A17)

External influences

Schedule differences affect the amount of time available to use MTSDs

The amount of time that adolescents spent on MTSDs was variable from day to day, mainly due to their different schedules of activities, which affected the amount of free time available to use MTSDs. Adolescents who were more occupied on certain weekends and weekdays with more homework, studying especially during exam periods, school extra-curricular activities, tuition, sports or outings with family or friends reported that they did not have as much time available to use MTSDs, and hence did not use them as much as other days when they had more free time available. For example:

> "On Saturday and Sunday, I don't actually use my phone that much because in the morning I have activities. I go Aikido [martial art], then when I come back I usually have some stuff to do like assignments… so I don't have much spare time in between... I usually use it for about one and a half [hour] after dinner, because I'm completely occupied before dinner." (A35)

During weekends and school holidays, most adolescents reported using MTSDs for longer durations than during school weekdays. Some adolescents even used MTSDs for longer periods before bedtime which delayed their sleep, as they did not have to wake up early the next day for school. The amount of free time available also affected the types of activities carried out on MTSDs. For example, some adolescents mentioned that they were only able to check messages or notifications from social media when they were free for short durations (e.g. when preparing to go to school in the morning or waiting for transport) but watched shows/videos when they had longer durations available (e.g. after finishing homework at home).

High use among peers and family members, and for school related matters

Many of the adolescents frequently reported high MTSD use among their peers and family members (parents, siblings and/or relatives), and the need to use MTSDs to communicate with their friends, family, schoolmates and even teachers (e.g. to discuss homework or school projects or obtain updates about school events or lessons). A few parents have also pointed out that they spent considerable amount of time on MTSDs themselves, for example:

> "We parents get carried away as well. So when we get carried away, they [adolescents] also see and will say: okay, now is the time I [adolescent] can also use phone right?" (P26)

Some adolescents also reported that they and their peers frequently used smartphones and even messaged each other when they were together. MTSDs were also used to play multiplayer games, watch shows/videos, share and take photos together or others, such that it becomes a social activity. Some parents also agreed with their adolescents about the prevalent use of MTSDs among peers and for school related matters, which made it difficult for them to control or limit their adolescents' use:

> "So, we cannot totally stop it [phone use], we also have to take care of her sensitive…her feelings you see...so we kind of got to balance that. She will be faced with all the peer pressure, and this is the time when she makes friends. She is learning how to socialize, so we cannot cut that off totally." (P18)

Control measures by the school and parents/caregivers

All the adolescents reported that their schools have rules on MTSD use in school, which limited the amount of their use during school hours. Adolescents were generally compliant with these rules and were allowed to bring MTSDs to school, but not allowed to use them during lessons unless allowed by teachers. A few adolescents mentioned that their schools even disallowed MTSD use during recess or allowed its use only at certain common areas in the school. There were penalties such as confiscation of MTSDs if adolescents disobeyed the rules. For the adolescents in post-secondary schools, the rules seemed to be generally less strict; they were able to use MTSDs at any area in the school, and at any other time except during lessons unless allowed by teachers.

Some parents/caregivers reported implementing rules or restrictions on their adolescents' MTSD use and were strict in ensuring that they observe them, especially for the younger adolescents (in primary and lower secondary school). Other parents were more relaxed about the rules or did not enforce any, especially for the older adolescents, as they required more autonomy and greater use of MTSDs for communication with peers and schoolwork.

The majority of parental measures implemented were restrictions on duration (e.g. setting time limit, disallowing use during certain periods such as meals, before finishing homework or exam period), access to MTSDs (e.g. parents keeping away MTSDs at night, not providing adolescents with their own MTSD), types of activities or applications (e.g. permission required to download games or post on social media), or amount of internet data plan on MTSDs. Some adolescents reported being compliant with the measures at times which helped to prevent them from using MTSDs excessively.

Non-compliance with parental control measures

Although some adolescents were compliant with parental control measures, the compliance was not consistent and there were often instances of non-compliance reported by parents and adolescents. Some adolescents reported attempts to hide from their parents' supervision when using MTSDs, e.g. using MTSDs in a locked bedroom or secretly switching on home Wi-Fi access. Hence, parents were sometimes unsure if their adolescents were compliant with the measures.

In addition, the younger adolescents (in primary school) who did not have their own MTSDs, as their parents did not allow them to have one, often tried to find ways to access their parents' MTSDs without asking or obtaining permission. For example, they took their parents' MTSD to use when their parents were occupied or tried to hack the password that it was locked with:

> "…sometimes they manage to hack it [password]… they will see the pattern that we punch so they can guess. Sometimes they manage to get the first number and last number, then they start guessing [the other numbers]." (P36)

Many parents expressed difficulties and frustrations in implementing rules or restrictions on their adolescents' MTSD use, and in ensuring compliance and appropriate use of MTSDs even after relaxing or removing the rules. Some parents mentioned that they often had to "tell" their adolescents to stop using MTSDs; to the adolescents, this was often perceived as "nagging" by their parents which they had become accustomed to hearing. If adolescents still did not comply even after repeated "nagging" or reminders, some parents eventually relented on their rules or restrictions. For example:

> "I will tell them that [to stop using] but eventually if they don't listen to me, then I think it is no point in doing the nagging…not worth it, no point. I have said too many times already… and he [adolescent] don't practice [listen], it is meaningless to worry, so don't go to the extend." (P19)

> "Sometimes my mother will keep on nagging. Never stop nagging… sometimes I will listen and go study, sometimes I just continue using." (A27)

It was difficult for parents to regularly monitor their adolescents' MTSD use and ensure compliance with the rules or restrictions, especially when they were away at work or when adolescents were in school or out by themselves. A few parents articulated that it was important for adolescents to be aware of and exercise self-discipline on their usage, as they were not able to control their use all the time, for instance:

> "I mean we can only remind this much…control this much right? They have to realise for themselves, whether through the hard way or the easier way of listening to advice. The hard way is [for them to] see their [exam] results, know already then they will really wake up and try to put things right." (P25)

Table 3.3 provides further examples of participant quotes on influences of MTSD use.

Table 3.3 Findings on influences of MTSD use

Influences of MTSD use	
Functional influences	
Device performance and internet availability	"When I go home, there is no internet so I don't really use it [tablet]. So if I'm bored I will play like the offline games, but I don't play for very long, maybe half an hour." (A6) "Because my school doesn't have a wireless Wi-Fi, so I have to use my own data to go to social networks. I like to go to Instagram but Instagram really takes up a lot of data so I can't go much." (A8)
Multiple functions and activities	"I can use my phone to do a lot of things. I mainly use my phone to watch YouTube and use WhatsApp...it's convenient cause it's nice for watching. When I need to check something else I can Google and WhatsApp… and [go] back and forth between them." (A35)
Entertainment or relaxation	"… when parents ordering the food [in restaurant], I will play [phone] for a while [be]cause I'm bored. When the food come already, I won't [use], I will keep [it]." (A27) "When I do homework after one hour I will watch one short video, then I go back to work…[be]cause sometimes when I do my work [homework], I will get very bored you know." (A20) "I will go do my work [homework]. Then after a while, I will come out and use my phone again… then I go and do my work. When cannot take it already, then I use my phone again… I will use it to SMS, then afterwards I will use it to look at Twitter, Instagram." (A17)
Personal influences	
Irresistibility of MTSDs	"My pants [have] almost all no pocket[s]. So I have to hold my phone in my hand…hold[ing] in your hand has [created] temptation to keep using [the] phone." (A1) "Sometimes people will spam me [with] messages, so I have no choice but to reply them until I feel tired…" (A11)

	"I'll just check my phone when messages come. Check [phone] already, then won't be distracted as much, phone makes you know what is happening around [in] the group chat." (A1) "I usually use WhatsApp or that kind of group chat...because I don't want to be like left out in a way. I want to know what's going on, [so] I'll just look." (A28) "When I'm doing homework, the phone can be distracting [be]cause usually in group chats, they [friends] will usually message us, and you will always see the messages popping out." (A8) "He always finds [a] reason to use [phone]. He will ask for permission in between his homework [to use]… he got a lot of reasons." (P29)
Lack of self-control	"I'll take and just play every day, busy playing until almost forget homework." (A36) "Sometimes I overstretch what I should be doing, for example I accidentally spent 1 or 2 hours on the phone when I should be doing my homework… basically is when I get into the chain of watching YouTube videos, or when reading this [online] book [be]cause the book is very long." (A25) "There's this particular blog right, I watch most of their videos. I find it very nice, so I watch it over and over again or find more of these videos [be]cause they seem interesting…then I cannot stop, so I keep on using." (A34)
External influences	
Schedule differences affect the amount of time available to use MTSDs	"During weekend, if I need to wake up early the next day, I will just sleep at 11. But if don't have to, we can stay up until like maybe 12 or 1 then we sleep. So, I use my phone until then… also depends on if I've a lot of homework [to do] or not." (A30)
High use among peers and family members, and for school related matters	"Sometimes like when my parent's friends come to play with us, their kids right, we all play Minecraft together [on tablet or phone] for quite long, sometimes from 12am to 3am." (A15) "We have like WhatsApp groups for the class to update us about the next day school or homework and stuff. Sometimes the teacher will post the homework online for us to do, and sometimes we also have to do to hand it up online, so I will [have to] use the phone." (A21)
Control measures by the school and parents/caregivers	"School only allow [us] to use phone during recess in the canteen…outside canteen, we cannot use." (A11) "Can only use [phone] before school, during recess and after school. If you are found using [phone] during lessons, it will just get confiscated." (A4) "There are a few restrictions [from parents] like you can't download anything, and if we like break the time limit, then we might have to…I don't know…maybe face consequences like get scolded or something." (A14)

Non-compliance with parental control measures	"During night time when I sleep, he hides inside the room. He locks the door, I also don't know if he uses phone or not." (P4) "She will purposely hide the fact that she is using her phone. Now I think she can't be bothered because now when I'm at home, she will just use it in front of me. I tried to tell her not to use your phone for like Facebook or Instagram, they are just to trap people but she never listens." (P8) "Our phone has got password. So sometimes if I happen to use it and then I didn't lock it, and [when] I put it down and he sees it, he will grab it and run away [with it] and hope you don't notice." (P5) "I told them, that's why I told them. But you know right, when you don't see them, even when you see them, if they are doing that [using tablet or phone] so often, I myself am sick of telling them [not to use]." (P19) "When I saw that they are sticking to the discipline, then I stop the policing [of their phone use]. But after that I noticed they are not really obeying to our rule already, they slowly slipped back to their old habit." (P34) "The father has set up some rules for them, but I [am] hardly at home, so I seldom see whether they do [follow] it or not… he said that there's a schedule for them [to use phone], when to when, what time to what time, but I really don't know whether they practice it or not." (P15-16) "My mum is constantly working so she is mostly not at home. So, I just keep using [phone]. No one to control me." (A4)

3.3.2.4 Concerns on MTSD use

Concerns from adolescents and parents

The adolescents generally did not raise many concerns on their MTSD use; only a few mentioned that their eyesight might have been affected from it. Some adolescents did not usually keep track of the amount of time spent using and tended to use MTSDs continuously for long periods without taking breaks. Breaks were usually perceived by the adolescents as the time when they stopped using MTSDs, rather than a conscious effort to take a break. Hence, some adolescents were not conscious of taking breaks and usually stopped using only when they need to carry out other tasks or activities:

> "No, I don't consciously take a break to rest my eyes. I just keep on using until maybe I'm like tired or something then I'll off the phone, so I don't usually tell myself "ok stop [using]". For the iPad, I don't think I took breaks…I just keep on using it until I had to stop because of other reasons like my friends calling me to go outside." (A8)

On the other hand, almost all of the parents expressed concerns regarding their adolescents' MTSD use, and were worried about possible negative impact on their adolescents’ mental health and behaviours (e.g. energy levels, ability to focus, time management or tendency to violence), physical development (e.g. eyesight, postures, bodily discomfort, physical activity level), social development (e.g. social skills, family bonding) and exposure to inappropriate content online or bad peer influence (e.g. cyberbullying).

Perspectives on amount of use

Most adolescents perceived their amount of MTSD use as appropriate and did not see the need to change or limit their use. They felt that their usage was appropriate as they implemented self-control measures on their MTSD use or did not spend as much time on MTSDs as compared to their friends. On the other hand, a few adolescents perceived their usage as excessive but did not take any active measures to control their usage, as they felt that it was difficult to change their habits of use:

> “…it’s too much, but I also cannot help it, you cannot help me…I see [phone] again I forget about [that] I use too much also.” (A29)

> “Too much, of course too much, but it’s a bit hard to you know, to stop it [be]cause it becomes an addiction.” (A15)

There were disagreements between adolescents and their parents on the amount of use; most parents perceived their adolescents’ usage as excessive which was often in contrast with their adolescents’ perception. A few parents reported that the contrasting perceptions had even caused unhappiness and discord between them and their adolescents, for example:

> “…there is a disagreement that we think she use the phone too much, she thinks she use it just nice. So, this cannot come to an understanding, that’s why always have quarrel between us. Yeah so, we have certain rules, then she not happy, we also not happy.” (P3)

3.4 Discussion

In this qualitative study, the rich descriptions by both adolescents and parents provided insights into MTSD use by adolescents including perceived high, frequent and ubiquitous MTSD use, multitasking as a common activity, factors that influence MTSD use, and the perceived appropriateness of their use by adolescents and parents.

3.4.1 High, frequent and ubiquitous MTSD use

Both adolescents and parents perceived adolescents' MTSD use to be high, frequent and ubiquitous, especially that of smartphones, which were consistent with recent survey studies (Australian Communications and Media Authority 2016, Rideout 2015, Robb et al. 2017). Many adolescents used MTSDs ubiquitously at various locations, and frequently throughout the day upon waking up in the morning, in school and at home, even when outdoors or while commuting. Night time or before bedtime use in their bedrooms were also a standard routine of use for many adolescents, which is consistent with other studies showing prevalent technology use at night or before sleeping (Carter et al. 2016, Ofcom 2017, Rideout 2015). These patterns of use, integrated into daily routines, may explain findings from previous survey studies of how adolescents were able to have high total technology use, of up to nine hours a day on average (Rideout 2015), and smartphone and tablet being the devices with the highest amount of use compared to other devices (Straker et al. 2018a). This integration of use into their everyday life has indeed provided benefits such as convenience, communication with peers and family or access to information for homework (Odgers 2018). However, if such usage becomes excessive or problematic, it can be detrimental to their academic performance, social relationships (Seo et al. 2016), mental (Jean et al. 2017) and physical health (Straker et al. 2018a). Their MTSD use is expected to increase even further with time (eMarketer 2016). Future studies therefore need to examine what the right balance of MTSD use is for adolescents.

In addition, this study has also highlighted a common pattern of MTSD use among adolescents - multitasking during MTSD use, which is consistent with survey studies indicating increased prevalence of multitasking with multiple devices in adolescents (Australian Communications and Media Authority 2016, Cain et al. 2016). The most common way of multitasking reported was using smartphone, for homework or personal activities (e.g. messaging or social media) while doing homework, which was also commonly observed among adolescents in a nationwide survey study in USA (Rideout 2015). This high use of multitasking might be due to convenience, useful tools, communication with peers for homework, relief from fatigue or boredom from homework, or while waiting for an activity (e.g. shows/videos to load). Other studies have also found that adolescents perceived multitasking as enjoyable (Jago et al 2011), effortless and an integral part of life (Carrier et al. 2009). However, negative outcomes such as impaired learning (Chen and Yan 2016), reduced academic performance (Cain et al. 2016), poorer social and psychological well-being (van der Schuur et al. 2015) have been associated with multitasking. Much about the nature and impact of multitasking during MTSD use in adolescents still remains unknown; further research on the appropriate extent of multitasking MTSD use with homework, other tasks and devices is therefore needed.

3.4.2 Influences of MTSD use

Data from this study has also suggested several influences that facilitate adolescents' high, frequent and ubiquitous MTSD use, which could be categorized into: functional (portability, internet availability, multiple functions and activities, entertainment or relaxation), external (peers/family/school use) and personal (irresistibility and lack of self-control) influences. Portability of MTSDs has enabled adolescents to use MTSDs ubiquitously; almost everywhere and anywhere was possible, even in various areas of the house including the toilet as reported by adolescents and parents. Availability of internet, coupled with the multiple functions and activities offered especially when online, including use for entertainment or relaxation to occupy themselves, further encouraged adolescents to use MTSDs.

The findings also suggest that the high use of MTSDs among peers and family members has an influence on adolescents' use of MTSDs. Many adolescents felt the need to frequently use these devices, usually for messaging or social media, in order to communicate and feel involved with their peers. MTSDs were also used as a social activity for example, to play games or watch shows/videos when together with their peers or family. This is supported by other studies which have found that feelings of belonging, peer pressure (Walsh et al 2009), and frequent use of technology by parents were associated with increased technology use by children (Vaala and Bleakley 2015, Xu et al 2015).

Irresistibility of MTSD use to the adolescents and their lack of self-control were also reported influences that may account for their high and frequent use. Findings in this study strongly suggest that some adolescents were very attached to and unable to resist using their MTSDs, especially smartphone. Some of them reported frequently checking their MTSDs, unable to exercise self-control to stop using or resist using MTSDs when they were supposed to do homework or other tasks, or comply with parental rules or restrictions. Previous quantitative studies similarly showed high frequency of checking and inclination to use; with adolescents checking their phones an average of 150 times per day (Mayyasi 2016), and a large proportion of adolescents checking at least once an hour and feeling "addicted" to their MTSDs (Robb et al. 2017). Although this study did not examine addiction nor had any criteria to identify those who were addicted to MTSD use, some of the adolescents' descriptions on their inclination and lack of self-control to resist using MTSDs were suggestive of addictive behaviour. One of the reasons for this behaviour was the notifications or updates received on MTSDs, which many adolescents felt the need to respond to immediately (Robb et al. 2017). It is also important to consider the types of activities that the adolescents engage with on MTSDs that draw them into continued use. Social networking and media use, playing games (Jeong et al 2016, Lopez-Fernandez et al 2017) and watching shows (Lopez-Fernandez et al. 2017) were related to increased risk for dependence or addiction to smartphones. Moreover, the use of social media and other activities on phones have also been found to release feel-good neurochemicals such as dopamine (Crone and Konijn 2018, Sherman et al 2016). Each use of MTSD may therefore promote reward seeking behavior that could lead to compulsive device use, and distraction or irritability when adolescents are separated from their phones. Adolescents' brains were more responsive to reward than adults, which may thus make them more vulnerable to addiction than adults (Sturman and Moghaddam 2012). With a lack of self-control, and excessive attachment and inclination to use MTSDs, they may be even more susceptible to excessive MTSD use. Addiction to MTSD use should be avoided as it can result in detrimental effects such as stress, depression or reduced physical activity (De-Sola Gutiérrez et al 2016, Haug et al. 2015). There appears to be a need to address this irresistibility of MTSDs reported by the adolescents, and develop strategies to help adolescents use MTSDs appropriately without putting them at risk of addiction.

3.4.3 Implications for research and practice

3.4.3.1 Control measures on MTSD use

Findings from this study have raised some important implications for further research and practice related to developing strategies for school, parents and adolescents to support wise MTSD use by adolescents. In this study, control measures by schools appeared to help reduce the amount of time and activities that adolescents can carry out on their MTSDs. Whilst this control from schools may limit overall MTSD use, it makes integration of MTSDs into education difficult, and is not preparing adolescents to be adults in charge of their MTSD use. Further research is required on how schools and adolescents can prevent misuse of MTSDs while maximizing benefits for education.

Adolescents whose parents had implemented control measures, such as restrictions on ownership, access to types of activities and/or duration of use had limitations in their use of MTSDs. Adolescents who did not have their own MTSD (younger adolescents in primary school), appeared to have less usage than those who owned a MTSD. This is supported by a survey study which showed an association between ownership of devices and higher sedentary time involving technology use (Sandercock et al 2016). Parental restriction of access to internet and mobile data also limited time spent on social media or content online by adolescents. This is consistent with other studies which have indicated mediation of children's technology use by parental rules or restrictions (Ramirez et al. 2011, Xu et al. 2015). Both school and parents/caregivers thus play an important role in regulating adolescents' use of MTSDs.

This study also highlights the fact that many parents/caregivers had difficulty implementing control measures and ensuring compliance from adolescents. One of the most common difficulties reported was being away at work most of the time and not being able to monitor adolescent's MTSD use, possibly due to Singapore having a high percentage of dual income working parents (Department of Statistics Singapore 2016b). Portability and the variety of activities and social media platforms available on MTSDs made it even harder for parents to monitor or limit their use. Contrasting perceptions on the amount of use between parents and their adolescents found in this study might also contribute to non-compliance from adolescents. Most parents in this study seemed to adopt measures that were restrictive on the usage rather than attempting to communicate or seek mutual agreement with their adolescents. Earlier research has shown that authoritative and restrictive ways of parental mediation of technology use do not contribute well to compliance (Minges et al 2015, Symons et al. 2017). Moreover, parents should also moderate their own MTSD use, as their use can have an impact on adolescents' technology use (Vaala and Bleakley 2015, Xu et al. 2015). Future research should thus examine effective strategies for parental mediation and seeking mutual understanding between parents and adolescents on MTSD use.

3.4.3.2 Lack of self-control

This study has also pointed out a general lack of awareness, concerns and self-control of MTSD use from the adolescents, which could have contributed to high and frequent

MTSD use, and non-compliance with parental rules or restrictions. Studies have indicated that control measures from school and parents/caregivers can only limit adolescents' technology use to a certain extent (Livingstone and Helsper 2008); strategies aimed at effectively reducing screen time should target self-motivation (Babic et al 2016). It is thus important to increase adolescents' own awareness of MTSD use, empower them to take charge and self-manage their usage. As seen from our data, incoming notifications, messages or updates received were often a source of irresistibility to use MTSDs. Strategies to help them self-manage their use should therefore target the incoming notifications or messages, such as silencing them or setting time limits to attend to them. Other self-management strategies may involve avoiding or setting time limits on activities that tempt continued use e.g. social media or watching shows/videos, putting MTSDs away and out of reach, use of applications to lock devices or deter its use, or setting appropriate goals e.g. using only after finishing homework. It is important for adolescents to ultimately be able to appropriately self-manage their MTSD use and bring forth good habits of use into adulthood.

Adolescents also reported that it was natural for them to turn to using MTSDs when they were free as they had "nothing to do" which were consistent with previous findings (Francis and Kentel 2008). Engaging in alternative activities that are non-screen based, such as sports, hobbies or extra school activities might help to reduce the amount of MTSD use. However, it might be challenging to do so as adolescents may find screen technology use more appealing than other activities. Future studies should also examine strategies that gain adolescents' interest and encourage engagement in more non-screen activities.

3.4.3.3 Measurement of MTSD use

Our findings raise some important issues for consideration in the measurement of MTSD use. Data from this study showed that patterns of MTSD use are different from traditional electronic devices. MTSD use may be continuous for long periods or of sporadic short periods, and breaks are often perceived as the time when they stopped using MTSDs instead of a conscious effort to take breaks. Patterns of MTSD exposure may also be different on different types of days e.g. weekdays, weekends, holidays and exam period. In order to capture accurately patterns of MTSD use in self-reports or other techniques, there is a need to consider patterns over time, the frequent sporadic short periods of use as well as multitasking among multiple devices.

3.4.4 Strengths and limitations

Strengths of this study include a fairly large number of participants, and the semi-structured individual interview format which allowed free expression and exploration of arising issues. Moreover, perspectives from parents were sought which helped to triangulate data obtained from the adolescents and to indicate important discrepancies between the perceptions of the adolescent and the parent. One of the limitations of this study was that it reflected use at the time of data collection, but with technology hardware and software constantly changing, future use patterns might be different. In addition, during interviews with a few adolescents, their parents were sometimes within hearing distance in surrounding areas (e.g. common areas in the house), hence they might have felt unable to express their views freely. However, given that data saturation was achieved, along with the diversity and richness of information obtained, we are confident that perspectives provided by the adolescents truly reflects their opinions.

3.5 Conclusions

This qualitative study has provided useful insights and rich information on patterns and influences of adolescents' MTSD use, as well as implications for future research. Many adolescents and their parents felt that adolescents' MTSD use were high, frequent and ubiquitous. Use of MTSDs was integrated into adolescents' daily routines, often involving multitasking with other tasks or devices. There also seemed to be a strong inclination for adolescents to frequently check and use their MTSDs. Several influences of MTSD use were reported which either facilitated or limited adolescents' MTSD use. There is a need to establish good habits of MTSD use during adolescence, so as to maximise their benefits for learning and education while minimizing any potential adverse impact on their health and development. Future research should focus on developing guidelines for wise use, and effective strategies for self-control and parental mediation of adolescents' MTSD use.

Chapter 4 Study A2: Qualitative study on the discomfort and postures during MTSD use by adolescents

This Chapter presents results from the second part of the qualitative study as outlined in Chapter 3. Perspectives from both adolescents and their parents on the discomfort experienced (if any) and postures adopted during MTSD use by adolescents are presented here.

4.1 Introduction

The use of mobile touch screen devices (MTSDs), typically smartphones and tablet computers, is especially high among adolescents today (Australian Communications and Media Authority 2016, Ofcom 2019, Rideout 2015). There has been a surge in the ownership and usage of MTSDs among adolescents in the recent years (Ofcom 2019, Rideout 2015), which has raised concerns among parents, educators and researchers about the potential risk MTSD use can pose for discomfort in adolescents (Binboğa and Korhan 2014, Straker et al. 2018a).

However, current research on MTSD use and discomfort or musculoskeletal symptoms is still limited, especially in adolescents (Toh et al. 2017, Xie et al. 2017). A few cross-sectional survey studies have showed significant associations between smartphone and/or tablet use and musculoskeletal symptoms, including discomfort at neck/shoulder, back and distal upper extremities, in adolescents (Shan et al. 2013, Straker et al. 2018a, Yang et al. 2017). Laboratory studies, mostly conducted with young adults, have also indicated discomfort after use of a smartphone/tablet (Chiang and Liu 2016, Shin and Kim 2014, Toh et al. 2017).

Given that discomfort can lead to undesirable consequences in adolescents, such as school absenteeism, disrupted physical activities and chronic pain (Kamper and Williams 2017, O'Sullivan et al. 2012), it is important to prevent or reduce possible discomfort associated with their use of MTSDs. However, current research on the nature of discomfort associated with MTSD use in adolescents is still limited (Straker et al. 2018a, Yang et al. 2017). There is a lack of qualitative studies and perspectives from adolescents and parents on discomfort associated with adolescents' MTSD use. Qualitative studies are useful as they allow deeper exploration of relevant issues, and provide rich information that could not be captured by quantitative study methods (Rich and Ginsburg 1999). Information gained from adolescents' and parents' perspectives on discomfort related to MTSD use would thus be helpful in developing strategies and interventions for wise use of MTSDs by adolescents.

Prior studies have suggested that awkward or non-neutral postures of MTSD use may be a possible cause of discomfort or musculoskeletal symptoms associated with MTSD use (Kietrys et al. 2015, Sommerich et al. 2007, Straker et al. 2008c, Werth and Babski-Reeves 2014, Xie et al. 2016, Yu et al. 2018). A survey of high school adolescents found that the frequency of awkward postures during tablet use was correlated with discomfort (Sommerich et al. 2007). Some laboratory studies have also found that smartphone/tablet use was associated with greater non-neutral head/neck (Straker et al. 2008c, Yu et al. 2018), neck/shoulder and distal upper extremity postures (Kietrys et al. 2015, Xie et al. 2016), than when using desktop computer or physical keypad phone. These non-neutral postures can result in increased biomechanical demands and may pose a risk for discomfort. However, the majority of these studies were conducted with adults and tended to focus on MTSD use in constrained postures and traditional workstations (e.g. sitting on a chair or in standing), hence lacking consideration of MTSD use in various postures (e.g. long sitting, side-lying, supine or prone lying) and settings including non-traditional workstations (e.g. sofa, bed) (Toh et al. 2017).

The types or configurations of postures adopted during MTSD use by adolescents are thus not well understood, especially in the home setting where adolescents tend to spend most of their technology use time (Straker et al. 2010, Szeto et al 2014). Qualitative studies, with perspectives from adolescents on their postures of MTSD use, would help to provide useful information and insights on the various configurations and possible influences on postures of use.

Therefore, this study aimed to explore perspectives from adolescents and their parents on discomfort experienced (if any), and common postures adopted during MTSD use by adolescents via qualitative methods. Information gained from this study will allow a better understanding of associated discomfort and postures during MTSD use, which can help in developing strategies and interventions to support wise use of MTSDs by adolescents.

4.2 Methods

4.2.1 Recruitment and participants

This study was the second part of the study described in Chapter 3. Therefore, the participant recruitment and demographics are the same (see section 3.3.1). In brief, adolescents and their parents/caregivers (from the same families) were recruited together via convenience sampling. Parents/caregivers were recruited to provide triangulation and greater context to data obtained from adolescents (Carter et al. 2014). Inclusion criteria for adolescents were: aged 11 to 18 years old, used any type of MTSDs, and could speak English. Recruitment was also carried out in such a manner that adolescents from both genders and across age groups of 11 to 12, 13 to 15 and 16 to 18 years old were represented. Participation of parents/caregivers was not a prerequisite for participation by the adolescents. Recruitment continued until data saturation occurred, when no new information was being obtained across three consecutive interviews (Francis et al. 2010, Greg et al. 2006).

4.2.2 Interviews

As already described in Chapter 3, semi-structured interviews were conducted during June to September 2016, with both adolescents and their parents/caregivers by one of the authors (SHT) who had received training on interviews for qualitative research prior to the study. Interviews were conducted based on an interview guide with question prompts (see Appendix R). Questions specifically related to this chapter covered discomfort experienced (if any) during or after using MTSDs and the common postures adopted during MTSD use. Adolescents were also being asked to demonstrate their common postures of MTSD use, especially in their home settings.

Interviews were conducted individually with each adolescent and his or her parent/caregiver in English. Attention was given to ensure that adolescents and parents were not in the same room during each other's interviews. Most of the interviews were carried out in participants' homes. Another location such as restaurant, café or parent's workplace was used if it was not convenient to conduct the interviews at the participant's home. Common postures and settings of MTSD use were demonstrated by the adolescents and photographs were taken. Where it was not convenient to demonstrate postures of use in public places such as restaurant or café, postures were verbalised by the adolescent.

Ethics approval for this study had been obtained from Curtin University Human Research Ethics Committee (RDHS-77-15). For adolescents aged 11 to 17 years, written informed parental consent and written youth assent were obtained for conducting the interviews as well as for photograph taking. For adolescents aged 18 years, youth consent was also obtained. Written consent was also obtained from the parents/caregivers for the interviews.

4.2.3 Data analysis

With permission from participants, each interview was audio-recorded and transcribed verbatim by the first author. Transcripts were coded independently by one of the authors (SHT) and reviewed by another author (EKH), using NVivo 11 software based on areas of research questions, i.e. discomfort experienced (if any) and postures adopted during adolescents' MTSD use. Coding for each adolescent's transcript was done first, followed by his or her own parent/caregiver's transcript. Adolescent and his or her parent/caregiver's transcripts were then compared for triangulation of data (Carter et al. 2014), and separate codes on any agreement and/or disagreement between adolescents and their parent/caregiver were generated. For the photographs of postures taken, general descriptions of overall postures, postures at head/neck, shoulders, back, arms and hands/wrists, external support used (if any, e.g. device accessories or cushions) and settings of use (e.g. living room or bedroom) were made and also coded.

Thematic analysis was carried out with themes generated from the codes using an inductive approach. The research questions set the broad areas for analysis, and coding and theme generation were refined throughout the analysis period (Braun and Clarke 2006, Vaismoradi et al. 2013). All themes were reviewed and discussed by all the authors, and differences in interpretation were resolved.

4.3 Results

From the analysis, five overall themes were generated and organized by the research questions, with the first theme being the nature of discomfort experienced by adolescents during or after using MTSDs. The second theme explored perceived causes of discomfort, while the third theme explored strategies used by adolescents to relieve discomfort. The fourth theme reported on the varied postures adopted by adolescents during MTSD use at various settings, especially at home. The last theme explored the main influences of postures perceived by adolescents and their parents. Themes and their sub-themes are elaborated below, where quotes from adolescents (A) and parents (P) are also presented.

4.3.1 Nature of discomfort

Many of the adolescents reported experiencing some form of discomfort during or after using MTSDs. Discomfort was most commonly reported at neck/shoulder; it was also reported at other areas including back, arms, hand/wrist and eyes. Some described the discomfort as “stiff”, “painful”, “sore”, “uncomfortable” or “aching”. Most of them reported that their discomfort occurred after prolonged use of MTSDs (e.g. one to a few hour(s)), while a few reported that it occurred after using for a short while only (e.g. 10 or 15 minutes). Moreover, some reported that the discomfort experienced was recurrent; it occurred on more than one episode, with varying frequency of occurrence ranging from daily to once every few days or month(s).

Most adolescents reported that their discomfort was often of mild intensity, short lasting of several minutes to a few hours, and that it generally went away by itself, when they stopped using MTSDs or change postures of use, for example:

> “My neck may feel stiff sometimes, when I’m using and even when I’m not using [my phone]. It happens occasionally only…it [is] just a bit stiff but it’s not major…it will go away after a while, like after 1, 2 hours, [so] the discomfort is not very lasting.” (A28)

> “After [using my phone for] a while, you are like used to it. Sometimes, it will be pain[ful] again, but it’s not very bad, yea it’s just slightly only.” (A8)

Moreover, it did not usually cause any significant disruptions to their daily activities and school work. Hence, most of the adolescents did not seek any medical treatment or consultation, nor informed their parents about it.

4.3.2 Perceived causes of discomfort

4.3.2.1 Poor sustained postures during MTSD use

Some of the adolescents reported that the ‘poor’ postures adopted during their use of MTSDs were possible causes of their discomfort, especially when they sustained such ‘poor’ postures for prolonged periods of time. These ‘poor’ postures were commonly referred to by the adolescents as postures consisting of head/neck “bending” or “looking down”, “slouching” or “hunching” in sitting, or “lying down” on their sofa or bed, as opposed to upright sitting postures. There was a general perception by some adolescents and parents that the ‘correct’ posture to have when using MTSDs should be sitting in upright positions. For example:

> “…like sitting and looking down at [my] phone [for] too long, then my neck will be pain[ful].” (A12)

> “Because I bend my neck… for very long period [when using my phone], that’s why [I have] has discomfort.” (A3)

> “I think I’m not maintaining the correct posture that’s why [I have] has discomfort. I [will] suddenly just find myself like sliding [down] the chair [be]cause I’m too engrossed [with] using the phone, [then] I try to sit up straight. I don’t think sliding off the chair when sitting on it is very good.” (A25)

Some parents have reported that they commonly observed their adolescents using MTSDs in non-upright sitting postures such as lying down or slouching when sitting. These postures were also similarly perceived as ‘poor’ postures by some of the parents and attributed as possible causes of their adolescents’ discomfort. A few parents reported that they tried to advise and correct their adolescents’ postures. However, their adolescents did not always comply and tend to return to those ‘poor’ postures when not being supervised by parents, as seen in such instances below:

> “Usually we will ask them to stay [sitting] upright when using the device. They might follow in that instance, but if you walk away, they will go back to their usual comfortable position. [They] require constant reminding.” (P32)

> “…we ask her to sit up straight [when using her phone]…and not to use it on the bed. But somehow, if you don’t see them with your own eyes, they still do it. Sometimes [when] I step into the room…I [still] see them lying on the bed and using their phone, so I told them it’s not right…not advisable to use your phone when lying down or when you sleep. It will also affect their eye sight.” (P15-16)

4.3.2.2 Prolonged use of MTSDs

In addition, many adolescents also perceived their prolonged and continuous use of MTSDs as possible causes of their discomfort, especially when they were using and holding MTSDs in ‘poor’ postures. Some of them also reported that prolonged use with continuous screen viewing on MTSDs had placed a strain on their eyes too. Moreover, a few adolescents reported that they were so engrossed with what they were doing on their MTSDs that they were not aware of their discomfort, even after prolonged use. They usually realized their discomfort only after some time or after finished using MTSDs, for example:

> "The discomfort usually [occurs] about 1 hour after started using [phone]…then you start to feel the discomfort. You know sometimes [when] you are so occupied you won't feel it that much…after a while then you feel that it is painful." (A13)
>
> "When [I'm] watching shows [on my phone] for [a] long time, then my neck will like [become] very painful, [be]cause my neck [is] lying down on the bed. So sometimes, I [will] stop using for a short while…move a bit then I watch again." (A26)

Some parents also similarly reported that prolonged and continuous use of MTSDs by their adolescents without taking breaks, especially in 'poor' postures, might have resulted in their adolescents' discomfort:

> "…he would be in that position [lying down] for a long period of time, very engrossed in playing games [on his phone]." (P34)

4.3.3 Strategies used to relieve discomfort

Certain strategies were adopted by some of the adolescents in attempts to relieve their discomfort from MTSD use. The most common strategy reported was a change or adjustment of posture when discomfort was experienced during or after using MTSDs. For instance, the adolescents reported changing their gross postures, such as from lying down to sitting up, prone lying to lying on their side or back, or from sitting or lying down to standing up and walking about when they felt discomfort. They also reported making adjustments in their postures at neck, back, arms or hands, such as straightening their back to sit more upright or reducing the amount of bending down at neck. They also adjusted handhold support for their device, such as changing from one to two handhold or resting their arms, hands and/or device on a table instead of handholding it in the air. For example:

> "…by sitting up straight when I use the phone has lessened [the] amount of pain..." (A13)
>
> "Because I keep on looking down [on table] so my neck really hurts, so sometimes I stop [using phone] for a while and let the pain go away." (A27)
>
> "My arm will be tired so I [will] switch hands [to hold phone]." (A20)

If discomfort occurred again after some time, the adolescents changed or adjusted their postures again in order to relieve their discomfort, for example:

"[When] you hold the phone [for] too long, your whole arm becomes numb…when my arm gets numb, I just change my hands, just a bit uncomfortable and can't feel your arm, [but] at the beginning it feels very comfortable. After a while, I will change position again." (A4)

"My back sometimes also very uncomfortable…so I'll like shift my position here or there…[after] I sit for [a] very long time already, [if] discomfort come[s] again, I [will] change [position] again." (A24)

"Sometimes [I'll be] on the floor or on the bed…[when] I'm like very uncomfortable in this position then I'll change [position]…keep changing every time…sometimes [when] I just cannot lie on the tummy already, then I'll just turn to lie on the side of body." (A36)

Other strategies reported also included stretching such as moving or rotating neck, moving arms, hands or fingers, massage or seeking medical advice or consultation on their discomfort, for example:

"Just [take a] break for a while, 'twist' the neck, stretch a bit and then go back to the same position." (A23)

"…my mum and dad just take medical oil and start rubbing for me [massage]…[on] either here on the neck or back area, [be]cause sometimes [when] I lie down on my back [for] too long, it becomes very sore…" (A36)

However, a few adolescents seemed to be unconcerned about their discomfort and disregarded it when it occurred. This was likely due to them perceiving their discomfort as mild and non-disruptive to their studies or activities, and that it was normal to experience discomfort from MTSD use, as seen from examples below:

"The neck might get a little bit stiff. Then [but] I just ignore it and keep watching shows [on phone]." (A4)

"…because after I stop [using phone] for a while, it [discomfort] always goes away so I think it's pretty normal. I mean I expected it since I have been slouching in weird positions for some time." (A8)

4.3.4 Varied postures used in various settings

A variety of postures commonly adopted during use of MTSDs were demonstrated by the adolescents, ranging from upright sitting, long sitting (with legs or knees stretched out), side-lying, supine, prone to standing (as seen in Figures 4.1 to 4.7 with brief descriptions of the postures adopted). MTSDs were also used by the adolescents in varied postures at various areas in their homes, including living room, dining area, study area, kitchen, toilet and bedroom. Postures reported during use outdoors or in the community whilst commuting in public transport or when dining out or shopping with family or friends included sitting, standing and walking, for example:

> "I use [phone] in the bus and train when going home…sometimes sit, sometimes stand because no space [to sit]…[for] around 30 minutes." (A24)

> "I use [phone] for one hour plus, and I continue using when they [parents are] shopping in the [shopping] mall…[when] we leave the mall, I [also] still use all the way until [we] reach home… [use] while walking and standing." (A1)

Many of the postures demonstrated were observed to be non-neutral, with head/neck flexed downwards, protruded and/or extended backwards, shoulders rounded, elevated and/or of uneven height, and/or upper/lower back flexed, rotated, side flexed and/or extended. Legs/feet were also observed to be either supported or unsupported, e.g. resting on the sofa, bed or floor, legs crossed, long sitting or dangling off the floor.

Varied postures were also observed for holding MTSDs, ranging from one or two-handed holding with or without support for the arms, hands or the device itself, or no handholding with device supported on a surface (e.g. Figure 4.1(e) or (f)). MTSDs were also handheld or placed on a surface at varying levels, most commonly at the chest level (e.g. Figure 4.2 (b) or (c)), and other levels such as at the eye, shoulder, waist or lap level (e.g. Figure 4.2(a) or (d)). In the same setting on the same furniture such as chair, bed or sofa, the same adolescent may also commonly adopt more than one posture or interchange among multiple postures when using MTSDs, for example A18 might be sitting cross-legged on the sofa whilst handholding a tablet, or sitting on the sofa with feet on the floor and tablet supported on the table (as seen in Figure 4.2(g) and (h); other examples seen in Figure 4.2(e) and (f) or Figure 4.5(e) and (f)).

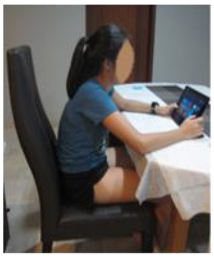
Figure 4.1 Sitting postures on chair in the bedroom (a to c) or living room (d to f)

(a) A8 – both hands holding phone, sitting on a stool with neck bent forward, forearms on table, feet resting on steps of stool

(b) A28 - right hand holding phone at chest level, with both elbows and left forearm resting on table

(c) A1 - both hands holding phone at lap level, with neck bent down, shoulders rounded, elbows on lap, back bent forward

(d) A31 - both hands holding phone at lap level, with legs crossed on chair, back slouching against backrest



(e) A21 - both hands holding tablet tilted up on table via a tablet holder, with forearms on table, lower back against backrest

(f) A5 - phone tilted up against tissue box on table, with forearms on table, back against backrest

Figure 4.2 Sitting postures on sofa in the living room

(a) A10 - both hands holding phone at lap level, with neck bent down, rounded shoulders, back bent forward, elbows resting on lap

(b) A3 - both hands holding phone at chest level, right elbow rested on armrest, back against corner of sofa

(c) A24 - both hands holding phone at chest level, long sitting with neck bent down, forearms resting on double cushions on lap

(d) A14 - both hands holding phone at lap level, with forearms resting on lap, back slouching against corner of sofa

(e) A20 - both hands holding phone at lap level, with elbows resting on lap, back bent forward

(f) A20 - tablet tilted up on table via a tablet holder, with back slouching against cushion at backrest

(g) A18 - both hands holding tablet up at chin level, with shoulders rounded, back slouching against backrest, legs crossed on sofa

(h) A18 - tablet tilted up on tablet via a tablet holder, with back against backrest

Figure 4.3 Sitting postures on bed in the bedroom

(a) A8 - both hands holding phone at chest level, with forearms resting on lap, knees bent up, back against pillow at headboard

(b) A35 - both hands holding phone at lap level, with neck bent down, shoulders rounded, back slouching against pillow at ledge beside bed, legs crossed

(c) A15 - both hands holding phone at chest level towards right side, with right elbow resting on bolster on bed, legs crossed, back leaning towards right side

(d) A16 - both hands holding phone at chest level, long sitting with neck bent down, hands resting on bolster on lap, back slouching against pillow at wall

(e) A32 - both hands holding phone at chin level, long sitting with neck side flexed to right, elbows resting on pillow, back side flexed against pillow and wall

(f) A10 - left hand holding phone at chest level, with neck bent down, right forearm resting on bed, left knee bent, back slouching against pillow at headboard

Figure 4.4 Side-lying postures on sofa in the living room (a to b) or bed in the bedroom (c to d)

(a) A4 - both hands holding phone at eye level, with left side of head/neck on pillow, right knee bent and left knee stretched out on sofa

(b) A29 - both hands holding phone at eye level, with left side of head/neck on armrest of sofa, legs stretched out on sofa

(c) A4 – phone tilted up at bedside table with no handhold, with left side of head/neck resting on bolster, arms and body hugging bolster

(d) A2 – both hands holding phone at eye level, with neck bent forward, left side of head/neck resting on bolster and body hugging bolster, knees bent on bed

(e) A28 – left hand holding phone at chest level, with neck bent forward, right side of head/neck resting on pillow, legs stretched out on bed

Figure 4.5 Supine lying postures on sofa in the living room (a to c) or bed in the bedroom (c to f)

(a) A5 - both hands holding phone at chin level, with head/neck on cushion, elbows on sofa, legs stretched out

(b) A32 – left hand holding phone at eye level, with head/neck on armrest of sofa, elbows on sofa, legs stretched out

(c) A29 – both hands holding phone at eye level, with head/neck on armrest of sofa, right leg crossed over left leg on sofa

(d) A8 - both hands holding phone at eye level, with head/neck flexed against headboard, shoulders on cushion, elbows on bed, legs stretched out

(e) A27 - both hands holding phone supported at lap, with head/neck on pillow, elbows on bed, knees bent

(f) A27 - both hands holding phone up in the air, with head/neck on pillow, elbows stretched upwards, knees bent

Figure 4.6 Prone lying postures on sofa (a) or floor in the living room (b to c) or bed in the bedroom (d to f)

(a) A9 - both hands holding tablet at chest level, tablet tilted up on sofa, with forearms on sofa, back extended, legs stretched out on sofa

(b) A19 - both hands holding phone at eye level, with neck extended, chin and forearms resting on floor, shoulders stretched out on floor

(c) A32 – tablet tilted up on floor via tablet holder at chin level, with neck extended, forearms on floor, back extended

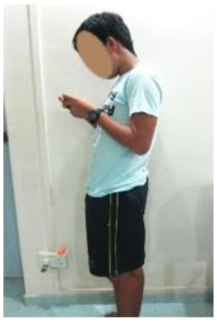
(d) A7 – both hands holding phone on pillow, with neck extended, elbows bent and resting on bed, back extended, legs stretched out

(e) A32 – both hands holding phone, with neck extended, forearms on bed, back extended, knees bent

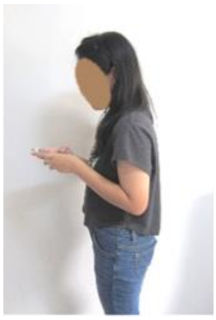
(f) A31 – tablet flat on bed with no handhold, with left hand supporting chin, neck and back extended

Figure 4.7 Standing postures at home or outdoors

(a) A8 – both hands holding phone at tummy level, with neck bent down, elbows bent, back leaning against the wall



(b) A8 – both hands holding phone at chest level, with neck bent down, elbows bent



(c) A8 – both hands holding phone at chest level, with neck bent down, elbows bent

4.3.5 Influences on postures assumed during MTSD use

4.3.5.1 Perceived comfort and discomfort

Adolescents' perception of 'comfort' and discomfort played a major influence on their postures adopted during MTSD use. Many adolescents explained that they assumed those postures, including the non-neutral or awkward postures, as they felt 'comfortable' and 'relaxed' in them – requiring minimal effort to maintain the postures. They also generally perceived non-neutral or awkward postures, especially non-upright sitting postures, such as inclined lying, side-lying or supine lying on bed or sofa to be more 'comfortable' than upright sitting. For example:

> "I really cannot get myself to sit completely straight [on chair]. It feels very uncomfortable. So, I will lean my back [sideways] like that when I use the phone…in some ways it is comfortable." (A13)

> "I use phone [while] sitting on the sofa but most of the time I get lazy and lie down because it's more comfortable…while I find that [sitting] at study desk [is] not [as] comfortable." (A32)

> "…whichever position I feel comfortable with [and] that doesn't ache, on the chair in the room or the sofa or both. I [will] raise my legs up and then I just lie down on my back." (A29)

> "When I'm doing homework, very tired or [when] my back is very uncomfortable, then I [will] just go to the bed and lie down and watch videos [on phone] …[be]cause the bed [is] more comfortable." (A24)

Some adolescents also reported that when they felt discomfort in the postures that they were in, they tried to change their postures to make themselves comfortable, as mentioned in section 4.3.3 (Strategies used to relieve discomfort).

4.3.5.2 Environmental setup

From the perception and demonstration of common postures by adolescents during their use of MTSDs, the environmental setup, which included the surrounding furniture (e.g. chair, desk, sofa, bed or wall) and external support available (e.g. cushions or device accessories) at home, as well as use of MTSDs whilst commuting or when outdoors, were observed to be important influences of their postures. Examples of how surrounding furniture influenced the adolescents' postures were use of inappropriately sized furniture such as a stool of seemingly inappropriate height for the desk (e.g. Figure 4.1(a)), or leaning their back on the wall, headboard or wardrobe beside their bed (e.g. Figure 4.3(a), (b) and (f)):

> "…sit at the bed…[be]cause there's a cupboard beside the bed, so I just lean on the cupboard." (A11)

> "…there is this small table upstairs…it's quite short…not much space that I could use so what I do is that, I will put one leg on the chair and it will be close to my chest and I will just slouch…I use it because I could get better internet there." (A6)

Interestingly, the adolescents also commonly reported that they often used their MTSDs, especially smartphones, where they usually charged their MTSDs at home due to the limited length of the charging cable and the devices running out of battery easily. Hence, they also reported using their MTSDs whilst sitting or lying down on the chair, sofa or bed that were beside the charging spots for their MTSDs, for example:

> "…when I sit on the mattress [bed] to use my phone, I usually lean against the backrest [ledge] or lean forward a bit like this as it is more comfortable. This is [also] the place where I charge [my phone]…" (A35)

The external support(s) available to support their head/neck, arms, hands or the device itself in the adolescents' surrounding environment were also observed to influence their postures and provided 'comfort' for them whilst using MTSDs. For example, the adolescents reported resting their elbows or forearms on the table, sofa or bed whilst handholding MTSDs (e.g. Figure 4.1(a) or (b), Figure 4.5(a) or (d)), using surrounding pillows or cushions to support their head/neck, arms or back (e.g. Figure 4.2(c) or Figure 4.3(a) to (f)), or using a tablet holder or surrounding items to support the device (e.g. Figure 4.1(e) or (f), or Figure 4.6(c)).

4.4 Discussion

This qualitative study has provided rich information on the perspectives of adolescents and parents on the discomfort experienced, and postures adopted during use of MTSDs by adolescents. Many adolescents in this study reported experiencing some discomfort during or after using MTSDs, which were usually mild and non-disruptive to their activities. This is consistent with the general perception of musculoskeletal symptoms during adolescence as trivial (Kamper and Williams 2017), and the majority of adolescents who had musculoskeletal symptoms reporting pain being of low intensity (Aartun et al. 2014, Fuglkjaer et al. 2017a).

The adolescents also perceived their discomfort to be caused mainly by poor sustained postures and prolonged MTSD use. Current research on associations between MTSD use and discomfort is still limited, especially among adolescents. Nonetheless, their perception of causes of discomfort is consistent with the few existing survey studies which found awkward postures (Sommerich et al. 2007) and longer durations (Kwok et al. 2017, Straker et al. 2018a) of MTSD use to be related to musculoskeletal symptoms in adolescents. Moreover, laboratory findings also suggest that sustained postures (including postures at non-traditional workstations such as lying down on sofa or bed) and prolonged use of MTSDs posed greater biomechanical stresses that could lead to discomfort, though research has been mainly conducted with adults (Toh et al. 2017, Werth and Babski-Reeves 2014).

Findings from this study also showed that certain strategies were adopted by some of the adolescents to relieve their discomfort from MTSD use. This indicates that some of them had awareness of their discomfort and were proactive in taking measures to alleviate it. The most common strategy reported was change or adjustment of postures when they felt discomfort, such as gross posture changes (e.g. from lying down to sitting), or smaller postural adjustments such as reducing the amount of bending or adding support for head/neck or back. Prior studies have suggested that variation in postures and muscle activities during technology use may potentially help to reduce the risk of discomfort (Binboğa and Korhan 2014, Straker et al. 2010, Straker et al. 2008c). This suggests that change or adjustment of postures may have introduced variations to the adolescents' postures and help to prevent or reduce their discomfort.

In addition, this study has showed that a large variety of postures at various settings, including various areas at home and outdoors, were adopted by the adolescents when using MTSDs. The findings have added important knowledge about the various configurations of postures adopted by adolescents during MTSD use. These have not been well described in previous research. Many of the postures reported were at non-traditional workstations and settings, such as side-lying with head and legs supported with pillows on the bed or sitting with legs crossed on the sofa. Portability of MTSDs has facilitated use in various postures and settings. However, current research on the impact of postures during MTSD use, especially at non-traditional workstations, and their associations with discomfort is limited (Toh et al. 2017, Werth and Babski-Reeves 2014). The variety of postures and settings also pose further challenges in accurate measurement of postures during MTSD use in real life settings.

In this study, the variety of postures adopted during MTSD use was found to be influenced by adolescents' perceived 'comfort' and discomfort. Many of the postures adopted were at non-traditional workstations and of non-neutral or awkward postures (e.g. sitting cross legged or side-lying on the sofa or bed), as the adolescents felt more 'comfortable' or 'relaxed' in them – lesser effort required to maintain posture, than upright sitting. This is, however, in contrast with findings from some laboratory studies (Lee et al. 2018b, Lin et al. 2015, Werth and Babski-Reeves 2014, Xie et al 2018). For example, higher discomfort at neck/shoulder and back were reported during tablet use at non-traditional workstation - inclined sitting on a bed with tablet placed on the lap compared to on a desk (Lin et al. 2015). Another study also suggests that neck/shoulder pain may be associated with greater non-neutral postures during smartphone texting, as participants with chronic neck/shoulder pain were observed to have greater neck flexion than those who were asymptomatic (Xie et al. 2018). Despite the findings from these laboratory studies, adolescents appear to use MTSD in a wide variety of non-traditional and non-neutral or awkward postures, which may be of benefit to them. However, some of the non-neutral or awkward postures, such as prone lying, may be wrongly perceived by adolescents as poor postures. Whilst prone lying is a non-neutral posture, it could be beneficial for adolescents as it offers opportunities for their cervical, thoracic and lumbar regions to be in relative extension. It may also help to counter biomechanical stresses associated with the common spinal and neck flexion postures during slouched sitting (Caneiro et al 2010).

Given the portability and ubiquity of use of MTSDs at various settings (Lauricella et al. 2014, Rideout 2015), it may not be desirable to use MTSDs in only the constrained posture options available with traditional workstations designed for desktop computers (Werth and Babski-Reeves 2014). The ability to use MTSDs for only short periods of time before changing to vary postures, regardless of the type of workstations or awkwardness of postures, may be protective against discomfort. Future studies should therefore examine the potential for greater posture variations during MTSD use to be beneficial for preventing discomfort.

This study also showed that the environmental setup, including the use of furniture, surrounding objects and device accessories at home, and the environment whilst commuting or when outdoors, has an influence on the postures adopted by adolescents during use of MTSDs. It can also affect the level of discomfort and the biomechanical demands of the postures adopted. For example, some adolescents were observed to use MTSDs on mismatched furniture such as inappropriately sized chair at the desk, which has been shown to result in constrained and awkward postures (Szeto et al. 2014). Some of them also used a tablet holder or surrounding objects to support and tilt their MTSDs (e.g. Figure 4.1(e) or (f), or Figure 4.6(c)), which has been shown to result in lower head/neck flexion and higher comfort at neck with tablet tilted up compared to flat on a table (Chiu et al. 2015). Moreover, a field study has observed that various postures were adopted during smartphone use whilst commuting in the train, for example standing with one hand holding a phone and another hand on a standing pole for balance (Liang and Hwang 2016). Findings from these studies therefore suggest that it is important for adolescents to consider the appropriateness of the environmental setup, as well as supporting head, neck, shoulders, arms or back and the device itself when using MTSDs, as they can affect their postures of use and discomfort.

In this study, some of the adolescents appeared to lack awareness and were unconcerned about their discomfort and postures during MTSD use. They reported getting too engrossed with using their MTSDs that they did not realise their discomfort, possibly due to reduced sensitivity or perception of pain when highly engaged with activities, such as videos or games, on their MTSDs (Weger and Loughnan 2014). Perception of discomfort experienced by some of the adolescents as mild and non-disruptive, and being 'comfortable' in their postures, might also explain their lack of concern. However, current research has shown that musculoskeletal symptoms had important impacts in adolescents, such as school absenteeism (Bejia et al. 2005, Kamper et al. 2016), disruption to physical activities (Drozda et al. 2011), or continued pain into adulthood (Brattberg 2004). Previous studies have also suggested that sustained postures or awkward postures over time could result in cumulative biomechanical stresses and pose a risk for musculoskeletal symptoms (Mikkonen et al 2012, van Oostrom et al 2012). Raising awareness about the impact of discomfort and sustained awkward postures, and encouraging a variety of postures and postural changes during MTSD use may thus be important for wise use of MTSDs among adolescents.

Strengths of this study included a fairly large number of participants and rich information collected on the discomfort experienced and the types and influences of postures by adolescents during use of MTSDs. Photographs of postures taken have also provided useful visual information on common postures during MTSD use at various home settings. Moreover, perspectives from parents obtained in this study have also provided triangulation of data provided by the adolescents. This study is limited in that postures were not captured during their actual MTSD use but were demonstrated by the adolescents from their perspectives. For a few of the adolescents' interviews, it was noted that parents were sometimes within hearing distance in common areas in the house, which might have affected their freedom of expression of views.

4.5 Conclusion

In conclusion, this qualitative study has provided rich information on the discomfort and postures adopted during use of MTSDs from adolescents' and parents' perspectives. Findings from this study showed that many adolescents reported discomfort during or after using MTSDs. Some adolescents employed strategies to relieve their discomfort, most commonly by changing or adjusting their postures, while some were unaware or unconcerned about their discomfort. A large variety of posture configurations and settings during MTSD use were demonstrated, which were influenced by adolescents' perceived comfort and discomfort and the environmental setup. It is important to address discomfort and awkward postures associated with MTSD use to avoid possible adverse effects on adolescents' daily activities, and physical health and development. Future studies should examine strategies to prevent or reduce discomfort from MTSD use and the impact of varied postures at various settings, especially at non-traditional settings, on discomfort in adolescents.

Chapter 5 Study B: Cross-sectional associations of MTSD use with musculoskeletal symptoms and visual health

This Chapter presents results from the baseline survey study and its findings on contemporary technology and MTSD use by adolescents, including patterns of use (i.e. bout length, types of activities, multitasking), and their cross-sectional associations with musculoskeletal symptoms and visual health outcomes (i.e. visual symptoms, myopia). An online questionnaire was conducted with a representative sample of 1884 adolescents (50.4% girls) from grades primary 5 to post-secondary year 1 (10-18 years old), recruited from 13 schools. This study obtained ethics approval from Curtin University Human Research Ethics Office (RDHS 100-15) (Appendix S) and written informed consent/assent from the participants (Appendix T). Findings from this study have been published and are presented verbatim in this chapter. This is an Accepted Manuscript of an article published by Taylor & Francis in *Ergonomics* on 23 Apr 2019, available online: https://www.tandfonline.com/doi/abs/10.1080/00140139.2018.1562107. Full reference of paper:

> Toh SH, Coenen P, Howie EK, Mukherjee S, Mackey DA, Straker LM (2019) Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents. *Ergonomics* 62: 778-793.

5.1 Introduction

Technology use by children has exponentially increased in recent years, especially following the introduction of mobile touch screen devices (MTSDs), primarily smartphones and tablet computers. Recent large-scale surveys have shown high and increasing use of MTSDs amongst adolescents (Australian Communications and Media Authority 2016, Ofcom 2017, Rideout 2015), and there is concern about its potential negative impact on adolescents' musculoskeletal and visual health (Lissak 2018, Straker and Howie 2016). However, there is a dearth of evidence to support this hypothesis. Whilst extensive research has been conducted on associations between musculoskeletal symptoms and computer use, studies on MTSD use have been limited and mostly conducted in adult populations (Toh et al. 2017, Xie et al. 2017).

Musculoskeletal symptoms can adversely affect adolescents' health, leading to school absenteeism, reduced physical activity (Bejia et al. 2005, O'Sullivan et al. 2012), and an increased risk of musculoskeletal problems during adulthood (Brattberg 2004). Similarly, existing research has shown associations between computer use/video gaming (Bao et al 2015) and impaired vision or symptoms such as eye strain (Gowrisankaran et al. 2015, Lissak 2018). MTSD use from a young age raises the concern of eye-related developmental problems (Akinbinu and Mashalla 2014). In addition, blue light emitted from screens has been proposed to increase the risk for age-related macular degeneration (Tosini et al. 2016). Given the current ubiquity of MTSD use by adolescents, it is important to examine associations between MTSD use and musculoskeletal and visual symptoms among adolescents.

The quality of available evidence on MTSD use and musculoskeletal and visual outcomes in adolescents is limited by convenience sampling, a focus on Western populations and simple exposure measures of MTSD use. Even with a large sample size, convenience sampling can introduce a selection bias and recruited participants may not be representative of the population (Tyrer and Heyman 2016). Moreover, to date, the majority of epidemiological studies on technology use, including MTSDs, have been conducted in Western countries, such as the USA, Australia and Europe (Houghton et al. 2015, Rideout 2015, Torsheim et al. 2010), while studies in Asian countries have recently gained interest amongst researchers (Kwok et al. 2017, Shan et al. 2013, Woo et al. 2016). Compared to the Western countries, adolescents in Asian countries may exhibit different patterns of technology use due to cultural differences (Jackson et al. 2008, Recabarren et al. 2008) or even more widespread internet availability than in some Western countries (We Are Social 2017).

Research to date investigating MTSD use has mostly reported simple measures of use and duration of use, with a lack of comprehensive reporting on patterns of use, including weekday weekend use, types of activities, bout length of use or extent of multitasking. Patterns of computer use, such as the types of activities (Straker et al. 2013, Torsheim et al. 2010) and bout use duration (Menéndez et al. 2008) have been found to be related to musculoskeletal symptoms. A recent review has also found gaming and texting on mobile handheld devices (inclusive of physical keypad phones) as risk factors for musculoskeletal symptoms (Xie et al. 2017). These findings suggest that patterns, and not just duration, of MTSD use may influence the risk for musculoskeletal symptoms. However, these studies on use of other digital devices may not be applicable to MTSDs as patterns of use and risks for symptoms may be different for MTSDs due to their greater portability, multifunctionality and different biomechanical demands (Gustafsson et al 2018, Straker et al. 2008c, Xie et al. 2018). There is, therefore, a need to examine the contemporary patterns of technology use, especially MTSD use among adolescents, which can inform public health recommendations for use and interventions. This study aimed to examine among a nationally representative group of adolescents in Singapore the:

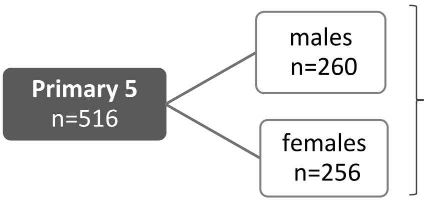
- amount and patterns of contemporary technology use, particularly MTSDs
- associations of MTSD use with musculoskeletal symptoms and visual health.

5.2 Methods

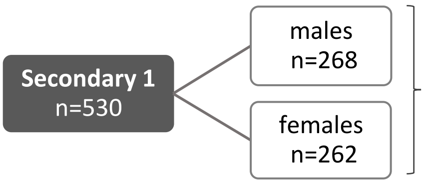
5.2.1 Study design and sample

This cross-sectional study involved administering an online survey to 2009 adolescents recruited from schools in Singapore, using a sampling matrix stratified on socioeconomic and academic indicators (see Figure 5.1). Four school year levels were selected to capture adolescents from 10 to 18 years of age: primary 5, secondary 1, secondary 3, and post-secondary year 1 (equivalent to grades 6, 8, 10 and 12, respectively, of the US education system), using a list of all the schools that was obtained from the Ministry of Education Singapore (2015). Primary schools were selected from different types of school (government or government-aided) and location (higher and lower socioeconomic status based on the top and bottom 50th percentile of median monthly household income of each planning area, according to the last census report from the Department of Statistics Singapore (2010). Secondary schools were also selected from different types of school (government or government-aided) and educational stream (Express [higher academic] or Normal [lower academic] stream, based on students' primary school leaving examination performance). Post-secondary schools were selected from different types of schools (junior college, polytechnic or vocational [Institute of Technical Education]). Using G*Power software, a sample size of 2000 was estimated to enable the detection of an odds ratio (OR) of 1.17 with 80% power and an alpha probability of 0.05. This expected effect size was based on the OR reported by a survey study on risk of neck/shoulder and back pain with computer and tablet use in adolescents (Shan et al. 2013). Within each sampling cell, schools were invited in random order until ~2000 adolescents had agreed to participate.

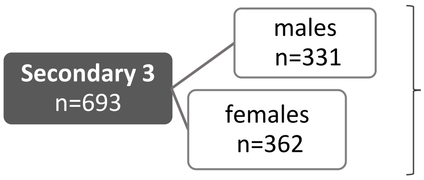
Figure 5.1 Stratified sampling matrix and sample number for each school



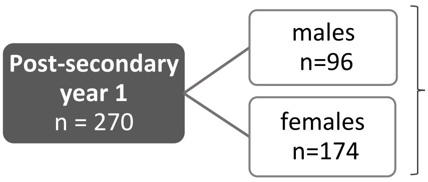
Sampling matrix by type of school and location	Government schools	Government-aided schools
Schools located in planning area of top 50th percentile of median household income	n=166	n=94
Schools located in planning area of bottom 50th percentile of median household income	n=116	n=140



Sampling matrix by type of school and class streaming	Government schools	Government-aided schools
Express course	n=125	n=146
Normal course	n=130	n=129



Sampling matrix by type of school and class streaming	Government schools	Government-aided schools
Express course	n=175	n=184
Normal course	n=137	n=197



Sampling matrix by type of school/ institution	
Junior college	n=145
Polytechnic	n= 125 *(excluded from analysis)*
Vocational (Institute of Technical Education)	- *(no approval obtained)*

Ethics approval was obtained from Curtin University Human Research Ethics Committee (RDHS-100-15), and approval for data collection in schools was obtained from the Singapore Ministry of Education and a polytechnic institution, as well as the school principal of each participating school. Assent from adolescents and written informed consent from parents/guardians were obtained for participants less than 18 years old, while adolescents who were at least 18 years old provided written consent. The primary and secondary school participants completed an online questionnaire in a school classroom or computer laboratory using a laptop or tablet computer, while the junior college students did so on a smartphone (due to facility constraints). A research team member was present to answer any questions during administration of the questionnaire. Due to ethical and logistics constraints at the polytechnic institution, it was not possible to administer the questionnaire during the students' curriculum time or to recruit students from a wide variety of courses. Instead, a short information session regarding the study was given to the polytechnic students from one course. Brochures containing the survey link were distributed to them and they were asked to complete the online survey on their own time within a stipulated timeframe. There were no participants from the vocational school (Institute of Education) as none of the principals provided approval.

5.2.2 Measures

The Technology Use Questionnaire (TechU-Q) (Appendix U) was administered online through Qualtrics. It has been developed based on prior studies and pilot testing by the investigators (Harris et al 2017). Test-retest reliability of TechU-Q for total technology use was high, with an intraclass correlation for total technology use of 0.90 (Straker et al. 2018a). It had also been shown to be acceptable and understandable by a sample of grade 5 children in an Australian school (Straker et al. 2018a). To ensure feasibility and comprehensibility by adolescents in Singapore, the questionnaire was pilot-tested with 15 adolescents in Singapore from different school levels and across ages of 10 to 17 years. After obtaining feedback, the text and formatting of the questionnaire were slightly amended to make the questions clearer and ensure cultural applicability.

Questions covered duration (for a typical weekday and weekend day) and frequency (number of weekdays and weekend days) of technology use for multiple devices, including MTSDs and other devices, i.e. TV, desktop, laptop, handheld electronic games (e.g. PSP, Nintendo DS), active (playing actively and moving about, e.g. XBOX Kinect, Wii Remote, PS3 MOVE) and non-active game consoles (playing in sitting position, not actively moving, e.g. gamepad operated XBOX, PS3). Usage for weekdays and weekend days was assessed separately. The TechU-Q also included questions on use in the last 12 months, ownership, bedroom usage, types of activities on weekdays and weekend (i.e. homework, social, watching videos, games or other general use), extent of multitasking with other devices (i.e. never, a little of the time, some of the time or most of the time) and bout length of use (typical duration of usage before stopping). Answer options for duration of device use, types of activities and bout length of use range from five, 15 or 30 minutes, to one hour, two hours, three hours and so forth with an increment of one hour up to a maximum of 12 hours or more. Device use across the whole week and duration for the types of activities were tabulated by multiplying duration and frequency for weekdays and weekend days.

In addition, demographic information, i.e. date of birth, gender, age, housing type, father's and mother's education level, and typical school marks (Short et al 2013) were also collected from the participants. Musculoskeletal symptoms for neck/shoulders, upper back, low back, wrist/hand were reported using a modified Nordic Musculoskeletal Questionnaire (Kuorinka et al 1987), which included questions on prevalence in the last month, frequency (i.e. almost never [<1 time/month], occasionally [1-3 times/month], often [1-3 times/week], always [>3 times/week]), intensity and interference with normal activities (scale 0 to 10). Questions on visual health included visual symptoms (i.e. eye strain (irritation, heaviness), tiredness, watering, redness, itching of eyes, blurring of vision, dry eye, double vision or headache as adapted from symptoms of computer vision syndrome) (Seguí et al 2015) experienced during or after use of MTSDs, use of glasses or contact lenses, trouble seeing far (myopia) and trouble seeing near (hyperopia) (Ojaimi et al 2005). Mental health (using the Depression Anxiety Stress Scale 21 (DASS-21) (Szabo 2010)) and physical activity (using the Physical Activity Questionnaire for Adolescents (PAQ-A) (Kowalski et al 2004)) were also reported as covariates. To ensure cultural applicability and comprehensibility, certain physical activities for question one in PAQ-A, i.e. "football, soccer, floor hockey, street hockey, bicycling, tag, in-line skating, ice skating, cross-country skiing, ice hockey/ringette" were amended to "rugby/touch rugby, soccer/football, hockey (outdoors/indoors), netball, bicycling/cycling, tag/catching chasing game, in-line skating/roller skating, tennis, captain's ball" respectively, according to the top 15 sports by teens (13-19 years old) (Singapore Sports Council 2011).

In order to obtain an overview of technology use in schools, a short questionnaire on the types and amount of technology use by adolescents in school was completed by a teacher from each participating school.

5.2.3 Data analysis

Descriptive statistics were calculated for technology use for each device and total technology use, by weekdays and weekend days, gender and school levels. Both mean (SD) and median (IQR) of daily use duration were estimated. As usage data were not normally distributed, comparisons between weekdays and weekend days, genders and among school levels were conducted using chi-square, Mann-Whitney U, Wilcoxon signed rank or Fisher's exact tests. Musculoskeletal and visual symptoms were also reported by gender and school levels. Associations between MTSD use (mean daily use across the whole week (hrs/day)) and musculoskeletal symptoms (prevalence of discomfort in the last month) were examined using binary logistic regression, while those between MTSD use and visual symptoms were examined using ordered logistic regression. These associations were adjusted for gender, school level, mental health, physical activity and total technology use duration of the other devices (excluding smartphone or tablet use) (see Table 5.4) using STATA 14. Adjustment for total technology use of the other devices was conducted in view of potential co-linearity between MTSD use and use of the other devices. ORs with 95% confidence interval were estimated and a p-value lower than 0.05 was adopted to be statistically significant.

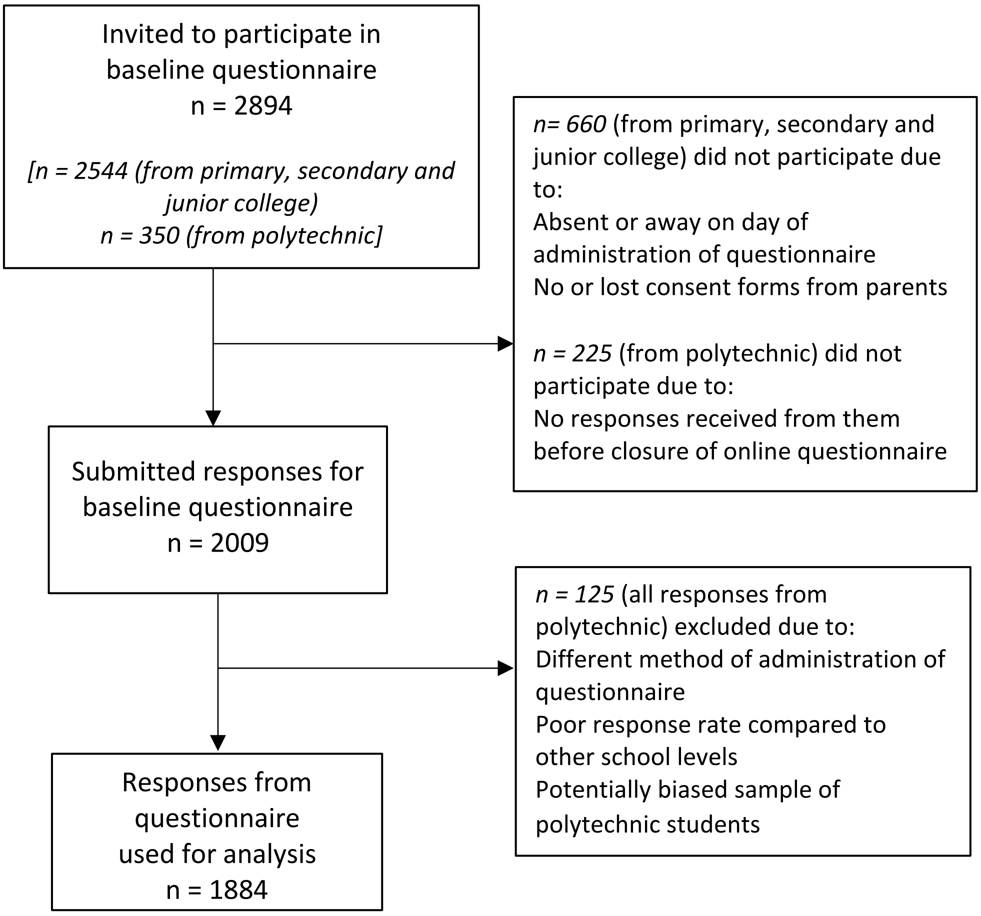
5.3 Results

5.3.1 Sample

A total of 2009 adolescents from 14 schools provided responses to at least one question in the survey that was conducted from January 2016 to June 2016. Four primary schools, eight secondary schools, two post-secondary schools (one junior college and one polytechnic institution) participated. All responses from polytechnic students (n=125) were excluded from further analysis in this paper due to: different method of administration of questionnaire (participants did the questionnaire online at their own time as the polytechnic did not agree to in-class completion); poor response rate; and difficulties recruiting an unbiased sample of polytechnic students (participants were all from a single course and had many more girls (n=105) than boys (n=20)). Therefore, data from 1884 respondents (74.1% response rate) were included for further analysis (see Figure 5.2).

There was a similar percentage of girls and boys in the total sample of 1884 adolescents (50.4% girls) and across each school level of primary 5, secondary 1 and 3, and junior college 1 (Figure 5.1). Mean age (SD) of participants was 13.3 (2.0) years, ranging from 10 to 18 years. The majority of participants were of Chinese race (73.1%), followed by Malay (14.3%), Indian (6.0%) and others (6.6%); these races were all represented across each school level. Gender and race demographics of the sample were comparable to that for the adolescent population in Singapore, according to data from the Department of Statistics Singapore (2016a).

Figure 5.2 Flowchart of number of participants



The number of participants for each stratum of the stratified sampling matrix is presented in Figure 5.1. Different socioeconomic strata (SES) and academic levels were well represented in the matrix, with generally higher percentages of students with higher SES for housing types and parents' education in government-aided than government schools, and higher percentages of students with higher typical school marks in the Express compared to the Normal course (Appendix V).

Overall mean DASS-21 score (SD) was 13.6 (11.4), with poorer mental health scores for girls (14.9(11.2)) than boys (12.4(11.4), p<.001). Mental health also decreased with increasing school levels (p<.001; e.g. 11.0(9.8) in primary 5 to 19.3(11.4) in junior college 1). Mean PAQ-A score (SD) was 2.4 (0.7), with higher level of physical activity for boys

(2.6(0.7)) than girls (2.3(0.7), p<.001). Physical activity level also decreased with increasing school levels (p<.001; e.g. 2.6(0.7) in primary 5 to 2.1(0.5) in junior college 1).

5.3.2 Technology use

Across the included sample of 1884 adolescents, the smartphone was the most widely used device (95.1%), followed by TV, laptop, tablet (71.1%), desktop, non-active game consoles, active game consoles and handheld games (Table 5.1). Ownership and bedroom usage of devices was highest for the smartphone at 88.9% and 83.1% respectively, followed by laptop (61.2% and 48.8%, respectively) (Appendix W and X). Although responses from polytechnic students were excluded from analysis, descriptives of their technology use including MTSDs are provided in supplementary information (Appendix Y and Z).

There were no significant gender differences in the last 12 months' usage for smartphone and tablet (Table 5.1). Girls had significantly higher smartphone ownership and bedroom usage than boys, while boys had higher ownership as well as bedroom usage of desktop and all the gaming devices (handheld games, non-active and active game consoles) (Appendix W and X). With increasing school levels, smartphone and laptop usage in the last 12 months increased while that for tablet generally decreased (Table 5.1). Smartphone use for the younger adolescents (in primary 5) was high at 88.2%; it then increased rapidly to 96.2% for secondary 1 and continued to increase for secondary 3 and junior college 1. Similar increasing ownership and bedroom usage for both smartphone and laptop were observed with increasing school levels (Appendix W and X). Smartphone ownership was already high at 70.2% for primary 5 and increased to 99.3% by junior college 1. On the other hand, tablet ownership and bedroom usage were similar among the school levels.

Total technology use, obtained by summing mean daily use across the whole week for each of the devices, was 537 (471) minutes. None of the participants reported total technology use greater than 3600 minutes/day (five or more devices with max use of 12hours/day) as implausible data. Among all the devices, the adolescents used smartphone the most throughout the entire week, with mean usage (SD) of 264 (243) minutes, or 4 (4) hours per day (Appendix AA). TV was the next most used device (106 (138) minutes), followed by laptop (63 (114) minutes), then tablet (53 (124) minutes). Mean technology use on weekends was significantly higher than on weekdays for all the devices (Appendix F). Median (IQR) daily use for smartphone was 180 (51-429) minutes while that for tablet was much lower at 2 (0-39) minutes (see Appendix AA for the other devices).

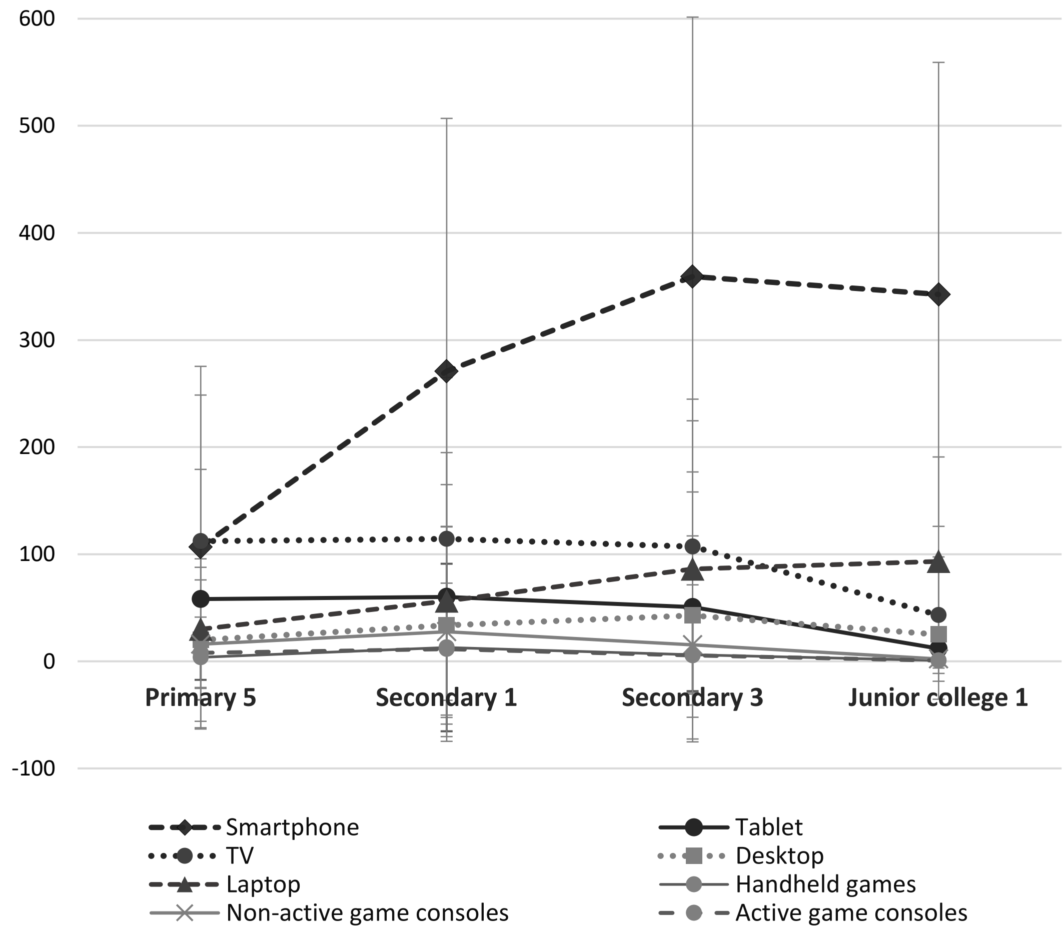
Table 5.1 Percentage of adolescents using technology in the last 12 months by gender and school level

	Total *(n=1884)*	**Boys** (n=935)	**Girls** (n=949)	**Primary 5** (n=516)	**Secondary 1** (n=530)	**Secondary 3** (n=693)	**Junior college 1** (n=145)
Smartphone	95.1	94.3	95.8	88.2	96.2	98.3	100.0***
Tablet	71.1	69.0	73.2*	77.7	72.1	66.2	67.6***
TV	92.7	91.0	94.3**	94.0	92.8	91.3	93.8
Desktop	59.1	60.5	57.7	57.6	60.4	58.0	65.5
Laptop	82.9	81.9	83.9	76.4	81.2	85.9	97.2***
Handheld games	22.1	26.3	18.0***	18.4	25.5	22.1	23.5
Non-active console games	35.4	43.7	27.1***	30.2	38.1	37.4	33.8*
Active console games	32.5	34.6	30.5	33.5	34.2	31.0	29.7

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between boys and girls using chi-square test, and differences among all the school levels using chi-square or Fisher's exact tests (for only smartphone and laptop as one of the cells has n<5)*

Some gender and school level differences were also noted in technology use. Mean smartphone use was higher for girls than boys (p<.001), while desktop, laptop, as well as handheld, non-active and active game consoles were higher for boys (p<.05) (Appendix F). Total technology use and mean daily use of the smartphone, tablet, TV, laptop and non-active game consoles were different among the school levels (Figure 5.3) (p<.03). Total technology use increased from primary 5 to secondary 3, and dropped in junior college 1 to lower than that for secondary 1. Daily smartphone use was fairly similar to daily TV use in primary 5 students, but smartphone use increased steeply while TV use remained similar in secondary 1 and 3, and both dropped slightly in junior college 1. Among secondary 1 and 3 and junior college 1 students, smartphone use dominated, and was much higher than all the other devices, as presented in Figure 5.3. Tablet use was similar among primary 5, secondary 1 and 3, and lowest for junior college 1. Laptop use increased with increasing school level.

Figure 5.3 Mean daily minutes of technology use for each school level



Note: each marker represents a subsample of device use at a school level which are independent of the other subsamples

Regarding technology use in school, questionnaire responses from the teachers indicated that MTSDs were being used in school, sometimes during lessons, but not formally incorporated into the school curriculum. Smartphones (students' own), and tablets (provided by the school) were used at times during lessons (ranging from few times per week to few times throughout the semester), when allowed by teachers for browsing information, gathering survey responses from students, or used to aid in teaching. Laptops (provided by the school) were generally used more frequently than MTSDs, usually once a week or more in school computer laboratory for computer lessons. Online checking and/or submission of homework were sometimes given during the school semester or holidays. Some teachers also reported that students commonly used messaging on smartphones to communicate with each other regarding homework and other school-related matters.

5.3.3 Types of activities

Smartphone use dominated for each type of activity: homework, social, videos, games and general use among the devices (see Figure 5.4). Social activity, e.g. messaging and social media, had the highest amount of use among the activities on smartphone, while watching videos had the highest usage for tablet, desktop and laptop. However, there were different patterns of use as a result of gender, school level, device and types of activities. Figure 5.5 shows the greater use of smartphones for homework (panel A), watching videos (panel C) and social activities (panel E) by girls compared to boys across all the school levels, although the gender differences in primary 5 were much smaller than at other school levels. On the other hand, panel F highlights the greater use of smartphones for games by boys compared to girls across all the school levels, and this greater game use by boys was also consistent across tablet, desktop and laptop computers. Boys and girls had similar use of devices, other than smartphone, for all activities except games: e.g. homework on a laptop (which increased fairly equally with increasing school levels, panel B), or watching videos on a tablet (panel D).

Figure 5.4 Daily technology use for various activities (across whole week)

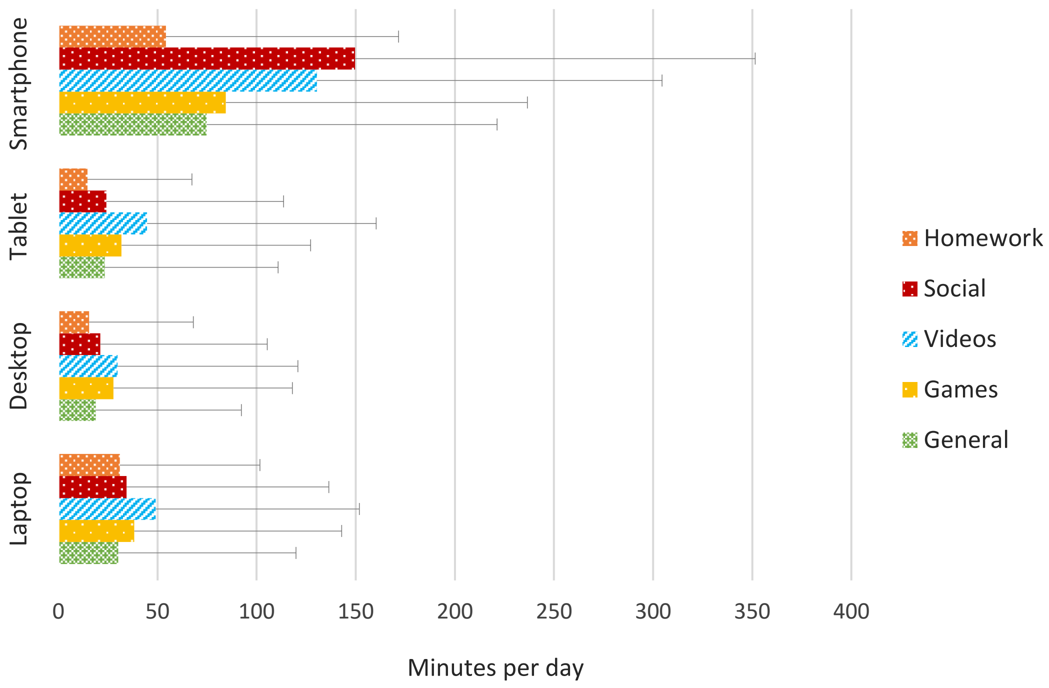
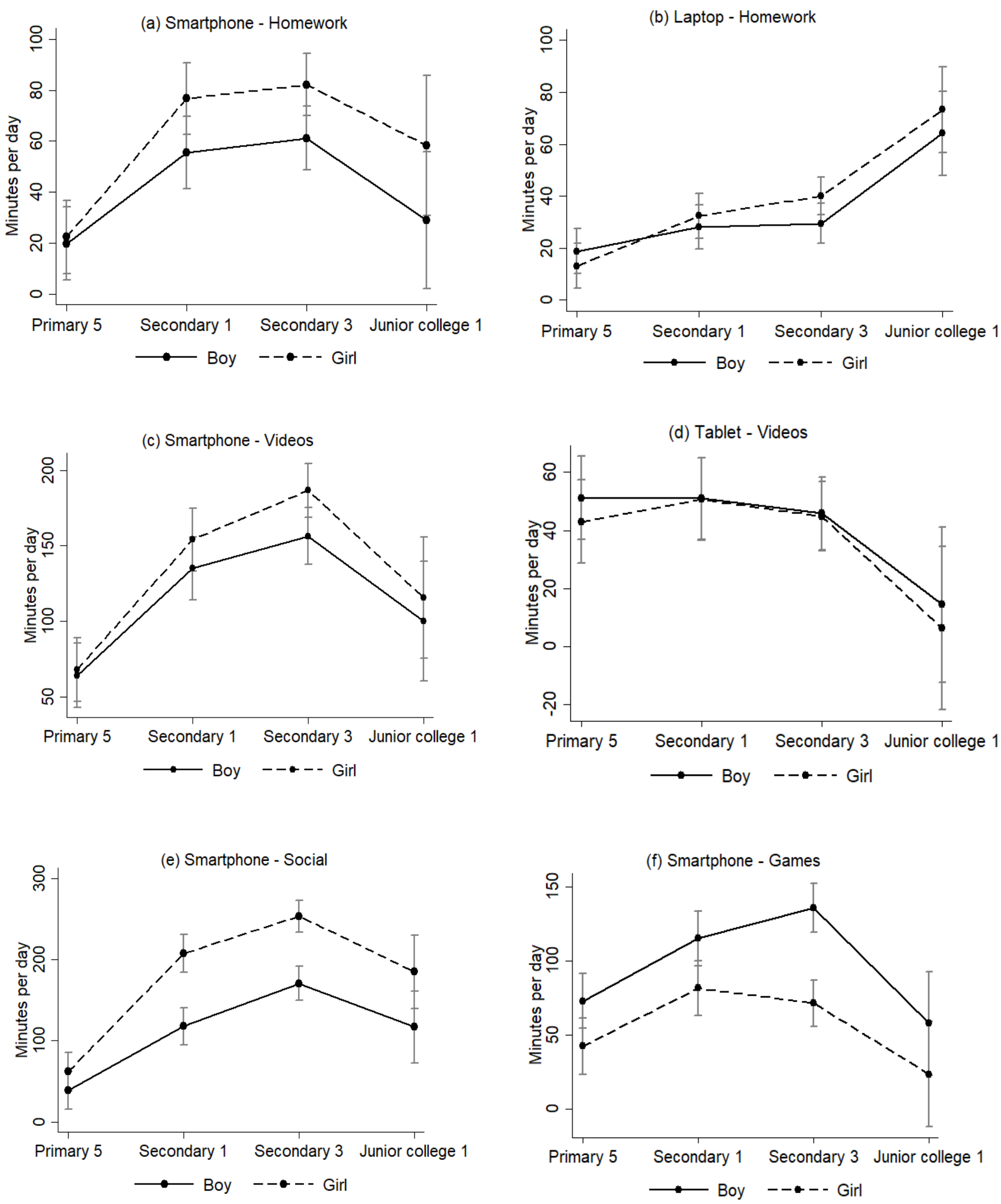


Figure 5.5 Mean (standard deviation) daily minutes of technology use across school levels for boys and girls for panel (a) homework on a smartphone, (b) homework on a laptop, (c) watching videos on a smartphone, (d) watching videos on a tablet, (e) social activities on a smartphone and (f) playing games on a smartphone



5.3.4 Multitasking

The percentage of adolescents reporting frequent multitasking (some or most of the time) with other devices was highest for smartphone use (69.4%), followed by TV (57.3%), then laptop (41.8%), tablet (30.8%), desktop (23.1%) and game consoles (<11.4%) (Appendix BB). A higher proportion of girls (71.9%) reported frequent multitasking during smartphone use compared to boys (66.8%), while multitasking was fairly similar between boys and girls during tablet use (31.5% and 30.1%, respectively). Percentages of frequent multitasking for smartphone increased from primary 5 (53.2%) to secondary 1 (70.4%) and remained high thereafter; whilst for tablet it remained stable and reduced at junior college 1.

5.3.5 Bout length of use

Mean bout length of use, was the highest for smartphone with bout lengths of 191 (221) minutes, followed by TV (101 (133 mins), laptop (100 (148) mins) and tablet (69 (127) mins) (Appendix CC). There were no gender differences for smartphone and tablet bout length. Smartphone bout length increased from primary 5 (118 (176) mins) to secondary 3 (239 (239) mins), and then decreased fairly steeply in junior college 1 (128 (173) mins). Tablet bout length was the highest at primary 5 (81 (138) mins) and it then similarly reduced at junior college 1 (28 (59) mins). Median (IQR) bout length for each device was also estimated (see Appendix CC).

5.3.6 Musculoskeletal symptoms

Musculoskeletal symptoms in the previous month were most commonly reported in the neck/shoulder region (42.4%), followed by arms (33.3%), upper back (29.1%), wrist/hand (26.8%) and low back (22.7%) (Table 5.2). In those adolescents with symptoms in the past one month, at least 26.1% reported having symptoms 'often or always' for all the body regions. Moreover, in those with symptoms, the intensity of discomfort and interference to daily activities were fairly similar among the different body regions, ranging from mean scores of 4.0 to 4.4 (out of 10), and 3.4 to 3.6 (out of 10), respectively. Girls had a significantly higher prevalence of symptoms at neck/shoulder in the previous month compared to boys. Prevalence of having symptoms increased with increasing school levels for all the body regions.

Table 5.2 Number (percentage) of adolescents reporting musculoskeletal symptoms in the last month by body regions, gender and school levels, and in those with symptoms the number (percentage) reporting high frequency symptoms in the last month of "Often or always", mean (standard deviation) of discomfort intensity (out of 10) and interference with daily activities (out of 10)

		Total (n=1875)	**Boys** (n=929)	**Girls** (n=946)	**Primary 5** (n= 513)	**Secondary 1** (n=527)	**Secondary 3** (n=690)	**Junior college 1** (n=145)
Neck/ shoulders	Last month prevalence	795 (42.4%)	360 (38.8%)	435 (46.0%)**	139 (27.1%)	214 (40.6%)	347 (50.3%)	95 (65.5%)***
	Often or always	222 (27.9%)	120 (33.3%)	102 (23.4%)	34 (24.5%)	74 (34.6%)	87 (25.1%)	27 (28.4%)
	Intensity	4.4 (2.1)	4.2 (2.1)	4.5 (2.0)*	4.2 (2.0)	4.4 (2.2)	4.4 (2.0)	4.5 (2.1)
	Interference	3.5 (2.5)	3.7 (2.5)	3.4 (2.5)	3.6 (2.6)	3.8 (2.5)	3.3 (2.3)	3.5 (2.8)
Upper back	Last month prevalence	545 (29.1%)	255 (27.4%)	290 (30.7%)	89 (17.3%)	167 (31.7%)	227 (32.9%)	62 (42.8%)***
	Often or always	176 (32.3%)	87 (34.1%)	89 (30.7%)	21 (23.6%)	50 (29.9%)	81 (35.7%)	24 (38.7%)
	Intensity	4.3 (2.2)	4.4 (2.2)	4.3 (2.2)	3.9 (2.4)	4.2 (2.1)	4.5 (2.1)	4.7 (2.4)
	Interference	3.5 (2.6)	3.5 (2.6)	3.5 (2.6)	3.1 (2.6)	3.5 (2.6)	3.6 (2.5)	3.9 (2.7)
Low back	Last month prevalence	424 (22.7%)	198 (21.3%)	226 (23.9%)	64 (12.5%)	108 (20.5%)	192 (27.8%)	60 (41.4%)***
	Often or always	132 (31.1%)	65 (32.8%)	67 (29.6%)	12 (18.8%)	35 (32.4%)	59 (30.7%)	26 (43.3%)*
	Intensity	4.4 (2.4)	4.4 (2.5)	4.4 (2.3)	4.1 (2.5)	4.0 (2.5)	4.6 (2.3)	5.1 (2.3)*
	Interference	3.6 (2.6)	3.6 (2.7)	3.6 (2.6)	3.4 (2.8)	3.6 (2.6)	3.5 (2.5)	4.0 (2.9)

		Total (n=1875)	**Boys** (n=929)	**Girls** (n=946)	**Primary 5** (n= 513)	**Secondary 1** (n=527)	**Secondary 3** (n=690)	**Junior college 1** (n=145)
Arms	Last month prevalence	699 (37.3%)	336 (36.2%)	363 (38.4%)	148 (28.8%)	189 (35.9%)	288 (41.7%)	74 (51.0%)***
	Often or always	189 (27.0%)	93 (27.7%)	96 (26.4%)	31 (20.9%)	49 (25.9%)	82 (28.5%)	27 (36.5%)
	Intensity	4.1 (2.2)	4.1 (2.3)	4.2 (2.1)	4.0 (2.3)	4.1 (2.1)	4.2 (2.2)	4.4 (2.1)
	Interference	3.4 (2.5)	3.5 (2.6)	3.3 (2.4)	3.4 (2.6)	3.6 (2.5)	3.3 (2.4)	3.6 (2.6)
Wrist/ hand	Last month prevalence	501 (26.8%)	235 (25.4%)	266 (28.1%)	114 (22.2%)	133 (25.2%)	204 (29.6%)	50 (34.5%)**
	Often or always	131 (26.1%)	62 (26.4%)	69 (25.9%)	21 (18.4%)	34 (25.6%)	62 (30.4%)	14 (28.0%)
	Intensity	4.0 (2.3)	4.0 (2.4)	4.1 (2.3)	3.9 (2.4)	3.8 (2.2)	4.0 (2.4)	4.5 (2.5)
	Interference	3.6 (2.6)	3.6 (2.7)	3.5 (2.6)	3.5 (2.6)	3.5 (2.6)	3.5 (2.6)	4.0 (2.9)

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between boys and girls and among all the school levels using chi-square test (for last month prevalence and having symptoms often or always), one-way ANOVA (for intensity) and Kruskal Wallis test (for interference)*

5.3.7 Visual symptoms

The number of visual symptoms reported during or after using MTSDs was 2.2 (2.0) (out of a list of nine symptoms), with tiredness of eyes being most commonly reported (56.2%) (Appendix DD). The number of symptoms reported by girls was slightly higher compared to boys, with number of symptoms increasing after secondary 1 school level. 63.6% of adolescents reported wearing glasses or contact lenses. Among those who wore glasses or contact lenses, 83.0% reported having trouble seeing far (myopia) (Table 5.3). The percentage of adolescents wearing glasses or contact lenses and having trouble seeing far (myopia) was higher for girls than boys and increased with increasing school levels.

5.3.8 Associations of MTSD use with musculoskeletal and visual symptoms

A greater amount of hours/day smartphone use was associated with a higher last month prevalence of neck/shoulder, upper back, arms and wrist/hand symptoms (OR=1.04 (1.01-1.07) to 1.07 (1.03-1.10); $p<.05$) (Table 5.4), as well as with a greater number of visual symptoms (OR=1.05 (1.02-1.08), $p<.001$) and with decreased odds of trouble seeing far (myopia) (Table 5.4). Using regression models consisting of MTSD use (yes/no) and MTSD use duration (mean daily hours across whole week) resulted in the same findings. Greater tablet use was not significantly associated with musculoskeletal symptoms at any location/site, or visual symptoms or wearing glasses or having trouble seeing far.

Table 5.3 Mean (standard deviation) number of visual symptoms, number (percentage) of students reporting wearing glasses/ contact lenses, and in those wearing glasses/contact lenses reporting trouble seeing far (myopia) or near (hyperopia) or both, by gender and school levels

	Total	Boys	Girls	Primary 5	Secondary 1	Secondary 3	Junior college 1
Visual symptoms	2.2 (2.0)	2.0 (2.0)	2.4 (2.0)***	2.0 (2.0)	2.0 (2.0)	2.3 (2.1)	2.6 (2.0)***
Wearing glasses/ contact lenses	1188 (63.6%)	544 (58.8%)	644 (68.2%)***	272 (53.3%)	326 (62.1%)	479 (69.5%)	111 (76.6%)***
Far (myopia)	986 (83.0%)	432 (79.4%)	554 (86.0%)***	203 (74.6%)	270 (82.8%)	407 (85.0%)	106 (95.5%)***
Near (hyperopia)	122 (10.3%)	64 (11.8%)	58 (9.0%)	37 (13.6%)	31 (9.5%)	49 (10.2%)	5 (4.5%)
Both	51 (4.3%)	23 (4.2%)	28 (4.3%)	12 (4.4%)	12 (3.7%)	24 (5.0%)	3 (2.7%)

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between boys and girls and among all the school levels, using Kruskal Wallis test (for visual symptoms) and chi-square test (for glasses/contact lenses, myopia, hyperopia and both)*

Table 5.4 Association between hours/day of MTSD use and prevalence of discomfort in the last month in various body regions, number of visual symptoms, wearing glasses or contact lenses, and trouble seeing far (myopia)

	Adjusted for gender, school level, DASS-21, PAQ-A and total technology use of other devices^				**Unadjusted**	
	Smartphone		Tablet		Smartphone	Tablet
	N	OR (95% CI)	N	OR (95% CI)	OR (95% CI)	OR (95% CI)
Neck/ shoulders	1827	1.04* (1.01-1.07)	1839	1.02 (0.97-1.08)	1.09*** (1.06-1.11)	1.02 (0.98-1.07)
Upper back	1825	1.07*** (1.03-1.10)	1837	0.97 (0.91-1.03)	1.09*** (1.07-1.12)	0.99 (0.94-1.04)
Low back	1824	1.01 (0.98-1.04)	1836	1.02 (0.96-1.09)	1.06*** (1.04-1.09)	1.00 (0.96-1.06)
Arms	1824	1.04** (1.01-1.07)	1836	0.98 (0.93-1.03)	1.06*** (1.03-1.08)	0.99 (0.95-1.04)
Wrist/ hand	1824	1.04* (1.01-1.07)	1836	1.03 (0.98-1.09)	1.06*** (1.03-1.09)	1.04 (0.99-1.09)
Visual symptoms	1812	1.05*** (1.02-1.08)	1824	1.02 (0.98-1.07)	1.07*** (1.05-1.09)	1.03 (0.99-1.07)
Glasses/ contact lenses	1821	0.98 (0.95-1.00)	1833	0.98 (0.93-1.03)	1.01 (0.99-1.04)	0.95* (0.91-0.99)
Trouble seeing far (myopia)	1821	0.97* (0.94-0.99)	1833	0.99 (0.94-1.05)	1.01 (0.99-1.04)	0.95* (0.91-1.00)

*OR = odds ratio; significance values *p<.05, **p<.01 or ***p<.001 for associations between MTSD use and musculoskeletal symptoms or visual health; DASS-21: Depression Stress Anxiety Stress Scale 21; PAQ-A: Physical Activity Questionnaire for Adolescents; ^refers to adjustment for total technology use of other devices (excluding smartphone) in analysis for smartphone use, and total technology use of other devices (excluding tablet) in analysis for tablet use*

5.4 Discussion

To the best of our knowledge, this is the first study to examine associations between MTSD use and musculoskeletal symptoms and visual health, in a nationally representative population of adolescents. There was a remarkably high prevalence of technology use, with smartphone use having the highest usage (total use and longest bout length) across all the school levels among the devices. Adolescents used technology for both school and leisure purposes including homework, social activities (e.g. social media or messaging), games, watching videos and other general use. Multitasking was also common during technology use, with the highest prevalence of frequent multitasking during smartphone use. A higher prevalence of musculoskeletal symptoms and a greater number of visual symptoms, but a lower prevalence of myopia, were significantly associated with a greater amount of smartphone use, but not with tablet use.

5.4.1 Dominance of smartphone use

This study has revealed substantial total technology use of 8.9 hours/day (537 (471) mins/day across the whole week) by adolescents and dominance of smartphone use among all the devices. Smartphone had the highest prevalence of use, ownership, amount of use (twice as much as the second most highly used device – TV), and also the highest amount of use for each type of activity. Differences between the means and medians of smartphone and tablet daily use (Appendix CC) shows that use duration was not normally distributed, and also further highlighted the much higher usage of smartphone compared to tablet. Likely reasons for the high smartphone use included portability, convenience and the multiple functions offered, such as ease of accessing internet, social media and messaging, and use for daily functions.

Similar to recent large studies conducted in the USA (Rideout 2015) and UK (Ofcom 2017), the smartphone was the most used device among the older adolescents; however, daily smartphone use among adolescents was higher (4h 23mins) in the current study than in USA (2h 42mins) and UK (2h 24mins on school day, 3h 12mins on weekend day). The higher smartphone use might be due to higher smartphone ownership among adolescents in this study (88.9% among 10-17 years old) compared to in the USA (67% among 13-18 years old) (Rideout 2015) and UK (83% among 12-15 years old) (Ofcom 2017). Another reason might be the greater proliferation of mobile technology use in Singapore than in USA and UK, as revealed by a survey of multiple nations (We Are Social 2017).

5.4.2 School policies appear to influence technology use

The prevalence and amount of tablet use among adolescents in this study were lower than that of smartphone. This may be due to the much lower tablet ownership and, from anecdotal evidence, tablets being mostly shared among the family. This lower tablet use is in contrast to high tablet use reported by adolescents in a recent study in Australia, who used tablets and/or laptops frequently as part of their school curriculum (Straker et al. 2018a). To date, only a few schools in Singapore have incorporated tablet use as part of their regular school curriculum under the "Future Schools" program (Yang 2016). Schools that participated in this study only had tablet used sometimes during lessons to aid in learning, hence possibly the lower tablet use in this study. The amount of laptop use was also lower than that reported in the Australian study (Straker et al. 2018a), which again might be likely due to lesser laptop use in Singapore schools. Nonetheless, despite not being used frequently during lessons, a considerable amount of MTSD use was reported for homework or school-related purposes by adolescents in this study. MTSD use may also increase further among adolescents in Singapore, with ongoing plans to integrate more technology use in schools (Infocomm Media Development Authority 2018). School policies for technology use in education can thus drive changes in MTSD use and play an important role in patterns of technology use among adolescents.

Differences in technology use among school levels were also noted in this study. For adolescents in primary 5, unlike the other school levels, tablet users were higher than smartphone users. This might be due to the lower ownership of and accessibility to smartphones in younger than older adolescents. In addition, smartphone and laptop prevalence, ownership and bedroom usage increased with increasing school levels, which is consistent with other studies showing greater technology use among older adolescents (Babey et al 2013, Harris et al. 2013). However, interestingly, although there was a steep increase in use from secondary 1 to secondary 3, it dropped in junior college 1. This drop also occurred for use of tablet and other devices except laptop. Anecdotally, adolescents in junior college 1 might be more occupied with schoolwork or other activities and hence use technology less often than those in secondary 3, except for laptop which they likely use more for schoolwork. Also, bout length of smartphone use by adolescents in junior college 1 was much lower than in secondary 3. These findings suggest that secondary 3 adolescents or certain school levels might be at higher risk for increased technology use, hence guidelines or strategies for appropriate use may need to be tailored to each school level.

5.4.3 Technology use is substantial on weekdays but even higher on weekends

This study has also shown that greater use of all devices on weekend days than weekdays, possibly due to more discretionary time being available on weekends. Nevertheless, the amount of technology use, especially smartphone and TV, was substantial even on weekdays when there was school. These findings further highlight the high and ubiquitous use of technology by adolescents and the importance of targeting strategies for wise use for all days of the week.

5.4.4 Girls socialise and boys play games on technology

Gender differences were observed regarding the types of activities on MTSDs, desktop and laptop in this study. Similar to other survey studies (Lenhart 2015, Straker et al. 2018a), girls used the smartphone for social activities more than boys, which might account for their greater smartphone use. On the other hand, boys participated in gaming across all the devices more than girls, consistent with existing research (Ofcom 2017, Straker et al. 2018a). Hence, the types and purposes of activities that adolescents engage in and potential gender differences should be considered when developing guidelines for wise use of technology.

5.4.5 Smartphones frequently used in multitasking

This study has also highlighted the prevalence of multitasking during technology use, especially with smartphones which had the highest prevalence of frequent multitasking among all the devices. Recent surveys have also indicated increasing prevalence of multitasking with other tasks or devices, e.g. use of smartphone for messaging or schoolwork at the same time as doing homework (Australian Communications and Media Authority 2016, Rideout 2015). This may be due to the portability of MTSDs, incoming messages or notifications, or poor self-regulation or habits of use with adolescents finding it hard to resist the urge to check their devices (Rideout 2015, Robb et al. 2017, Rosen et al 2013). Moreover, this study has found an increasing prevalence of frequent multitasking with increasing school levels during use of smartphone, TV, desktop and laptop, suggesting that multitasking may increase with age over adolescence. Given that multitasking with multiple devices has been shown to be associated with negative outcomes such as poorer academic performance, cognitive and socioemotional functioning (Cain et al. 2016, van der

Schuur et al. 2015), there is a need for further research on the nature of, and strategies for self-regulation on, the extent of multitasking by adolescents.

5.4.6 High bout length of use for smartphones may increase health risks

Typical bout length of use was the highest for smartphone, almost twice as high as for TV which had the second highest duration. This suggests that adolescents tend to use smartphone for the longest uninterrupted duration among the devices, further highlighting the importance of smartphone use. Studies on computer use have shown that continuous use, or the lack of or reduced breaks, were related to greater musculoskeletal symptoms, possibly due to muscle overloading and sustained postures (Brewer et al 2006, Galinsky et al. 2007). Hence, this suggests that smartphone use, with its longest bout length of use, may pose a risk for negative musculoskeletal outcomes. However, it is unclear whether a bout of smartphone use results in sustained muscle activation and postures, as noted for computer use, due to multitasking with other tasks or devices. More detailed usage patterns for smartphones, including bout lengths, should be examined to determine if there are any risks posed for adverse outcomes.

5.4.7 Smartphone use associated with musculoskeletal symptoms

The increasing musculoskeletal symptom prevalence with increasing school levels (and thus age) is consistent with other studies on musculoskeletal complaints in adolescents (Jeffries et al. 2007). Neck/shoulder region had the highest prevalence rates of musculoskeletal symptoms reported, which is similar to that reported in other studies conducted with adults and adolescents (Xie et al. 2017). The greater amount of smartphone use was associated with a higher prevalence of musculoskeletal symptoms in neck/shoulders, upper back, arms and wrist/hand, even after adjustment for gender, grade, mental health, physical activity and total technology use of the other devices. Potential mechanisms for this link include altered muscle activity or awkward postures from MTSD use, as suggested by recent laboratory studies with adults (Gustafsson et al. 2018, Kietrys et al. 2015). The current study thus showed smartphone use may pose a risk for musculoskeletal symptoms, with an increase in odds of having pain or discomfort in the past month of 4% to 7% for every hour increase in smartphone usage per day. The amount of increase in risk can be considered as clinically meaningful in view of adolescents spending up to several hours daily on their smartphone. This finding is also consistent with other studies on smartphone use conducted with college students and adults (Toh et al. 2017), and had relatively similar odds ratio as the few recent studies with adolescents in an Australian school (Straker et al. 2018a), and in primary and secondary schools in Hong Kong (Kwok et al. 2017). However, the temporal association between MTSD use and musculoskeletal symptoms is not known and there is a need for longitudinal studies to provide more information on the nature of the relationship.

5.4.8 Low tablet use may explain lack of association with musculoskeletal symptoms

In contrast to smartphone use, a greater amount of tablet use was not significantly associated with musculoskeletal symptoms. This is in contrast to the few existing other studies, which showed tablet use was related to musculoskeletal symptoms in adolescents (Shan et al. 2013, Sommerich et al. 2007, Straker et al. 2018a). One of these studies (Shan et al. 2013) only examined association between musculoskeletal symptoms and prevalence of tablet use (instead of amount of use as in the current study). For the other two studies in the USA (Sommerich et al. 2007) and Australia (Straker et al. 2018a), the amount of reported tablet use was substantially higher than in the current study, likely due to tablet use being incorporated into their school curriculum (Sommerich et al. 2007, Straker et al. 2018a). The low tablet use in the current study, potentially due to low ownership and no school requirement, may account for the lack of associations between tablet use and musculoskeletal symptoms.

5.4.9 Smartphone, but not tablet, use associated with visual symptoms

Similar to musculoskeletal symptoms, a greater amount of smartphone use was significantly associated with visual symptoms experienced during or after use of MTSDs and showed a clinically meaningful increase in risk of having visual symptoms. Visual symptoms reported included eye strain, tiredness of eyes and dry eyes. Prior research has shown that continuous computer use increased the risk of having visual symptoms, thought to be due to prolonged near vision work, impaired blink reflex and blue light emitted from screens (Gowrisankaran et al. 2015, Lurati 2018). Use of smartphone also involves near vision of the screen, which might thus explain its association with visual symptoms, especially when smartphone use was substantial and of longest bout length of use among all the devices.

However, no association was found between tablet use and visual symptoms, which might again be due to the low tablet exposures in this sample.

5.4.10 Lower smartphone use associated with myopia

In contrast to the generally held belief that greater technology use can lead to vision problems, a higher amount of smartphone use was related to *decreased* risk of having myopia in this study. However, the causality in this association is not known due to the cross-sectional design of this study. It might be that adolescents who had myopia used smartphones less to prevent worsening of their eyesight. In Singapore, concern about myopia and awareness of eye care have been promoted with health campaigns and promotions held by schools and the government, in attempts to tackle the high prevalence of myopia (Seet et al 2001). Moreover, several studies have shown that technology use or screen time alone are of minimal risk to myopia, whilst more time spent outdoors is related to reduced risk of myopia and myopic progression (Ramamurthy et al 2015b, Sherwin et al. 2012). Possible mechanisms for this association include increased light intensity outdoors, low accommodative demand for distance vision, and increased time spent outdoors reducing time spent on near-work activities such as using technology. Further research is required on the possible interplay of technology use and outdoor time as risk factors for myopia, and longitudinal studies are needed to determine the direction of association.

5.4.11 Strengths and limitations

Major strengths of this study include the representative sample of a substantial number of participants obtained through stratified sampling (which included socioeconomic status and educational achievement levels), high response rate of participation and adjustment for important confounders (i.e. gender, grade, mental health and physical activity). One of the limitations for this study was that the sample size was less than the proposed 2000 participants, mainly due to recruitment of only junior college students from post-secondary schools. There were difficulties with obtaining approval from polytechnic and vocational schools (there are fewer of these institutions compared to primary and secondary schools). Results presented for post-secondary students may thus not be representative of the population for this school level. Nonetheless, the results were statistically significant. This study also captured details on device specific exposure frequency and duration, and other patterns of use including types of activities, multitasking and bout length of use, using a reliable questionnaire adjusted for local cultural applicability. However, the self-report method used to obtain technology exposure might present recall bias from participants. Total technology use obtained by summing use of all the devices might have also overestimated the total daily technology use, as it had not accounted for possible multitasking among the devices. Lastly, the cross-sectional study design adopted in this study is not able to determine the direction of the associations examined.

5.5 Conclusion

There was high technology use, especially smartphones, among Singaporean adolescents. This study also showed that technology was used for various types of school-related and leisure activities, and prevalent multitasking during technology use. Smartphone use was the most prevalent and its usage dominated among all the devices. Moreover, greater amount of smartphone use was associated with more musculoskeletal and visual symptoms. The high MTSD exposures are therefore a cause for concern, and further research on the implications of its use among adolescents are warranted.

Chapter 6 Study C: Prospective longitudinal associations of MTSD use with musculoskeletal symptoms and visual health

This chapter presents results from the follow-up survey study, which includes prospective associations between the use of MTSDs and musculoskeletal symptoms and visual health outcomes in adolescents. This study is a follow-up of the baseline study outlined in the previous chapter (Chapter 5). Prospective associations between patterns of MTSD use (i.e. bout length, types of activities, multitasking) and musculoskeletal symptoms are also presented in this chapter. This chapter is a verbatim copy of a paper that has been submitted to Applied Ergonomics journal and is currently under review.

6.1 Introduction

Adolescents' use of mobile touch screen devices (MTSDs), namely smartphones and tablet computers, has increased rapidly in recent years (Rideout 2015). Several large-scale surveys have highlighted the high use of MTSDs, with their use becoming an integral part of adolescents' everyday lives (Australian Communications and Media Authority 2016, Ofcom 2017, Rideout 2015). This high use has raised concerns about the potential negative impact on health, including musculoskeletal and visual health (Ramamurthy et al. 2015a, Straker et al. 2018a).

Cross-sectional surveys conducted in young adults (Toh et al. 2017) and, less commonly, in adolescents (Kwok et al. 2017, Straker et al. 2018a) have shown that neck/shoulder, back and/or upper extremity discomfort were associated with greater MTSD use. Several laboratory studies, conducted primarily in adults, reported increased non-neutral postures and sustained muscle loading in neck/shoulder and upper extremity regions with MTSD use, which may pose a risk for musculoskeletal disorders (Gustafsson et al. 2018, Toh et al. 2017). Smartphone use has also been shown to be related to visual symptoms among adolescents (Kim et al. 2016, Straker et al. 2018a), and excessive screen time may increase the risk of myopia, directly or indirectly as a result of reduced time spent outdoors (Ramamurthy et al. 2015a). However, the majority of these studies on MTSD use and musculoskeletal and visual outcomes were cross-sectional in nature; there are no longitudinal studies known to date in adolescents. In cross-sectional studies, it is difficult to determine the cause and effect as exposure to the risk factor and outcome variables are simultaneously evaluated (Sedgwick 2014). Hence, the temporal associations of MTSD use and musculoskeletal and visual health in adolescents are still largely unknown.

Prior research has shown that musculoskeletal symptoms can adversely affect adolescents' health and activities, such as development of chronic pain (El-Metwally et al. 2004), school absenteeism or reduced physical activity (Bejia et al. 2005, O'Sullivan et al. 2012), and visual symptoms that can lead to eye-related developmental problems (Akinbinu and Mashalla 2014) or age-related macular degeneration (Tosini et al. 2016). Given the potential negative impact of musculoskeletal and visual symptoms on adolescents' growth and development, and the ubiquity of MTSD use among adolescents today, it is relevant to examine the possible casual relationships in this particular age group.

In addition, studies examining patterns of MTSD use, and their longitudinal associations with musculoskeletal symptoms, are limited. Prior cross-sectional studies have demonstrated that patterns of computer use, such as usual duration (Harris et al. 2015a), break frequency (Menéndez et al. 2008), and the types of activities (Straker et al. 2013), impact musculoskeletal symptoms. Although MTSDs differ from computers in their portability and usage biomechanics, emerging evidence suggests patterns of MTSD use may influence the risk for musculoskeletal symptoms (Toh et al. 2017, Xie et al. 2017). Another pattern of MTSD use, multitasking with other devices or tasks, has become prevalent among adolescents and has been shown to disrupt learning and socioemotional functioning (van der Schuur et al. 2015). However, its impact on musculoskeletal health is still unknown.

Therefore, this study aimed to examine if:

1a) prevalence of baseline MTSD use (yes/no) and use duration predicts musculoskeletal symptoms at follow-up,

1b) baseline patterns of MTSD use (i.e. bout length, types of activities, multitasking) predict musculoskeletal symptoms at follow-up,

1c) change in MTSD use duration (from baseline to follow-up) predicts change in severity of musculoskeletal symptoms (from baseline to follow-up),

2) prevalence of baseline MTSD use (yes/no) and use duration predicts visual health outcomes (i.e. visual symptoms, wearing glasses/ contact lenses, myopia) at follow-up.

6.2 Methods

6.2.1 Study design and sample

In this prospective longitudinal study, baseline data were collected February-June 2016, and one-year follow-up data were collected March-June 2017. Results from baseline data were reported by Toh et al (2019a). Sample size was calculated using G*Power software. It was estimated that a sample size of 2000 would enable the detection of an odds ratio (OR) of 1.17 with 80% power and an alpha probability of 0.05. This expected effect size is based on the OR reported by a survey study on risk of neck/shoulder and back pain with computer and tablet use in adolescents (Shan et al. 2013).

Reporting of this study was carried out according to the STROBE checklist (von Elm et al. 2007). Four school grade levels were selected to include adolescents from 10 to 19 years of age: grades primary 5, secondary 1, secondary 3 and post-secondary year 1 at baseline. Adolescents were recruited from schools in Singapore using a sampling matrix stratified on socioeconomic (i.e. type of school and location of school based on household income) and academic indicators (i.e. educational stream). A list of all the schools in Singapore was obtained from the Ministry of Education Singapore (2015). Primary schools were stratified on different types of school (government or government-aided) and location (higher and lower socioeconomic status based on the top and bottom 50th percentile of median monthly household income of each planning area). Secondary schools were also stratified on different types of school (government or government-aided) and educational stream (Express [higher academic] or Normal [lower academic] stream). Post-secondary schools were stratified on different types of schools (junior college, polytechnic or vocational) (see Toh et al. (2019a) for further details of sampling reported in article on baseline results). Within each stratified sampling cell, schools were invited in random order.

Ethics approval was obtained from Curtin University Human Research Ethics Committee (RDHS-100-15). Approval for data collection was obtained from the Singapore Ministry of Education and the Principal of each participating school. Assent from adolescents and written informed consent from parents/guardians were obtained for participants younger than 18 years old, while adolescents who were at least 18 years old provided written consent. For participants younger than 18 years old, consent forms were distributed to the parents by teachers who distributed the forms to their students. The forms were then collected from the teachers, from students whose parents have provided written informed consent for their participation in the study.

Adolescents completed an online questionnaire in a school classroom using a laptop/tablet computer (or a smartphone for junior college students). During administration of the questionnaire, a research team member was present to answer questions. Follow-up was conducted with the same classes of students in schools, and a class attendance list was used for checking of students who were present during administration of the questionnaire. Anonymous identifiers entered into the questionnaire were used to match responses provided at follow-up with those at baseline.

6.2.2 Measures

The same questionnaire administered at baseline, Technology Use Questionnaire (TechU-Q), was administered to participants online at one-year follow-up via Qualtrics (Qualtrics Provo UT 2015). It had been developed based on prior studies by the investigators (Harris et al. 2017) and feasibility, face validity and test-retest reliability (moderate-high ICC) were pilot-tested in a sample of Australian grade 5 children (Straker et al. 2018a). Further pilot-testing with 15 adolescents in Singapore was conducted to ensure cultural applicability, resulting in minor changes to the text and formatting.

Questions covered: duration (for a typical weekday and weekend day) and frequency (number of weekdays and weekend days) of technology use of MTSDs and other devices, i.e. TV, desktop, laptop, handheld electronic games, active and non-active game consoles. Bout length of use (typical duration of usage before stopping), duration for types of activities (i.e. homework, social, watching videos, games or other general use such as visiting websites, online shopping, emails), and the extent of multitasking while using the device (i.e. never; a little, some, or most of the time) were also captured. Answer options for duration of device use, duration of types of activities and bout length ranged from five, 15 or 30 minutes, to one hour, two hours and so forth in hourly increments up to 12 hours or more. Duration for daily use across the whole week and types of activities were calculated by multiplying duration by frequency, summing weekdays and weekend days. Bout length was dichotomised into </≥1 hour (Harris et al. 2015a, Menendez et al 2009).

Change scores were calculated for MTSD use duration and severity index of musculoskeletal symptoms between baseline and follow-up.

Musculoskeletal symptoms for neck/shoulders, upper back, low back, arms and wrist/hand (with body parts illustrated), were reported using a modified Nordic Musculoskeletal Questionnaire (Kuorinka et al. 1987). Questions included: prevalence (last 12 months, last month), frequency (i.e. almost never [<1 time/month], occasionally [1-3 times/month], often [1-3 times/week], always [>3 times/week]), intensity (numerical rating scale 0 to 10) and interference with normal activities (numerical rating scale 0 to 10). A severity index of musculoskeletal symptoms (0 to 30), was obtained by summing scores for frequency (score 0 to 10 with 'almost never' scored as 0, while 'occasionally', 'often' and 'always' were scored as 3.3, 6.7 and 10 respectively, to spread equally to a maximum score of 10), intensity and interference (each using 0 to 10 rating scale) (Coenen et al 2016).

Questions on visual health included: visual symptoms (i.e. eye strain [irritation, heaviness], tiredness, watering, redness, itching of eyes, blurring of vision, dry eye, double vision or headache; as adapted from symptoms of computer vision syndrome (Seguí et al. 2015)) experienced during or after use of MTSDs in the last 12 months, use of glasses/contact lenses, trouble seeing far (myopia) and trouble seeing near (hyperopia) (Ojaimi et al. 2005).

Mental health, using the Depression Anxiety Stress Scale 21 (DASS-21) (Szabo 2010), and physical activity, using the Physical Activity Questionnaire for Adolescents (PAQ-A) (Kowalski et al. 2004), were also obtained as covariates. Certain types of physical activities for question one in PAQ-A had been amended (according to the top 15 sports by Singapore teens in Singapore Sports Council (2011)), to ensure cultural applicability and comprehensibility by adolescents in Singapore.

6.2.3 Data analysis

Descriptive statistics were obtained for MTSD usage, musculoskeletal symptoms, visual health and covariates. Both mean (SD) and median (IQR) of MTSD use duration were estimated. For aims 1a) and 2) using baseline prevalence of MTSD use (yes/no; as binary variable) and use duration (continuous variable) as the exposure variable, logistic regression was used to determine the associations with the following binary dependent variables at one-year follow-up: presence of musculoskeletal symptoms in the last 12 months (aim 1a) and presence of visual health outcomes (aim 2) (see Table 6.3 and 6.4). For aim 1b), logistic regression was also used to determine the associations between baseline patterns of MTSD use (i.e. bout length (<1 hour (reference group) or ≥1 hour), participation in type of activities (use [yes/no] and use duration models), multitasking (use [yes/no] and extent of multitasking models)) and presence of musculoskeletal symptoms at follow-up (see Table 6.3).

All logistic regressions were used with piecewise models to separate out the effect of any use versus no use, from the amount of use among MTSD users. Each MTSD usage exposure variable was thus separated into two components: i) a binary indicator variable of any use, and ii) a continuous variable of hours of use duration, to allow a distinction between the effect of any use and dose response. Therefore, the exposure was separated for aims 1a) and 2) into: MTSD use (yes/no) and use duration (mean daily use across the whole week as exposure 'dose' to examine dose-response relationships), and for aim 1b) into: types of activities (use [yes/no]) and use duration (as exposure 'dose'), and multitasking (use [yes/no]) and extent of multitasking (as exposure 'dose')." All logistic regressions were adjusted for baseline: gender, school level, presence of musculoskeletal symptoms last month/visual health measures, mental health, physical activity and total technology use of other devices. Adjustment for total technology use of other devices was conducted in view of potential co-linearity between use of MTSDs and other devices. It was tabulated by summing mean daily use duration across the whole week of all the other devices, except for the exposure variable - smartphone or tablet use. ORs with 95% CIs were estimated.

For aim 1c), linear regression was used to assess associations between change in MTSD use duration and change in musculoskeletal symptom severity index, for subgroup analysis with participants who used smartphone/tablet at both baseline and follow-up (see Table 6.3). Unstandardized regression coefficients and 95% CIs were presented. Interactions between baseline MTSD use and gender were tested and not significant. Statistical analyses were carried out using STATA 14 and statistical significance was set at $p<.05$.

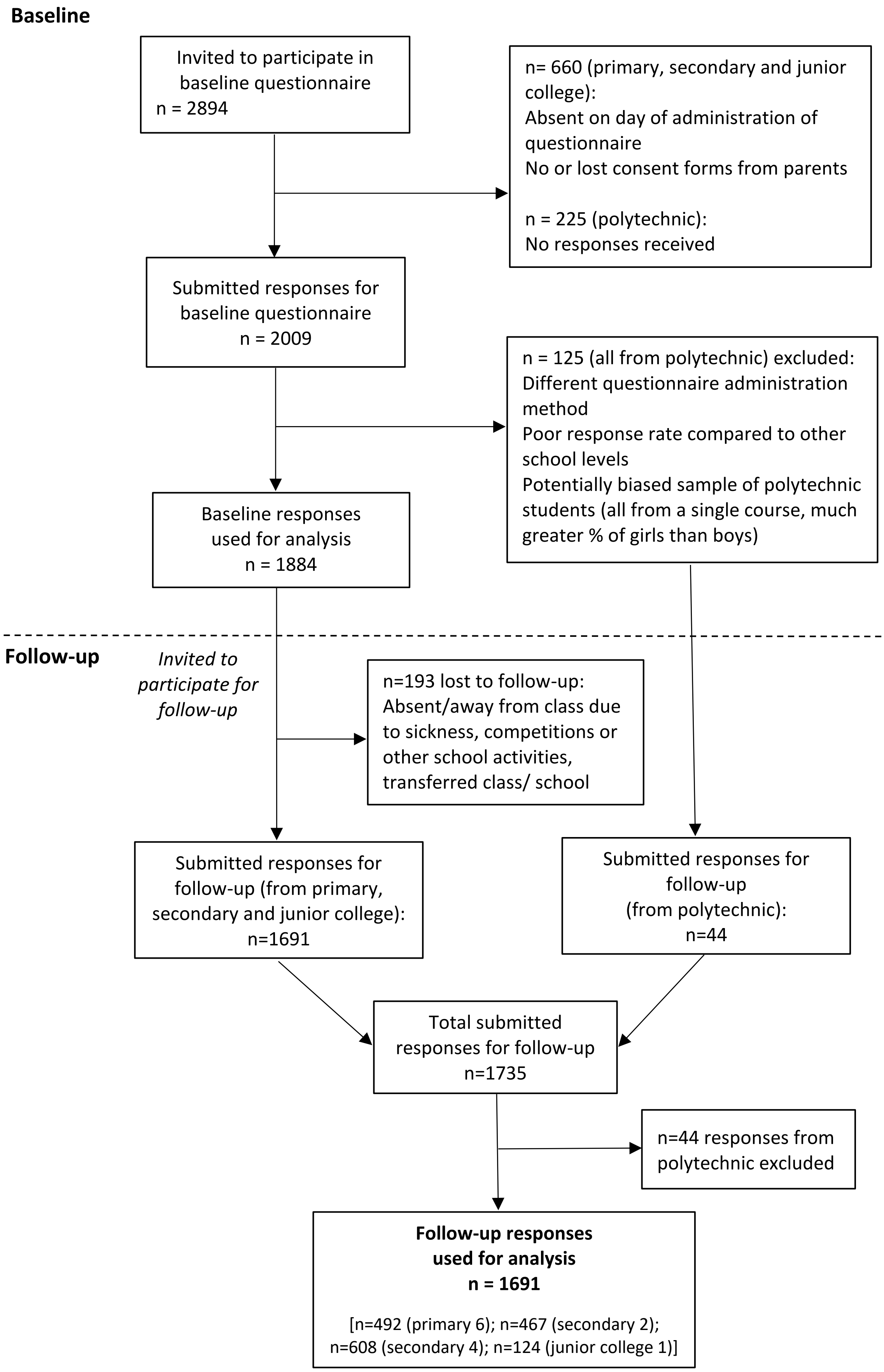
6.3 Results

6.3.1 Sample

A total of 1735 participants from 14 schools provided responses to at least one question at follow-up. No school had dropped out at follow-up. All follow-up responses from polytechnic students were excluded from our analysis (n=44) due to different questionnaire administration method, poor response rate and difficulties recruiting an unbiased sample of polytechnic students. Hence, a total of 1691 responses from adolescents reporting baseline and follow-up data were included for our analysis (retention rate: 1691/1884=89.8%, see Figure 6.1). Baseline key characteristics of adolescents lost to follow-up (n=193; 10.2%) were compared with those who remained in the study; all were not significantly different except for higher baseline smartphone use duration, prevalence of neck/shoulder, upper back and low back symptoms in the last month among those lost to follow-up.

At follow-up, the male:female ratio was similar in the total included sample (51% girls (n=862), 49% (n=829) boys) and at each school level. Mean age (SD) of participants was 14.3 (2.0) years (range 11-19 years). The majority of participants were of Chinese ethnicity (75%, n=1269), followed by Malay (13%, n=218), Indian (6%, n=96) and others (6%, n=108). Gender and race demographics of the sample were comparable to the adolescent population in Singapore, according to data from the Department of Statistics Singapore (2016a).

Figure 6.1 Flowchart of number of participants



6.3.2 Descriptive statistics

Descriptive statistics of MTSD use, musculoskeletal symptoms, visual health and covariates (DASS-21 and PAQ-A scores) are reported in Tables 6.1 and 6.2. At baseline, 92% of adolescents reported using a smartphone while 52% reported using a tablet (Table 6.1). Baseline mean (SD) use duration for smartphone was 255 (238) mins/day, while that for tablet was 53 (123) mins/day. Baseline median (IQR) smartphone use was 180 (51-420) minutes while tablet use was 2 (0-39) minutes. Median (IQR) smartphone/tablet use, bout length and use duration for types of activities at both baseline and follow-up are reported in Appendix GG.

At baseline, a high percentage of adolescents (70%) engaged in smartphone use with a typical bout length of ≥1 hour, whereas for tablet use it was only 36% (Table 6.1). Smartphones were more likely to be used for social activities and tablets for watching videos, and multitasking was more common with smartphones (83% versus 49%).

At follow-up, musculoskeletal symptoms were most commonly reported in the neck/shoulder (74%) region (Table 6.2). There was little change in the severity index of symptoms, ranging from +0.3 (7.1) at wrist/hand to +0.9 (7.6) at neck/shoulder among participants who used a smartphone (n=1424) or tablet (n=471) at both baseline and follow-up (Appendix HH).

The mean number of visual symptoms reported at follow-up was 2.4 (2.1) (out of 9) (Table 6.2). The number of adolescents experiencing one or more visual symptoms, wearing glasses/contact lenses or reporting myopia at follow-up were 1336 (80%), 1121 (67%) and 945 (61%), respectively.

Table 6.1 MTSD usage and patterns of MTSD use at baseline and follow-up

Independent variables	Smartphone		Tablet	
	Baseline	Follow-up	Baseline	Follow-up
MTSD usage				
Yes[a] *(n (%))*	1513 (92%)	1568 (95%)***	862 (52%)	605 (36%)***
Use duration *(mins/day (SD))*	255 (238)	279 (232)***	53 (123)	34 (95)***
△ MTSD use duration *(hrs/day (SD))*				
Subgroup only[b]	+0.4 (3.7)		-0.3 (2.7)	
Bout length *(mins/day (SD))*	185 (217)	189 (216)	71 (130)	49 (107)***
≥ 1 hour *(n (%))*	1116 (70%)	1183 (73%)[c]***	586 (36%)	455 (28%)[c]***
Types of activities				
Homework				
Yes[a] *(n (%))*	977 (60%)	1035 (63%)***	456 (28%)	263 (16%)***
Duration *(mins/day (SD))*	53 (118)	52 (115)	15 (53)	8 (44)***
Social activities				
Yes[a] *(n (%))*	1360 (84%)	1451 (88%)***	452 (28%)	278 (17%)***
Duration *(mins/day (SD))*	144 (197)	153 (199)**	23 (86)	12 (62)***
Games				
Yes[a] *(n (%))*	1138 (71%)	1114 (69%)***	617 (38%)	391 (24%)***
Duration *(mins/day (SD))*	84 (150)	81 (149)	32 (94)	18 (72)***
Watching videos				
Yes[a] *(n (%))*	1320 (82%)	1417 (87%)***	705 (43%)	471 (29%)***
Duration *(mins/day (SD))*	127 (171)	142 (171)***	45 (114)	28 (88)***
General use				
Yes[a] *(n (%))*	1111 (68%)	1228 (75%)***	498 (30%)	329 (20%)***
Duration *(mins/day (SD))*	71 (142)	81 (153)**	23 (84)	13 (63)***
Multitasking				
Yes[a] *(n (%))*	1387 (83%)	1447 (86%)	803 (49%)	601 (36%)
Extent of multitasking *(n (%))*				
Never	286 (17%)	226 (14%)	846 (51%)	1049 (64%)
A little of the time	237 (14%)	228 (14%)	293 (18%)	229 (14%)
Some of the time	370 (22%)	424 (25%)	287 (17%)	195 (12%)
Most of the time	780 (47%)	795 (48%)[c]***	223 (14%)	177 (11%)[c]***

*[a]yes to prevalence of smartphone/tablet use, participation in the types of activities or multitasking (with no as reference group); SD: standard deviation; △ changes in; [b]among participants who used smartphone/tablet at both baseline and follow-up; [c]among the different categories of extent of multitasking/ bout length at baseline and follow-up; *p<.05, **p<.01 or ***p<.001 for differences between baseline and follow-up using up using chi-squared (for MTSD usage - Yesa, multitasking, bout length ≥ 1 hour) or Wilcoxon signed rank test (for MTSD usage - use duration, types of activities, bout length (mins/day))*

Table 6.2 Musculoskeletal symptoms, visual health outcomes and covariates (DASS-21 and PAQ-A scores) at baseline and follow-up

Dependent variables	N	Baseline	Follow-up
Musculoskeletal symptoms			
Last 12 months (*n (%)*)			
Neck/shoulder	1678	966 (57%)	1244 (74%)***
Upper back	1678	645 (38%)	851 (51%)***
Low back	1678	495 (30%)	707 (42%)***
Arms	1678	790 (47%)	991 (59%)***
Wrist/hand	1678	556 (33%)	762 (45%)***
Last month *(n (%))*			
Neck/shoulder	1678	692 (41%)	781 (47%)***
Upper back	1678	475 (28%)	524 (31%)***
Low back	1678	365 (22%)	431 (26%)***
Arms	1678	625 (37%)	668 (40%)***
Wrist/hand	1678	454 (27%)	453 (27%)***
Severity index[a] (*mean (SD)*)			
Neck/shoulder	1691	4.7 (6.7)	5.5 (7.1)***
Upper back	1691	3.2 (6.0)	3.7 (6.5)*
Low back	1691	2.6 (5.8)	3.1 (6.3)***
Arms	1691	3.8 (6.2)	4.5 (6.7)**
Wrist/hand	1691	3.0 (5.9)	3.2 (6.3)
Visual health			
Visual symptoms *(mean (SD))*	1670	2.2 (2.0)	2.4 (2.1)***
Presence of visual symptoms *(n (%))*	1670	1279 (77%)	1336 (80%)***
Wearing glasses/ contact lenses *(n (%))*	1663	1071 (64%)	1121 (67%)***
Myopia *(n (%))*	1551	892 (58%)	945 (61%)***
Covariates			
DASS-21 *(mean (SD))*	1691	13.5 (11.2)	14.2 (11.7)*
PAQ-A *(mean (SD))*	1675	2.44 (0.7)	2.37 (0.7)***

*[a]severity index of symptom last month, obtained from sum of scores for frequency, intensity and interference; *p<.05, **p<.01 or ***p<.001 for differences between baseline and follow-up; DASS-21: Depression Stress Anxiety Stress Scale 21; PAQ-A: Physical Activity Questionnaire for Adolescents, *p<.05, **p<.01 or ***p<.001 for differences between baseline and follow-up using chi-squared (for last month, last 12 months, presence of visual symptoms, glasses/contact lenses, myopia), Wilcoxon signed rank test (for severity index, visual symptoms, DASS-21) and paired t tests (for PAQ-A)*

6.3.3 Prospective associations between mobile touch screen device usage and musculoskeletal symptoms

After adjusting for potential confounders (i.e. baseline values of gender, school level, presence of musculoskeletal symptoms last month, mental health, physical activity and total technology use of other devices), significant prospective associations were found between baseline prevalence of smartphone use (yes/no) and presence of neck/shoulder (OR=1.61 (95%CI=1.06-2.44)) and low back (OR=1.86 (1.10-3.14)) symptoms (aim 1a) (Table 6.3; unadjusted ORs in Appendix EE). Baseline tablet use (yes/no) was also associated with one-year follow-up presence of neck/shoulder (OR=1.33 (1.04-1.71)), low back (OR=1.52 (1.18-1.95)) and arms (OR=1.36 (1.07-1.73)) symptoms. No statistically significant dose-response relationships were found between smartphone or tablet use duration (hours/day) and musculoskeletal symptoms. Additional adjustments for visual symptoms, which had shown associations with musculoskeletal symptoms (Gowrisankaran et al. 2015), did not substantially change the results.

Regarding associations between patterns of use and musculoskeletal symptoms (aim 1b), bout length of ≥1 hour of smartphone use at baseline was associated with presence of neck/shoulder (OR=1.20 (1.01-1.41)) and upper back (OR=1.29 (1.01-1.64)) symptoms at follow-up, while that for tablet was associated with only low back (OR=1.28 (1.01-1.63)) symptoms (bout length <1 hour as reference group) (Table 6.3).

Participating in certain types of activities (i.e. social activities, games, watching videos, general use) on smartphone/tablet at baseline was also associated with musculoskeletal symptoms at follow-up (see Table 6.3). Multitasking on smartphone at baseline was found to be associated with neck/shoulder (OR=1.66 (1.03-2.66)) and arms symptoms (OR=1.74 (1.10-2.74)) at one-year follow-up (Table 6.3). There were no dose-response relationships between smartphone/tablet use duration (hours/day) for each type of activities or extent of multitasking and musculoskeletal symptoms (Table 6.3). Changes in MTSD use between baseline and follow-up were not associated with changes in severity index of symptom (aim 1c), for subgroup analysis with participants who used a smartphone (n=1424) or tablet (n=471) at both baseline and follow-up (Table 6.3). We confirmed similar lack of relationships between changes in MTSD use and severity index in those who did use MTSD at baseline but not at follow-up, in those who did use at follow-up but not at baseline, and also in different analysis model consisting of MTSD use at baseline and follow-up and an interaction term between them. No significant interactions were found between baseline

MTSD use and baseline symptoms, or baseline MTSD use and gender in analyses for musculoskeletal outcomes.

Table 6.3 Prospective associations between MTSD usage, bout length, types of activities and multitasking (at baseline) and musculoskeletal symptoms in the last 12 months (at follow-up), and between change in MTSD use duration and change in severity index of symptom last month in various body regions, adjusted for baseline symptom, gender, school level, DASS-21, PAQ-A scores and total technology use of other devices[b]

Independent variables	Dependent variables											
	Smartphone						Tablet					
	Presence of musculoskeletal symptoms in last 12 months (at follow-up)											
		Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand		Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand
	N	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	N	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
MTSD usage												
Yes[a]	1617	**1.61* (1.06-2.44)**	1.11 (0.72-1.72)	**1.86* (1.10-3.14)**	1.35 (0.89-2.05)	1.27 (0.80-2.00)	1628	**1.33* (1.04-1.71)**	1.20 (0.95-1.53)	**1.52** (1.18-1.95)**	**1.36* (1.07-1.73)**	1.22 (0.95-1.56)
Use duration *(hrs/day)*	1617	1.02 (0.98-1.05)	1.02 (0.99-1.05)	1.00 (0.96-1.03)	1.03 (1.00-1.06)	1.01 (0.98-1.05)	1628	0.98 (0.96-1.11)	0.97 (0.91-1.03)	0.94 (0.88-1.00)	1.01 (0.87-1.32)	1.01 (0.95-1.08)
Bout length												
≥ 1 hour[c]	1566	**1.20* (1.01-1.41)**	**1.29* (1.01-1.64)**	1.01 (0.79-1.31)	1.15 (0.91-1.46)	1.25 (0.97-1.61)	1594	1.15 (0.91-1.47)	1.09 (0.86-1.37)	**1.28* (1.01-1.63)**	1.20 (0.95-1.50)	1.19 (0.94-1.50)
Types of activities												
Homework												
Yes[a]	1608	1.12 (0.87-1.43)	1.02 (0.80-1.30)	1.14 (0.88-1.47)	1.21 (0.95-1.53)	0.93 (0.72-1.19)	1618	1.20 (0.90-1.59)	1.15 (0.88-1.52)	1.37 (0.99-1.83)	1.06 (0.81-1.39)	1.04 (0.79-1.38)
Duration *(hrs/day)*	1608	0.97 (0.91-1.04)	1.00 (0.95-1.07)	1.02 (0.96-1.08)	0.98 (0.92-1.04)	0.98 (0.92-1.04)	1618	0.92 (0.78-1.08)	0.92 (0.79-1.08)	0.90 (0.76-1.06)	0.92 (0.79-1.10)	1.00 (0.85-1.17)
Social activities												
Yes[a]	1598	**1.98*** (1.43-2.74)**	1.20 (0.86-1.68)	1.45 (1.00-2.11)	**1.94*** (1.40-2.69)**	1.19 (0.84-1.67)	1608	1.28 (0.96-1.69)	1.22 (0.93-1.59)	**1.36* (1.03-1.80)**	1.18 (0.90-1.54)	1.02 (0.77-1.34)
Duration *(hrs/day)*	1598	1.00 (0.95-1.04)	1.00 (0.96-1.04)	1.03 (1.00-1.07)	1.02 (0.98-1.06)	1.02 (0.98-1.06)	1608	0.96 (0.85-1.05)	0.94 (0.86-1.03)	1.00 (0.91-1.09)	0.95 (0.87-1.04)	1.03 (0.94-1.13)

Table 6.3 Prospective associations between MTSD usage, bout length, types of activities and multitasking (at baseline) and musculoskeletal symptoms in the last 12 months (at follow-up), and between change in MTSD use duration and change in severity index of symptom last month in various body regions, adjusted for baseline symptom, gender, school level, DASS-21, PAQ-A scores and total technology use of other devices[b]

Independent variables	Dependent variables										
	Smartphone						Tablet				
	Presence of musculoskeletal symptoms in last 12 months (at follow-up)										
		Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand		Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand
	N	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	N	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Games												
Yes[a]	1585	1.06 (0.81-1.38)	1.13 (0.87-1.46)	**1.36* (1.03-1.79)**	1.13 (0.88-1.46)	1.08 (0.83-1.40)	1607	1.21 (0.93-1.57)	0.98 (0.76-1.27)	1.10 (0.84-1.44)	1.24 (0.96-1.60)	1.06 (0.81-1.37)
Duration *(hrs/day)*	1585	1.02 (0.97-1.08)	1.05 (1.00-1.10)	1.01 (0.96-1.06)	1.03 (0.98-1.08)	1.03 (0.98-1.08)	1607	0.95 (0.87-1.04)	1.00 (0.92-1.09)	1.01 (0.92-1.11)	0.97 (0.82-1.08)	1.01 (0.92-1.10)
Watching videos												
Yes[a]	1596	1.19 (0.88-1.61)	0.97 (0.72-1.32)	1.37 (0.98-1.91)	**1.35* (1.01-1.82)**	0.95 (0.70-1.30)	1615	1.28 (1.00-1.66)	1.16 (0.91-1.49)	1.30 (1.00-1.69)	**1.29* (1.01-1.65)**	1.22 (0.95-1.58)
Duration *(hrs/day)*	1596	1.00 (0.94-1.04)	1.03 (0.98-1.08)	1.00 (0.95-1.04)	1.00 (0.95-1.04)	1.02 (0.97-1.07)	1615	0.97 (0.85-1.02)	0.98 (0.92-1.05)	0.96 (0.89-1.03)	1.00 (0.96-1.05)	0.98 (0.92-1.06)
General use												
Yes[a]	1604	**1.39* (1.08-1.80)**	1.21 (0.94-1.56)	**1.52** (1.15-2.00)**	**1.60*** (1.24-2.06)**	**1.54** (1.18-2.01)**	1612	1.22 (0.94-1.60)	1.19 (0.92-1.54)	**1.34* (1.03-1.77)**	1.10 (0.85-1.42)	**1.35* (1.04-1.75)**
Duration *(hrs/day)*	1604	1.02 (0.96-1.08)	1.04 (0.99-1.10)	1.02 (0.97-1.07)	1.01 (0.96-1.06)	1.00 (0.94-1.05)	1612	1.00 (0.85-1.10)	1.03 (0.94-1.14)	1.00 (0.90-1.10)	0.94 (0.85-1.03)	0.96 (0.87-1.06)
Multitasking												
Yes[a]	1645	**1.66* (1.03-2.66)**	1.33 (0.84-2.12)	1.49 (0.90-2.45)	**1.74* (1.10-2.74)**	1.42 (0.88-2.29)	1621	1.15 (0.73-1.80)	0.95 (0.62-1.45)	1.21 (0.77-1.88)	1.34 (0.88-2.04)	0.92 (0.59-1.42)
Extent of multitasking[d]	1645	0.98 (0.83-1.15)	0.96 (0.82-1.12)	1.01 (0.86-1.19)	0.93 (0.80-1.09)	0.96 (0.82-1.12)	1621	1.03 (0.84-1.26)	1.11 (0.91-1.34)	1.05 (0.86-1.29)	0.92 (0.76-1.12)	1.11 (0.91-1.35)

Table 6.3 Prospective associations between MTSD usage, bout length, types of activities and multitasking (at baseline) and musculoskeletal symptoms in the last 12 months (at follow-up), and between change in MTSD use duration and change in severity index of symptom last month in various body regions, adjusted for baseline symptom, gender, school level, DASS-21, PAQ-A scores and total technology use of other devices[b]

Independent variables	Dependent variables											
	Smartphone						Tablet					
	△ Severity index of symptom last month											
		Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand		Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand
	N	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	N	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
△ MTSD use duration *(hrs/day)*												
Subgroup only[e]	1424	0.09 (-0.02-0.20)	0.03 (-0.07-0.13)	0.03 (-0.07-0.13)	0.07 (-0.04-0.19)	0.01 (-0.09-0.11)	471	0.09 (-0.18-0.35)	0.15 (0.09-0.28)	0.13 (-0.10-0.36)	0.12 (-0.14-0.38)	0.09 (-0.15-0.32)

*[a]ORs obtained from prevalence of smartphone/tablet use, participation in the types of activities and multitasking yes/no (with binary exposure variables); [b]adjustment for total technology use of other devices (excluding smartphone) in analysis for smartphone use, and total technology use of other devices (excluding tablet) in analysis for tablet use; [c]bout length <1 hour used as reference group in regression analysis; [d]among the categories of extent of multitasking (i.e. never; a little, some, or most of the time); [e]among participants who used smartphone/tablet at both baseline and follow-up; △ changes in; *p<.05, **p<.01 or ***p<.001, significant findings in bold*

6.3.4 Prospective associations between mobile touch screen device usage and visual health

No significant associations were found between baseline smartphone or tablet use (yes/no) and presence of visual symptoms, wearing glasses/contact lenses and myopia at one-year follow-up after adjusting for potential confounders (i.e. baseline values of gender, school level, presence of visual health measures, mental health, physical activity and total technology use of other devices) (aim 2) (Table 6.4; unadjusted ORs in Appendix FF). There were no dose-response relationships between baseline smartphone/tablet use duration (hours/day) and visual health outcomes at follow-up. No significant interactions were found between baseline MTSD use and baseline visual outcomes, or baseline MTSD use and gender in analyses for visual outcomes.

Table 6.4 Prospective associations between MTSD usage (at baseline) and visual health outcomes (at follow-up), adjusted for baseline visual health measures, gender, school level, DASS-21, PAQ-A scores and total technology use of other devices[b]

	Dependent variables											
	Smartphone						Tablet					
	Presence of visual health outcomes											
Independent variables	Presence of visual symptoms		Wearing glasses/ contact lenses		Myopia		Presence of visual symptoms		Wearing glasses/ contact lenses		Myopia	
	N	OR (95% CI)	N	OR (95% CI)	N	OR (95% CI)	N	OR (95% CI)	N	OR (95% CI)	N	OR (95% CI)
MTSD usage												
Yes[a]	1602	1.00 (0.61-1.62)	1616	1.07 (0.53-2.16)	1407	0.87 (0.42-1.81)	1614	1.14 (0.84-1.55)	1627	0.85 (0.55-1.30)	1413	0.74 (0.48-1.15)
Use duration *(hrs/day)*	1602	1.01 (0.97-1.05)	1616	0.94 (0.89-1.00)	1407	0.97 (0.91-1.03)	1614	1.00 (0.92-1.08)	1627	1.02 (0.92-1.13)	1413	0.98 (0.87-1.10)

[a]ORs obtained from prevalence of smartphone/tablet use yes/no model; [b]adjustment for total technology use of other devices (excluding smartphone) in analysis for smartphone use, and total technology use of other devices (excluding tablet) in analysis for tablet use

6.4 Discussion

To the best of our knowledge, this is the first longitudinal study examining prospective associations between smartphone and tablet use and musculoskeletal symptoms and visual health among adolescents. Baseline smartphone use was associated with one-year follow-up neck/shoulder and low back symptoms, and between baseline tablet use and one-year follow-up neck/shoulder, low back and arms symptoms. Additionally, patterns of MTSD use at baseline i.e. bout length of ≥1 hour, participating in certain types of activities (i.e. social, games, watching videos, general use) and multitasking were also associated with one-year follow-up musculoskeletal symptoms. However, no dose-response relationships between MTSD use duration (hours/day), use duration (hours/day) of the type of activities or extent of multitasking, and musculoskeletal symptoms were found. There were also no significant associations between baseline MTSD usage and visual health outcomes at follow-up. These findings challenge common perceptions and point to the importance of considering the nature of use to understand the link with musculoskeletal symptoms.

The longitudinal associations between MTSD use versus non-use and neck/shoulder, low back and/or arms symptoms found in this study possibly implies a causal relationship. The use of smartphone/tablet increased the odds of having musculoskeletal symptoms (OR=1.33 (1.04-1.71) to 1.86 (1.10-3.14)). This is consistent with previous cross-sectional findings (Kwok et al. 2017, Shan et al. 2013, Straker et al. 2018a) and a recent longitudinal study where prospective associations were found between text messaging (on mobile devices including physical keypad phones) and maintained neck symptoms in young adults (Gustafsson et al 2017). These associations may be explained by the increased head/neck flexion, non-neutral postures and muscle activity in neck/shoulder, low back and/or upper extremities during MTSD use (Toh et al. 2017, Xie et al. 2017). Another possible reason might be social factors associated with the lack of MTSD use, such as parental restrictions of not allowing MTSD use or ownership that protect non-MTSD users in some way. Whilst the majority of the non-MTSD users were of younger age and prevalence of musculoskeletal symptoms is lower in younger adolescents (Jeffries et al. 2007), grade (proxy for age) was accounted for in the models.

It was noted that prospective associations were found between baseline smartphone use and follow-up neck/shoulder and low back symptoms, while tablet use was also associated with arms symptoms in addition to neck/shoulder and low back symptoms. This might be due to the larger screen and heavier weight of a tablet and a preference to place tablet on the lap compared to use of a smartphone (Kietrys et al. 2015, Pereira et al. 2013), thereby posing possibly greater stress and fatigue at shoulders and arms with tablet use.

Importantly, despite longitudinal associations found between prevalence of MTSD use and musculoskeletal symptoms, no dose-response relationships were found in this study; greater MTSD use duration (hours/day) at baseline did not predict greater risk of having musculoskeletal symptoms at one-year follow-up. While some of the cross-sectional studies showed no significant dose-response relationship (Chiang and Liu 2016, Woo et al. 2016), others showed that greater smartphone/tablet use was related to musculoskeletal symptoms (Kwok et al. 2017, Shan et al. 2013, Straker et al. 2018a). Patterns of MTSD use (such as bout length, type of activity and multitasking) are likely to be important in determining dose-response relationships.

The current study found typical bout length of ≥1 hour on smartphone/tablet posed a risk for having musculoskeletal symptoms, consistent with previous studies on computer use (Menéndez et al. 2008, Menendez et al. 2009). This might be due to reduced cumulative stress with shorter bout lengths (Zennaro et al 2003). Limiting consecutive use to bout lengths of less than one hour may therefore help prevent musculoskeletal symptoms.

Additionally, the current study found that adolescents commonly engaged in playing games, social activities (including online messaging) and watching videos on MTSDs, consistent with findings from recent survey studies (Cha and Seo 2018, Kwok et al. 2017, Rideout 2015, Straker et al. 2018a). The most common activity was social activities with the highest use duration reported. There appears to have been a shift in the importance of the types of activities for which adolescents use a MTSD. A consumer survey around a decade ago found adolescents in Asia, including Singapore, (where most adolescents used a mobile or cell phone with a physical keypad and less functionality), also commonly engaged in social activities such as messaging or calling and playing games but that voice call and SMS were more common than online instant messaging and social networking (Synovate 2010). Our study findings also showed that certain types of activities – i.e. social, games, videos or general use – pose a risk for prospective musculoskeletal symptoms. Social activities may involve extensive messaging/texting, hence findings are consistent with previous studies showing associations between texting on mobile devices and musculoskeletal symptoms (Gustafsson et al. 2017, Xie et al. 2017). Our prospective findings reinforce previous cross-sectional relationships found for gaming (Chiang and Liu 2016, Xie et al. 2017), watching movies and browsing (Kwok et al. 2017) on mobile devices with musculoskeletal symptoms. As with the overall relationship between MTSD use and symptoms, the potential mechanisms for the associations between these activities and symptoms could be biomechanical, such as increased muscle loading and non-neutral neck/shoulder, low back and upper extremities postures from repetitive movements of texting and/or gaming on MTSDs (Kietrys et al. 2015, Ning et al. 2015), or psychosocial, such as social anxiety (Caplan 2007) or negative self-esteem (Barker 2009) related to use of social activities or internet browsing, or escape motives and stress related to gaming (Young 2009).

This study also showed that multitasking during smartphone use at baseline was related to musculoskeletal symptoms at follow-up, although no dose-response relationships with the extent of multitasking were found. Multitasking with other device(s) such as television or desktop/laptop computer, or doing other task(s) such as homework, while using a MTSD has become prevalent among adolescents (Rideout 2015, van der Schuur et al. 2015). Previous qualitative studies have revealed that some adolescents perceived multitasking to be enjoyable (Jago et al. 2011) and was a form of relaxation or break from doing homework (Toh et al 2019b). Multitasking during MTSD use might therefore prompt continuous use without rest breaks, and predispose to increased biomechanical stress and musculoskeletal symptoms. Another possible reason might be the adverse psychosocial outcomes, e.g. depression and social anxiety (Becker et al 2013) that have been linked with multitasking in adolescents, thereby predisposing them to musculoskeletal symptoms, although the analysis was adjusted for depression, anxiety and stress symptoms. This study has shown that multitasking during MTSD use may have implications for increased risk for musculoskeletal symptoms in adolescents, but the nature of multitasking and potential mechanisms of how it may impact on musculoskeletal health are yet to be elucidated.

Nonetheless, although this study did not show any dose-response relationship, smartphone or tablet use versus non-use still showed substantial effect sizes for an increased risk for musculoskeletal symptoms. Greater use in the longer term may increase long-term risk due to accumulated exposure. Thus future studies should examine MTSD use and symptoms with a longer follow-up period, ideally into adulthood, and also consider lifetime MTSD exposure or use prior to baseline measure.

Regarding visual health outcomes, no longitudinal associations were found between baseline MTSD usage and one-year follow-up presence of visual symptoms, wearing glasses/contact lenses and myopia among adolescents in this study. This finding is in contrast to recent cross-sectional studies showing positive associations of greater amount of MTSD use with visual symptoms (Kim et al. 2016, Straker et al. 2018a), but in concurrence with recent studies suggesting that technology use alone seems to be of minimal risk for myopia, whilst less time spent outdoors is related to developing myopia and myopic progression (Xiong et al. 2017). Lifetime use, however, may be more relevant (Kim et al. 2016, Kucer 2008). These adolescents may have developed habits of use, such as using blue light filters or reducing screen brightness to help them avoid visual symptoms. Unlike desktop computers, MTSDs may also be used outdoors due to their portability, which may reduce the occurrence of confounding.

6.4.1 Strengths and limitations

A major strength of this study is that it is the first longitudinal study on associations between MTSD use and musculoskeletal symptoms and visual health outcomes among adolescents, using a large representative sample with high follow-up. This study also adopted detailed measures of MTSD use across the whole week, by obtaining use separately for weekdays and weekend days, and frequency and duration of use across a large range. Moreover, patterns of MTSD use, not just total amount of use, were also examined. We have also adjusted for confounding factors known to influence musculoskeletal symptoms, i.e. gender, grade, mental health, physical activity and total technology use of other devices.

Some of the limitations in this study include self-reported measures (which might introduce recall bias and inaccuracy), some bias linked with attrition and the lack of multiple time point measures of symptoms which may occur episodically. MTSD lifetime exposure or use prior to baseline measures was not measured in this study and cumulative exposure may pose more of a risk for symptoms (Kim et al. 2016, Kucer 2008). The group of adolescents who were lost to follow-up had significantly higher smartphone use duration and prevalence of musculoskeletal symptoms; however, their omission likely made the findings more conservative. Further, there was a low risk of bias as adolescents who were lost to follow-up did not intentionally drop out of the study but were absent due to valid reasons (Figure 6.1).

6.5 Conclusions

Prospective longitudinal associations were found between MTSD use and musculoskeletal symptoms, as well as between patterns of MTSD use (i.e. bout length ≥1 hour, participating in certain types of activities, multitasking) and musculoskeletal symptoms among adolescents after adjusting for confounders. However, there were no dose-response relationships between MTSD use duration, use duration of the type of activities or extent of multitasking, and musculoskeletal symptoms. The results imply that MTSD use (though not the duration of use) and patterns of MTSD use can pose a prospective risk for musculoskeletal symptoms. No longitudinal associations were found between MTSD use and visual health outcomes. The study results are generalizable to adolescents in Singapore, but cultural and other differences across countries suggest normal caution should be used to generalize to other countries or communities. Whilst the findings point to potential risk reduction strategies around reducing bout length and multitasking, they also highlight the complex nature of the MTSD use and its likely associations with musculoskeletal symptoms. Further research on the patterns of use, with longer follow-up on the longitudinal associations, and the exact mechanisms behind these associations will help inform detailed guidelines for wise use of MTSDs.

Chapter 7 Discussion

This thesis examined mobile touch screen device use (MTSD) and associations of their use with musculoskeletal symptoms and visual health outcomes in adolescents. In the following sub-sections of this chapter, each of the aims and associated findings from this thesis, will be discussed in the context of prior research.

The first section will provide a summary of the main findings. Section 7.2 discusses prevalence, amount and influences of MTSD use, while the next section 7.3 discusses patterns of MTSD use. The relationships between MTSD use and musculoskeletal symptoms and visual health outcomes in adolescents are discussed in section 7.4. Strengths together with limitations of the thesis studies are discussed in section 7.5, while section 7.6 outlines areas for further research. Lastly, section 7.7 discusses implications for wise use of MTSDs.

7.1 Summary of main findings

This section reports the major findings which are summarised under the study's objectives as below:

To explore perspectives from adolescents and parents on:

i. **patterns of MTSD use by adolescents including routines, bout length, types of activities and multitasking**
ii. **rules, restrictions and concerns from parents/caregivers on adolescents' MTSD use**

- Smartphones were used and/or owned by almost all the adolescents, while only some used a tablet.
- Many adolescents and their parents perceived adolescents' MTSD use to be high, frequent and ubiquitous. Use was integrated into their daily routines, with frequent checking of device and multitasking with multiple devices, especially while doing homework.
- Several functional, personal and external influences of MTSD use were reported which either facilitated or limited MTSD use. Reported influences of use included irresistibility of MTSDs, lack of self-control, entertainment or relaxation value and high use by peers, family and for schoolwork that contributed to high use, or school/parental control measures and lack of internet availability that limited use.
- Most adolescents were generally unconcerned about their use and perceived their usage as appropriate, while most parents expressed several concerns about their adolescents' use and perceived their usage as excessive.

iii. **postures and discomfort associated with MTSD use**

- In the qualitative study, discomfort, most commonly at neck/shoulder, was reported by many of the adolescents after or whilst using MTSDs. Nonetheless, discomfort experienced was generally perceived as of mild intensity and non-disruptive to activities by the adolescents.
- A variety of postures adopted during MTSD use at various settings at home, were demonstrated by the adolescents and comprised mostly of non-neutral postures.

To examine among a representative sample of adolescents the:

i. **amount and patterns of contemporary technology use (i.e. bout length, types of activities, multitasking), particularly MTSDs**

- Screen technology and MTSD use by adolescents was high and smartphone use was dominant among the devices, with smartphone having the highest prevalence of use in the last 12 months (95.1%) and mean daily use (264 (243) mins/day), while for tablet use was lower (71.1% and 53 (124) mins/day respectively).

- Typical mean bout length of use was the highest for smartphone among all the devices, and percentage of bout length of ≥1 hour was higher for smartphone (70%) than tablet (36%).

- Mean daily use for each type of activities (i.e. homework, social activities, games, videos, general use) were highest for smartphone among the devices. Smartphones were used mostly for social activities while tablets were used mostly for watching videos.

- Multitasking with multiple devices was common, with smartphone having the highest percentage of frequent multitasking (69.4%).

- Gender differences were observed. Girls had significantly higher smartphone ownership (91.6% vs 86.2%) and daily use than boys (297 (249) vs 230 (233) mins/day). Girls also had significantly greater use of smartphones for homework, social activities, videos and general use than boys, while boys had greater use of smartphone and tablet for games (see Appendix II).

- School level differences were also observed. Smartphone use and ownership increased with increasing school levels. However, daily smartphone use was the highest at around mid-adolescence. Tablet daily use was fairly similar among the school levels, with a drop of MTSD use at late adolescence (junior college 1).

ii. **cross-sectional associations of MTSD use with musculoskeletal symptoms and visual health outcomes**

- Musculoskeletal symptoms were commonly reported among adolescents, with highest prevalence in the last month at neck/shoulder (42.4%), followed by arms (33.3%), upper back (29.1%), wrist/hand (26.8%) and low back (22.7%).
- After adjusting for confounders, greater hours/day of smartphone use, but not tablet use, was significantly associated with higher prevalence of musculoskeletal symptoms at neck/shoulder, upper back, arms and wrist/hand (OR=1.04 (95% CI 1.01-1.07) to 1.07 (1.03-1.10)).
- Greater hours/day of smartphone use was significantly associated with higher number of visual symptoms, but lower prevalence of myopia. No significant associations were found between tablet use and these visual outcomes.

iii. **prospective longitudinal associations of:**
   - **MTSD use, including patterns of use with musculoskeletal symptoms**
   - **MTSD use with visual health outcomes**

- After adjusting for confounders, prospective associations were found between baseline use of smartphone/tablet and follow-up neck/shoulder, low back and/or arms symptoms (OR=1.33 (1.04-1.71) to 1.86 (1.10-3.14)). However, there were no dose-response relationships between the amount of MTSD use duration and musculoskeletal symptoms.
- Baseline patterns of smartphone/tablet use (bout length of ≥1 hour, participating in certain types of activities and/or use of multitasking) were also associated with follow-up musculoskeletal symptoms, but no associations were found with use duration for each type of activity and the extent of multitasking.
- No prospective associations were found between smartphone/tablet use and visual outcomes.

7.2 Prevalence, amount and influences of MTSD use

7.2.1 High prevalence and amount of MTSD use

Findings from the qualitative study in this thesis showed that many of the adolescents and their parents perceived high and frequent use of MTSDs by adolescents, especially for smartphones. This is also supported by findings from the baseline quantitative survey in this thesis, which revealed high prevalence and duration of MTSD use by adolescents in Singapore (n=1884; 10 to 19 years old). Smartphone use dominated among all the screen devices, including traditional electronic devices such as TV or desktop/laptop computers. Smartphone had the highest reported prevalence of use in the last 12 months (95.1%) and mean daily use across the whole week (SD) (264 (243) mins/day or 4.4 (4.1) hours/day). Tablet prevalence of use and daily use (71.1% and 53 (124) mins/day respectively), though lower than that for smartphone, it was higher than other devices such as desktop computer.

Several other epidemiological survey studies have also similarly shown high usage of MTSDs among adolescents. Surveys have often reported over 80% adolescents used a smartphone and/or tablet (Kwok et al. 2017, Ofcom 2017, Rideout 2015, Straker et al. 2018a). Recent studies have also indicated higher or increased usage of smartphone/tablet, while usage of traditional electronic devices such as TV or desktop computers was lower or has decreased over the years (Nielsen 2015, Ofcom 2017, Ofcom 2019, Rideout 2015, Straker et al. 2018a). Among USA adolescents, daily use of smartphone use was close to 3 hours, which was almost double computer or TV use (Rideout 2015). The incidence of watching TV also decreased from 99% in 2011 to 96% in 2014 (Nielsen 2015). Another large-scale survey of UK adolescents has also shown trends of increasing smartphone and tablet use, with decreasing TV and desktop/laptop computer use from 2007 to 2017 (Ofcom 2017). These findings have therefore highlighted the changing landscape of screen technology use, and the high and increased usage of MTSDs among adolescents today.

High duration of MTSD use among adolescents in urbanised Western and Asian countries had also been reported by several surveys. However, reported duration of smartphone use seemed to be generally lower in urbanized Western countries than what was found in the baseline survey among adolescents in Singapore (4.4 (4.1) hours/day). Lower daily use duration of smartphone of approximately 2 to 3 hours were reported among adolescents in a large-scale survey in USA (Rideout 2015) and UK (Ofcom 2017).

Another smaller study of adolescents in Australia (n=924) has reported lower smartphone daily use of approximately 1 hour 40 minutes (Straker et al. 2018a). On the other hand, higher mean daily smartphone use of approximately 5 hours was reported among adolescents in South Korea (n=1824) (Cha and Seo 2018), and in Hong Kong where 90% of adolescents (n=500) spent an average of 3.5 hours/day on a smartphone (The Cabin Hong Kong 2017). Moreover, a global consumer survey involving adolescents and young adults (16 to 30 years old), has found that several Asian countries had high daily smartphone usage of more than 3 hours on average, with highest usage of 4.2 hours/day reported in Thailand (Kantar TNS 2015). It appears that smartphone use by adolescents in Singapore and urbanised Asian countries may be higher than in some of the developed Western countries, possibly due to higher technology penetration (Deloitte Technology Media and Telecommunications 2017). The higher technology use in urbanised Asian countries also fits with higher prevalence of insufficient physical activity among adolescents in Asian compared to Western countries (World Health Organization 2019).

It should be noted that differences in MTSD usage among adolescents across the studies might also be due to different age groups, representativeness or gender distribution of the sample, and/or different outcome measures used for MTSD use exposures. These differences make direct comparisons among the studies difficult. The survey in this thesis involved a representative sample of early to late adolescents (ranging from 10 to 19 years), while adolescents in some other studies were not from a representative sample (Queiroz et al. 2017, Shan et al. 2013), involved pre-adolescents of less than 10 years old (Mascheroni and Cuman 2014, Ofcom 2017) and/or a specific age group only (e.g. 12 to 15 years) (Cha and Seo 2018, Yang et al. 2017). There was an uneven gender distribution in some studies (Sommerich et al. 2007, Yang et al. 2017). Given that gender differences had been shown in MTSD usage (Kwok et al. 2017, Straker et al. 2018a) and in the baseline survey, which found for example significantly higher smartphone ownership and daily use in girls than boys, uneven gender distribution in a sample may thus render inaccurate findings of population usage.

Different methods used to capture MTSD use exposures may also explain the reported differences in prevalence and amount of MTSD use across studies. Some studies reported mean daily use duration (Cha and Seo 2018, Straker et al. 2018a), while some reported the prevalence of certain hours/day use (Kwok et al. 2017, Shan et al. 2013, Yang et al. 2017). Moreover, unlike the survey studies in this thesis, most studies did not capture frequency of use and/or weekday and weekend usage separately (Cha and Seo 2018, Shan et al. 2013, Yang et al. 2017), nor indicate the reliability and/or validity of self-reports or questionnaires being used (Kwok et al. 2017, Shan et al. 2013, Sommerich et al. 2007). Future studies should thus consider age and gender differences and adopt reliable and valid self-reports (with frequency of use and weekday and weekend usage captured), to ensure accurate measurement of use exposures and valid comparisons among studies.

7.2.2 Influences contributing to high MTSD use

Findings from the qualitative study have provided rich information and useful insights into adolescents' MTSD use, and supplemented findings from the survey. Some of the patterns and influences of MTSD use found in the qualitative study may have explained how adolescents could attain or accumulate such high prevalence and amount of daily MTSD use. One of the patterns of use found was the integration of MTSD use into daily routines and ubiquitous use during weekdays and weekend days. These patterns of use are consistent with findings from other quantitative surveys which showed adolescents using MTSDs during various time periods throughout the day, including at night before bedtime (Australian Communications and Media Authority 2016, Cha and Seo 2018, Rideout 2015), and at various locations such as public areas (Australian Communications and Media Authority 2016), restaurants (Radesky et al. 2014) or whilst commuting in a train (Yang et al. 2017). The qualitative study has, however, provided more detailed and descriptive information on how adolescents used MTSDs throughout the day and integrated MTSD use into their daily routines and activities. They described how they commonly used MTSDs, especially smartphones, throughout the day - upon waking in the morning, before, during and after school hours till evening and night time, interspersed with their daily activities or tasks such as eating, whilst commuting or doing homework. Their use of MTSDs was also ubiquitous at various locations at home, in school and outdoors in the community, as the adolescents tended to bring their MTSDs along with them wherever they went.

Moreover, findings from the qualitative study also revealed major influences of adolescents' MTSD use as irresistibility of MTSDs, and a lack of self-control on resisting use of MTSDs. The majority of adolescents reported that they often were unable to resist using their MTSDs, especially smartphones, and felt the need to have it with them at all times. They also frequently 'checked' their smartphones throughout the day, with frequent notifications from messaging, social media or other applications received. These influences of use may also thus explain why adolescents had such high, frequent and ubiquitous use of

MTSDs, as seen in the qualitative and baseline survey studies. Perception of MTSDs as irresistible among the adolescents was also reflected in other survey studies, for example Common Sense Media in USA found a high percentage of adolescents feeling ‘addicted’ to their MTSDs (50%) and them checking MTSDs at least hourly (78%) (Rideout 2015). Other studies have also found the majority of adolescents (44%) often checking their smartphones as soon as they wake up (Pew Research Center 2018), and adolescents missed their mobile phone the most among their screen devices (57%; among 12 to 15-year-olds) (Ofcom 2017).

Although the studies in this thesis did not examine ‘addiction’, some of the adolescents’ descriptions on irresistibility to their MTSDs, especially smartphones, were suggestive of ‘addictive’ behaviours or over-dependency on their MTSDs. These behaviours may be due to the incoming notifications and messages which prompted them to frequently check their MTSDs (Pew Research Center 2018, Robb et al. 2017). The type of activity or content on MTSDs that they tend to engage in, such as shows/videos, games or social networking, can draw them into continued use or binge watching (Jeong et al. 2016, Lopez-Fernandez et al. 2017). Another reason could be the immediacy of reward from use of MTSDs, which has been found to release dopamine that results in ‘feel good’ feelings (Crone and Konijn 2018). This can thus make them want to keep using MTSDs, and lead to compulsive use or irritable behaviour when detached from their phones (Oulasvirta et al 2012, Sherman et al. 2016). Given the various negative effects associated with ‘addiction’ or over-dependency on technology use, such as stress or reduced cognitive performance (Haug et al. 2015, Panova and Carbonell 2018, Ward et al 2017), it is important to address adolescents’ irresistibility of MTSDs and develop strategies to help them exercise self-discipline on their usage.

Another influence of MTSD use found from the qualitative study, the high use of MTSDs by peers, family and for school related matters, may account for the high usage of MTSDs by adolescents. Many adolescents reported using MTSDs, especially smartphones, in order to communicate, play games or watch shows/video together as a social activity, with their peers, parents and/or siblings who also commonly used MTSDs. This seemed to be a phenomenon of “fear of missing out”, as acknowledged by prior studies also where adolescents felt the peer pressure to use or even own a MTSD so as to keep updated and be involved with their peers (Elhai et al 2016, Walsh et al. 2009). They also commonly used smartphones to consult with their schoolmates or even teachers or search for information for homework. Recent studies have also observed prevalent use of MTSDs by adolescents in their homework (Kwok et al. 2017, Rideout 2015, Straker et al. 2018a). These findings are supported by results from our baseline survey which found high daily use of MTSDs for social activities (including social networking or messaging), and also substantial usage for homework.

Moreover, some of the adolescents felt that their amount of MTSD use was appropriate and were unconcerned about it, since their peers, parents and/or siblings also frequently used MTSDs. These perceptions can contribute to the high MTSD use, with reduced awareness and underestimation of problems associated with their usage (Oulasvirta et al. 2012). Parents also serve as important role models; their frequent use of technology had been associated with increased technology use by children (Vaala and Bleakley 2015, Xu et al. 2015). The prevalent use of MTSDs by peers, family and for school related matters thus has an important influence over adolescents' MTSD use.

Overall, studies in this thesis have provided useful quantitative information on adolescents' MTSD use, and qualitative information on important influences of their use. The use of MTSDs is high, frequent and ubiquitous among adolescents in Singapore and has become integrated into their daily routines and activities. Their use is expected to increase further with greater penetration and advancement of technology over time. While use of MTSDs can provide benefits including ease of communication with peers and family or assistance with schoolwork, adolescents need to achieve a balance in their usage to prevent usage from becoming problematic. It is thus important to examine the implications of MTSD use, raise awareness of their usage and mediate adolescents' use due to irresistibility of MTSDs, lack of self-control and influence from peers, family and school.

7.2.3 Smartphone versus tablet usage

Some differences between smartphone and tablet usage were noted from the studies in this thesis. Findings from the studies showed that smartphone usage was considerably higher than that for tablet by adolescents in Singapore. In the baseline survey (n=1884), smartphone prevalence of use in the last 12 months (95.1% versus 71.1%) and mean daily use duration across the whole week (SD) (264 (243) mins/day versus 53 (124) mins/day) were higher than that for tablet. Moreover, from baseline to follow-up at one-year (n=1691), the prevalence and mean daily use duration of smartphone (SD) increased (92%

to 95%, 255 (238) to 279 (232) mins/day respectively), but decreased for tablet (52% to 36%, 53 (123) to 34 (95) mins/day respectively).

Other quantitative surveys have similarly found higher usage of smartphone than tablet among adolescents (Mascheroni and Cuman 2014, Ofcom 2019, Rideout 2015). For example, in the UK, 53% of adolescents (12 to 15 years old) mostly used a smartphone to access the internet while only 23% used a tablet to do so (Ofcom 2019). Among USA adolescents, the mean daily smartphone use was 2 hours 42 minutes versus only 45 minutes for mean daily tablet use (Rideout 2015). The higher smartphone usage might be due to adolescents' preferences to use a smartphone over a tablet. However, there was a lack of qualitative research and perspectives from adolescents on reasons for preferences between smartphone and tablet use. The qualitative study in this thesis has shown that many of the adolescents preferred to use a smartphone over a tablet due to its greater portability, convenience and ease of use for messaging, social media or search for information while on the move. Nonetheless, a few of them reported that there were also instances when they preferred to use a tablet, such as when they wanted to watch videos or search for information on a bigger screen.

Higher ownership and/or bedroom usage of smartphone than tablet may also explain the higher usage and preference of smartphone among the adolescents. The baseline survey found a much higher percentage of smartphone ownership (88.9%) than tablet ownership (47.9%), which was consistent with several other survey studies in adolescents (DQ Institute 2016, Ofcom 2019, Rideout 2015) and findings from the qualitative study. Moreover, in the qualitative study, most of the adolescents used a tablet which was mostly a shared device with their parents or siblings. Preference of smartphone over tablet use was also noted when the younger adolescents reported reducing or stopping their use of tablet after starting to own a smartphone (as allowed by their parents). The higher bedroom usage of smartphone than tablet (83.1% versus 40.2%) may also facilitate greater smartphone usage. Use of technology in one's own bedroom has been associated with higher usage (Jiwoo et al 2018, Vernon et al 2017), which could be due to privacy of use and avoidance of supervision from parents, as per findings from the qualitative study.

However, a few other studies found higher usage or ownership of tablets than smartphones among adolescents (Lauricella et al. 2014, Straker et al. 2018a). The use of tablets formally for school lessons or homework may have facilitated their greater tablet usage. Mean daily tablet use (SD) was higher (139 (147) mins/day) compared to that for smartphone (100 (141) mins/day) among adolescents recruited from a school in Australia (n=924), which had students bringing tablets to school and using them often for lessons or homework (Straker et al. 2018a). In the studies of this thesis, information gathered from the participating schools indicated that students only used tablets sometimes during lessons, providing a possible explanation for the lower tablet use in this study. This is also consistent with findings from the qualitative study, except for a few adolescents who reported using a tablet during lessons as their school was under the “Future Schools” program (Yang 2016) – a pilot program with a few schools incorporating technology use including tablet as part of the regular curriculum. Hence, students in these schools brought a tablet to school and tended to use it for longer durations than the other adolescents. This is also supported by a prior review suggesting that adolescents who bring their own device to school are likely to have greater screen time both in school and at home (Merga 2015). Furthermore, use of MTSDs for educational purposes is expected to further increase, with schools rolling out plans to further integrate technology use into the school curriculum (Infocomm Media Development Authority 2018, Pegrum et al. 2013). School policies for technology use in education can thus be a major influence on adolescents’ use of MTSDs and technology use patterns.

In addition, differences between smartphone and tablet usage could also be due to different prevalence of use and use duration among age groups or school levels. The baseline survey showed that across school levels, prevalence of use was highest for tablet but lowest for smartphone for the early adolescents (at primary 5), though smartphone and tablet mean daily use were relatively similar. The lower smartphone use but fairly higher tablet use by the early adolescents, were likely due to the majority of adolescents using a tablet as they did not yet have their own smartphone. The different age groups of adolescents may thus account for differences in MTSD usage across reported studies, especially if pre or early adolescents were involved as they exhibit different MTSD usage. For example, the lower smartphone ownership (20%) than that of tablet (26%) in a study in USA involving pre-adolescents (aged 8 to 17 years old) (Lauricella et al. 2014), was in contrast to findings of the baseline survey.

Another difference noted in MTSD usage at the baseline survey was that smartphone daily use increased with increasing school levels to be highest at around mid-adolescence, while tablet daily use was fairly similar among the school levels, with a drop of smartphone and tablet use during late adolescence (junior college 1) (Figure 5.3 in section 5.3.2). These findings are in contrast with other studies which found significantly higher smartphone and/or tablet usage with increasing age or school levels (Kwok et al. 2017, Lauricella et al. 2014, Rideout 2015), but similar to a few recent studies which showed differential usage across age or school levels (Coyne et al. 2017, Straker et al. 2018a). Some recent studies showed that smartphone and tablet mean daily use (Straker et al. 2018a), and texting and social media use on mobile phones were highest during mid-adolescence (in middle grades) instead of late adolescence (Coyne et al. 2017). The drop in MTSD use among older adolescents could be due to their different activity needs and greater amount of schoolwork than the younger adolescents. Older adolescents were likely to be more occupied with their studies and preparation for their major school examinations in the later school years, hence less time was spent on using MTSDs. This is supported by findings from the qualitative study where adolescents reported having less time to use MTSDs when they had more homework or when studying for exams. Examination of other technology use in the baseline survey also showed an increase in laptop use for the late adolescents at junior college 1; which might be due to their better functionality for use in schoolwork than MTSDs (Straker et al. 2018a). Therefore, findings in this thesis suggest that MTSD use may be different among school levels, and guidelines for wise use should be tailored to each school level or age group.

In summary, there are differences between smartphone and tablet usage among adolescents with seemingly different usage preferences. School policies on use of technology in education and peer and parental use and perceptions are important influences of adolescents' MTSD use. Future studies should examine use exposures of smartphone and tablet separately and also consider school level or age group differences, as they can affect guidelines or interventions needed for wise use of MTSDs.

7.3 Patterns of MTSD use

7.3.1 Bout length of use

One aspect of the patterns of MTSD use examined in this thesis was bout length of use, which refers to the typical duration of continuous use each time. It is important to examine bout length regardless of the total amount of daily use; as use may be intermittent throughout the day in short or long bouts of use duration, which can have implications for discomfort and other health outcomes. Prior studies on desktop/laptop computer use have found that prolonged continuous use or the lack of breaks taken, were associated with musculoskeletal symptoms or discomfort (Brewer et al. 2006, Galinsky et al. 2007, Menendez et al. 2009), while breaks taken had been shown to provide short-term relief of symptoms (Balci et al. 2007, Galinsky et al. 2007). This suggests that longer bout length of MTSD use may pose a risk for musculoskeletal symptoms, but this is still relatively unknown given the paucity of prior research on MTSD bout length of use, especially in adolescents.

From the qualitative study, perspectives from adolescents on their MTSD use showed the majority of adolescents did not stop consciously to take a break when they were using their MTSDs, but rather tended to stop using only when they needed to carry out other tasks or activities. They also reported using their MTSDs, ranging from short durations of few minutes of 'checking' their smartphones to longer durations of several hours, depending on the amount of time or leisure time available for use. Hence, it may be more appropriate to measure bout length instead of breaks taken during adolescents' MTSD use. In the survey, typical bout length of use, ranging from a few minutes of 5, 10, 15 or 30 minutes to several hours were thus measured. The baseline survey found that smartphones had the highest mean bout length of use among all the devices, suggesting a tendency for adolescents to use smartphones for the longest duration without a break and again showing the dominance of smartphone usage.

The baseline survey also showed that there was a high percentage of adolescents (70%) who used smartphones for a typical bout length of ≥1 hour, compared to only 36% for tablets. In contrast, Lee and Song (2014) reported that among university students (n=2353), a much lower percentage of them reported using smartphone for a usual bout length of more than one hour (4.5%), while most used for 10 to 30 minutes each time (48.2%). The higher percentage of longer typical bout length of use by adolescents might be due to them being able to use MTSDs more frequently when they had larger available periods of time, such as after school, after finishing homework or during leisure time when their use was not restricted by parents or school, as suggested by findings from the qualitative study. Hence, adolescents' usual MTSD use duration might be longer, of at least an hour or more each time, compared to the university students who were likely able to frequently check their smartphone for short bursts of time without parental or school restrictions on their usage. This also highlights the differences in patterns of MTSD use between adolescents and adults.

Findings from studies in this thesis have provided information on bout length of MTSD use by adolescents, as well as their perception of breaks or bout length of use and possible reasons for the variations in bout length. Considering that use of MTSDs can be sporadic with varied durations of use at various times of the day, it might be hard to capture or recall accurately the typical bout length of use. Further research is still needed on the measurement of bout length of MTSD use.

7.3.2 Types of activities on MTSDs

In this thesis, the more common types of activities on MTSDs, i.e. homework, social activities, games, videos and general use, as reported in prior studies (Australian Communications and Media Authority 2016, Cha and Seo 2018, Kwok et al. 2017, Rideout 2015), were examined in the survey studies. The baseline survey showed that mean daily use for each type of activity was higher for smartphones than tablets, which again showed the higher usage and preference for smartphone use by the adolescents. The amount of daily use for leisure or personal activities, i.e. social activities, games, videos and general use, on either smartphone or tablet was also found to be higher than that for homework. This is consistent with prior studies which found adolescents generally using MTSDs more for leisure or personal purposes compared to homework or school use (Kwok et al. 2017, Straker et al. 2018a). Greater use of MTSDs for leisure or personal use was also supported by findings from the qualitative studies, which showed adolescents reporting frequent use of MTSDs for messaging, social networking as well as entertainment and relaxation.

Nonetheless, it is important to note that the amount of MTSD use for homework (mean use (SD)=54 (117) mins/day) in the baseline survey was still substantial. As mentioned in section 7.2.2, the qualitative study found many adolescents using MTSDs to consult with schoolmates or search for information for their homework. Recent studies have also observed increased prevalence of MTSD use in homework and/or school lessons (Haßler et al. 2016, Rideout 2015, Sung et al 2016). Future studies should consider how school policies on technology use can influence MTSD use among adolescents, and possible implications of their use in homework versus leisure or personal use.

At baseline, mean daily use for certain type of activities, i.e. social activities, videos, games and general use, on smartphone/tablet were also significantly higher on weekend days than on weekdays, except for homework on smartphones which had similar usage (see Appendix II). This is not surprising as the adolescents may tend to have more leisure time available on weekends compared to weekdays when they have school. However, it may not be the case for some adolescents, as a few mentioned in the qualitative study that they had less time to use MTSDs on weekends instead due to tuition (external supplementary lessons), extra school curricular activities, leisure sports or other activities. Although there was no school during weekends, daily MTSD use for homework on weekends was fairly similar to that on weekdays, which is in contrast to another study of Australian adolescents which found much higher tablet use for homework on weekdays than weekends (Straker et al. 2018a). Their higher usage for homework might be due to frequent tablet usage in school as part of their school curriculum, or cultural differences where there was less expectation for students to do homework on weekends in Western countries like Australia.

In addition, studies in this thesis have found differences in preferences for types of activities on a smartphone versus tablet. The baseline survey showed that among the different types of activities on MTSDs (i.e. homework, social, games, videos, general use), social activities had the highest proportion of usage for smartphone while that for tablet was watching videos (see Appendix II). This is consistent with a consumer survey study on adults and adolescents which found smartphones being predominantly used for communication and social networking, whereas tablets were used for entertainment purposes including games and videos (Flurry Analytics 2012). Recent survey studies with adolescents have also reported that the most common activity on smartphone was messaging and/or social networking (Cha and Seo 2018, Kwok et al. 2017, Rideout 2015, Straker et al. 2018a). These differences might be due to adolescents' different preferences of use for types of activities on a smartphone/tablet as seen in the qualitative study. Some adolescents have reported that it was easier to use online messaging and social media on a smartphone than a tablet, due to its greater portability and accessibility to social media applications. A few of them have also reported that they preferred watching videos on a tablet than a smartphone due to its larger screen.

Gender differences were also observed in daily usage of types of activities on MTSDs. Consistent with other survey studies (Lenhart 2015, Straker et al. 2018a), girls had significantly higher usage of smartphones for homework, social activities and watching videos than boys. This might also explain why girls had higher total daily use duration of smartphone than boys in the baseline survey. On the other hand, boys engaged in games on smartphone and tablet more than girls across all the school levels, similar to other studies (Ofcom 2017, Straker et al. 2018a). These gender differences can have implications on how adolescents use MTSDs, since playing games had been found to be linked with problematic smartphone usage in boys (Chen et al 2017, Lee et al 2018c), whereas use of social networking had been linked with problematic usage in girls (Chen et al. 2017).

As noted in section 7.2.3 of the Discussion, there were differences in the amount of technology use duration across school levels, with smartphone use decreasing in later adolescence (junior college 1) and laptop use increasing. Differences in daily use for types of activities across school levels were also observed, with highest usage for homework on laptop in junior college 1, but lowest usage for social, games and videos on smartphone (see Figure 5.5 in section 5.3.3). As seen in the qualitative study, this might be due to older adolescents being more occupied with schoolwork, exams or other activities, hence less time for them to use MTSDs for leisure or entertainment purposes compared to use for homework. Similar patterns of MTSD usage highest at around mid-adolescence, with reduced usage among late adolescents at Grade 12 were also observed in another study (Straker et al. 2018a). The authors also found from anecdotal evidence that it might be due to adolescents in Grade 12 being occupied with more schoolwork and their major school leaving examinations.

Overall, these findings suggest that there were different amount of usage and preferences for types of activities on smartphones/tablets by adolescents. It is important to examine the types of activities on MTSDs as they can have different implications on the physical, social and mental well-being and development of adolescents. There is also a need for future studies to consider potential gender and school level/age group differences in the types of activities on MTSDs, to develop gender or age group-targeted strategies or interventions for wise use.

7.3.3 Multitasking during MTSD use

Another pattern of MTSD use that was examined in the studies in this thesis was multitasking. The baseline survey showed a high prevalence of multitasking with multiple screen devices by adolescents during smartphone use (83%) and tablet use (49%). This is consistent with several prior studies which have reported increased (Rideout et al. 2010) and prevalent (Cain et al. 2016, Jago et al. 2011, van der Schuur et al. 2015) multitasking among adolescents.

However, most prior studies examined multitasking with general screen technology use, non-specific to the type of device, or with TV; research on the extent and nature of use of MTSDs in multitasking among adolescents was still limited despite their high prevalence of use and portability. The baseline survey has demonstrated that MTSDs, especially smartphones, were used more frequently during multitasking compared to the other devices. In fact, smartphones had the highest percentage of frequent multitasking with multiple devices (“some of the time” or “most of the time”) (69.4%). This is also supported by findings from the qualitative study where the majority of adolescents reported commonly multitasking with other devices (e.g. TV or desktop/laptop computers) or tasks (e.g. homework) during smartphone or tablet use.

The qualitative study also provided perspectives by adolescents on reasons for their frequent use of MTSDs for multitasking. They felt that it was “natural” or normal, and effortless for them to multitask with their MTSDs, especially with MTSDs being portable and often beside or near them, making it convenient for them to multitask. They also reported engaging in multitasking due to boredom with a particular activity or task (e.g. homework) or whilst waiting for programs or shows (e.g. streaming videos on desktop/laptop computer or during advertisements on TV). Moreover, they were drawn in to multitasking with their MTSDs when they received notifications such as messages or social media updates on them. These reasons were illustrated in a literature review on multitasking with general screen technology use in children and adults (Carrier et al. 2015), which may be applicable to MTSDs also though it was not specific to any device type. Other contributing factors found in the review, including ‘addiction’ to internet or phone and a desire to communicate and keep updated with their peers via messaging or social networking on their smartphones, may also explain the frequent multitasking (Carrier et al. 2015). The influences of MTSD use found in the qualitative study, i.e. irresistibility of MTSDs and high use of MTSDs among peers, could also explain their high use of multitasking.

A closer look at the nature of multitasking during MTSD use in the qualitative study has found that adolescents not only multitasked with multiple devices, but also often multitasked with other tasks e.g. homework, eating or dressing, or among different types of activities on MTSDs by switching among them. Instances of multitasking with multiple devices included use of MTSD(s) whilst using TV (often during advertisements) and/or desktop/laptop computer at the same time; where they often used their MTSDs to check for messages or social media updates, play games, watch videos or listen to music or browse the internet.

Multitasking technology use with other tasks, especially with homework, has been reported to be increasing among adolescents (Rideout 2015, van der Schuur et al. 2015). This is also shown in the baseline survey which found a substantial proportion of smartphone and tablet use duration for purposes of homework. As seen in the qualitative study and other survey studies (Cain et al. 2016, Rideout 2015, Rosen et al. 2013), they often used MTSDs to browse for information or consult with peers regarding their homework, or for other personal uses instead e.g. messaging, social media, videos or games, whilst multitasking with homework. However, negative outcomes on learning, academic performance, cognitive function and ability to focus have been associated with multitasking technology use during homework (Cain et al. 2016, Chen and Yan 2016, David et al 2014, van der Schuur et al. 2015). Nonetheless, there seemed to be a lack of concern about it among the adolescents. The qualitative study found that some of the adolescents felt that it was normal for them to multitask. A substantial proportion (31%) of adolescents in another survey also did not think that multitasking technology use with homework would affect their quality of work (Rideout 2015).

The qualitative study also showed that some of the adolescents multitasked among different activities on their MTSDs, by switching and alternating repeatedly back and forth from one activity or application to another. For example, repeatedly switching between online messaging and playing games and/or watching videos on a smartphone. They were prompted to multitask among different activities due to boredom with the activity on their MTSDs, notifications received from incoming messages or social media updates, and the capability of MTSDs to allow multiple windows or applications simultaneously (Carrier et al. 2015).

The prevalence of multitasking among adolescents could have implications on the measurement of MTSD use exposures. Use duration captured for each type of device or activity in current studies might be an overestimation of total MTSD usage, as it had not accounted for possible multitasking among the devices or activities.

In summary, although multitasking can provide convenience and benefits for the adolescents such as alleviating their boredom with one activity or assistance in their homework, current literature suggests that multitasking can also pose negative effects on learning, academic and cognitive performances (Cain et al. 2016, Uncapher et al. 2017). There is a need to raise awareness about potential negative effects of multitasking among the adolescents, and develop strategies on how they can achieve a balance or purposeful use of MTSDs whilst doing homework. Future studies should also examine methods for accurate measurement of multitasking, with consideration of the different devices, tasks and activities that may be involved.

7.4 Associations of MTSD use with musculoskeletal symptoms and visual health outcomes in adolescents

The survey in this thesis has contributed important knowledge on the associations between MTSD usage and musculoskeletal symptoms and visual health outcomes in adolescents. They have also addressed limitations in prior research, by including a representative sample, adopting reliable and valid measurement methods, adjusting for important confounders and conducting a longitudinal study. To the best of our knowledge, the longitudinal study is the first to examine prospective associations between MTSD usage and musculoskeletal symptoms and visual health among adolescents. In the following sections below, findings on associations of MTSD use and patterns of MTSD use with musculoskeletal symptoms, and of MTSD use with visual health outcomes among adolescents will be discussed.

7.4.1 Associations of MTSD use and amount of use with musculoskeletal symptoms

At baseline, a high prevalence of musculoskeletal symptoms was reported among adolescents, with highest prevalence in the last month at neck/shoulder (42.4%). This is consistent with other studies among adolescents which found highest prevalence of symptoms generally at neck/shoulder region (Mohd Azuan et al. 2010, Straker et al. 2018a, Yang et al. 2017). The baseline survey also showed that greater hours/day of smartphone use, but not tablet use, was significantly associated with musculoskeletal symptoms. There was an approximate 4% to 7% increase in odds for having musculoskeletal symptoms for every hour increase in daily smartphone usage (OR=1.04 (1.01-1.07) to 1.07 (1.03-1.10)), similar to a few other cross-sectional studies showing associations between smartphone/tablet use duration and musculoskeletal symptoms among adolescents (Kwok et al. 2017, Straker et al. 2018a). This amount of increase in odds can be considered as clinically meaningful, given that adolescents can spend up to several hours daily on smartphones.

At one-year follow-up, the use of a smartphone/tablet was associated prospectively with neck/shoulder, low back and/or arms symptoms (OR=1.33 (1.04-1.71) to 1.86 (1.10-3.14)). However, no dose response relationship was found at follow-up; the amount of smartphone/tablet use duration was not associated prospectively with musculoskeletal symptoms. In both the baseline and follow-up survey studies, important confounders of gender, grade, mental health, physical activity and total technology use of other devices had been considered and adjusted for in the association analysis.

Prospective associations found between the use of smartphone/tablet and neck/shoulder, low back and/or arms symptoms showed that there was a substantial increase in odds (by 30% to 80% more) of having musculoskeletal symptoms in a MTSD user compared to a non-MTSD user. There are no other known prospective longitudinal studies which have examined associations between MTSD use and musculoskeletal symptoms among adolescents. Nonetheless, findings are similar to prior cross-sectional studies among adolescents in China where similar odds of having neck/shoulder pain were found with the use of a mobile phone and a tablet (OR=1.31 (1.05-1.64) and 1.31 (1.12-1.54) respectively) (Shan et al. 2013), and among adolescents in Brazil where the percentage of participants who used a mobile phone was significantly higher in those with musculoskeletal symptoms (93%) than those without symptoms (81%) (Queiroz et al. 2017). Moreover, in a recent longitudinal study, though not conducted with adolescents but young adults, similar high odds of having prospective musculoskeletal symptoms (OR=1.6 (1.03-2.35) to 2.0 (1.34-3.13)) were also found with high number of texts on mobile phones (inclusive of physical keypad phones) (Gustafsson et al. 2017). The prospective study in this thesis has therefore provided evidence for a temporal relationship between the use of a smartphone/tablet and presence of musculoskeletal symptoms among adolescents.

Findings from the qualitative study have also suggested associations between the use of MTSD and musculoskeletal symptoms, where many of the adolescents reported experiencing discomfort during or after using MTSDs. Qualitative information from the study has also provided possible explanations for the associations, including poor sustained postures and prolonged use of MTSDs which were perceived as possible causes of their discomfort. These are in line with recent laboratory studies showing altered muscle activity and non-neutral postures (e.g. increased head/neck flexion) during use of MTSDs, especially in varied and non-traditional workstations, which may pose a risk for musculoskeletal symptoms (Gustafsson et al. 2018, Kietrys et al. 2015, Werth and Babski-Reeves 2014, Yu et al. 2018).

Associations between the use of MTSD and musculoskeletal symptoms could also be due to social factors or restrictions involved with the non-MTSD users, which helped to protect them from symptoms. In the survey studies, although the non-MTSD users were of a relatively small group compared to MTSD users, they consisted mostly of early adolescents. As seen from the qualitative study, many of the early adolescents (in primary school level) reported not having their own MTSDs due to parental restrictions. Hence, parental attitudes associated with restrictions of not allowing use or ownership of MTSDs among the non-MTSD users might have protected them from symptoms.

Interestingly, in contrast to cross-sectional findings at baseline, longitudinal results in the follow-up study revealed no dose response relationship between smartphone/tablet use duration and musculoskeletal symptoms, suggesting that greater amount of MTSD use may not necessarily pose a risk for prospective musculoskeletal symptoms. There are no other known longitudinal studies to compare these findings with. Findings from prior cross-sectional studies had been inconsistent on the associations between the MTSD use duration and musculoskeletal symptoms in adolescents; the lack of dose response relationship is therefore consistent with a few prior cross-sectional studies (Chiang and Liu 2016, Woo et al. 2016, Yang et al. 2017), but contrary to a few others conducted with adolescents which found significant associations between use duration and symptoms (Kwok et al. 2017, Shan et al. 2013, Straker et al. 2018a). It is also contrary to prolonged use of MTSDs being perceived as a cause of discomfort by adolescents in the qualitative study. The lack of dose response relationship at follow-up could be due to several reasons, one of which is the potential importance of patterns of MTSD use, which were also examined in this study. At follow-up, patterns of MTSD use (i.e. bout length, types of activities and multitasking) were found to be prospectively associated with musculoskeletal symptoms, suggesting that patterns of use, rather than simple use duration, may be the critical risk for musculoskeletal symptoms. Associations between patterns of use and symptoms will be discussed further in the next section (section 7.4.2).

Another possible reason for the lack of dose response relationship between MTSD use duration and prospective musculoskeletal symptoms might be adolescents' different habits of MTSD use. Anecdotally a large majority of the participants had already been using a smartphone/tablet before baseline (especially for the older adolescents), and might have adopted or developed habits of use which helped them to avoid or cope with symptoms. Examples of habits of use can be seen in the qualitative study where adolescents reported adopting strategies to relieve their discomfort when using MTSDs, such as varying or adjusting their postures frequently at different workstations (e.g. sofa or bed), or making use of the environmental setup (e.g. device accessories, pillows or surrounding furniture) to help provide support for their neck, back or arms. Although prior laboratory studies showed that the use of MTSDs induced greater non-neutral postures than traditional devices such as desktop/laptop computers (Kargar et al. 2018, Straker et al. 2008c, Szucs et al 2018), they also introduced greater variations in posture and muscle activity which may be beneficial in reducing biomechanical stresses and alleviating discomfort (Binboğa and Korhan 2014, Straker et al. 2010). Therefore, adolescents' habits of MTSD use such as variations or adjustments in postures may be protective against discomfort, such that greater MTSD use duration may not necessarily pose a risk for symptoms.

Moreover, as seen from the qualitative study, some of the adolescents perceived discomfort from use of MTSDs as mild and non-disruptive to their daily activities, and were generally unconcerned about it. This is consistent with the low average scores obtained for intensity of musculoskeletal symptoms and disruption to activities in the survey studies. Previous studies have also indicated a lack of awareness of problems including musculoskeletal symptoms associated with MTSD use by adolescents (Oulasvirta et al. 2012). Hence, there may be underreporting of musculoskeletal symptoms in the survey studies, by some adolescents who might not be aware of their discomfort.

Lastly, MTSD lifetime exposure or use prior to measurement at baseline, which was not examined in the survey studies, may have confounded the relationship between MTSD use duration and prospective musculoskeletal symptoms. In prior studies, lifetime mobile phone exposure has been shown to pose a risk for symptoms (Kim et al. 2016, Kucer 2008). MTSD use in the longer term may thus pose greater risk for musculoskeletal symptoms as a result of cumulative exposure to biomechanical and non-biomechanical factors.

In conclusion, although no dose-response relationship was found, the use of a smartphone or tablet still showed substantial effect sizes for an increased risk for prospective musculoskeletal symptoms in adolescents. Given the ubiquitous use of MTSDs in daily routines and activities including school use, it seems unreasonable to advise adolescents, especially for the older adolescents, against using a MTSD in order to avoid musculoskeletal symptoms. Rather, guidelines and strategies on how adolescents can use

MTSDs wisely to prevent or reduce symptoms are therefore warranted. Future studies should also consider adolescents' patterns and habits of MTSD use, lifetime exposure or use prior to baseline measure, and examine use exposures and symptoms with a longer follow-up period.

7.4.2 Associations of MTSD use patterns with musculoskeletal symptoms

The importance of patterns of MTSD use and their longitudinal associations with musculoskeletal symptoms were highlighted by the studies in this thesis, where baseline patterns of use (i.e. bout length of ≥1 hour, participating in certain types of activities, multitasking) were found to be significantly associated with symptoms at one-year follow-up. Similar to a few recent cross-sectional studies conducted by Yang et al. (2017) and Queiroz et al. (2017) with adolescents, no dose response relationship but significant associations between patterns of MTSD use (i.e. types of activities or multitasking) and musculoskeletal symptoms were demonstrated.

Longitudinal results showed that typical bout length of ≥1 hour of smartphone/tablet use at baseline posed a risk for prospective musculoskeletal symptoms compared to <1 hour of use (OR=1.20 (1.01-1.41) to 1.29 (1.01-1.64)). Current research examining associations between bout length of use specifically on MTSDs and musculoskeletal symptoms is still very limited. A survey study with young adults showed that bout length of smartphone use was positively correlated with neck pain intensity (Lee and Song 2014), while another study conducted with adolescents on bout length of tablet use, only in sitting postures, did not find any significant correlation with musculoskeletal symptoms (Sommerich et al. 2007). Nonetheless, the longitudinal results on bout length are consistent with prior cross-sectional studies on desktop/laptop computer use, which showed that lower break frequency, i.e. longer bout length, was associated with symptoms (Harris et al. 2015a, Menéndez et al. 2008, Menendez et al. 2009). These associations might be due to reduced muscle loading and biomechanical stress with shorter bout lengths (Zennaro et al. 2003). The results therefore suggest that limiting consecutive use to bout lengths of less than one hour and avoiding prolonged MTSD use may help prevent musculoskeletal symptoms.

In addition, the current study also found engaging in (but not use duration of) certain types of activities on MTSDs, i.e. social, games, videos and general use (including internet browsing), pose a risk for prospective musculoskeletal symptoms at neck/shoulder, low back, arms and/or wrist/hand (OR= 1.29 (1.01-1.65) to 1.98 (1.43-2.74)). Social activities examined in the studies included texting/messaging and use of social networking, which are consistent with previous cross-sectional surveys (Berolo et al. 2011, Xie et al. 2017) and a recent longitudinal study (Gustafsson et al. 2017) showing associations between texting on mobile devices and musculoskeletal symptoms. The prospective findings have also reinforced the potential causality of prior cross-sectional associations found for gaming (Chiang and Liu 2016, Xie et al. 2017), watching movies and internet browsing (Kwok et al. 2017) on mobile devices with symptoms. Potential mechanisms for the associations between these activities and symptoms could be due to the repetitive movements of texting and/or gaming, resulting in increased muscle loading and non-neutral postures at neck/shoulder, low back and upper extremities (Kietrys et al. 2015, Ning et al. 2015).

The various types of activities performed on MTSDs were also found to be associated differently with prospective musculoskeletal symptoms at different body regions of neck/shoulder, low back, arms and wrist/hand. Previous research has indicated different activities on MTSDs posing different postural demands and muscle activities at various body regions. For example, active tasks (e.g. typing or gaming) were associated with higher head/neck flexion (Chiang and Liu 2016, Lee et al. 2015, Ning et al. 2015) and upper trapezius muscle activity (Chiu et al. 2015, Young et al. 2013) compared to passive tasks (e.g. watching videos or internet browsing). Prospective results from the survey studies showed inconsistent associations between each type of activity on smartphone versus tablet and symptoms at each body region. This suggests that each type of activity on smartphone/tablet may not be just purely an active or passive task, but one that needs consideration of other factors such as postures of use, or different behaviours of use such as multitasking among different activities. Further research is still required on the use of different types of activities on MTSDs and how they may impact on musculoskeletal symptom risk at various body regions in adolescents.

Unlike the other types of activities, homework on smartphone/tablet was found to be not associated with any prospective musculoskeletal symptoms. This finding is similar to a recent study with adolescents in Hong Kong which showed no associations between use of smartphone for study purposes and musculoskeletal symptoms (Kwok et al. 2017). Prior studies have found that the use of smartphone for non-study related activities, such as social networking, gaming or entertainment, were significant predictors of smartphone addiction or problematic usage in adolescents (Cha and Seo 2018, Jeong et al. 2016). This suggests that engaging in non-homework related activities such as social, videos and gaming on MTSDs, may pose greater risk for musculoskeletal symptoms, possibly due to different patterns of use with different activities. For example, during homework, adolescents may have shorter bouts of MTSD use compared to gaming or watching videos - as supported by findings from the qualitative study, where adolescents have reported that they tended to get carried away and hence ended up using MTSDs for longer durations when gaming or watching videos.

In addition, although certain types of activities were associated prospectively with musculoskeletal symptoms, there were no dose response relationships observed. This is contrary to a few cross-sectional studies which found greater use duration of texting and browsing being associated with musculoskeletal symptoms (Kwok et al. 2017, Yang et al. 2017). This may be, again, due to habits of use such as varying postures of MTSD use, or insufficient follow-up period (of only one year) obscuring potential associations.

Another pattern of MTSD use examined in the survey studies was multitasking. The studies showed significant association between multitasking during smartphone use and prospective musculoskeletal symptoms, although no dose-response relationship with the extent of multitasking was found. This is also suggested by results from a recent cross-sectional study, which found significantly higher percentage of adolescents who multitasked with multiple devices, including MTSDs, among those with musculoskeletal pain than those without pain (Queiroz et al. 2017). However, there is a paucity of current research on musculoskeletal outcomes related to multitasking, especially on prospective outcomes; findings from the survey studies have thus added important knowledge on this area.

Possible reasons for the association between multitasking during smartphone use and prospective musculoskeletal symptoms could be continuous or prolonged use of MTSDs prompted by multitasking. This is supported by descriptive information provided in the qualitative study, where multitasking was observed to be prevalent and perceived by many adolescents as effortless, convenient and even a form of relaxation or break from their activities such as homework. Hence, multitasking might have encouraged them to use MTSDs for longer periods without awareness of their usage, thereby predisposing them to increased biomechanical stress and musculoskeletal symptoms. Moreover, a prior qualitative study also found adolescents perceiving multitasking with multiple screen devices, including that of television and mobile phone, to be enjoyable (Jago et al. 2011). The association might be also due to negative psychosocial states, e.g. depression and social anxiety (Becker et al. 2013), that have been associated with multitasking in adolescents, thereby predisposing them to musculoskeletal symptoms, although the analysis in the follow-up study was adjusted for depression, anxiety and stress symptoms.

In summary, findings from the thesis studies have highlighted the importance of understanding patterns of MTSD use by adolescents, in addition to the amount of use, and their longitudinal associations with musculoskeletal symptoms. Bout length of ≥1 hour, participating in certain types of activities and multitasking during MTSD use have implications for increased risk of prospective musculoskeletal symptoms in adolescents. However, the potential mechanisms of how they may impact on musculoskeletal health are still not well understood.

7.4.3 Associations of MTSD use with visual health outcomes

Concerns of potential harm to adolescents' visual health, especially myopia, from use of MTSDs were commonly raised among parents/caregivers as well as adolescents in the qualitative study. Moreover, vision and musculoskeletal symptoms have been associated in prior studies (e.g. significant interaction found between visual symptoms and neck/shoulder symptoms), due to possibly increased postural demands from higher visual stress during computer use (Gowrisankaran et al. 2015, Hoyle et al 2011, Richter et al 2011). Therefore, the survey in this thesis also examined associations between MTSD use and visual health in adolescents, but as a secondary outcome. Findings revealed that cross-sectionally at baseline, greater hours/day of smartphone use was significantly associated with higher number of visual symptoms, but lower prevalence of myopia. However, at follow-up, no significant associations were found between smartphone/tablet use and prospective visual symptoms or myopia.

Although the baseline survey found positive associations between hours/day of smartphone use and visual symptoms, similar to results from a few prior cross-sectional studies in adolescents (Kim et al. 2016, Straker et al. 2018a), prospective results at follow-up showed that the use of smartphone/tablet was not significantly associated with visual symptoms. Nevertheless, although the survey showed that the use of MTSDs was not prospectively associated with visual symptoms, recent studies suggest that patterns of use can pose a risk for visual symptoms. A recent study indicated that adolescents who spent greater time browsing the internet and watching TV/movies on MTSDs had higher odds of having eye discomfort, while for messaging there were lower odds for eye discomfort (Kwok et al. 2017), possibly due to intermittent use of MTSDs during messaging. Shorter bout length of MTSD use may thus result in reduced duration of continuous near screen viewing and hence strain on eyes. Future studies should also examine the prospective associations between patterns of MTSD use and visual symptoms in adolescents to determine their temporal relationships.

The lack of prospective association might also be due to habits of MTSD use and lifetime exposure of use by the adolescents, which were not examined in the survey studies. The majority of adolescent participants had used a MTSD before baseline measure and possibly developed habits of use, such as using anti-reflection films (Miyake-Kashima et al 2005) or short bouts of intermittent use (Jaiswal et al 2019, Sheppard and Wolffsohn 2018) to help them avoid visual symptoms. Habits of screen viewing distances during MTSD use may also have an effect on visual symptoms experienced, as closer viewing distances have been found to be related to greater eye strain after smartphone use in the laboratory setting (Long et al 2017). In addition, lifetime exposure of MTSDs may be the main risk factor instead of just baseline use, as suggested by some cross-sectional studies indicating lifetime use being associated with visual symptoms (Kim et al. 2016, Kucer 2008).

Regarding myopia, although cross-sectionally at baseline, greater use duration of smartphone was found to be associated with lower odds of having myopia, the longitudinal analyses showed that there was no association between the use of smartphone/tablet and myopia. The lack of longitudinal association is consistent with some prior studies showing near work activities (involving general screen use with or without MTSD use) posing no risk for myopia in adolescents (Ip et al. 2008, Jones-Jordan et al. 2012, Lin et al. 2017), but is in contrast with associations found in some other studies (Cooper and Tkatchenko 2018, French et al. 2013, Huang et al. 2015). Recent evidence has, however, consistently shown that screen time use alone may pose minimal risk for myopia, while greater amount of outdoor time is linked with reduced risk of myopia (Ramamurthy et al. 2015b, Sherwin et al. 2012). Moreover, recent studies have suggested that habits of use such as having close distance for near work, inadequate lighting, and continuous near work without taking eye breaks, were associated with myopia or myopic progression (Ramamurthy et al. 2015a, You et al 2016). Although the near work activities examined in these recent studies consisted mainly of general screen use such as computer or TV and/or reading on print, these findings indicate that time outdoors and habits of MTSD use may be important factors in posing a risk for myopia, rather than purely the use of MTSDs.

In conclusion, findings from the studies in this thesis have added evidence to the current literature on cross-sectional and longitudinal associations between the use of MTSDs and visual symptoms and myopia in adolescents. The lack of longitudinal association between the use of MTSDs and these visual outcomes may be due to the importance of patterns, habits and lifetime exposure of use, which may pose risks for adolescents' visual health. It may also be that there is simply no temporal association between MTSD use and these visual outcomes. A follow-up period of one-year for the survey study may also have been too short a timeframe for effects of MTSD use on visual health to be detected. Future studies should therefore adopt a longer follow-up period, and examine patterns, habits, and lifetime exposure of use, in addition to the use of or use duration of MTSDs, as possible risk factors for adolescents' visual health.

7.5 Strengths and limitations

Strengths of studies in this thesis include the survey study being the first longitudinal study to examine associations between MTSD use and musculoskeletal symptoms and visual health outcomes, in a representative sample of adolescents across the range of ages. There was also high response rate by participants who completed the questionnaire in class during school curriculum time. Moreover, associations with patterns of MTSD use and not just use duration, were also examined. Potential confounders known to influence associations between MTSD use and musculoskeletal symptoms and visual health outcomes (i.e. gender, grade, mental health, physical activity and total technology use of other screen devices), were also adjusted for in the association analyses. The studies have thus provided important knowledge on the temporal relationships between MTSD usage and musculoskeletal symptoms and visual health in adolescents.

In addition, detailed MTSD use exposures which included device specific frequency and duration of use, separate usage on weekdays and weekends and patterns of use - bout length, along with types of activities and multitasking, were also captured in the survey studies. Through the qualitative studies, rich information and useful insights on influences of adolescents' MTSD use, discomfort experienced and the types and influences of postures, were also obtained from a substantive sample of adolescents and their parents.

Perspectives from parents were also useful in providing triangulation of data provided by the adolescents.

Limitations of the studies included the use of self-report, which may present recall bias from the adolescent participants and affect the accuracy of reported MTSD use duration, patterns of use, and estimated associations with outcomes. Prior studies have shown that self-report can introduce errors, and underestimate or overestimate technology use exposures compared to direct measurement or observation (Lee et al 2017, Schmitz et al 2004). Cognitive abilities, language and communication skills are still developing in children and adolescents, hence they may have more issues with the accuracy of their recall and abilities in comprehending questionnaires. Nonetheless, if the questionnaire has been structured appropriately to children's abilities of comprehension, prior studies have shown that they are able to answer them reliably (Borgers et al 2004, Varni et al 2007). Self-report has also been commonly adopted by various studies and often deemed as the most appropriate and feasible method to capture technology use exposures in both adults and children, especially if the sample population is large (Clark et al 2009, Rideout 2016). Moreover, children's self-report of time spent in different activities throughout the day, including screen technology use e.g. computer or TV, has been found to be valid when compared with observations (Ciccarelli et al 2011). The TechU-Q questionnaire used in the survey studies had previously had reliability and face validity tested with adolescents (Straker et al. 2018a). For this thesis, it was also further pilot tested with some local adolescents across the ages to check for comprehension and cultural applicability. With the large sample involved in the survey studies, self-report can hence be deemed as appropriate for the studies.

Another limitation is the content validity of measures used to capture MTSD use duration and patterns of use. In the baseline study, use duration captured for each specific device and all the devices (total technology use obtained by summing use of all devices), might have overestimated the amount of usage for each or all the device(s) as it had not accounted for possible multitasking among the devices. Prior studies have similarly noted this possible overestimation of usage, in view of increasing prevalence of multitasking among adolescents (Rideout 2015, Rosenberg et al. 2018, Straker et al. 2018a). Measures for accurately capturing patterns of MTSD use have also not been well developed as yet; existing research has recognized that measuring time spent on a particular activity accurately is challenging, especially with adolescents engaging in multitasking and spontaneous or sporadic use of MTSDs throughout the day (Rideout 2015, Rideout 2016).

There might also have been some bias associated with attrition at the follow-up study. The group of adolescents who were lost to follow-up had significantly higher smartphone usage and prevalence of musculoskeletal symptoms. Nonetheless, their omission likely made the findings more conservative. The risk of bias is likely to be low as the percentage of adolescents lost to follow-up was small; they also did not intentionally withdraw from the study but were absent due to valid reasons such as sickness, competitions or other school activities or had transferred to another class or school. Furthermore, longer-term effect of MTSD usage on symptoms is unknown due to follow-up period of only one-year. With only one follow-up time point, musculoskeletal and visual symptoms might also not have been captured as accurately since they can occur episodically. Temporal fluctuations of self-reported symptoms could also be another limitation of the accuracy of reported symptoms (Ge et al 2014).

Lastly, there is limitation of generalizability of the findings to other populations as data were collected in a fairly high technological society (Singapore). With continuing advancements of technology hardware and software, future use patterns by adolescents and technology use in schools may be different, since findings from the studies reflected use at the point of data collection. However, from anecdotal evidence and current research, MTSDs are still highly relevant and prevalent among adolescents today.

7.6 Further research

In order to provide evidence-based guidelines for wise use of MTSDs by adolescents, further research is warranted on the effects of MTSD use on musculoskeletal symptoms and visual health. Given the limitations of the existing studies, there is a need for further research on outcome measure development, with longer follow-up period and multiple time points of measurement. Findings from the thesis studies have also provided some directions for future research, and areas to target for developing guidelines for wise use.

The studies showed that MTSD use was highly prevalent and ubiquitous among adolescents, and that the use of MTSDs as well as patterns of use (i.e. bout length, participating in certain types of activities, multitasking), have implications for posing a risk for prospective musculoskeletal symptoms in adolescents. The lack of dose response relationship between MTSD use duration and prospective symptoms may be due to the importance of patterns of use. Future studies should thus, like in this study, also examine the effect of patterns of MTSD use on musculoskeletal and visual outcomes, instead of solely on its prevalence of use or total use duration. Although findings showed that participating in certain types of activities (i.e. social, games, videos, general use) and multitasking may predict musculoskeletal symptoms, the exact mechanisms behind these associations with symptoms are still not well understood and should be investigated further.

Habits of use and lifetime exposure or use prior to baseline measurements should also be taken into consideration, when examining associations between MTSD usage and musculoskeletal symptoms and visual health. Future longitudinal studies should have a longer follow-up period with multiple time points of measurement, so that the episodic nature or occurrence of musculoskeletal and visual symptoms can be better captured. They should also adjust for potential confounders including gender and age or school level. Further research is also required on tailoring guidelines and strategies for wise use to each gender and age group or school level, as suggested by findings showing significant differences in MTSD usage and associated outcomes across gender and school levels.

In addition, accurate measures to capture MTSD use exposures, including patterns of use such as bout length, types of activities, and the nature and extent of multitasking, need to be developed. The measures need to factor in sporadic periods of MTSD use as well as multitasking among devices, which are still lacking in current measures used for capturing technology use exposures. It will also be important to establish the reliability and validity of measures used including those of self-reports, for example by validating questionnaires of smartphone usage against the newer phone applications for tracking actual usage.

Findings from the thesis studies also showed a wide variety of postures and non-traditional workstations been adopted by adolescents during use of MTSDs. For example, side or prone lying postures on the sofa or bed, with use of pillows or cushions to support neck/shoulders, back or arms. Further research should be carried out to examine the biomechanical effects of these varied postures and workstations, and their impact on musculoskeletal health of adolescents. The adolescents also reported changing or adjusting their postures intermittently which might have helped to prevent or reduce their discomfort when using MTSDs. Further research on the potential for greater posture variations during MTSD use to be beneficial for preventing musculoskeletal symptoms is also needed.

Additionally, findings on influences of MTSD use showed that schools and parents play an important role in regulating use of MTSDs by adolescents. However, further research is still required on how different school policies and parental behaviours of technology use, can influence adolescents' amount and behaviours of MTSD use. There is also a limit to how much schools and parents can regulate adolescents' MTSD use, as much of their use is still generally unsupervised. It is important for adolescents to ultimately take charge of their own usage and establish good habits of MTSD use. Future studies should thus examine effective strategies and interventions that raise awareness and encourage adolescents' self-management of their MTSD usage.

7.7 Implications for wise use

Results from the studies in this thesis have provided an important contribution to the scientific literature pertaining to adolescents' use of MTSDs and associated prospective outcomes of musculoskeletal symptoms and visual health. The studies have shown MTSD use being an integral part of adolescents' daily routines, including use for school and homework and keeping connected with family and peers. Nonetheless, the longitudinal study has also shown that the use of smartphone/tablet and patterns of use were associated with prospective musculoskeletal symptoms, which can impact negatively on adolescents' daily activities and health (Bejia et al. 2005, Kamper et al. 2016). Musculoskeletal symptoms associated with MTSD use are thus not trivial and adolescents need to be able to use MTSDs wisely, to minimize potential harm while maximizing benefits from its use. Findings from the studies have provided some insights and suggestions on how adolescents can use MTSDs wisely.

Results from the longitudinal study showed that the prevalence of MTSD use was associated with musculoskeletal symptoms, suggesting that it may be best to simply not use MTSDs to reduce risk of symptoms. However, it is not be feasible for adolescents to refrain from using MTSDs given the importance of such technology in participating in the current digitally enmeshed society. This is likely to be even more so in the future, given that the use of MTSDs is anticipated to increase and integrate further into adolescents' daily routines and functions (eMarketer 2016, Rideout 2015, Rideout 2016). Moreover, a recent study found that adolescents who did not engage in any screen technology use including smartphones, had poorer psychological well-being than those who used moderately or purposefully (Twenge et al 2018), suggesting that patterns and contents of MTSD use may be more important in mediating the risk for adverse associated outcomes than abstinence. This is also supported by findings from the longitudinal study, which has demonstrated associations of patterns of MTSD use with prospective musculoskeletal symptoms.

Guidelines for wise use of MTSDs should hence target patterns of use too. Findings from the longitudinal study showed that bout length of ≥1 hour on MTSDs posed a risk for prospective musculoskeletal symptoms. This suggests that adolescents should avoid using MTSDs for prolonged periods, but engage in short periods of less than an hour of use each time to reduce the risk of musculoskeletal symptoms. They should also be more aware of their usage when engaging in leisure or social activities on MTSDs, as participating in these types of activities: social, games, videos and general use (including internet browsing) showed associations with musculoskeletal symptoms, whereas homework did not. Multitasking with multiple devices while using MTSDs should be avoided if possible, as it also showed association with symptoms.

Changing or adjustment of postures during MTSD use was one of the strategies reported by adolescents in the qualitative study to help relieve their discomfort, which may also be a habit of use confounding the lack of dose response relationship between MTSD use duration and musculoskeletal symptoms observed. These findings suggest that adolescents should avoid sustained postures and vary or adjust their postures frequently when using MTSDs, which may be protective against musculoskeletal symptoms. The qualitative study also showed that the environmental setup, including the use of furniture and device accessories at home and outdoors, has an important influence on postures adopted; adolescents should hence consider the appropriateness of the environment, and ensure adequate support for their body and/or the device itself when using MTSDs.

As seen from findings of influences of MTSD use in the qualitative study and the substantial amount of use for homework, it is evident that schools and parents play an important role in mediating adolescents' use of MTSDs. Schools should be mindful of the potential adverse outcomes of MTSD use when implementing their use in the school curriculum, and educate adolescents on how to achieve a balance between use for education and leisure or personal purposes. Parental control measures may help to regulate adolescents' MTSD usage. However, when implementing such measures, mutual understanding should be sought between parents and adolescents, and parents should serve as role models, to enhance compliance and minimise disruption of family relationships.

Findings from the thesis studies suggest that wise use of MTSDs by adolescents should involve bout lengths of less than an hour and frequent changes of postures, and avoiding multitasking as much as possible to reduce the risk for musculoskeletal symptoms. Additionally, adolescents also need to take responsibility and increase awareness of their own usage, implement self-management on their irresistibility to MTSDs, including the need to frequently ‘check’ them. Government agencies and organisations, educators and researchers should also work together with schools, parents and adolescents to develop guidelines and provide appropriate advice on wise use of MTSDs for adolescents, to minimize potential for harm on their health and development while maximising the benefits of MTSD use in daily functions and education.

Chapter 8 Conclusion

The use of mobile touch screen devices (MTSDs), which are typically smartphones and tablets, is highly prevalent among adolescents today. Concerns of possible adverse effects of MTSD use on adolescents' musculoskeletal symptoms and visual health have therefore been raised. However, research on the associations between MTSD use and musculoskeletal symptoms and visual health outcomes was limited, especially among adolescents. The majority of prior studies on MTSD use and these associated outcomes were of cross-sectional design, convenience sampling and adopted simple exposure measures of MTSD use. Moreover, prior understanding of MTSD use exposures, including patterns of use, and perspectives from adolescents and their parents on adolescents' MTSD use was also limited.

The aims of this thesis were therefore to:

1) systematically review current literature on musculoskeletal symptoms and exposures associated with the use of MTSDs
2) explore perspectives from adolescents and parents on adolescents' MTSD use
3) examine associations of MTSD use with musculoskeletal symptoms and visual health outcomes

The systematic review found limited evidence available on associations of MTSD use and various aspects of its use (i.e. amount of usage, features, tasks and positions) with musculoskeletal symptoms. This was due to mainly low quality experimental and case-control laboratory studies, with few cross-sectional and no longitudinal studies.

The thesis qualitative study, which consisted of semi-structured interviews conducted with adolescents and their parents, provided useful insights and rich descriptions on the patterns and influences of MTSD use, as well as discomfort experienced and postures adopted by adolescents during use. MTSD use was perceived to be high, frequent and ubiquitous by many adolescents and their parents, and has become an integral part of adolescents' daily routines. There were several functional, personal and external influences which either facilitated or limited their use. Multitasking MTSD use with other devices or tasks, especially during homework was also commonly reported. Moreover, there seemed to be a strong inclination for adolescents to frequently check and use their MTSDs. Discomfort, particularly at neck/shoulder, during or after using MTSDs was commonly reported by adolescents, although it was generally mild and non-disruptive to activities. A variety of postures during MTSD use at various home settings were demonstrated by the adolescents, which consisted mostly of non-neutral postures.

The prospective quantitative study comprised of surveys conducted at baseline and one-year follow-up in a nationally representative sample of adolescents. It provided detailed information on contemporary technology use and MTSD use exposures by adolescents, including patterns of use, and associations with musculoskeletal symptoms and visual health outcomes. This study showed that technology and MTSD use is high among the adolescents. Smartphone use was the most prevalent; it had the highest daily use, longest bout length of use and highest daily use for each type of activities. Multitasking was also commonly reported during technology use. Moreover, gender and school level differences were observed in MTSD use exposures, such as in the daily use duration and types of activities.

Baseline data from this study revealed that musculoskeletal symptoms, especially at neck/shoulder, were prevalent among adolescents. Greater hours/day of smartphone use, but not tablet use, was found to be associated with more musculoskeletal and visual symptoms, after adjusting for confounders. Moreover, longitudinal results revealed that the use of smartphone/tablet, though not the amount of use, and patterns of use (bout length of ≥1 hour, participating in certain types of activities and/or use of multitasking) were associated with prospective musculoskeletal symptoms. However, no prospective associations were found between smartphone/tablet use and visual health.

In conclusion, findings from this thesis have provided a better understanding of MTSD use exposures, including patterns of use, and their associations with musculoskeletal symptoms and visual health in adolescents. The results demonstrated that MTSD use is high among adolescents and may predict prospective musculoskeletal symptoms. MTSD use therefore appears to have physical health implications for adolescents. Given that MTSD use has become ubiquitous and integrated into everyday lives, strategies to support wise use by adolescents are thus warranted. Information gained in this thesis will assist researchers, policy makers, educators, parents and adolescents to develop informed guidelines and interventions for wise use of MTSDs. This will also help to maximize benefits of adolescents' use for learning and education while minimizing any potential adverse impact on their health and development.

Chapter 9 References

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APPENDICES

Appendix A S1. Search strategy

Database	EMBASE	
Date	13/6/2016	
Strategy	#1 AND #2 AND #3	
#1	Mobile touch screen devices	Minicomputer/ OR Microcomputer/ OR Mobile phone/ OR Information technology/ OR ("touch screen*" OR "touchscreen*" OR "touch-screen*" OR "touch interface*" OR "touch technolog*" OR "tablet comput*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR "tablet PC*" OR "smart phone*" OR "smartphone*" OR "smart-phone" OR "mobile phone*" OR "cell* phone*" OR "mobile technolog*" OR "mobile device*" OR "information communication* technolog*" OR "information technolog*" OR "information and communication* technolog*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*").ti,ab,kw.
#2	Posture muscle activity musculos-keletal symptoms	Body posture/ OR Skeletal muscle/ OR Musculoskeletal system/ OR Musculoskeletal injury/ OR Muscle injury/ OR Electromyography/ OR Motor activity/ OR "movement (physiology)"/ OR Body movement/ OR Musculoskeletal function/ OR Musculoskeletal pain/ OR Pain/ OR Back ache/ OR Neck pain/ OR Low back pain/ OR ("posture*" OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR "discomfort" OR "symptom*" OR "pain").ti,ab,kw.
#3	Limit to year 1993 (inclusive) onwards	limit to yr="1993-Current"

Database	Medline	
Date	13/6/2016	
Strategy	#1 AND #2 AND #3	
#1	Mobile touch screen devices	Minicomputer/ OR Computers, handheld/ OR Human engineering/ OR Cell phones/ OR ("touch screen*" OR "touchscreen*" OR "touch-screen*" OR "touch interface*" OR "touch technolog*" OR "tablet comput*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR "tablet PC*" OR "smart phone*" OR "smartphone*" OR "smart-phone" OR "mobile phone*" OR "cell* phone*" OR "mobile technolog*" OR "mobile device*" OR "information communication* technolog*" OR "information technolog*" OR "information and communication* technolog*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*").ti,ab.

#2	Posture muscle activity musculoskeletal symptoms	Posture/ OR Muscle, skeletal/physiology OR Musculoskeletal system/ OR Movement/physiology OR Electromyography/ OR Motor activity/physiology OR Musculoskeletal pain/ OR Pain/ OR Back pain/ OR Low back pain/ OR Neck pain/ OR (“posture*” OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR “discomfort” OR “symptom*” OR “pain”).ti,ab.
#3	Limit to year 1993 (inclusive) onwards	limit to yr="1993 -Current”

Database	**PsycINFO**	
Date	13/6/2016	
Strategy	#1 AND #2 AND #3	
#1	Mobile touch screen devices	Microcomputers/ OR Computer Peripheral Devices/ OR Human Factors Engineering/ OR Cellular phones/ OR Mobile devices/ OR Computer usage/ OR Human computer interaction/ OR Information technology/ OR ("touch screen*" OR "touchscreen*" OR "touch-screen*" OR "touch interface*" OR "touch technolog*" OR "tablet comput*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR “tablet PC*” OR "smart phone*" OR "smartphone*" OR "smart-phone" OR “mobile phone*” OR “cell* phone*” OR "mobile technolog*" OR "mobile device*" OR "information communication* technolog*" OR "information technolog*" OR "information and communication* technolog*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*").ti,ab,id.
#2	Posture muscle activity musculos-keletal symptoms	Posture/ OR Musculoskeletal system/ OR Musculoskeletal disorders/ OR Electromyography/ OR Pain/ OR Back pain/ OR (“posture*” OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR “discomfort” OR “symptom*” OR “pain”).ti,ab,id.
#3	Limit to year 1993 (inclusive) onwards	limit #3 to yr=”1993 –Current”

Database	Proquest	
Date	14/6/2016	
Strategy	#1 AND #2 AND #3	
#1	Mobile touch screen devices	TI,AB,IF("touch screen*" OR "touch-screen*" OR touchscreen* OR "touch interface*" OR "touch technolog*" OR “tablet PC*” OR "tablet comput*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR "cell* phone*" OR "mobile phone*" OR "hand phone*" OR "handphone*" OR "smartphone" OR "smart-phone" OR "smart phone" OR "mobile technolog*" OR "mobile device*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*" OR "information technolog*" OR "information communication* technolog*" OR "information and communication* technolog*")
#2	Posture muscle activity musculos-keletal symptoms	(TI,AB,IF("posture*" OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR "musculoskeletal disorder*" OR "discomfort" OR "symptom*" OR pain))
#3	Limit to year 1993 (inclusive) onwards; exclude newspapers, trade journals, wire feeds, magazines, blogs podcasts and websites	(YR(>=1993) ((TI,AB,IF("touch screen*" OR "touch-screen*" OR touchscreen* OR "touch interface*" OR "touch technolog*" OR "tablet comput*" OR "tablet PC*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR "cell* phone*" OR "mobile phone*" OR "hand phone*" OR "handphone*" OR "smartphone" OR "smart-phone" OR "smart phone" OR "mobile technolog*" OR "mobile device*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*" OR "information technolog*" OR "information communication* technolog*" OR "information and communication* technolog*")) AND (TI,AB,IF("posture*" OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR "musculoskeletal disorder*" OR "discomfort" OR "symptom*" OR pain)))) NOT stype.exact("Newspapers" OR "Trade Journals" OR "Wire Feeds" OR "Magazines" OR "Blogs, Podcasts, & Websites")

Database	Scopus	
Date	14/6/2016	
Strategy	#1 AND #2 AND #3	
#1	Mobile touch screen devices	TITLE-ABS-KEY ("touch screen*" OR "touch-screen*" OR touchscreen* OR "touch interface*" OR "touch technolog*" OR "tablet comput*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR "cell* phone*" OR "mobile phone*" OR "hand phone*" OR "handphone*" OR "smartphone" OR "smart-phone" OR "smart phone" OR "mobile technolog*") OR TITLE-ABS-KEY ("mobile device*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*" OR "information technolog*" OR "information communication* technolog*" OR "information technolog*") OR TITLE-ABS-KEY ("information and communication* technolog*")
#2	Posture muscle activity musculoskeletal symptoms	TITLE-ABS-KEY ("posture*" OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR "musculoskeletal disorder*" OR "discomfort" OR "symptom*" OR pain)
#3	Limit to year 1993 (inclusive) onwards	(TITLE-ABS-KEY ("touch screen*" OR "touch-screen*" OR touchscreen* OR "touch interface*" OR "touch technolog*" OR “tablet PC*” OR "tablet comput*" OR "slate comput*" OR "mobile comput*" OR "portable comput*" OR "cell* phone*" OR "mobile phone*" OR "hand phone*" OR "handphone*" OR "smartphone" OR "smart-phone" OR "smart phone" OR "mobile technolog*" OR "mobile device*" OR "screen time" OR "screen us*" OR "screen based activit*" OR "screen-based activit*" OR "screen activit*" OR "information technolog*" OR "information communication* technolog*" OR "information technolog*" OR "information and communication* technolog*")) AND (TITLE-ABS-KEY ("posture*" OR "electromyograph*" OR "motor activit*" OR "muscle activit*" OR "musculoskeletal activit*" OR "musculoskeletal disorder*" OR "discomfort" OR "symptom*" OR pain)) AND (PUBYEAR > 1992)

Appendix B S2. Methodological quality assessment list

1. Study purpose	
+	A specific clearly stated purpose is well described and appropriate.
-	A specific clearly stated purpose is well described but not appropriate.
?	Unclear or insufficient information.
2. Study design	
+	Design used is well described and is appropriate to address the study purpose.
-	Design used is well described but not appropriate to address the study purpose.
?	Unclear or insufficient information.
3. Study Population	
+	Definition and description (eligibility criteria, methods of selection and possible selection bias) of the subject group(s) involved in the study are well described and appropriate.
-	Definition and description (eligibility criteria, methods of selection and possible selection bias) of the subject group(s) involved in the study are well described but not appropriate.
?	Unclear or insufficient information.
4. Musculoskeletal exposures and/or physiological responses	
+	Musculoskeletal exposure and/or physiological responses variable(s), e.g., physical load during the test conditions measured by electromyography/kinematics, duration/frequency of device use etc., are well described and appropriately collected using standardized method(s) of acceptable quality (reliability and validity).
-	Musculoskeletal exposure and/or physiological responses variable(s), e.g. physical load during the test conditions measured by electromyography/kinematics, duration/ frequency of device use etc., are well described but not appropriately collected using standardized method(s) of acceptable quality (reliability and validity).
?	Unclear or insufficient information.
5. Musculoskeletal symptoms (if applicable)	
+	Musculoskeletal symptoms, i.e. pain, discomfort, soreness, injuries are well described and collected using appropriate standardized method(s) of acceptable quality (reliability and validity).
-	Musculoskeletal symptoms, i.e. pain, discomfort, soreness, injuries are well described but not collected using appropriate standardized method(s) of acceptable quality (reliability and validity).
?	Unclear or insufficient information.
6. Statistical analyses	
+	The statistical analyses applied are well described and appropriate for the outcome studied.
-	The statistical analyses applied are well described but not appropriate for the outcome studied.
?	Unclear or insufficient information.
7. Results	
+	Results are well described and appropriately reported in sufficient details.
-	Results are well described but not appropriately reported in sufficient details.
?	Unclear or insufficient information.

Note: (+) positive; (-) negative; (?) unclear, i.e. insufficient information

Appendix C S3. Summary of included cross-sectional studies (MTSD use and musculoskeletal symptoms)

Author (year)	Study population	Type of MTSD examined	Study design and conditions	Musculoskeletal symptoms measurement	Musculoskeletal symptoms results
Chiang and Liu (2016) *Study 1* *(an experimental laboratory study was also conducted (study 2) and is listed in Appendix H)*	**n** = 80 **Age:** > 20 years **Gender:** 26 males, 54 females **Other specific:** College students in Taiwan	Tablet computer	**Design:** Cross-sectional study (study 1) Questionnaire conducted and tablet tilt angle set up on tablet cases for various tasks by participants measured in the lab **Conditions:** NA	**1) Type of symptoms:** Discomfort of the neck, right and left shoulder, waist, back and distal upper extremities (i.e. wrist, upper arm, forearm) **Measurement method:** Questionnaire on discomfort/pain due to tablet use, indicating the body part(s) and pain using a visual analogue scale (VAS) from "no pain" to "worst pain imaginable" with the length of 10 cm **Variable(s):** • Discomfort and pain score	- 55% (44 out of 80 participants) reported discomfort after using a tablet - Neck (37.5%) and shoulders (30% right shoulder, 26.3% left shoulder) were the most frequent areas of discomfort reported; - 7.5% (6 out of 80 participants) reported discomfort in the back after using a tablet - Mean VAS scores after using a tablet by participants who reported discomfort: back 5.6 (1.49); neck 4.91 (2.35), right shoulder 4.98 (2.51), left shoulder 5.26 (2.39)

					- No statistically significant differences were present between discomfort and reported daily tablet usage - Significantly more participants who tended to play games reported discomfort after playing game on tablet; no differences with the other tasks
Kim and Kim (2015)	**n** = 292 (300 completed survey, 8 excluded due to incomplete data) **Age:** 21.4 (1.6) years **Gender:** - **Other specific:** Dental hygiene students in South Korea	Smartphone	**Design:** Cross-sectional study Questionnaire on screen size, purposes, location, daily usage and postures of smartphone use **Conditions:** NA	**1) Type of symptoms:** Pain in the neck, shoulder, waist, distal upper extremities (i.e. hands, wrists, fingers), legs and feet **Measurement method:** Questionnaire on symptoms in the above-mentioned body regions **Variable(s):** • Pain at body regions	- Neck and shoulder were the most common areas of pain reported by participants (neck 55.8%, shoulder 54.8%, arms 19.2%, hands 19.2%, wrists 27.1%, fingers 19.9%, waist 29.8%, 9.6% legs and feet) - Significant positive correlation between pain in the waist region and screen size (r=0.129), no significant correlations of screen size with pain in any other body region - Significant negative correlation between pain in the legs and feet and daily usage (r=

					-0.127), no significant correlations of daily usage with pain in any other body region - Only descriptive information was available for the following results (no statistical analyses were performed): - There was a higher prevalence of pain in those who use smartphones whilst sitting and lying on their back compared to those who adopted other postures (standing, lying on the face or others); - There was a higher prevalence of pain in those who use smartphones for searching internet and chatting compared to those who use smartphone for other purposes; - There was a higher prevalence of pain in those who used a smartphone for >2 hours daily compared to those who used a smartphone for <2 hours daily
Shan et al (2013)	**n** = 3016 **Age** = 15-19 years **Gender:** 1,460 males, 1,556 females **Other specific:** High school students from 30 randomly selected schools in Shanghai, China; 83.8% response rate	Tablet computer	**Design:** Cross-sectional study Questionnaire on: - Daily tablet usage (<1hour/ 1-1.5 hours/ 1.5-2hours/ >2 hours) - Posture during tablet use (standing/ lying/ semi-reclining/ sitting) - Eye-to-screen distance while using tablet	**1) Type of symptoms:** Neck/shoulder and low back pain **<u>Measurement method:</u>** Questionnaire on discomfort in the neck/shoulder and lower back and its frequency during the past 6 months ("almost never" (<1/month); "occasionally" (1-3x/month); "often" (1-3x/week); "always" (>3x/week); frequency of	

			Conditions: NA	"often" and "always" denoted as presence of pain) **<u>Variable(s):</u>** • Neck/shoulder pain • Low back pain	 - Prevalence of neck/shoulder pain: 40.8% - Females had a significantly higher odds of neck/shoulder pain than males (OR 1.293, 95% CI 1.108-1.509) - Tablet use was significantly associated with neck/shoulder pain (OR 1.311, 95% CI 1.117-1.538) - No significant association of tablet daily usage, posture during tablet use and eye-to-screen distance while using tablet with neck/shoulder pain - Prevalence of low back pain: 33.1% - Females had a significantly higher odds of low back pain than males (OR 1.296, 95% CI 1.102-1.523) - No significant association of tablet use, tablet daily usage, posture during tablet use and eye-to-screen distance while using tablet with low back pain
Sommerich et al (2007)	**n** = 77 **Age:** - **Gender:** 19 males, 58 females **Other specific:** Grade 11 or 12 students from a school in USA	Tablet computer	**Design:** Cross-sectional study Questionnaire on: - Frequency and duration of tablet use - Frequency of awkward postures when using tablet - Moving/carrying tablet	**1) Type of symptoms:** Discomfort in the neck, shoulder, distal upper extremities (i.e. forearm/elbow, hand/wrist), upper back, lower back, buttocks and legs/feet, eyes and head (headache)	

	(73% completion rate)		- Tablet temporal usage patterns - Activities on the tablet - Tools and peripheral devices for tablet (e.g. external key board) **Conditions:** NA	**<u>Measurement method:</u>** Questionnaire on discomfort associated with tablet use and moving/carrying tablet, its body region and frequency (never/ rarely/ sometimes/ quite often/ almost always) **<u>Variable(s):</u>** • Discomfort score	- 50% or more reported discomfort in the eyes, neck, head (headache), right hand/wrist and upper back, upper and lower back - 30-40% reported discomfort in the neck, lower back and eyes at least "sometimes", <10% reported "quite often" or "almost always" - Shoulder was the most common region reported (21.6%) for discomfort when moving/carrying tablet - Frequency of awkward postures when using tablet use was significantly correlated with overall discomfort scores (r=0.40), and discomfort in the right shoulder, neck, upper back, low back, buttocks, eyes and head (headache) - No significant correlation between discomfort and duration of continuous tablet use in sitting, moving/carrying tablet, and other aspects of tablet use were shown

Appendix D S4. Summary of included case-control laboratory studies (MTSD use and musculoskeletal symptoms)

Author (year)	Study population	Type of MTSD examined	Study design and conditions	Musculoskeletal symptoms measurement	Musculoskeletal symptoms results
Kee et al (2016)	**n** = 100 **Age:** Normal group 16.9 (1.6) years; addicted group 17.0 (2.0) years **Gender:** 28 males, 72 females **Other specific:** Teenagers and patients recruited from a hospital department in South Korea	Smartphone	**Design:** Case-control laboratory study **Conditions:** All participants have temporomandibular disorders, and were (based on smartphone addiction scale) grouped into: - Normal group - Addicted group Further categorised into sub-diagnosis of muscular, joint or mixed problems	**1) Type of symptoms:** Temporomandibular disorders **Measurement method:** Based on complaints, clinical histories, x-rays of temporomandibular joint and lateral cephalometric and clinical examinations; diagnosis further subdivided into joint, muscular or mixed problems **Variable(s):** • Sub-diagnosis of temporomandibular disorders	- Normal group had 36 participants with joint problems, 9 with muscular problems, and 5 with mixed problems - Addicted group had 22 participants with joint problems, 21 with muscular problems, and 7 with mixed problems
Lee et al (2012)	**n** = 125 **Age:** 21.4 (2.0) years **Gender:** 32 males, 93 females **Other specific:** Students from university in South Korea, and no wrist symptoms or injuries	Smartphone	**Design:** Case-control laboratory study Based on Nomophobia syndrome questionnaire, participants were grouped into 3 groups for each of the categories below: - Smartphone addiction degree	**1) Type of symptoms:** Hypesthesia or dysesthesia in areas controlled by the median nerve **Measurement method:** Phalen's and reverse Phalen's tests	

			- Daily usage duration - Continuous using time - Total periods of use **Conditions:** NA	**<u>Variable(s):</u>** • Hypesthesia or dysesthesia	- There was a significantly shorter time for paraesthesia to appear in the smartphone addiction degree group of ≥30 points, than in the lesser addicted groups (with 20-29 and ≤19 points, respectively) - There was a significantly shorter time for paraesthesia to appear in the long continuous smartphone usage group of (≥60 mins), than in groups with shorter usage (<60mins and <30mins, respectively) - There was significantly shorter time for paraesthesia to appear in a group with longer duration of smartphone usage (≥8 hours), than in groups with shorter duration of usage (3-7 hours and ≤3 hours, respectively) - There were no significant differences in hypesthesia or dysesthesia among groups with different total periods of use (≤12, 13-24 or ≥25 months, respectively)
Inal et al (2015)	**n** = 102 **Age:** 18 to 23 years **Gender:** 30 males, 72 females **Other specific:** Students from a university in Turkey, 66 of them had a habit of one handed smartphone use	Smartphone	**Design:** Case-control laboratory study Based on a smartphone addiction scale, participants were grouped into (with the median score of 84 used to classify high and low users): - High users (≥84 score), vs - Low users (≤84 score) vs - Non-users **Conditions:** NA	**1) Type of symptoms:** Pain in the hand **<u>Measurement method:</u>** Visual analogue scale (VAS) (0 to 10cm) for pain in the dominant hand at rest and during movement (in the previous week) **<u>Variable(s):</u>** • Pain score	- Pain during movement was significantly higher in high smartphone users (1.06 (2.18)) than in low smartphone users (0.06 (0.34))

					- There were no difference in pain at rest among non-smartphone users, low and high smartphone users - Significant correlations between pain at rest (r=0.272) and during movement (r=0.345) with smartphone addiction scale scores
Xie et al (2016)	**n** = 40 **Age:** 23.9 (3.2) years **Gender:** 16 males, 24 females **Other specific:** Right handed participants, recruited from universities in Hong Kong	Smartphone	**Design:** Case-control laboratory study Based on questionnaires responses, grouped into: - Case group (n=20, with neck/shoulder discomfort) vs - Control group (n=20, without neck/shoulder discomfort) **Conditions:** While sitting for 10 minutes, participants performed: - Two-handed texting (both thumbs) at chest level vs - One-handed texting (right thumb) at chest level vs - Two-handed typing on desktop computer **Task:** Typing	**1) Type of symptoms:** Discomfort in the neck, and dominant shoulder, upper back and distal upper extremity (i.e. elbow, wrist/hand and thumb/fingers) **<u>Measurement method:</u>** Scores from numeric rating scale (0 to 10) for all the above body regions summed up **<u>Variable(s):</u>** • Discomfort score	- Discomfort scores were significantly higher in the case group than in the control group for one and two-handed texting on smartphone and two-handed typing on desktop - There were no significant differences in discomfort among smartphone texting and desktop typing tasks within each group

Appendix E S5. Summary of included experimental laboratory studies (MTSD use and musculoskeletal symptoms)

Author (year)	Study population	Type of MTSD examined	Study design and conditions	Musculoskeletal symptoms measurement	Musculoskeletal symptoms results
Ahn et al (2016)	**n** = 26 **Age:** 24.7 (3.4) years **Gender:** 19 males, 7 females **Other specific:** College students in South Korea	Smartphone (mock up device)	**Design:** Experimental laboratory study **Conditions:** Using the smartphone with one hand (preferred hand) for 50 minutes, tasks were executed with: - Touch screen flat surface - Less curved surface (400R) - More curved surface (100R) Participants were divided into groups according to: - Hand size (small/ large hands) - Hand shape (long palms/ long fingers) **Task:** Tapping and dragging	**1) Type of symptoms:** Comfort in the hand **Measurement method:** Subjective rating on a 100 point scale **Variable(s):** • Comfort rating	- Comfort was significantly higher when using the less curved surface smartphone compared to the flat surface smartphone; no differences between more curved surface and less curved or flat surface were shown - No significant effect of hand size and hand shape on comfort were reported - A significant interaction effect of hand size and shape on comfort was found with lower comfort in participants with large hands long fingers compared to those with large hands long palms
Albin and Mcloone (2014)	**n** = 10 **Age:** - **Gender:** -	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Using the tablet in portrait orientation while sitting, the	**1) Type of symptoms:** Comfort in the hands and arms **Measurement method:** Likert scale 1 (strongly agree) to 7 (strongly disagree)	

	Other specific: Right handed university students from the USA		following tilt angles were varied: - 0°, 30°, 45°, 60° and a self-chosen angle **Task:** Reading and tapping	**Variable(s):** • Comfort score	- The highest comfort scores were seen with self-selected tilt angle of 34° (19)) - The lowest comfort scores were seen with 60° tilt angle
Chiu et al (2015)	**n** = 30 **Age:** 23.5 (2.8) years **Gender:** 16 males, 14 females **Other specific:** Right handed participants	Tablet computer	**Design:** Experimental laboratory study **Conditions:** With a tablet on a desk and the participant sitting, tablet tilt angles were varied: - 22.5° vs 45° vs 67.5° **Task:** Movie watching vs game playing (for 15 minutes)	**1) Type of symptoms:** Comfort in the neck, shoulder, upper arm, forearm, wrist and finger (right side) **Measurement method:** Visual analogue scale (VAS) (0=extreme discomfort, 10=extreme comfort) **Variable(s):** • Comfort score	- A significant main effect of tilt angle on perceived neck comfort was shown, but no differences among tilt angles were found in the post-hoc analysis - No main effect of tilt angle were found for any of the other body regions - Significantly lower comfort in the shoulder, upper arm, forearm, wrist and finger (but not in the neck) was found during game playing compared to when watching movie
Kim et al (2014)	**n** = 19 **Age:** 24.3 (6.4) years	Virtual (touch screen) keyboard on a laptop	**Design:** Experimental laboratory study **Conditions:** While sitting for 10 minutes, tasks were performed on:	**1) Type of symptoms:** Comfort in the hand/wrist and arm/shoulder **Measurement method:**	

	Gender: 10 males, 9 females **Other specific:** Participants were experienced touch typists, 17 participants were right handed		- A virtual keyboard on laptop vs - A physical keyboard on laptop vs - A desktop computer keyboard **Task:** Typing	Modified Likert scale (1=least comfortable; 7=most comfortable) adapted from ISO keyboard comfort questionnaire **Variable(s):** • Comfort score at hand/wrist • Comfort score at arm/shoulder	- Significant lower comfort when typing on a virtual keyboard (2.9 (1.7)) than on a physical keyboard on a laptop (5.4 (1.1)) or desktop (5.4 (1.2)) were found - Significant lower comfort when using a virtual keyboard (3.4 (1.7)) compared to a physical keyboard on a laptop (5.3 (1.2)) or a desktop (4.9 (1.2)) were found
Kim et al (2014)	**n** = 21 (data analysed for 19 only) **Age:** 24.5 years (18 to 49 years) **Gender:** 12 males, 9 females **Other specific:** Participants were experienced USA touch typists, 19 participants were right handed	Notebook computer with virtual (touch screen) keyboard	**Design:** Experimental laboratory study **Conditions:** While sitting, 2x5minute tasks were performed on 4 virtual keyboard with different key sizes: - 13, 16, 19, and 22mm (width and height), and vertical center-to-center key spacing of 15, 18, 21, and 24mm **Task**: Typing	**1) Type of symptoms:** Comfort in the arm/shoulder and hand/wrist **Measurement method:** 7-point Likert scales adapted from the ISO keyboard comfort questionnaire **Variable(s):** • Comfort score	- Arm/shoulder and hand/wrist comfort generally increased with increasing key sizes - Smallest key size (13mm) was associated with significantly lower comfort in the hand/wrist (2.3 (0.2)) and arm/shoulder (2.7 (0.3)) compared to the larger key sizes (19 & 22mm);

					- No differences on comfort across the other 3 larger keyboard key sizes (16, 19, & 22mm) were seen
Lin et al (2015)	**n** = 18 **Age:** males 24.8 (3.5); females 23.1 (0.9) years **Gender:** 9 males, 9 females **Other specific:** All were right handed	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use on different workstations: - Desk (flat on desk) vs - Lap (flat on lap) vs - Bed (inclined sitting on bed, tablet on lap) Using different virtual keyboard designs: - Standard vs - Wide vs - Split **Task:** Typing	**1) Type of symptoms:** Discomfort in the neck, shoulder, upper back, lower back, distal upper extremity (i.e. wrists, arms) and buttocks **Measurement method:** Borg's category rating scale and body map with perceived discomfort **Variable(s):** • Discomfort score	- Discomfort in all the body regions significantly increased with time - Discomfort in the shoulder, neck, upper and lower back and buttocks was significantly higher with using the tablet on the lap compared to on a desk or bed - In general, discomfort in the wrists and arms was significantly higher with tablet on the lap compared to on a desk - In general, discomfort in all body regions was significantly higher while using it on a bed compared to on a desk - In general, discomfort in the shoulder, wrists and arms was significantly lower while using a split keyboard compared to a standard keyboard - No differences in neck, upper lower back and buttocks discomfort were shown among different keyboard designs

Shin and Kim (2014)	**n** = 15 **Age**: 26.1 (5.7) years **Gender**: - **Other specific:** Participants had no history of neck pain or spinal injuries in the past year	Smartphone	**Design:** Experimental laboratory study **Conditions:** Smartphone use with two-handed hold for 15 minutes, while sitting with: - A neutral neck posture with smartphone on a desk vs - A flexed neck with smartphone on the lap **Task:** Free use of applications of choice	**1) Type of symptoms:** Neck pain **Measurement method:** Visual analogue scale (VAS) ranging from 0 to 10 **Variable(s):** • VAS score	- Neck pain Increased from 0 to 1.7 during the condition of smartphone use with a neutral neck posture on desk - Neck pain increased from 0 to 5.2 during the condition of smartphone use on the lap with a flexed neck posture (no results of a statistical test were reported)
Trudeau et al (2013)	**n** = 12 **Age:** 30.0 (5.1) years **Gender:** 6 males, 6 females **Other specific:** All participants were right handed	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use with two handed hold while sitting for 2 minutes, during 11 conditions in which the following independent variables were varied: - Tablet orientation (portrait/ landscape) - Keyboard layouts (standard/ split) - Keyboard locations (top/ middle/ bottom) **Task:** Typing	**1) Type of symptoms:** Discomfort of the neck, back and/or distal upper extremities (i.e. arm, hand, thumbs) **Measurement method:** Visual analogue scale (VAS) ranging from 1 to 10 for physical discomfort or pain experienced in any part of the above body regions **Variable(s):** • Discomfort score (one overall score reported for each condition)	- Significantly higher discomfort was reported when using a tablet in landscape orientation (3.6 (0.6)) compared to in portrait orientation (2.9 (0.6)) - Significantly higher discomfort was reported when typing on a tablet in standard keyboard layout (3.7 (0.6))

					compared to when using a split keyboard layout (2.8 (0.6)) when tablet was in landscape orientation; however, no significant differences regarding keyboard layout were seen in tablet portrait orientation - No differences among different keyboard locations were shown

Appendix F S6. Summary of included cross-sectional studies (MTSD use and musculoskeletal exposures)

Author	Study population	Type of MTSD examined	Study design and conditions	Musculoskeletal exposures measurement	Musculoskeletal exposures results
Guan et al (2016)	**n** = 429 **Age:** 19.8 (2.6) years **Gender:** 219 males, 210 females **Other specific:** University students in Shanghai, China	Smartphone	**Design:** Cross-sectional study *(an experimental laboratory study was also conducted and is listed in Appendix Ih)* **Conditions:** NA	**1) Type of exposures:** Mobile phone usage **Measurement method:** Questionnaire on type, years of usage and daily usage of smartphone **Variable(s):** • Mobile phone usage	- 97.7% (419/429) used a smartphone, 1.2% (5/429) used a non-smartphone - Years of mobile phone usage: ≤1 year: 91/429; >1 and ≤ 3 years: 111/429; >3 and ≤6 years: 148/429; >6 years: 78/429 - Daily mobile phone usage: ≤ 1 hour: 36/429; >1 and ≤ 3 hours: 193/429; >3 and ≤ 5 hours: 123/429; >5 hours: 72/429
Liang and Hwang (2016)	**n** = 1230 **Age:** <20 to >60 years (estimated) **Gender:** 454 males, 776 females **Other specific:** Passengers in	Smartphone	**Design:** Cross-sectional study **Conditions**: NA	**1) Type of exposures:** Arms, trunk and leg posture **Measurement method:** Observation checklist adapted from a previous study for standing and sitting	

	Taipei, Taiwan metro train who were using mobile phones (sample of 400 observation trips)			**Variable(s):** • Arms, trunk and leg posture	- Among sitting users, the most frequently observed posture was trunk against the backrest, wrist/forearm supported and both feet on the floor (31.6%), followed by a similar posture but free from armrests (26.6%), and trunk against backrest, elbow supported and legs free, both feet on floor (8.9%) - Among standing users, the most frequently observed posture was trunk against a wall/pole, arms free from support and both feet on the floor (30.8%), followed by a similar posture, but with the trunk free from support (23%), and back against wall/pole, arms free from support and single-foot stance (16.5%)
				2) Type of exposures: Screen operating styles **Measurement method:** Categorized into 4 groups: - Both hands hold and operate - One hand hold and operate - Different hands hold and operate - Others (unclassified) **Variable(s):** • Screen operating styles	- The majority of passengers (~78%) used one hand rather than two hands to hold their mobile phones; using the left hand only was more common than using the right hand

					- Most common style is different hands to hold and operate (39.5%), followed by one hand (30%), both hands (22%) and others (unclassified) (8.5%) - The majority of standing users used one hand to hold and operate (45.8%), while the majority of the sitting users used a different hand for holding (45.5%) versus operating (22%) - **For users sitting**, postures of trunk against backrest, feet on floor and with or without arm support most commonly observed across the 4 groups - **For users standing**, both hands and different hands group used a high proportion of postures - trunk supported or not, arm free and both feet on the floor; one hand group most frequently used postures - trunk unsupported, holding a pole/handstrap and both feet on floor

Appendix G S7. Summary of included case-control laboratory studies (MTSD use and musculoskeletal exposures)

Author	Study population	Type of MTSD examined	Study design and conditions	Musculoskeletal exposures measurement	Musculoskeletal exposures results
Jung et al (2016)	**n** = 50 **Age:** 21.0 (2.4) years **Gender:** - **Other specific:** Participants were recruited from a university in South Korea	Smartphone	**Design:** Case-control laboratory study Categorised into 2 groups according to reported smartphone usage: - Low users (n=50; <4 hours/day) - High users (n=50; >4 hours/day) **Conditions:** NA	**1) Type of exposures:** Neck postures **<u>Measurement method:</u>** Lateral image taken in usual standing posture using a digital camera **<u>Variable(s):</u>** • Neck flexion WRT horizontal **2) Type of exposures:** Shoulder postures **<u>Measurement method:</u>** Scapular index calculated using body landmarks measured via measuring tape in standing **<u>Variable(s):</u>** • Scapular index	- Significantly lower in smartphone high users (53.0° (6.3)) than low users (54.5° (4.2)) - Significantly lower (i.e. greater rounded shoulder postures) in smartphone high users (65.5 (6.5)) than low users (67.5 (4.2))
Kee et al (2016)	**n** = 100 **Age:** normal group 16.9 (1.6) years; addicted group 17.0 (2.0) years **Gender:**	Smartphone	**Design:** Case-control laboratory study **Conditions:** All participants have temporomandibular	**1) Type of exposures:** Neck posture **Measurement method:** Lateral skull radiograph assessment in resting posture **<u>Variable(s):</u>**	

	28 males, 72 females **Other specific:** All teenagers and patients recruited from a hospital department in South Korea		disorders; based on smartphone addiction scale (short version), grouped into: - Normal group - Addicted group Further categorised into sub-diagnosis of muscular, joint or mixed problems	• Cervical lordosis angle and craniocervical angle **2) Type of exposures:** Neck ROM **<u>Measurement method:</u>** Cervical ROM instrument on head **<u>Variable(s):</u>** • Cervical flexion (during habitual sitting posture when using smartphone) • Cervical flexion, cervical extension, right and left lateral flexion, right and left rotation, and cervical protrusion (when not using any device)	- No differences in cervical lordosis and craniocervical angles between normal and addicted group - Cervical flexion when using smartphone in sitting significantly higher in the addicted group (28.0° (13.0)) than in the normal group (12.9° (10.6)) - All neck ROM variables were significantly lower in the addicted group than in the normal group, except for cervical protrusion where no differences were detected - Significant differences in all neck ROM measurements between the addicted and normal groups with temporomandibular disorder muscular problems, except for lateral flexion - Significant differences in all neck ROM measurements between the addicted and normal groups with joint problems, except for right lateral flexion and cervical flexion - No difference in neck ROM between the addicted and normal groups with mixed problem, except for cervical flexion
Kim (2015)	**n** = 27 **Age:** control group 20.6 (1.6) years; mild neck pain	Smartphone	**Design:** Case-control laboratory study	**1) Type of exposures:** Neck posture **<u>Measurement method:</u>** Using an ultrasound motion analysis system	

	group 20.6 (1.5) years **Gender:** 12 males, 15 females **Other specific:** All experienced cervical symptoms while using a smartphone within the last year; participants were recruited from a university in South Korea		Based on neck disability index (NDI) score, participants were grouped into: - Mild neck pain group (n=13, score >8) - Control group (n=14, score ≤8) **Conditions:** Smartphone use for 3x5 minutes **Task:** Free use of text messaging and internet browsing	**<u>Variable(s):</u>** Mean angles at 100s, 200s and 300s: • Upper and lower cervical flexion	- Both upper and lower cervical flexion angles were significantly higher in the mild neck pain group than in the control group during smartphone use - No differences for in neck flexion over time between the mild neck pain and control group - Significant variations in lower cervical flexion angles over time in mild neck pain group than in the control group were seen; but not in upper cervical flexion
Park et al (2015)	**n =** 20 **Age:** 23.3 (2.3) years **Gender:** - **Other specific:** Recruited from a university in South Korea	Smartphone	**Design:** Case-control laboratory study **Conditions:** According to scores on the smartphone addiction scale, participants were grouped into: - Heavy user group (n=10, scores 45.1 (3.6)) - Control group (n=10, scores 26.5 (4.5))	**1) Type of exposures:** Head and neck posture **<u>Measurement method:</u>** Posture were observed by a physical therapist with a plumb line and analysed using Adobe Acrobat software (no information on the exact method) **<u>Variable(s):</u>** • Craniovertebral angle • Head position angle	- No differences in craniovertebral angle between heavy smartphone user and control group - Significantly lower head position angle in heavy user group (34.9° (5.4)) than in the control group (39.7° (3.0))

Xie et al (2016)	**n** = 40 **Age:** 23.9 (3.2) years **Gender:** 16 males, 24 females **Other specific:** All were right handed and recruited from universities in Hong Kong	Smartphone	**Design:** Case-control laboratory study Based on questionnaires responses, grouped into: - Case group (n=20; with neck shoulder discomfort) - Control group (n=20; no discomfort) **Conditions:** In sitting for 10 minutes: - Two-handed texting (both thumbs) at chest level vs - One-handed texting (right thumb) at chest level vs - Two-handed typing on desktop computer **Task:** Typing	**1) Type of exposures:** Neck, shoulder, wrist, fingers and thumb muscle activity **Measurement method:** EMG on CES, UT, LT, ECR, ED, FDS and APB **Variable(s):** 10th, 50th (median) and 90th percentile APDF of: • CES (neck) • UT and LT (neck/shoulder)	- No differences between case and control group, but a trend of consistently higher muscle activity in the case group compared to the control group were shown in all tasks - CES activity was significantly higher (10th percentile) during two-handed smartphone texting than during desktop typing in both groups - No differences between one-handed and two-handed texting for both groups - UT median activity was significantly higher in the case group than in the control group; no differences in LT activity between case group and control group were seen - UT and LT median activity was significantly lower during two-handed smartphone texting than during desktop typing - Higher UT and LT activity (but non-significant differences) in one-handed compared to two-handed smartphone texting for both groups were seen

				• ECR, ED, FDS and APB (wrist, fingers and thumb)	- No differences between case group and control group for all the 4 distal muscles - ECR and ED median muscle activity was significantly lower, APB activity was significantly higher during two-handed smartphone texting than during desktop typing for both groups - All median muscle activity of 4 distal muscles was significantly lower during two-handed than during one-handed smartphone texting for both groups
Xiong and Muraki (2016)	**n** = 48 **Age:** youth 23.6 (1.8) years; elderly 67.5 (3.7) years **Gender:** 24 males, 24 females	Smartphone	**Design:** Case-control laboratory study Grouped into: - Shorter thumb vs longer thumb group - Youth (n=24) vs elderly group (n=24) **Conditions:** Tapping self-identified points (far and close) on the screen while sitting, with the right hand holding two phone types: - Smaller touch screen size vs - Larger touch screen size	**1) Type of exposures:** Thumb coverage on screen **<u>Measurement method:</u>** Tapping points recorded via pre-scale pressure imaging, connected together to obtain coverage area and intersection point for centre of gravity **<u>Variable(s):</u>** • Thumb coverage area • Centre of gravity in thumb coverage area	- Thumb coverage area was significantly greater for those with longer thumbs than those with shorter thumbs in both screen sizes - Thumb coverage area increased significantly with larger screen size compared to smaller screen size, but it did not increase at the same ratio as the increase in screen size - Elderly and longer thumb groups tend to have more unreachable space (i.e. how far the thumbs can reach) at the right side and bottom of touch screens, compared to the youth and shorter thumb groups

Abbreviated terms: *APB: abductor pollicis brevis; CES: cervical erector spinae; ECR: extensor carpi radialis; ED: extensor digitorium; FDS: flexor digitorium superficialis; LT: lower trapezius; ROM: range of motion; UT: upper trapezius; WRT: with respect to*

Appendix H S8. Summary of included experimental laboratory studies (MTSD use and musculoskeletal exposures)

Author	Study population	Type of MTSD examined	Study design and conditions	Musculoskeletal exposure measurement	Musculoskeletal exposures results
Ahn et al (2016)	**n** = 26 **Age:** 24.7 (3.4) years **Gender:** 19 males, 7 females **Other specific:** College students in South Korea	Smartphone (mock-up device)	**Design:** Experimental laboratory study **Conditions:** Using one hand (preferred side) to operate a smartphone for 50 minutes in three different conditions/participant groups: - Screen surface (flat/ less curved (400R)/ more curved (100R)) - Hand size (small/ large hands) - Hand shape (long palms/ long fingers) **Task:** Tapping and dragging	**1) Type of exposures:** Fingers and thumb muscle activity **<u>Measurement method:</u>** EMG on FDS, ADM, OP, FPL **<u>Variable(s):</u>** Mean muscle activity of: • FDS, ADM, OP and FPL (fingers and thumb)	- No difference in muscle activity for all muscles among different surface curvatures were shown - Significant interaction effect of hand size and shape on muscle activity; ADM, OP, and FPL activity was higher in participants with small hands compared to large hands, while FPL activity was higher in participants with long fingers compared to long palms

Albin and Mcloone (2014)	**n** = 10 **Age:** - **Gender:** - **Other specific:** Right handed students from a university in the USA	Tablet computer	**Design:** Experimental laboratory study **Conditions:** A tablet was used in portrait orientation while sitting with tablet tilt angles varying in: - 0° - 30° - 45° - 60° - Self-chosen angle **Task:** Reading and tapping	**1) Type of exposures:** Head, neck, forearm and wrist posture **Measurement method:** Video analysis for head and neck, goniometer and torsiometer on forearm and wrist **Variable(s):** • Head/neck flexion • Forearm rotation, wrist flexion and lateral deviation	- Head/neck flexion decreased significantly with increasing tablet tilt angles (35° (8.9) head/neck flexion at 0° tablet tilt; 24° (4.5) head/neck flexion at 30° tilt; 22° (6.2) at 45° tilt; 18° (3.8) head/neck flexion at 60° tilt) - No significant differences between tablet tilt angles for forearm or wrist postures were seen
Billinghurst and Vu (2015)	**n** = 20 **Age:** psychologists 30.2 (6.8) years; engineers 30.1 (9.5) years **Gender:** 19 males, 7 females **Other specific:** All were right handed, recruited from a research centre in the USA; psychologists (n=10), engineers (n=10)	Smartphone and tablet computer	**Design:** Experimental laboratory study **Conditions:** - Smartphone vs tablet - Device tilted (hold device with one hand and mounted on a stand) vs flat on a desk - Psychologists vs engineers **Task:** Participants performed common web browsing tasks of form submission,	**1) Type of exposures:** Gestures performed **Measurement method:** Video cameras **Variable(s):** • Gestures performed	- The majority of gestures performed were made with one hand (dominant side), the index finger, and in a single motion - Gestures with five fingers were significantly more often performed on a tablet than on a smartphone - No differences in gestures between device tilted or flat on desk - Only small differences in hand gestures between psychologists and engineers were shown

			back and forward button, creating closing tabs, reloading page, return to home page, bookmarking and address bar		
Chiang and Liu (2016) *Study 2* *(a cross-sectional study was also conducted (study 1) and is listed in Appendix C)*	**n** = 30 **Age:** >20 years **Gender:** 4 males, 26 females **Other specific:** College students in Taiwan	Tablet computer	**Design:** Experimental laboratory study (study 2) **Conditions:** Tablet in landscape orientation placed on a desk while sitting was operated (for 5 minutes) with the following tilt angles: - 0° vs 45° vs 60° **Task:** Game playing vs reading	**1) Type of exposures:** Head and neck posture **Measurement method:** 3D motion analysis system **Variable(s):** • Head flexion WRT vertical • Neck flexion WRT vertical	- Head flexion decreases with increasing tilt angle; head flexion was significantly higher at 0° (115.2° (1.7)) than at 45° tilt angle (103.9° (1.8)), and also higher at 45° than at 60° (98.1° (1.4)) - No difference in head flexion between game playing and reading tasks were found - Neck flexion decreases with increasing tilt angle; neck flexion was significantly higher at 0° (79.7° (1.8)) than at 45° tilt angle (71.4° (2.3)), and also higher at 45° than at 60° (64.3° (2.0)) - Neck flexion was significantly higher during game playing (73.6° (2.2)) than during reading tasks (70.0° (1.6))
Chiu et al (2015)	**n** = 30 **Age:** 23.5 (2.8) years **Gender:** 16 males, 14 females **Other specific:** All were right handed	Tablet computer	**Design:** Experimental laboratory study **Conditions:** With the tablet on a desk and while sitting, the tablet was operated for 15 minutes in each of the	**1) Type of exposures:** Neck/shoulder and fingers muscle activity **Measurement method:** EMG on UT, anterior and middle deltoid, FDS of dominant arm	

			following tilt angle conditions - 22.5° vs 45° vs 67.5° **Task:** Movie watching vs game playing	**Variable(s):** Mean muscle activity of: • UT, anterior and middle deltoid (neck/shoulder) • FDS (fingers)	- Significantly higher muscle activity in UT, but lower in anterior deltoid during tablet use at lower tilt angle of 22.5°, than at higher tilt angles of 45° and 67.5°; there were no differences in middle deltoid muscle activity between different tilt angles - Significantly higher UT, anterior and middle deltoid muscle activity during game playing than during movie watching - Significantly higher FDS muscle activity during game playing than during movie watching; there were no differences between tilt angles
Choi et al (2016)	**n** = 15 **Age:** 23.6 (2.4) years **Gender:** 8 males, 7 females **Other specific:** College students in South Korea	Smartphone	**Design:** Experimental laboratory study **Conditions:** Continuous texting while sitting for 5 minutes with: - Neutral neck (upper part of phone screen at eye level) - Middle neck bending (neck bent in comfortable manner) - Maximum neck bending **Task:** Typing	**1) Type of exposures:** Neck/shoulder muscle activity **Measurement method:** EMG on right and left splenius capitis and UT **Variable(s):** Mean muscle activity of: • Splenius capitis and UT (neck/shoulder)	- No differences in all muscle activities between neutral, middle or maximum neck bending postures when texting on smartphone were seen

Guan et al (2015)	**n** = 186 **Age:** 21.0 years (17 to 31 years) **Gender:** 105 males, 81 females **Other specific:** University students in Shanghai, China	Smartphone	**Design:** Experimental laboratory study **Conditions:** - Holding and looking at a smartphone while standing vs - Normal standing (without holding or looking at any device) **Task:** No task given on phone	2) **Type of exposures:** Gaze angle, head and neck posture **<u>Measurement method:</u>** Photogrammetry (measurements on lateral photographs) **<u>Variable(s):</u>** • Head flexion WRT vertical • Neck flexion WRT horizontal • Forward head shift	- No differences in head flexion between males and females during normal standing were found; but significantly higher in males (97.8° (10.5)) than in females (91.9° (11.6)) while looking at smartphone in standing than in normal standing - Significantly lower head flexion during normal standing (73.6° (9.0)) than when looking at smartphone in standing (95.2° (11.3)) were found - Neck flexion was significantly lower in males than in females during both normal standing (53.8° (6.4) vs 55.8° (5.9)) and looking at smartphone in standing (35.9° (9.2) vs 42.4° (9.2)) - Neck flexion was significantly higher during normal standing (54.7° (6.2)) than when looking at a smartphone during standing (38.8° (9.7)) - Forward head shift was significantly higher in males than in females during both normal standing (11.2° (3.5) vs 10.0° (3.6)) and when looking at a smartphone during standing (14.5° (4.7) vs 12.9° (4.5)) - Forward head shift was significantly lower during normal standing (10.9° (3.5)) than when looking at a smartphone during standing (13.9° (4.6))

				• Gaze angle WRT horizontal	- No differences in gaze angle between males and females when looking at a smartphone during standing were found
Guan et al (2016)	**n** = 429 **Age:** 19.8 (2.6) years **Gender:** 219 males, 210 females **Other specific:** University students in Shanghai, China	Smartphone	**Design:** Experimental laboratory study *(a cross-sectional study was also conducted and is listed in S6)* **Conditions:** - Holding and looking at a smartphone in standing vs - normal standing (no holding or looking at any device) **Task:** No task given to perform on phone	**2) Type of exposures:** Gaze angle, head and neck posture **<u>Measurement method:</u>** Lateral photographs taken in front of a measuring board **<u>Variable(s):</u>** • Head and neck flexion WRT vertical • Gaze angle WRT horizontal	- When looking at a smartphone during standing, males had significantly larger head flexion (96.4° (12.2) vs. 93.6° (12.6)) and neck flexion (51.9° (9.6) vs. 47.1° (9.5)) than females - Head and neck flexion postural changes during normal standing compared to looking at a smartphone while standing were significantly larger in males compared to females - No significant correlations between head and neck postural changes and frequency of mobile phone usage in males and females were found - No differences in gaze angle between females and males were seen - No differences in normal standing head and neck postures between males and females
Hong et al (2013)	**n** = 26 **Age:** 21.9 (3.3) years **Gender:** 13 males; 13 females	Smartphone	**Design:** Experimental laboratory study **Conditions:** Typing standard text with: - One-handed hold on smartphone vs	**1) Type of exposures:** Wrist, fingers and thumb muscle activity **<u>Measurement method:</u>** EMG on right and left ECR, FCR, APL and ED	

	Other specific: Students from university in South Korea		- Two-handed hold on smartphone vs - Laptop keyboard **Task:** Typing	**Variable(s):** Mean muscle activity of: • Right ECR, FCR (wrist) • Right ED, APL (fingers and thumb) • Left ECR, FCR, ED, APL (wrist, fingers and thumb)	- Significantly lower during smartphone than during laptop keyboard typing, and in two handed than in one handed hold on smartphone - No significant differences between smartphone and laptop keyboard typing; significantly lower in two handed hold than in one handed hold on smartphone - Significantly lower during smartphone than during laptop keyboard typing, and in one handed than in two handed hold on smartphone
Jacquier-Bret et al (2014)	**n** = 10 **Age:** - **Gender:** - **Other specific:** Right handed and novice tablet users	Tablet computer (10" screen)	**Design:** Experimental laboratory study **Conditions:** Tablet computer use with: - Stylus vs - Fingers **Task:** Perform puzzle of 9 vs 16 pieces	**1) Type of exposures:** Elbow and wrist posture **Measurement method:** Motion capture system **Variable(s):** • Elbow and wrist flexion/extension ROM • Elbow/wrist interaction strategy (determined from slope of 95% confidence eclipse plot of wrist flexion/extension against elbow flexion/extension)	- Both elbow and wrist flexion/extension ROM for the 16 pieces puzzle were significantly higher compared to that for the 9 pieces puzzle - Elbow flexion/extension ROM was significantly higher than wrist flexion/extension ROM across all conditions - Wrist, elbow and mixed interaction strategies were shown, and differed between subjects and conditions

Kietrys et al (2015)	**n** = 20 **Age:** 21.2 (2.7) years **Gender:** 4 males, 16 females **Other specific:** Right handed students from a university in the USA	Smartphone (3.5” screen) and tablet computer (7” and 9.5” screen)	**Design:** Experimental laboratory study **Conditions:** Device type: - Smartphone vs - Tablet computer vs - Physical keypad phone Touch screen size: - 3.5” smartphone vs - 7” tablet vs - 9.5” tablet Handhold in sitting position: - Two-handed hold *(portrait orientation)* vs - One-handed hold (right hand; *portrait orientation)* vs - Preferred handhold *(portrait/landscape)* **Task:** Typing	**1) Type of exposures:** Neck and wrist posture **Measurement method:** Video analysis **Variable(s):** • Head/neck flexion • Wrist extension and ulnar/radial deviation **2) Type of exposures:** Neck/shoulder, wrist, fingers and thumb muscle activity **Measurement method:** EMG on UT, ECR, FDS, APB **Variable(s):** 50th percentile root mean square of: • UT (neck/shoulder)	- Head/neck flexion significantly increased with increasing screen size during two-handed hold and preferred handhold (21.9° (8.3) with 3.5” smartphone, 21.8° (9.5) with 7” tablet, 22.6° (7.0) with 9.5” tablet) - Head/neck flexion was significantly higher during smartphone use with two-handed hold (21.5° (8.3)) than one-handed hold (19.5° (8.4)) - Wrist extension was significantly higher during smartphone use than during physical keypad phone - Wrist extension and ulnar deviation increased with increasing touch screen size during two-handed hold and preferred handhold - No differences between handholds - No differences between smartphone and physical keypad phone use, and between handholds were shown - UT muscle activity increased significantly with increasing screen size during two handed hold

				• ECR (wrist)	- ECR muscle activity was significantly lower when using a smartphone than when using a physical keypad phone - ECR muscle activity increased significantly with increasing screen size during both two-handed and preferred handholds - ECR muscle activity was significantly higher during one handed than during two handed hold
				• FDS, APB (fingers and thumb)	- Both FDS and APB muscle activity were significantly lower when using a smartphone than when using a physical keypad phone - Mean muscle activity of the FDS (but not of the APB) increased significantly with increasing screen size during two handed hold - No differences for both FDS and APB between handholds were shown
				3) Type of exposures: Preferred texting styles **<u>Measurement method:</u>** Observation by investigators on participants' preferred style of holding device and texting **<u>Variable(s):</u>** • Preferred texting style	- The use of both thumbs only (without digits) was adopted by 90% of participants for 3.5" smartphone (smallest screen) - The use of right index finger with any combination of other digits was adopted by 70% of participants for 9.5" tablet, 15% of participants for 7" tablet and 0% for 3.5" smartphone - Use of device on the lap was adopted by 60% of participants for 9.5" tablet, 10% of participants for 7" tablet and 0% for 3.5" smartphone

Kim et al (2014)	**n** = 19 **Age:** 24.3 (6.4) years **Gender:** 10 males, 9 females **Other specific:** All were experienced touch typists, 17 participants were right handed	Virtual (touch screen) keyboard on a laptop	**Design:** Experimental laboratory study **Conditions:** While sitting for 10 minutes, tasks were performed on three types of keyboards: - Virtual keyboard on a laptop vs - Physical keyboard on a laptop vs - Desktop computer keyboard **Task:** Typing	**1) Type of exposures:** Neck/shoulder and fingers muscle activity **<u>Measurement method:</u>** EMG on right UT, EDC, FDS **<u>Variable(s):</u>** 10^{th}, 50^{th} and 90^{th} percentile muscle activity of: • Right UT (neck/shoulder) • Right EDC (fingers) • Right FDS (fingers) **2) Type of exposures:** Typing forces **<u>Measurement method:</u>** Force platform under keyboard **<u>Variable(s):</u>** • Median and peak typing and individual keystroke forces	- Muscle activity (10th percentile) was significantly higher during typing on a virtual keyboard than on a physical keyboard on laptop, but did not differ from typing on a desktop computer keyboard - Muscle activity (50th and 90th percentile) was significantly lower during typing on a virtual keyboard than on a desktop computer keyboard, no differences compared to physical keyboard on laptop - Muscle activity was significantly lower during typing on virtual keyboard than on a physical keyboard on both laptop and desktop - Median and peak typing and individual keystroke forces were significantly lower when typing on a virtual keyboard than on a physical keyboard, on both laptop and desktop computer

Kim et al (2014)	**n** = 21 (data analysed for 19 only) **Age:** 24.5 years (18 to 49 years) **Gender:** 12 males, 9 females **Other specific:** All were right handed experienced touch typists in the USA	Virtual (touch screen) keyboard on a notebook computer	**Design:** Experimental laboratory study **Conditions:** While sitting, 2x5minute tasks were executed on 4 virtual keyboard with different key sizes: - 13, 16, 19, and 22mm (width and height), and vertical centre-to-centre key spacing of 15, 18, 21, and 24mm **Task**: Typing	**1) Type of exposures:** Wrist posture **Measurement method:** Bi-axial electrogoniometers **Variable(s):** Median (50th percentile), and ROM (5th and 95th percentiles) of: • Wrist flexion/ extension and ulnar/ radial deviation **2) Type of exposures:** Neck/shoulder and fingers muscle activity **Measurement method:** EMG on right UT, FDS and EDC **Variable(s):** Static (10th percentile), median (50th percentile) and peak (90th percentile) APDF of: • UT (neck/ shoulder)	- In general, higher median wrist extension was associated with smaller key sizes (13 & 16 mm) compared to with larger key sizes (19 & 22mm) on a virtual keyboard - No differences in wrist radial/ulnar deviation between different key sizes were shown - Greater ROM in wrist radial/ulnar deviation (0.1° to 2.7°) and wrist flexion/ extension (1.8° to 3.5°) was required in the right hand with larger key sizes (19 & 22 mm) compared to with smaller key sizes; no ROM differences were seen between key sizes in the left hand - Smallest key size (13mm) had greater static muscle activity compared to the larger key sizes (16 & 19mm); there were no differences in

				• FDS and EDC	median and peak muscle activity between different key sizes - There were no differences in muscle activity between different key sizes
Kingston et al (2016)	**n** = 14 **Age:** 22.5 (1.6) years **Gender:** 7 males, 7 females **Other specific:** All were right handed	Tablet computer	**Design:** Experimental laboratory study **Conditions:** While sitting with a 135° thigh-to-trunk angle on a pivoting Locus chair, tasks of 4x15minutes on a hybrid workstation were performed: - Tablet vs desktop computer - Horizontal vs sloped 15° work surface **Tasks:** Reading vs Writing vs E-mail (5 minutes for each task)	**3) Type of exposures:** Shoulder, elbow and wrist postures **<u>Measurement method:</u>** Motion analysis system **<u>Variable(s):</u>** Median postures of: • Shoulder elevation and axial rotation • Elbow flexion	- Shoulder elevation during writing task (0° (2)) was higher than during reading (–6° (3)); there were no differences between emailing and writing or reading - Shoulder axial rotation when using a tablet (89° (2)) was higher than when using a desktop (82° (2)); and was higher on sloped (17° (4)) than a horizontal work surface (10° (2)) - Elbow flexion was significantly higher on a sloped work surface during reading (77° (6)) or writing (93° (4)) than on a horizontal work surface respectively by 4° and 19° ; however during emailing, elbow flexion is 9° lesser while working on a sloped work surface than on a horizontal work surface - Median elbow flexion was higher during tablet than desktop use - Range of elbow flexion was significantly smaller during tablet (28° (5)) than desktop use (42° (4))

				• Wrist ulnar deviation and pronation	- When using a tablet, wrist ulnar deviation during reading (9° (3)) was significantly lower than during writing (23° (2)) and emailing (17° (2)); wrist ulnar deviation was also significantly lower when using a desktop during emailing than (14° (2)) than when writing (20° (2)) and reading (19° (3)) - On a horizontal work surface, wrist ulnar deviation was significantly lower during reading (11° (2)), than during writing (20° (2)) or emailing (17° (2)); wrist ulnar deviation was also significantly lesser on sloped work surface during emailing (14° (2)), than during writing (24° (2)) and reading (17° (2)) - Wrist pronation was significantly lower during reading (60° (6)) than during writing or emailing - Median wrist pronation was higher during tablet than during desktop use - Range of wrist pronation was significantly smaller during tablet (27° (4)) than desktop use (42° (4))
Ko et al (2016)	**n** = 27 **Age:** 28.0 (4.5) years **Gender:** 15 males, 12 females **Other specific:** All were right handed, regular computer and smartphone users	Smartphone	**Design:** Experimental laboratory study **Conditions:** Smartphone use in portrait orientation, for 2 minutes with: - Two-handed hold at chest level - Two-handed hold at knee level (with trunk	**1) Type of exposures:** Neck, elbow and wrist postures **<u>Measurement method:</u>** Flexible electrogoniometers **<u>Variable(s):</u>** • Neck flexion relative to a reference posture (anatomical points not specified)	- Neck flexion was significantly higher during two-handed hold at chest level (20.8° (1.9)) and one-handed hold (18.5° (1.6)), than during two-handed hold at knee level (0.7° (2.0)) or eye level (3.4° (0.8))

			bent forward and elbows on the thighs) - Two-handed hold at eye level - One-handed hold (right side) **Task:** Typing	• Elbow flexion • Wrist flexion **2) Type of exposures:** Shoulder, elbow, fingers and thumb muscle activity **Measurement method:** EMG on UT, biceps brachii, FDS, EDC and FPB **Variable(s):** • Muscle activity of UT, biceps brachii, FDS, EDC and FPB	- Elbow flexion during two-handed hold at chest level (90.6° (2.6)) or one-handed hold (91.2° (2.3)) was significantly higher than during two-handed hold at knee (67.9° (3.2)) or eye level (77.7° (2.9)) - No differences in wrist flexion among all the conditions were found - One-handed hold resulted in the highest muscle activities for all muscles among all conditions - Two-handed hold at knee level resulted in the lowest muscle activities in UT, biceps brachii and EDC muscles - UT muscle activity (50th percentile APDF) during two-handed hold at eye level was significantly higher than while holding the device at knee level or chest level - FDS muscle activity (50th and 90th percentile APDF) during one-handed hold was significantly higher than during two-handed hold at chest level

					- In general, EDC and FPB muscle activity (50th percentile APDF) during one-handed hold were significantly higher than during two-handed hold
Lee et al (2015)	n = 18 Age: 20.1 (1.5) years Gender: 9 males; 9 females Other specific: All have at least 1 year experience using a smartphone	Smartphone	Design: Experimental laboratory study Conditions: Smartphone use for 2x2minutes for each task in: - Sitting vs - Standing Task: Text messaging vs web browsing vs video watching	**1)** Type of exposures: Head posture <u>Measurement method:</u> Motion analysis system <u>Variable(s):</u> • Head flexion WRT vertical	- Head flexion (10^{th} and 50^{th} percentile, but not the 90^{th} percentile) was significantly higher during text messaging than during web browsing and video watching - Head flexion was significantly higher in sitting than in standing across all 3 tasks (text messaging was higher by 10-14%, web browsing by 4-6% and video watching by 23-24%) - The results of the post-hoc analysis were not reported
Lin et al (2015)	**n** = 18 **Age:** males 24.8 (3.5); females 23.1 (0.9) years **Gender:** 9 males, 9 females **Other specific:** All were right handed	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use on different workstations: - Desk (flat on desk) vs - Lap (flat on lap) vs - Bed (inclined sitting on bed, tablet on lap) Using different virtual keyboard designs: - Standard vs - Wide vs	**1) Type of exposures:** Neck, elbow and wrist posture **<u>Measurement method:</u>** Flexible electrogoniometers **<u>Variable(s):</u>** Median (50^{th} percentile) and range of APDF of: • Neck flexion	- There were no differences in neck flexion among tablet use on a desk, lap or bed, but higher range of neck flexion was found during tablet use on a desk than on the lap or bed - There were no differences in neck flexion among keyboard designs

			- Split **Task:** Typing	• Wrist extension and ulnar deviation • Elbow flexion	- Median wrist extension was significantly higher with tablet was on a bed (>50°) than on the lap and on a desk; wrist extension was generally higher with a wide than with a standard or split keyboard - Median wrist ulnar deviation (the left side, but not the dominant right side) was significantly higher with tablet use on a desk than on the lap; wrist ulnar deviation was significantly lower with a split compared to a standard or wide keyboard - Median elbow flexion was significantly higher during tablet use on a bed than on a desk or lap; elbow flexion was higher with a split than with a wide keyboard
Ning et al (2015)	**n** = 14 **Age:** - **Gender:** 10 males, 4 females **Other specific:** All had no musculoskeletal disorders, neck pain or neck injury	Smartphone and tablet computer	**Design:** Experimental laboratory study **Conditions:** Device use in standing for 3x90s in each task with the conditions: - Smartphone vs tablet - Flat on table vs handheld (holding the device in the left hand) **Task:** Reading vs Typing vs Gaming	**1) Type of exposures:** Neck posture **<u>Measurement method:</u>** Motion analysis system **<u>Variable(s):</u>** • Head/neck flexion	- Head/neck flexion was significantly higher when using a smartphone (44.7°) than a tablet computer (43.0°) - Head/neck flexion was significantly higher when using a smartphone or tablet placed flat on a table (46.4°) than when holding it (41.4°); separate mean values for smartphone and tablet were not reported - Head/neck flexion was significantly higher when typing (45.6°), than when gaming (43.6°) and reading (42.4°)

				2) Type of exposures: Neck muscle activity **<u>Measurement method:</u>** EMG on right and left cervical extensors **<u>Variable(s):</u>** • Muscle activity of right and left cervical extensors	- There were no significant differences in cervical extensor muscle activity between smartphone and tablet use - Muscle activity was significantly higher for the left side when using a smartphone or tablet flat on the table than in when holding it (9.4% vs 8.8%); a similar (but non-significant) trend for right side was shown - Muscle activity was significantly higher for both right and left sides during gaming and typing, than during reading; there were no significant differences between gaming and typing
Pereira et al (2013)	**n** = 30 **Age**: 30.0 (11) years **Gender:** 15 males, 15 females **Other specific:** All were right handed, regular users of tablet or smartphone with "small hands"	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use with one-handed hold (left hand) while standing for 4 minutes, in 8 different configurations with 5 independent variables: - Tablet size (small/ middle/ large) - Orientation (landscape/ portrait) - Grip shape (flat/ ledge/ handle grip) - Surface texture (smooth/ rough)	**1) Type of exposures:** Gaze angle, trunk, left shoulder and wrist posture **<u>Measurement method:</u>** Motion analysis system **<u>Variable(s):</u>** • Gaze angle WRT ear–eye line, and trunk angle relative to a reference posture (anatomical points not specified) • Left shoulder moment	- There were no significant differences in gaze angle across all the configurations - Shoulder moment significantly increases when using a large tablet compared to a medium or small tablet - Shoulder moment significantly increases when holding a table with a flat grip (holding tablet by

			- Stylus shape (small/ large/ tapered diameter)		itself), compared to a tablet with a ledge handle and handle grip - There were no differences among different orientation and surface texture
			Tasks: Typing (using only the right hand)	• Left wrist extension and ulnar deviation	- Wrist extension significantly decreases when using a small (12.7° (29.5)) compared to a medium (19.3° (30.4)) and a large tablet (21.6° (29.2)); There were no differences for ulnar deviation - There was a significant decrease in wrist extension when using a tablet in portrait orientation (13.4 (25.7)) compared to in landscape orientation (19.6 (32.8)); There were no differences for ulnar deviation - There were no differences in wrist extension and ulnar deviation among different grip shapes and surface textures
				2) Type of exposures: Neck/shoulder, wrist and fingers muscle activity **<u>Measurement method:</u>** EMG on left UT, FCR, ECR, ED, FDS; right ECR and FPB when using stylus **<u>Variable(s):</u>** 50^{th} percentile APDF of: • Left UT (neck/shoulder)	- Left UT activity significantly decreased when using a small tablet compared to when using a large tablet - There were no significant differences for orientation, grip shape and surface texture
				• Left FCR, ECR (wrist)	- There was a significant increase in FCR (but not for ECR) muscle activity when using a large compared to a medium and small tablet; - No significant differences for orientation, grip shape and surface texture

				• Left ED, FDS (fingers) • Right ECR, FPB (wrist and thumb)	- There was a significant increase in FDS (but not for ED) muscle activity when using a large compared to a medium or small tablet; - No significant differences for orientation, grip shape and surface texture - There were no significant differences when using different stylus shapes
Shin and Kim (2014)	**n** = 15 **Age**: 26.1 (5.7) years **Gender**: - **Other specific:** All had no neck pain or spinal injuries in the past year	Smartphone	**Design:** Experimental laboratory study **Conditions:** Smartphone use with two-handed hold for 15 minutes while sitting with: - A neutral neck posture, with the smartphone on a desk vs - A flexed neck posture, with the smartphone on the lap **Task:** Free use of applications of choice	**2) Type of exposures:** Neck muscle activity **<u>Measurement method:</u>** EMG of CES **<u>Variable(s):</u>** • Flexion relaxation ratio *(calculated by dividing maximum muscle activity during cervical extension with return to starting position for 5s, by the average activation during sustained cervical full flexion for 5s)*	- No significant differences were found between using smartphone on a desk and on the lap - No significant differences were found before and after using smartphone on a desk or on the lap
Stoffregen et al (2014)	**n** = 36 **Age:** 21.3 (2.7) years **Gender:** 14 males, 22 females	Tablet computer	**Design:** Experimental laboratory study **Conditions:** While sitting till motion sickness sets in or after 50	**1) Type of exposures:** Head and trunk movement **<u>Measurement method:</u>** Magnetic tracking system for movement in medio-lateral	

	Other specific: Undergraduate students from a university in the USA		minutes tasks were performed with: - Tablet computer supported and tilted at 45° *(touch condition)* - Two-handed hold without support, while tilting the tablet manually *(tilt condition)* **Task:** Gaming (finger control game)	and anterior-posterior direction **Variable(s):** Movement variability *(standard deviation of position)* and movement dynamics *(using detrended fluctuation analysis)* of: • Head • Trunk	- There was a significant increase in movement variability of the head in medio-lateral and anterior-posterior direction over time; there were no differences between touch and tilt conditions - Movement dynamics of the head in medio-lateral and anterior-posterior direction increased over time; only in the anterior-posterior direction, dynamics was higher in touch condition than in tilt condition - There was a significant increase in movement variability of the trunk in medio-lateral direction over time; there were no differences between touch and tilt conditions - There were no differences in movement dynamics of the trunk between touch and tilt conditions
Straker et al (2008)	**n** = 18 **Age:** 5.8 (0.62) years **Gender:** 9 males, 9 females	Tablet computer	**Design:** Experimental laboratory study **Conditions:**	**1) Type of exposures:** Head, neck, shoulder, scapula posture and posture variability **Measurement method:** Motion analysis system	

	Other specific: All were right handed and used a computer regularly		While sitting at a desk, tasks (5 minutes) were executed using: - Tablet computer (using stylus) vs - Desktop vs - Paper **Task:** Colouring-in task	**Variable(s):** • Head flexion WRT vertical • Neck flexion WRT vertical • Cranio-cervical and cervico-thoracic angles • Trunk flexion • Head relative to trunk • Scapula elevation • Shoulder flexion • Posture variability (calculated via APDF and EVA)	- There was significantly higher head flexion when using a tablet (110.5° (2.8)) than a desktop (85.9° (1.6)), there were no differences than paper - There was significantly higher neck flexion when using a tablet (76.3° (3.1)) than a desktop (61.5° (2.0)), there were no differences than paper - There were significantly lower cranio-cervical and cervico-thoracic angles when using a tablet than a desktop; no differences were found between tablet and paper - There were no significant differences in trunk flexion between using a tablet, desktop or paper - There was significantly higher head relative to trunk angle when using a tablet than a paper - There was significantly higher left scapula elevation when using a tablet than when using a desktop and paper, there were no differences for right side elevation - There was significantly higher right shoulder flexion when using a tablet than when using a desktop; there were no differences for left shoulder flexion - There was significantly greater posture variability when using a tablet compared to a desktop

				2) Type of exposures: Neck/shoulder muscle activity **Measurement method:** EMG on right and left CES, UT **Variable(s):** • CES and UT mean muscle activity • Muscle activity variability (calculated via APDF and EVA)	computer for head flexion, neck flexion, cranio-cervical angle, cervico-thoracic angle, as well as right and left shoulder protraction and flexion - Significantly greater posture variability in head relative to trunk position when using a paper compared to a tablet - There were significantly higher muscle activity in right CES and right UT when using a tablet compared to a desktop - There were no significant differences in left CES and left UT between tablet and paper use - There was significantly higher muscle activity variability in left CES and right UT when using a tablet compared to a desktop - There was significantly lower muscle activity variability in left UT when using a tablet compared to paper; there were no differences for right UT and CES
Trudeau et al (2012)	**n** = 10 **Age:** 27.0 (7.0) years **Gender:** 5 males, 5 females **Other specific:** All participants were right handed	Smartphone	**Design:** Experimental laboratory study **Conditions:** One-handed hold on smartphone and tapping with thumb between 2 of 12 emulated keys on different locations on the whole screen	**1) Type of exposures:** Wrist and thumb posture **Measurement method:** Motion analysis system **Variable(s):** • Wrist flexion/extension, ulnar/radial deviation, thumb CMC and MCP flexion/extension, abduction/adduction and IP flexion/extension	- There were significant wrist and thumb postural differences among different key locations on the screen - During tapping on the *bottom right corner of screen*, the wrist was flexed and ulnar deviated,

					the CMC joint was flexed and pronated, the IP and MCP joints were most flexed than in all other key locations - During tapping on the *top left corner of screen*, the wrist was extended and ulnar deviated, the CMC joint was extended and supinated, the MCP joint was extended, and the IP joint was less flexed than in all other key locations - Wrist and thumb flexion/extension differences were greatest between the *top left and bottom right corners,* except for the CMC joint - Thumb CMC and MCP abduction differences were greatest between the *top right and bottom left corners*, with greatest CMC abduction and least MCP adduction associated with the bottom left corner
Trudeau et al (2013)	**n** = 12 **Age:** 30.0 (5.1) years **Gender:** 6 males, 6 females **Other specific:** All were right handed	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use with two handed hold while sitting performing tasks (for 2 minutes), for 11 configurations of 3 independent variables: - Tablet orientation (portrait/ landscape) - Keyboard layouts (standard/ split)	**1) Type of exposures:** Wrist and thumb posture **<u>Measurement method:</u>** Motion analysis system **<u>Variable(s):</u>** Median joint angle and ROM (differences between 90^{th} and 10^{th} percentile) of: • Wrist extension and ulnar deviation	- Significantly lower wrist ulnar deviation with tablet in portrait than in landscape orientation; there were no significant differences for wrist extension - Significantly lower wrist extension and ulnar deviation for split keyboard than standard keyboard layout

			- Keyboard locations (top/ middle/ bottom) **Task:** Typing		- Significantly lower wrist ulnar deviation for bottom keyboard location, than middle and top; there was significantly lesser wrist extension for top keyboard location than middle
				• Wrist flexion/extension, radial/ulnar deviation ROM	- Significantly lower wrist flexion/ extension ROM in portrait than in landscape orientation; there were no significant differences for radial/ulnar deviation - ROM in both flexion/extension and radial/ulnar deviation significantly higher when using a standard keyboard compared to a split keyboard layout - There were no significant differences between different keyboard locations
				• Thumb joint angles *(CMC extension, abduction, pronation; MCP extension, abduction; IP flexion)*	- Significantly higher IP flexion in portrait than in landscape orientation - Significantly higher CMC abduction and MCP extension when using a standard keyboard compared to a split keyboard layout - Significantly lower CMC extension, but higher CMC abduction and pronation, and MCP abduction, for bottom compared to top keyboard location
				• Thumb ROM *(CMC flexion/extension, abduction/adduction, supination/pronation, MCP flexion/extension, abduction/adduction, IP flexion/extension)*	- Significantly higher CMC abduction/adduction in portrait than in landscape orientation - Significantly higher CMC flexion/extension, MCP flexion/extension and abduction/adduction, and IP flexion while using a standard compared to a split keyboard layout

					- Significantly higher CMC flexion/extension, supination/pronation and IP flexion/extension for bottom compared to top keyboard location
Trudeau et al (2016)	**n** = 10 **Age:** 27.0 (7.0) years **Gender:** 5 males, 5 females **Other specific:** All were right handed	Smartphone	**Design:** Experimental laboratory study **Conditions:** Smartphone use with: - One-handed hold (phone in portrait orientation) vs - Two-handed hold (landscape orientation) **Task:** Reciprocal tapping between 2 of 12 emulated keys on screen	**2) Type of exposures:** Wrist and thumb posture **<u>Measurement method:</u>** Motion analysis system **<u>Variable(s):</u>** • Wrist extension and ulnar deviation • Thumb CMC and MCP joint • Thumb IP flexion	- Wrist extension (15° (3)) was significantly higher with two handed than with one handed hold (10° (3)); there were no differences in wrist ulnar deviation between the two holds - Thumb CMC joint was significantly more extended (5° (3) vs 0° (3)), abducted (27° (2) vs 24° (1)), and supinated (0° (7) vs -8° (7)) with two handed than with one handed hold - Thumb MCP joint was significantly more extended with two handed (6° (3)) than one handed hold (4° (3)); there were no differences in MCP abduction - There were no differences in thumb IP flexion between the two holds
Vasavada et al (2015)	**n** = 33 **Age:** 19 to 46 years **Gender:** 17 males, 16 females **Other specific:** Participants were recruited from a	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet was used in landscape orientation while sitting, executing tasks (2 to 5 minutes) in:	**1) Type of exposures:** Head, neck and trunk posture **<u>Measurement method:</u>** Analysis of photographs taken **<u>Variable(s):</u>** • Head flexion WRT horizontal	- Significantly less flexed during reading with a tablet tilted at a high angle on a desk (-5.1° (8.2)), than when flat on a desk (-13.6° (8.2)) and tilted low on the lap (-21.7° (9.4))

	university in USA and used tablet for ≥1 month		- Tilted high (73°) on desk - Tilted low (15°) on desk - Flat on desk - Tilted low (15°) on lap - Self-selected position **Task:** Reading or typing	• Neck flexion WRT horizontal	- Significantly less flexed during both reading and typing with tablet tilted low on a desk, than flat on desk and tilted low on the lap
				• Trunk flexion	- Significantly more flexed during reading with the tablet flat on a desk (100.5° (7.8)) than while tilted high on desk (95.7° (8.0))
				• Head-neck and neck-trunk angles	- Head/neck and neck/trunk angles were significantly higher during reading with tablet flat on the desk and tilted low on lap, than tilted high on a desk - Head/neck and neck/trunk angles were significantly higher during reading and typing with the tablet tilted low on the lap, than when tilted low on desk
				2) Type of exposures: Gravitational demand at head and neck **<u>Measurement method:</u>** Modelling done from photographs and radiographs taken **<u>Variable(s):</u>** • Gravitational demand at C6-C7 centre of rotation *(ratio of gravitational moment and muscle moment)*	- Gravitational demands were significantly higher in all the tablet conditions compared to neutral head/neck posture - Gravitational demands were significantly higher during reading with tablet flat on desk than tilted high on desk; no significant differences among other conditions - Significantly higher during typing with the tablet tilted low on the lap than tilted when low on a desk and flat on a desk - No significant differences between reading and typing tasks were found

Werth & Babski-Reeves (2014)	**n** = 12 **Age:** 23.3 (2.7) years **Gender:** 6 males, 6 females **Other specific:** Students from a university in the USA that were touch typists	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Device use while sitting performing tasks (30 minutes) on: - Tablet computer vs netbook vs laptop - Desk vs sofa **Task:** Typing	**1) Type of exposures:** Neck, elbow and wrist posture **<u>Measurement method:</u>** Electrogoniometers on neck, right and left upper and lower arms and wrists **<u>Variable(s):</u>**	
				• Neck flexion relative to a reference posture (anatomical points not specified)	- Significantly higher when using device on a sofa (9.46° (0.79)) than on a desk (3.03° (8.05)) - Higher (but non-significant differences) when using tablet compared to laptop or netbook
				• Neck rotation	- No significant differences in neck rotation between tablet, netbook and laptop use, and between use on a desk or sofa were found
				• Elbow flexion/extension	- Significantly higher elbow flexion when using device on a sofa (4.31° (14.62)) compared to on a desk (1.26° (14.79)) - There were no significant differences between tablet, netbook and laptop
				• Wrist flexion/extension	- Significantly higher wrist extension when using a device on a sofa compared to on a desk - Significantly higher wrist extension when using a tablet (wrist extension 12.61°) compared to a laptop (wrist flexion 2.06°)
				• Wrist radial/ulnar deviation	- Significantly lower wrist ulnar deviation when using a tablet (10.04°) than a laptop (17.30°) - There were no significant differences between use on desk and sofa

				2) Type of exposures: Neck/shoulder and wrist muscle activity **Measurement method:** EMG on SCM, UT, FCR, ECR **Variable(s):** Mean muscle activity of: • UT, SCM, ECR, FCR	- There were significantly lower muscle activity for all the tested muscles when using a tablet, compared to a netbook and laptop - Post-hoc analysis was unable to identify specific differences between activity of the different muscles and the conditions
Xiong and Muraki (2014)	**n** = 20 **Age:** 24.5 (2.2) years **Gender:** 10 males, 10 females **Other specific:** Participants were right handed students from a university in Japan	Smartphone	**Design:** Experimental laboratory study **Conditions:** Mock up smartphone use on desk, performing standardized tasks at: - Fixed vs max speed **Task:** Tapping *(large vs small buttons)* Moving *(abduction-adduction vs flexion-extension orientations*) Circling *(clockwise vs counter-clockwise directions)*	**1) Type of exposures:** Thumb muscle activity **Measurement method:** EMG on APB, FDI, FPB and ED *(FPB and ED results not reported by authors as no significant findings were found)* **Variable(s):** Integrated EMG (iEMG), muscle contraction time and iEMG divided by contraction time (iEMG/s) of: • APB	- For *tapping task* from large buttons to small buttons, iEMG and contraction time of APB increased significantly at both fixed and max speed; while iEMG/s of APB only increased significantly at max speed but not at fixed speed

				• FDI	- For *moving task* from adduction-abduction to flexion-extension task, iEMG, iEMG/s and contraction time of APB decreased significantly in both fixed and max speed - For *circling task*, no significant differences between clockwise and counter-clockwise, and between fixed and max speed - For *tapping task* from large buttons to small buttons, iEMG and contraction time of FDI increased significantly at both fixed and max speed; while iEMG/s of FDI only increased significantly at max speed but not at fixed speed - For *moving task* from adduction-abduction to flexion-extension task, iEMG, iEMG/s and contraction time of FDI increased significantly in both fixed and max speed - For *circling task,* no significant differences between clockwise and counter-clockwise and between fixed and max speed
Young et al (2012)	**n** = 15 **Age:** 29 (5.0) years **Gender:** 7 males, 8 females **Other specific:** All had experience with using tablet	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use in landscape orientation, sitting on lounge chair: - Smaller tablet (smaller screen size and lighter) vs - Larger tablet (larger screen size and heavier)	**1) Type of exposures:** Head and neck posture **<u>Measurement method:</u>** Motion analysis system **<u>Variable(s):</u>** • Head flexion WRT vertical	- Significantly higher when using a smaller tablet (98° (2)) than a larger tablet (95° (2)) (placed at different tilt angles) - Significantly lower when using a tablet in Tablet-Movie (85° (2)) compared to all the other conditions

			4 configurations of varied tablet location and support: - Lap-Hand *(on lap, one and two handed with self-selected tilt)* - Lap-Case *(on lap with lower case tilt - 15^0 for smaller tablet; 45^0 for larger tablet)* - Table-Case *(on desk with lower case tilt - 15^0 for smaller tablet; 45^0 for larger tablet)* - Table-Movie *(on desk with higher case tilt - 73^0 for smaller tablet; 63^0 for larger tablet)* **Task:** Movie watching *(only for Table-Movie)* Gaming *(only for Lap-Hand)* Internet browsing, reading or typing email *(for Lap-Hand, Lap-Case, Table-Case)*	• Neck flexion WRT vertical • Cranio-cervical angle	- No significant differences between Lap-Case, Table-Case and Lap-Hand conditions - Significantly higher when using a smaller tablet (50° (2)) than a larger tablet (47° (2)) (placed at different tilt angles) - Significantly lower when using a tablet in Lap-Hand (49° (2)) than a Lap-Case (52° (2)) and Table-Case (54° (2)), but higher than Table-Movie (40° (2)) conditions - Significantly lower when using tablet in Table-Movie than in Lap-Hand, Lap-Case and Table-Case conditions - No significant differences between Lap-Case and Table-Case - No significant differences between smaller and larger tablet (placed at different tilt angles) - Significantly lower when using tablet in Lap-Hand (129° (2)) and in Lap-Case (130° (2)), than in Table-Case (135° (2)) or Table-Movie (135° (2)) conditions - No significant differences between Lap-Hand and Lap-Case, and between Table-Case and Table-Movie
Young et al (2013)	**n** = 15 **Age:** 29 (5.0) years	Tablet computer	**Design:** Experimental laboratory study	**1) Type of exposures:** Shoulder and wrist posture **<u>Measurement method:</u>**	

	Gender: 7 males, 8 females **Other specific:** All had experience with using tablet		**Conditions:** Tablet use in landscape orientation, sitting on lounge chair: - Smaller tablet (smaller screen size and lighter) - Larger tablet (larger screen size and heavier) 7 configurations of varied tablet location, support and task: *No case tilt for:* - One-handed gaming - One-handed internet browsing - Two-handed internet browsing *With case tilt for tablet:* - On lap typing email - On lap internet browsing - On desk typing email - On desk internet browsing **Task:** Gaming (for 3 minutes) vs Typing email (for 3 minutes) vs Internet browsing (for 5 minutes)	Motion analysis system **<u>Variable(s):</u>** • Shoulder flexion, abduction and elevation • Wrist extension • Wrist ulnar/radial deviation and acceleration **2) Type of exposures:** Shoulder and wrist muscle activity **<u>Measurement method:</u>** EMG on anterior deltoid, UT, FCR, FCU and ECU/ED **<u>Variable(s):</u>** 10th, 50th and 90th percentile muscle activity of:	- Highest shoulder flexion (24° (2)), lowest shoulder abduction (7° (1)), highest shoulder elevation (6° (2)) when using the tablet on desk typing email - Significantly higher shoulder flexion and elevation when using tablet for typing email on a desk than on the lap - There were no significant differences between one handed gaming and one and two handed internet browsing - Highest wrist extension when using tablet on lap typing email (35° (2)) or internet browsing (30° (2)) were found compared to on a tablet or one or two handed use - There were no significant differences between smaller and larger tablet - There was significantly higher wrist ulnar deviation when typing email (7° (2)) than the other conditions - Highest wrist ulnar/radial deviation acceleration was found when typing email on the lap ($179°/s^2$ (13)) and on a table ($179°/s^2$ (13))

				• UT (neck/shoulder) • Anterior deltoid (shoulder) • ECU/ED (wrist) • FCR and FCU (wrist)	- Significantly higher (*10th and 50th percentile only)* activity was found during one compared to two handed gaming and internet browsing - Significantly higher when using a tablet on a desk than on the lap typing email and on the lap internet browsing - Significantly higher *(90th percentile only)* when using tablet on desk than on the lap for internet browsing - Significantly higher when using the tablet on the desk, typing email than on desk internet browsing - Significantly higher at wrist extensors when typing email than internet browsing on tablet (for both on desk and on lap) - Significantly higher *(50th percentile only)* during one handed than two handed internet browsing on tablet - Muscle activity in FCR and FCU were generally low across all the configurations - Significantly higher *(90th percentile only)* when typing email than internet browsing

***Abbreviated terms:** ADM: abductor digiti minimi; AP: adductor pollicis; APB: abductor pollicis brevis; APDF: amplitude probability distribution function; APL: abductor pollicis longus; CES: cervical erector spinae; CMC: carpometacarpal; ECR: extensor carpi radialis; ED: extensor digitorium; EDC: extensor digitorum communis; EMG: electromyography; EVA : exposure variation analysis; FCR: flexor carpi radialis; FDI: first dorsal interosseous; FDS: flexor digitorium superficialis; FPB: flexor pollicis brevis; FPL: flexor pollicis longus; IP: interphalangeal; MCP: metacarpophalangeal; OP: opponens pollicis; ROM: range of motion; SCM: sternocleidomastoid; UT: upper trapezius; WRT: with respect to*

Appendix I S9. Summary of included case-control laboratory studies (MTSD use and physiological responses)

Author	Study population	Type of MTSD examined	Study design and conditions	Physiological responses measurement	Physiological responses results
Inal et al (2015)	**n** = 102 **Age:** 18 to 23 years **Gender:** 30 males, 72 females **Other specific:** University students from Turkey (66 had a habit of one-handed smartphone use)	Smartphone	**Design:** Case-control laboratory study Based on smartphone addiction scale, participants were grouped into (using the median score of 84 to classify high and low users): - High users (≥84 score), vs - Low users (≤84 score) vs - Non-users **Conditions:** NA	**1) Type of physiological responses:** Hand function **Measurement method:** Duruöz Hand Index **Variable(s):** • Duruöz Hand Index median scores **2) Type of physiological responses:** Grip strength and pinch strength **Measurement method:** Jamar hand dynamometer and pinch meter **Variable(s):** • Grip strength and pinch strength median readings **3) Type of physiological responses:**	- No differences in hand functioning among non-smartphone users, low and high smartphone users were seen - Hand functioning correlated significantly with smartphone addiction scale scores (r=0.245) - No differences in grip and pinch strength were seen among non-smartphone users, low and high smartphone users - Pinch strength, but not grip strength, correlated significantly with smartphone addiction scale scores (r=-0.281)

				FPL (flexor pollicis longus) and median nerve cross-sectional area and ratio **Measurement method:** Ultrasound over bilateral median nerve at wrist joint, and FPL at mid thenar (FPL-MT) and metacarpophalangeal joint (FPL-MCP) **Variable(s):** • FPL and median nerve cross-sectional area	- FPL cross-sectional area was significantly larger in the dominant arm side compared to the non-dominant side for all the 3 groups - Median nerve cross-sectional area in the dominant arm side was significantly larger among high smartphone users compared to the non-dominant arm side; no differences between dominant and non-dominant arm were seen in low or non-smartphone users - FPL-MCP cross-sectional area correlated significantly positive with the duration of smartphone use
				• Median nerve, FPL-MT and FPL-MCP ratio	- Median nerve ratio in non-users was significantly higher compared to in the high users group, but did not differ from the low users group; higher values for the dominant hand compared to non-dominant hand in the high user group, but not in the other groups were seen. - For FPL–MT ratio, no between group differences, but higher values for the dominant hand compared to non-dominant hand in each of the groups were seen

					- For FPL–MCP ratio, significant group differences across all the groups; higher values for the dominant hand compared to non-dominant hand in each of the groups were seen - FPL-MT and median nerve ratio correlated significantly positive with the duration of smartphone use
Jung et al (2016)	**n** = 50 **Age:** 21.0 (2.4) years **Gender:** - **Other specific:** Recruited from a university in South Korea	Smartphone	**Design:** Case-control laboratory study Categorised into 2 groups according to reported smartphone usage - Low users (n=50, <4 hours/day) - High users (n=50, >4 hours/day) **Conditions:** NA	1) **Type of physiological responses:** Respiratory function **<u>Measurement method:</u>** Spirometer **<u>Variable(s):</u>** • Peak expiratory flow (PEF) • Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), ratio of forced expiratory volume in 1 second to forced vital capacity (FEV1/FVC)	- PEF was significantly lower in high smartphone users (4.3 (1.5)) compared to in low users (6.2 (2.3)) - No differences for FVC, FEV1 and FEV1/FVC were seen between high and low users
Lee and Seo (2014)	**n** =30 (selected out of 300 surveyed) **Age:** normal group 22.6 (1.3) years;	Smartphone	**Design:** Case-control laboratory study Based on smartphone addiction scale scores, grouped into:	1) **Type of physiological responses:** Cervical repositioning error **<u>Measurement method:</u>** ROM meter applied on head to measure repositioning error compared to target	

	moderate addiction 21.5 (1.9) years; severe addiction 22.4 (2.0) years **Gender:** 12 males, 18 females **Other specific:** Students from a university in South Korea		- Normal group (n=10; scores <40) - Moderate addiction (n=10; scores 40-43) - Severe addiction (n=10; scores >43) **Conditions:** NA	position of 30^0 cervical flexion from neutral cervical position **<u>Variable(s):</u>** Mean repositioning error for: • Cervical flexion • Cervical extension, right and left cervical lateral flexion	- Error in severe addiction group (3.2^0 (0.8)) was significantly higher than in the normal group (1.0^0 (0.2)), no differences with moderate group (1.7^0 (0.4)) were seen - Error in cervical extension, right and left cervical lateral flexion was higher in the moderate addiction compared to the normal group, and also the in severe addiction group compared to the normal group
Lee et al (2012)	**n** = 125 **Age:** 21.4 (2.0) years **Gender:** 32 males, 93 females **Other specific:** Students from a university in South Korea, and no wrist symptoms or injuries	Smartphone	**Design:** Case-control laboratory study Based on a nomophobia syndrome questionnaire, participants were grouped into 3 groups for each of the categories: - Smartphone addiction degree - Daily usage duration - Continuous using time - Total periods of use **Conditions:** NA	**1) Type of physiological responses:** Median nerve thickness **<u>Measurement method:</u>** Ultrasonography **<u>Variable(s):</u>** • Mean median nerve thickness	- No significant differences between median nerve thickness and smartphone addiction degree (≤19, 20-29 or ≥30 points), daily usage duration (≤3, 3-7 or ≥8 hours), continuous using time (≤30, <60 or ≥60 mins) and total periods of use (≤12, 13-24 or ≥25 months) on median nerve thickness were seen

Park et al (2015)	**n** = 20 **Age:** 23.3 (2.3) years **Gender:** - **Other specific:** Participants were recruited from a university in South Korea	Smartphone	**Design:** Case-control laboratory study **Conditions:** According to scores on the smartphone addiction scale, grouped into: - Heavy user group (n=10, scores 45.1 (3.6)) vs - Control group (n=10, scores 26.5 (4.5))	**1) Type of physiological responses:** Pressure pain threshold **Measurement method:** Electronic algometer, pressure applied over trigger points in SCM (sternocleidomastoid) and UT (upper trapezius) **Variable(s):** • Pressure pain threshold	- Significantly lower in heavy user group than in the control group
Xie et al (2016)	**n** = 40 **Age:** 23.9 (3.2) years **Gender:** 16 males, 24 females **Other specific:** Participants were right handed and recruited from universities in Hong Kong	Smartphone	**Design:** Case-control laboratory study Based on questionnaires responses, participants were grouped into: - Case group (n=20, with neck/shoulder discomfort) vs - Control group (n=20, no neck/shoulder discomfort) **Conditions:** While sitting for 10 minutes: - Two-handed texting (both thumbs) at chest level vs	**1) Type of physiological responses:** Perceived exertion **Measurement method:** Borg scale **Variable(s):** • Rating of perceived exertion	- Exertion was significantly higher in the case group than in the control group after either one- or two-handed smartphone texting or desktop typing - There were no differences among smartphone texting and desktop typing tasks within each group

			- One-handed texting (right thumb) at chest level vs - Two-handed typing on desktop computer **Task:** Typing		

Appendix J S10. Summary of included experimental laboratory studies (MTSD use and physiological responses)

Author	Study population	Type of MTSD examined	Study design and conditions	Physiological responses measurement	Physiological responses results
Choi et al (2016)	**n** = 15 **Age:** 23.6 (2.4) years **Gender:** 8 males, 7 females **Other specific:** College students in South Korea	Smartphone	**Design:** Experimental laboratory study **Conditions:** Continuous texting while sitting for 5 minutes with: - Neutral neck *(upper part of phone screen at eye level)* - Middle neck bending *(neck bent in comfortable manner)* - Maximum neck bending **Task:** Typing	**1) Type of physiological responses:** Neck/shoulder muscle fatigue **<u>Measurement method:</u>** EMG on right and left splenius capitis and UT (without information on how values for fatigue were calculated or obtained) **<u>Variable(s):</u>** • Mean muscle fatigue	- Significantly higher muscle fatigue was seen for right and left splenius capitis, and left UT during smartphone texting in a maximum compared to a middle neck bending posture; no differences between neutral and middle/ maximum neck bending postures were seen
Kim et al (2012)	**n** = 40 **Age:** 20-27 years **Gender:** 17 males, 23 females	Smartphone	**Design:** Experimental laboratory study **Conditions:** While sitting for 10 minutes two-handed use on: - Smartphone (n=15) vs - Computer keyboard (n=15) vs - Control group (n=10)	**1) Type of physiological responses:** Pressure pain threshold **<u>Measurement method:</u>** Digital pressure algometer on UT **<u>Variable(s):</u>** • Threshold force required for subjects to report "slight pain"	- Significantly lower pressure pain threshold after typing on smartphone (55.72 kg/cm^2) than before typing on smartphone (64.23 kg/cm^2) were seen - Differences between smartphone and computer keyboard typing were not reported

			Task: Typing	**2) Type of physiological response:** Neck/shoulder, elbow, wrist and thumb muscle fatigue **Measurement method:** EMG on UT, brachioradialis, FCU, APB **Variable(s):** Median frequency of EMG of: • UT (neck/shoulder) • Brachioradialis (elbow) • FCU and APB (wrist and thumb)	 - No significant differences between smartphone and computer keyboard typing were found - Significantly higher in the smartphone than in the control group; no significant differences between smartphone and computer keyboard were shown - Significantly lower after typing on a smartphone than before typing on a smartphone - No significant differences between smartphone and computer keyboard typing, and between before and after smartphone typing were seen
Pereira et al (2013)	**n** = 30 **Age**: 30.0 (11) years **Gender:** 15 males, 15 females **Other specific:** Participants were right handed,	Tablet computer	**Design:** Experimental laboratory study **Conditions:** Tablet use with one-handed hold (left hand) while standing for 4 minutes, in 8 different configurations varying 5 independent variables: - Tablet size (small/ middle/ large)	**1) Type of physiological responses:** Fatigue in the neck, shoulder, forearm and wrist **Measurement method:** Numeric scale 1 (highest) to 7 (lowest) **Variable(s):** • Mean score of fatigue in neck, shoulder, forearm and wrist	 - Significant increase in fatigue for all areas with increasing size of tablet were shown, and also for flat grip compared to ledge and handle grip

	regular users of tablet or smartphone and had “small hands”		- Orientation (landscape/ portrait) - Grip shape (flat/ ledge/ handle grip) - Surface texture (smooth/ rough) - Stylus shape (small/ large/ tapered diameter) **Tasks:** Typing (using only right hand)		- No differences among different orientation and surface textures were shown - Significant higher hand/wrist fatigue when using small stylus compared to tapered stylus
Shim (2012)	**n** = 20 **Age:** 22.3 (0.8) years **Gender:** - **Other specific:** All had no neck/should er and upper extremity symptoms	Smartphone	**Design:** Experimental laboratory study **Conditions:** Smartphone use while sitting for 30 minutes **Task:** Not reported	**1) Type of physiological responses:** Median nerve size **<u>Measurement method:</u>** Ultrasonography **<u>Variable(s):</u>** • Mean median nerve circumference (cm) • Mean median nerve area (mm^2) • Mean distance between highest and lowest point of median nerve to lunate	- Median nerve circumference was significantly lower after smartphone use (1.12 (0.08)) compared to before use (1.39 (0.08)) - Median nerve area was significantly lower after smartphone use (8.12 (1.4)) compared to before use (10.78 (0.95)) - Both were significantly higher after smartphone use compared to before use
Xiong and	**n** = 20	Smartphone	**Design:** Experimental laboratory study	**1) Type of physiological responses:** Thumb muscle fatigue	

Muraki (2014)	**Age:** 24.5 (2.2) years **Gender:** 10 males, 10 females **Other specific:** Right handed students from a university in Japan		**Conditions:** Mock-up smartphone use on desk, perform standardized tasks at: - Fixed vs maximum speed **Task:** Tapping *(large vs small buttons)* Moving *(abduction-adduction vs flexion-extension orientations)* Circling *(clockwise vs counter-clockwise directions)*	**<u>Measurement method:</u>** Time from start to end of tapping **<u>Variable(s):</u>** • Thumb muscle fatigue time **2) Type of physiological response:** Perceived exertion of thumb muscles **<u>Measurement method:</u>** Borg's CR-10 scale of perceived exertion of AP, FPB, APB, FDI and ED **<u>Variable(s):</u>** • Perceived exertion score	- For *tapping task*, significantly shorter fatigue time for small buttons than large buttons, but no significant differences between fixed and maximum speed were shown - For *moving and circling task*, no significant differences in both fixed and maximum speed between abduction-adduction and flexion-extension were shown - For *tapping task*, significantly higher perceived exertion for FDI when using small buttons compared to large buttons; no significant differences for other thumb muscles - For *moving task*, significantly higher perceived exertion for APB and APL during adduction-abduction than flexion-extension; while for FDI significantly higher perceived exertion during flexion-extension than adduction-abduction - For *circling task*, no significant differences between clockwise and counter-clockwise directions were shown

Abbreviated terms*: AP: adductor pollicis; APB: abductor pollicis brevis; EMG; electromyography; FCU: flexor carpi ulnaris; FDI: first dorsal interosseous FPB: flexor pollicis brevis; ED: extensor digitorium; UT: upper trapezius*

Appendix K PRISMA 2009 Checklist

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	2-3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	3
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	3-4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	S1 supporting information
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	3-4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	3-4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4 and S2 supporting information
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	3-4 and S2 supporting information
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	3-4

PRISMA 2009 Checklist

Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	4

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	4
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	NA
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	4 and Fig 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	4-5 and S3 to S10 supporting information
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	4-5 and Table 1
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	S3 to S10 supporting information
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	7-12
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	5
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	NA
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	13-15
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16-17
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	NA

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: www.prisma-statement.org.

Appendix L Ethics approval for Study A1 and A2 qualitative studies

MEMORANDUM

Curtin University

To:	Prof Leon Straker
	School of Physiotherapy and Exercise Science
CC:	Ms Siao Hui Toh
From:	Dr Catherine Gangell, Manager Research Integrity
Subject	Ethics approval Approval number: RDHS-77-15
Date:	06-May-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 5951

Adolescents' use of mobile touch screen devices, associated postures and musculoskeletal symptoms: a qualitative study of perceptions from adolescents and parents

Your application has been approved through the low risk ethics approvals process at Curtin University.

Please note the following conditions of approval:

1. Approval is granted for a period of four years from **06-May-15** to **05-May-15**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

Yours sincerely

Dr Catherine Gangell
Manager, Research Integrity

Appendix M Information sheet and informed consent/assent form

PARTICIPANT INFORMATION STATEMENT

HREC Project Number:	RDHS-77-15
Project Title:	Adolescents' use of mobile touch screen devices, associated postures and musculoskeletal symptoms: a qualitative study of perceptions from adolescents and parents
Principal Investigator:	Prof Leon Straker Professor of Physiotherapy
Student researcher:	Ms Toh Siao Hui PhD Candidate
Version Number:	2
Version Date:	14/May/2015

What is this study about?

Bodily discomfort, soreness, ache or pain is common among teenagers of your age, and we think this may be related to increased use of technology. Too much use of technology or use in awkward postures, may result in discomfort and/or increased inactivity. Mobile touch screen devices, such as tablet computers and smart phones, have only become available in recent years, yet many teenagers are already using them a lot.

However, we currently know very little about how teenagers are using mobile touch screen devices, or any physical effects related to teenagers using mobile touch screen devices.

Based on findings of this study and other available research, guidelines for sensible use of mobile touch screen devices can be provided to teenagers and parents.

Who is doing this study?

This study is being conducted by Ms Toh Siao Hui, a PhD candidate with Curtin University, Perth, Australia, under the supervision of Prof Leon Straker. The results of this study will be used by Ms Toh Siao Hui to obtain a Doctor of Philosophy at Curtin University. There will be no costs to you, and you will not be paid for participating in this study.

Why am I being asked to take part and what will I have to do?

We are looking for teenagers aged between 11 to 18 years old, and hope to have about 30 teenagers take part in this study. You and your parent/ guardian will be interviewed by the researcher, which will take 30 to 45 minutes, scheduled at your convenience in your home.

Interviews will be conducted in English, and we will make an audio recording so we can concentrate on what you have to say and not be distracted with taking notes. After the interviews, we will write up the recording of the interviews.

We will interview you first for around 20 to 30 minutes. We will ask you questions about your use of mobile touch screen devices during your normal routine on a typical weekday and weekend day, and also about your patterns of use (e.g. frequency and duration), type of activities carried out (e.g. gaming, social networking, internet), locations of use (e.g. home, school) and the extent of multitasking (use of more than one device at the same time). We will also ask you if you have any related discomfort, soreness, ache or pain, and your opinions on the extent of your device use.

You will also be asked about the common postures that you are in when using mobile touch screen devices, and to demonstrate those postures with the devices. Photographs of your common postures of use will then be taken.

We will then interview your parent/guardian for around 10 to 15 minutes, asking them questions on the common locations and postures of your device use. Questions on complaints of any discomfort, soreness, aches or pain from you, and their concerns regarding your use of mobile touch screen devices will also be asked.

Are there any benefits to being in this study?

You may get a better understanding of your use of mobile touch screen devices, and discomfort that you might have experienced during use. We will also give you a handout on wise use of electronic devices to prevent discomfort. Findings from this study will help to inform guidelines regarding the use of mobile touch screen devices.

Are there any risks, discomforts or inconveniences from being in the study?

Apart from your time taken up for the interviews, we do not expect that there will be any risks, discomforts or inconveniences associated with taking part in this study. Interviews will be scheduled at you and your parent/guardian's convenience.

Who will have access to my information?

The information collected in this study will be stored with only a code number representing you, rather than your name. Only the research team will have access to the key to match your code to your name. This means that the stored information will be re-identifiable. Any information we collect will be treated as confidential and used only in this study.

Electronic data (including audio and photograph files) will be password-protected and hard copy data (including consent forms) will be kept in locked storage. The following people will have access to the information we collect in this research: the research team and the Curtin University Human Research Ethics Committee. Photographs taken will not be shown to anyone outside of the research team unless you give permission.

The results of this study may be presented at conferences or published in professional journals. You and your parent/guardian will not be identified in any results that are published or presented. Unless you or your parent/guardian provide separate consent for public use of the images, it will not be possible to identify any individual in any report on this research.

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after completion of the research, or until participants have reached 25 years of age whichever is later.

Can I withdraw from the study at any time?

Taking part in a research study is voluntary. You will only participate if you are satisfied that you understand the purpose of the research, what is expected of you, and the risks and benefits of the study. You may refuse to take part in the study, and if you do agree to take part, you will be free to withdraw from the study at any time without problems. If you do decide to withdraw from the study then please contact the researcher at the earliest opportunity. If you withdraw, we will only use the information collected till then unless you tell us not to.

What happens next and who can I contact about the study?

If you decide to take part in the study, we will ask you to sign the consent/assent form. By signing the consent/assent form, you are telling us that you understand what you have read and what has been discussed, and that you agree to be in the study and have your information used as described. You will be given a copy of this information and the consent/assent form to keep.

You are encouraged to discuss any concerns regarding the study with the researcher at any time, and to ask any questions that you may have. Questions can be directed to the researcher, Ms Toh Siao Hui, phone +65 82185569, or siaohui.toh@postgrad.curtin.edu.au, or supervisor Prof Leon Straker l.straker@curtin.edu.au.

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). This study has been approved by the Curtin University HREC (RDHS-77-15). This project will be carried out according to the Australian National Statement on Ethical Conduct in Human Research (2007). If you have any concerns and/or complaints about the project, the way it is being conducted or your rights as a research participant, and would like to speak to someone independent of the study, you may contact the Curtin University Ethics Committee on +61 8 9266 2784 or email hrec@curtin.edu.au.

Thank you very much for your involvement in this research,
your participation is greatly appreciated ☺

PARTICIPANT CONSENT/ ASSENT FORM

HREC Project Number:	RDHS-77-15
Project Title:	Adolescents' use of mobile touch screen devices, associated postures and musculoskeletal symptoms: a qualitative study of perceptions from adolescents and parents
Principal Investigator:	Prof Leon Straker Professor of Physiotherapy
Student researcher:	Ms Toh Siao Hui PhD Candidate
Version Number:	2
Version Date:	14/MAY/2015

- I have read the information statement listed above and I understand its contents.
- I understand the purpose and procedures of this study.
- I voluntarily consent/assent to take part in this study.
- I understand that my involvement is voluntary and I can withdraw at any time without prejudice.
- I understand that no personal identifying information will be used.
- I have had an opportunity to ask questions.
- I understand that I will receive a copy of this Information Statement and Consent/Assent Form.

Name of Participant	
Signature of Participant	
Date	

Declaration by researcher: I have accurately read the consent/assent form to the participant, and they have had the opportunity to ask questions. I confirm that the individual has given consent/assent freely. I have supplied a copy of this Information Letter and Consent/Assent Form to the participant, and believe that they understand the purpose and procedures of their involvement in this study.

Researcher Name	
Researcher Signature	
Date	

Appendix N Consent form for Photograph release

Curtin University

PHOTOGRAPH RELEASE

HREC Project Number:	RDHS-77-15
Project Title:	Adolescents' use of mobile touch screen devices, associated postures and musculoskeletal symptoms: a qualitative study of perceptions from adolescents and parents
Principal Investigator:	Prof Leon Straker Professor of Physiotherapy
Student researcher:	Ms Toh Siao Hui PhD Candidate
Version Number:	1
Version Date:	21/APR/2015

By signing this Photograph Release, you are giving permission for us to use photographs of you/your teenager for the following project: Musculoskeletal symptoms and the use of mobile touch screen devices in adolescents. This is completely voluntary and up to you. If you do not assent/consent to use your/your teenager's photographs, your teenager and you are still able to participate in the study.

The researchers may use the photographs containing your/your teenager's image, likeness, and appearance for research and educational purposes, including use on web pages, but not for any commercial uses. You will not receive compensation for the use of you/your teenager's image, likeness, or appearance. Your/your teenager's name, or other identifying information will not be used with the images. Consent is assumed to be indefinite. However you may change your permission at any time.

By signing below, I understand and agree to the conditions outlined above. As a teenager I give assent to use of the images. As the parent or legal guardian of the participant named below and on behalf of my teenager, I give consent to use my teenager's image, likeness, and appearance, in photographs as described above.

Name of Participant/Teenager	
Signature of Participant/Teenager	
Name of Parent/Guardian	
Signature of Parent/Guardian	
Date	

Appendix O Recruitment flyer for qualitative study

Are you a teenager who uses mobile touch screen devices, such as tablet computers or smart phones?

Many teenagers are using mobile touch screen devices, e.g. tablet computers and smart phones, yet we currently know very little about their physical effects. This study is trying to find out how teenagers use these devices and how this use may be related to any discomfort.

If you are:

- ✓ 11 to 18 years old
- ✓ Use mobile touch screen devices, such as tablet computers or smart phones

We would like to invite you and your parent/guardian to take part in this study.

What does this study involve?

* We will have an interview with you for 20 - 30 minutes, and then with your parent/guardian for 10 - 15 minutes, scheduled at your convenience in your home.
* We will ask questions on:
  - your use of mobile touch screen devices
  - any related discomfort
  - common postures of use: and take photographs of these postures

To thank you for your participation, a handout on guidelines for wise use of electronic devices will be given to you.

For more information or to register your interest, please contact:

Toh Siao Hui
+65 8218 5569
siaohui.toh@postgrad.curtin.edu.au

Curtin University

This study has been approved by the Curtin University Human Research Ethics Committee (RDHS-77-15).

MSS & MTSD (Qualitative) - V3 - 11/6/15

Appendix P Wise use of technology handout for participants

Tips for Wise Use of Technology

Most of us live and breathe the online world today. We should use technology wisely, as inappropriate use may cause negative effects on health. Below are some useful tips to help prevent discomfort, overuse injuries and inactivity.
Do give them a try!

Possible effects of too much screen time

- Poor posture, strains and discomfort of thumbs, wrists, arms and shoulders; back and neck pain
- Vision problems, sleep problems
- Inactivity/sedentariness, with increased risk of becoming overweight

Do a mix of activities Exercise regularly

- Make sure you do a variety of activities, including activities that make you 'huff and puff'.
- Aim for 30 - 60 mins of exercise per day including walking, stairs climbing and etc.

Vary your postures regularly

- Do not stay in one position for too long without moving.
- Change positions, stretch and move every now and then.

Take regular breaks

- Take regular breaks from your device — around 5 mins every 30 mins.
- Rest your hands, arms, and your eyes during the breaks — move your body and stretch, get up, walk around, get a glass of water etc.
- Give your eyes something different to look at, such as looking out the window.

Limit your leisure screen time

Try to limit yourself to 2 hours per day maximum of leisure screen time, which includes desktop/ laptop/ tablet computers, TV, electronic games and mobile phones.

Maintain good posture

- Keep your body relaxed in neutral postures.
- Avoid excessive forward bending of neck and slouching of back.

Tips for desktop/ laptop use

- Your desktop/ laptop screen should be directly in front of you and about an arms length away.
- The top of the screen should be a little below your eye-level.
- Angle your screen to prevent glare and reflections.

Tips for tablet computer use

- Try to reduce how bent your neck is by maintaining the tablet computer at your chest, chin or eye level. You can place it on a table, or use a pillow to raise it up.
- Try to reduce the strain on your arms by resting the tablet on the table, or use a tablet case holder.
- Try to avoid hunching your back or slouching.
- If you are using a tablet for quite some time, use a separate keyboard and mouse to create a set up similar to a desktop.

Tips for mobile phone use

- Try to avoid too much bending of your neck by maintaining the phone at your chest, chin or eye level.
- Reduce the strain on your arms by supporting your phone on a pillow on your lap or on a table, when using it for a longer time.
- Keep your wrists in neutral position; avoid too much bending of your wrists.
- Avoid long periods of texting so you don't strain your fingers and thumbs.
- General safety reminder: Avoid using when walking, cycling or driving.

Keep moving,
change your position often,
take frequent breaks!

This guideline is produced for participants involved in study approved by Curtin University Human Research Ethics Committee (RDHS-77-15). V3. 20/6/2015

Curtin University

Appendix Q Interview guide and question prompts for Study A1 -qualitative study on patterns of MTSD use by adolescents

Adolescent

- What types of mobile touch screen devices (MTSD) do you use? any device with touch screen such as tablet computers, smartphones?
  - Are there any other types of device that you use, e.g. television, desktop and laptop computers or game consoles?
- Can you describe to me your routine of your use of tablet computer/ smartphones/ other MTSD on a typical *weekday?*
  - How often and for how long?
  - What activities do you use it for?
  - Where do you use it?
- Can you describe to me your routine of your use of tablet computer/ smartphones/ other MTSD on a typical *weekend day?*
  - How often and for how long?
  - What activities do you use it for?
  - Where do you use it?

- Do you usually use your tablet computer/ smartphones/ other MTSD for a long continuous time or do you take breaks in between? Why and why not? If so, how often do you take the breaks?
- What do you do during the breaks? *(sedentary or non-sedentary type of activities?)*

- Do you ever multitask - use your tablet computer/ smartphone/ other MTSD while you are doing something else, such as homework or computer? If yes, what type of devices?
- How do you multitask? What are you mainly doing when you multitask? And why do you multitask?

- Do you think your duration and frequency of use of tablet computer/ smartphones/ other MTSD is appropriate, too little or too much? Why do you think so?

Parent/caregiver

- What types of mobile touch screen devices does your child use? Does your child use any other forms of technology such as television, desktop or laptop computers, game consoles?
- How often does your child use his or her tablet computer/ smartphone/ other MTSD?
- What type of activities does your child carry out on his or her tablet computer/ smartphone/ other MTSD?
- What do you think of your child's amount of MTSD use? Is it appropriate, too little or too much?
- Do you have any concerns regarding your child's use of MTSD?
- Are there any agreements/rules in your household regarding the use of MTSD by your child, for example:
  - Any on ownership or accessibility to MTSD
  - Any on duration of use
  - Any on use during certain days of the week or periods of the day

Appendix R Interview guide and question prompts for Study A2 - qualitative study on discomfort and postures during adolescents' MTSD use

Adolescent

- Do you experience any discomfort, soreness, ache or pain anywhere on your body in the last week and/or last month?
- Do you notice this discomfort, soreness, ache or pain during or after using tablet/ smartphone use or any other specific activities?
- What do you think are the causes for the discomfort, soreness, ache or pain that you experience?
- Did you do anything to relieve the discomfort, consult anyone or seek any treatment about it?

- Can you show me what are the positions that you are normally in when you are using tablet computer/ smartphone/ other MTSD mentioned?

- Where do you usually use your tablet computer/ smartphone/ other MTSD mentioned? *[*Get participants to demonstrate the typical postures and location of MTSD use in the house and permission for photographs to be taken]*

Parent/caregiver

- Does your child complain to you of any bodily discomfort, soreness, ache or pain? If so, can you tell me more about it?

- What are the common postures that your child is in when using tablet computer/ smart phones/ other MTSD mentioned?

- Where are the common areas in the house that your child is using tablet computer/ smart phones/ other MTSD mentioned?

Appendix S Ethics approval for Study B and C

MEMORANDUM

Curtin University

To:	Prof Leon Straker School of Physiotherapy and Exercise Science
CC:	Ms Siao Hui Toh
From	Dr Catherine Gangell, Manager Research Integrity
Subject	Ethics approval Approval number: RDHS-100-15
Date	10-Jul-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 5974
Technology use and physical well-being in adolescents

Your application has been approved through the low risk ethics approvals process at Curtin University.

Please note the following conditions of approval:

1. Approval is granted for a period of four years from **08-Jun-15** to **08-Jun-19**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

Yours sincerely

Dr Catherine Gangell
Manager, Research Integrity

Appendix T Information sheet and informed consent/assent form

PARENT/ PARTICIPANT INFORMATION SHEET

Project title: Technology Use and Physical Well-being in Adolescents

Investigators: Toh Siao Hui, *KK Women's and Children's Hospital*
Professor Leon Straker, *Curtin University, Perth, Australia*
Assistant Professor Swarup Mukherjee, *National Institute of Education, Nanyang Technological University, Singapore*

Dear Parents,

As you would agree, technology use, especially the use of mobile touch screen devices i.e. smart phones and tablet computers have become a part of our day to day life. These devices are also increasingly being used among children nowadays, and there are concerns that children may be spending too much time on them. If technology is not being used appropriately, it may pose risk to children's physical well-being; they may become physically inactive, develop discomfort, or over strain their eyes – which will counter the positive impacts of use.

However, we currently do not know much about how children are using technology today, especially mobile touch screen devices and the influence of their use on physical well-being. Therefore, we want to understand if there are more effective ways for children to use technology wisely. This study will help to inform guidelines for wise use of technology, which can be provided for parents, children and educators.

Who is doing this study?

This study is conducted by trained international research scientists from KK Women's and Children's Hospital, Curtin University, Perth, Australia, and National Institute of Education (NIE), Nanyang Technological University (NTU), Singapore who are experts in this area.

How will the study be conducted?

The study involves filling up a simple survey by you/your child on your/your child's technology use which will take approximately 20 to 30 minutes to complete on two occasions. The survey will be completed online in the school classroom or computer laboratory.

The survey will broadly have the following areas:

- Technology use on the various devices on a typical weekday and weekend day
- Type of activities carried out on the devices
- Extent of multitasking (use of more than one device at the same time)
- Discomfort or aches
- Physical activity level
- Visual health, including eye strain and short sightedness/ myopia
- Mood and stress level

What are the benefits to being in this study?

You/your child's participation in this study will help us collect very useful information on children's technology use, especially of mobile touch screen devices, and their possible influence on physical well-being and how this changes over 12 months. This will help in development of guidelines for wise use of technology in children, prevent adverse effects of inappropriate use on their physical well-being, and make them more active and healthier in the future.

As a token of appreciation, a prize draw will be conducted among those who have completed the survey. You/your child will have a chance to win a first prize of $350 value of vouchers from Resort World Sentosa (can be used for tickets to Universal Studios, hotel accommodation, retail, dining etc.), or a second prize of $150 value of vouchers from CapitalMalls in Singapore.

Are there any risks/discomfort/inconveniences from being in the study?

Apart from your/your child's minimal time taken up for completing the survey, we do not expect that there will be any risks or inconveniences associated with taking part in this study. The survey will not be conducted during busy school period; care will also be taken to avoid any disruption to the school curriculum and class schedules.

Who will have access to my information?

The name or identity of you/your child will not be revealed and the results from you/your child will be treated as confidential, with access restricted to only researchers involved in the study. The group results of this study may be presented at conferences or published in professional journals. Only summarised group data will be used in the reporting, presenting or publishing of findings; you/your child's results will not be identifiable in any report.

Ethics for this study has been approved by the Curtin University Human Research Ethics Committee (RDHS-100-15). Ministry of Education, Singapore and the school administrators have also reviewed and endorsed the conduct of this study.

What happens next and who can I contact about the study?

Though you/your child's participation is both highly appreciated and is of vital importance to this study, participation is voluntary and you/your child can withdraw at any time without problems.

If you/your child agree to participate, please complete the consent form. Please make sure you sign **BOTH** your copy and the INSTITUTION copy. Keep your copy and return the INSTITUTION copy to the school/teachers.

If you/your child require any further information or have any questions, please feel free to contact Ms Toh Siao Hui, at +65 82185569 or siaohui.toh@postgrad.curtin.edu.au. Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on +61 8 9266 9223 or the Manager, Research Integrity on +61 8 9266 7093 or email hrec@curtin.edu.au.

Thank you very much for your involvement in this study.
Your participation is greatly appreciated and will
help improve the health of children ☺

PARENT/ PARTICIPANT CONSENT FORM

YOUR COPY
Please keep as a record of your participation.

Project title: Technology Use and Physical Well-being in Adolescents

I voluntarily consent to myself/my child to take part in the study described overleaf. I have read and understood the requirements of the study. Furthermore, I understand that (a) my/my child's participation is voluntary, (b) I/my child can withdraw at any time without prejudice, (c) no personal identifying information will be used and the data will treated in a secured and confidential manner.

Name of *Participant*	
Name of *Parent/ Guardian*	
Signature of *Parent/ Guardian*	
Date	

Please retain this copy as a record of your participation.

Please make sure you have signed, completed, and returned INSTITUTION copy on the next page. Thank you.

PARENT/ PARTICIPANT CONSENT FORM

INSTITUTION COPY
Please return to your child's teacher as soon as possible.
Thank you.

Project title: Technology Use and Physical Well-being in Adolescents

I voluntarily consent to myself/my child to take part in the study described overleaf. I have read and understood the requirements of the study. Furthermore, I understand that (a) my/my child's participation is voluntary, (b) I/my child can withdraw at any time without prejudice, (c) no personal identifying information will be used and the data will treated in a secured and confidential manner.

Name of *Participant*	
Name of *Parent/ Guardian*	
Signature of *Parent/ Guardian*	
Date	

Please make sure you have signed, completed, and returned this INSTITUTION copy.

Thank you.

Appendix U Technology use questionnaire (TechU-Q)

Section A

Some questions about yourself and your family...

1. What is your date of birth?

Date

Month

Year

2. What year are you in at school now?

Primary school year

Secondary school year

Post secondary school year (JC/ CI/ ITE/ Polytechnic)

3. What is your height and weight?

Height (cm)

Weight (kg)

4. What is your gender?

- Boy
- Girl

5. What is your race?

- Chinese
- Malay
- Indian
- Others (please specifiy):

6. What type of housing do you live in?

- 1 / 2 room HDB flat (public housing)
- 3 room HDB flat (public housing)
- 4 room HDB flat (public housing)
- 5 room / executive HDB flat (public housing)
- Private housing (e.g. condominium/ semi-detached/ terrace/ bungalow)

7. What is the highest level of school that your father completed?

- Primary or lower (≤6 years)
- Secondary (7-10 years)
- Post-secondary (≥11 years, including university)
- No one fills the role of father in my family
- I don't know

8. What is the highest level of school that your mother completed?

- Primary or lower (≤6 years)
- Secondary (7-10 years)
- Post-secondary (≥11 years, including university)
- No one fills the role of mother in my family
- I don't know

Section B

Some questions about the electronic devices that you use...

	Have you used any of the following devices **in the last 12 months**?		Do you **personally have or own** any of the following devices?		**In your bedroom, do you have or usually use** any of the following devices?	
	Yes	No	Yes	No	Yes	No
Television 						
Desktop computer 						
Laptop computer 						
Tablet computer (e.g. iPad, Samsung Galaxy Tab, Kindle e-reader, Microsoft Surface Pro) 						
Mobile phone - WITH touch screen (e.g. smart phone such as iPhone, Samsung Galaxy) 						
Handheld electronic games (e.g. PSP, Nintendo DS) 						
NON-ACTIVE game consoles (playing sitting, not actively moving) (e.g. XBOX, Wii, PS3) 						
ACTIVE game consoles (playing actively and moving about (e.g. XBOX Kinect, Wii, PS3 MOVE) 						

Section C

Some questions about how often and how long you usually use these devices…

	WEEKDAY (Mon-Fri) Over a typical **Monday to Friday period, on how many days** do you use this device?	**WEEKDAY (Mon-Fri)** On each of these weekdays, for about **how long do you use this device per day?**	**WEEKEND (Sat-Sun)** On a typical weekend **(Saturday to Sunday), on how many days** do you use this device?	**WEEKEND (Sat-Sun)** On each of these weekend day, for about **how long do you use this device per day?**
Television 	Please select ▾	Please select ▾	Please select ▾	Please select ▾
Laptop computer 	Please select ▾	Please select ▾	Please select ▾	Please select ▾
Tablet computer (e.g. iPad, Samsung Galaxy Tab, Kindle e-reader, Microsoft Surface Pro) 	Please select ▾	Please select ▾	Please select ▾	Please select ▾
Mobile phone **- WITH touch screen** (e.g. smart phone such as iPhone, Samsung Galaxy) 	Please select ▾	Please select ▾	Please select ▾	Please select ▾

Section D

Some questions about how long you usually use the devices before taking a break...

How long do you usually use these devices **before stopping** (stop using it or change to another activity or device use)?

	How long do you usually use these devices **before stopping** (stop using it or change to another activity or device use)?
Television 	Please select
Laptop computer 	Please select
Tablet computer (e.g. iPad, Samsung Galaxy Tab, Kindle e-reader, Microsoft Surface Pro) 	Please select
Mobile phone - WITH touch screen (e.g. smart phone such as iPhone, Samsung Galaxy) 	Please select

Section E

Some questions about how often you multitask – use another electronic device to do other activities at the same time...

	How often do you **multitask** – **use another electronic device to do other activities**, such as texting messages, play games or watch videos **at the same time** – **when you are using the following devices?**
Television 	Please select
Laptop computer 	Please select
Tablet computer (e.g. iPad, Samsung Galaxy Tab, Kindle e-reader) 	Please select
Mobile phone - WITH touch screen (e.g. smart phone such as iPhone, Samsung Galaxy) 	Please select

Section F

Some questions about the type of activities that you do on the devices...

	 **WEEKDAY (Mon – Fri)** Thinking about a typical **Monday to Friday,** about how long do you **spend doing the following activities on laptop computer each day**?	 **WEEKEND (Sat- Sun)** Thinking about a typical **Saturday to Sunday,** about how long do you **spend doing the following activities on laptop computer each day?**
Doing school work in school, and homework at home (e.g. using Microsoft Word, searching information online)	Please select	Please select
Social networking/ instant messenger (e.g. Facebook, Instagram, Twitter, WhatsApp, Snapchat, Skype, texting, voice calls)	Please select	Please select
Watching videos/ shows (e.g. watching movies, dramas, YouTube)	Please select	Please select
Playing games	Please select	Please select
Other general use, NOT for school work (e.g. visiting websites, Google, online shopping, downloading music, sending/receiving emails)	Please select	Please select

Section F

	 **WEEKDAY** (Mon-Fri) Thinking about a typical **Monday to Friday,** about how long do you **spend doing the following activities on tablet computer each day**?	 **WEEKEND** (Sat-Sun) Thinking about a typical **Saturday to Sunday,** about how long do you **spend doing the following activities on tablet computer each day?**
Doing school work in school, and homework at home (e.g. using Microsoft Word, searching information online)	Please select ▾	Please select ▾
Social networking/ instant messenger (e.g. Facebook, Instagram, Twitter, WhatsApp, Snapchat, Skype, texting, voice calls)	Please select ▾	Please select ▾
Watching videos/ shows (e.g. watching movies, dramas, YouTube)	Please select ▾	Please select ▾
Playing games	Please select ▾	Please select ▾
Other general use, NOT for school work (e.g. visiting websites, Google, online shopping, downloading music, sending/receiving emails)	Please select ▾	Please select ▾

Section F

	 **WEEKDAY** **(Mon-Fri)** Thinking about a typical **Monday to Friday,** about how long do you **spend doing the following activities on mobile phone (with touch screen) each day**?	 **WEEKEND** **(Sat-Sun)** Thinking about a typical **Saturday to Sunday,** about how long do you **spend doing the following activities on moible phone (with touch screen) each day?**
Doing school work in school, and homework at home (e.g. using Microsoft Word, searching information online)	Please select ▾	Please select ▾
Social networking/ instant messenger (e.g. Facebook, Instagram, Twitter, WhatsApp, Snapchat, Skype, texting, voice calls)	Please select ▾	Please select ▾
Watching videos/ shows (e.g. watching movies, dramas, YouTube)	Please select ▾	Please select ▾
Playing games	Please select ▾	Please select ▾
Other general use, NOT for school work (e.g. visiting websites, Google, online shopping, downloading music, sending/receiving emails)	Please select ▾	Please select ▾

Section G

Some questions about how long you spend on other sitting activities ...

	WEEKDAY (Mon – Fri) Thinking about a typical **Monday to Friday,** about how long do you spend **each day sitting down doing:**	WEEKEND (Sat - Sun) Thinking about a typical **Saturday to Sunday,** about how long do you spend **each day sitting down doing:**
Homework/ school work (at home & outside school) (NOT on a computer or other devices) 	Please select	Please select
Reading books/ paper (NOT on a computer or other devices) 	Please select	Please select
Playing/ practising any musical instrument(s) 	Please select	Please select
Art and crafts/ hobbies 	Please select	Please select
Other sitting down time, such as chatting with friends/ playing card or board games etc. (NOT on any electronic devices)	Please select	Please select

Section H

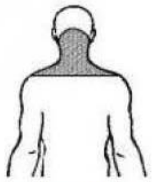
Skip logic used for Questions 1-3 in Section H; examples of responses and questions shown are indicated below

Some questions about any discomfort, soreness, ache or pain that you may have...

Please answer for every part of your body, ***one ANSWER only*** *for every question.*

The shaded area in the picture shows the listed body part. Limits are not sharply defined and certain parts overlap.
You should decide for yourself which part (if any) is or has been affected.

Questions on this page refer to your NECK/ SHOULDERS, area as shaded in the picture below.



1. Have you ever had any discomfort, soreness, ache or pain on your neck/shoulders?

- No
- Yes

2. Have you had any discomfort, soreness, ache or pain at any time on your neck/ shoulders during the last 12 months?

- No
- Yes

3. Have you had any discomfort, soreness, ache or pain at any time on your neck/ shoulders during the last month?

- No
- Yes

4. How often have you had the discomfort, soreness, ache or pain on your neck/ shoulders during the last month?

- Almost never (less than once a month)
- Occasionally (1-3 times a month)
- Often (1-3 times a week)
- Always (More than 3 times a week)

5. On average, what number (0-10 scale) best describes **the amount of discomfort, soreness, ache or pain** that you have had on your neck/shoulders in the **last month**?

0 = No discomfort
10 = Worst possible discomfort

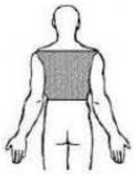
0	1	2	3	4	5	6	7	8	9	10

6. On average, what number (0-10 scale) best describes **the amount of interference to your normal studies/activities (at home or away from home)**, caused by the discomfort, soreness, ache or pain on your neck/ shoulders in the **last month**?

0 = No interference
10 = Most interference

0	1	2	3	4	5	6	7	8	9	10

Questions on this page refer to your <u>UPPER BACK,</u> area as shaded in the picture below.



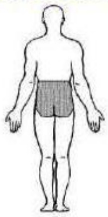
1. Have you <u>ever</u> had any discomfort, soreness, ache or pain on your upper back?

- No
- Yes

2. Have you had any discomfort, soreness, ache or pain at any time on your upper back during the <u>last 12 months</u>?

- No
- Yes

Questions on this page refer to your LOW BACK, area as shaded in the picture below.



1. Have you <u>ever</u> had any discomfort, soreness, ache or pain on your low back?

- No
- Yes

2. Have you had any discomfort, soreness, ache or pain at any time on your low back during the <u>last 12 months</u>?

- No
- Yes

3. Have you had any discomfort, soreness, ache or pain at any time on your low back during the <u>last month</u>?

- No
- Yes

4. <u>How often</u> have you had the discomfort, soreness, ache or pain on your neck/ shoulders during the last month?

- Almost never (less than once a month)
- Occasionally (1-3 times a month)
- Often (1-3 times a week)
- Always (More than 3 times a week)

5. On average, what number (0-10 scale) best describes **<u>the amount of discomfort, soreness, ache or pain</u>** that you have had on your low back in the **last month**?

0 = No discomfort
10 = Worst possible discomfort

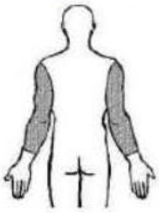
0 1 2 3 4 5 6 7 8 9 10

6. On average, what number (0-10 scale) best describes **<u>the amount of interference to your normal studies/activities (at home or away from home)</u>**, caused by the discomfort, soreness, ache or pain on your low back in the **last month**?

0 = No interference
10 = Most interference

0	1	2	3	4	5	6	7	8	9	10
○	○	○	●	○	○	○	○	○	○	○

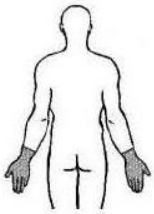
Questions on this page refer to your <u>ARMS (including elbows)</u>, area as shaded in the picture below.



1. Have you <u>ever</u> had any discomfort, soreness, ache or pain on your arms?

● No
○ Yes

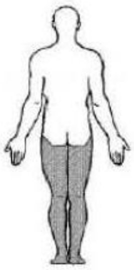
Questions on this page refer to your <u>WRISTS/ HANDS</u>, area as shaded in the picture below.



1. Have you <u>ever</u> had any discomfort, soreness, ache or pain on your wrists/hands?

● No
○ Yes

Questions on this page refer to your <u>LEGS (including thighs, knees, feet)</u>, area as shaded in the picture below.



1. Have you <u>ever</u> had any discomfort, soreness, ache or pain on your legs (including thighs, knees, feet)?

● No
○ Yes

8. If you have short sightedness/ myopia, what is the **degree of your glasses/ contact lens**?

- Between 0 to 300 'degrees' / 0.0 to −3.00 diopters
- Between 300 to 600 'degrees' / −3.00 and −6.00 diopters
- 600 'degrees' or worse / −6.00 diopters or worse
- I don't have short sightedness/ myopia

Section J

Some questions about your physical activity…

We are trying to find out about your level of physical activity from the ***last 7 days (in the last week).***
This include sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like skipping, running, climbing, and others.

Remember:
There are no right and wrong answers — this is not a test. Please answer all the questions as honestly and accurately as you can — this is very important.

1. Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times?

	No	1-2	3-4	5-6	7 times or more
Skipping					
Rowing/ canoeing					
In-line skating/ roller skating					
Tag/ catching chasing game					
Walking for exercise					
Bicycling/ cycling					
Jogging/ running					
Aerobics					
Swimming					
Baseball/ softball					
Dance					
Soccer/ football					
Badminton					
Skateboarding					
Rugby/ touch rugby					
Hockey (outdoors/ indoors)					
Volleyball					
Basketball					
Netball					
Tennis					
Captain's ball					
Gym workout					
Others (please list if any others):					

2. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)?

- I don't do PE
- Hardly ever
- Sometimes
- Quite often
- Always

3. In the last 7 days, what did you normally do <u>at lunch</u> (besides eating lunch)?

- Sat down (talking, reading, doing schoolwork)
- Stood around or walked around
- Ran or played a little bit
- Ran around and played quite a bit
- Ran and played hard most of the time

4. In the last 7 days, on how many <u>days right after school</u>, did you do sports, dance, or play games in which you were very active?

- None
- 1 time last week
- 2 or 3 times last week
- 4 times last week
- 5 times last week

5. In the last 7 days, on how many <u>evenings</u> did you do sports, dance, or play games in which you were very active?

- None
- 1 time last week
- 2 or 3 times last week
- 4 or 5 times last week
- 6 or 7 times last week

6. <u>On the last weekend</u>, how many times did you do sports, dance, or play games in which you were very active?

- None
- 1 time
- 2 - 3 times
- 4 - 5 times
- 6 or more times

7. Which one of the following describes you best for the last 7 days? Read <u>all five</u> statements before deciding on the <u>one</u> answer that describes you.

- All or most of my free time was spent doing things that involve little physical effort
- I sometimes (1 - 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics)
- I often (3 - 4 times last week) did physical things in my free time
- I quite often (5 - 6 times last week) did physical things in my free time
- I very often (7 or more times last week) did physical things in my free time

8. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	None	Little bit	Medium	Often	Very often
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					
Saturday					
Sunday					

9. Were you sick last week, or did anything prevent you from doing your normal physical activities?

- Yes
- No

If yes, what prevented you?

Section K

Some questions about your marks/ grades in school...

1. What marks/grades do you usually get in school?

- Mostly A's
- Mostly A's and B's
- Mostly B's
- Mostly B's and C's
- Mostly C's
- Mostly C's and D's
- Mostly D's
- Mostly D's and E's
- My school does not give marks/grades

2. How would you rate your academic performance in school?

- Very good
- Above average
- Average
- Below average
- Poor

Section L

Some questions about how you feel recently...

Please read each sentence and SELECT a number 0, 1, 2 or 3 which indicates how much the sentence applied to you over the past 7 days. *There are no right or wrong answers.*
Do not spend too much time on any sentence.

The rating scale is as follows:

0 Did not apply to me at all - NEVER
1 Applied to me to some degree, or some of the time - SOMETIMES
2 Applied to me to a considerable degree, or a good part of time - OFTEN
3 Applied to me very much, or most of the time - ALMOST ALWAYS

	NEVER 0	SOMETIMES 1	OFTEN 2	ALMOST ALWAYS 3
1. I found it hard to wind down				
2. I was aware of dryness of my mouth				
3. I couldn't seem to experience any positive feeling at all				
4. I experienced breathing difficulty (e.g. excessively rapid breathing, breathlessness in the absence of physical exertion)				
5. I found it difficult to work up the initiative to do things				
6. I tended to over-react to situations				
7. I experienced trembling (e.g. in the hands)				
8. I felt that I was using a lot of nervous energy				
9. I was worried about situations in which I might panic and make a fool of myself				
10. I felt that I had nothing to look forward to				
11. I found myself getting agitated				
12. I found it difficult to relax				
13. I felt down-hearted and blue				
14. I was intolerant of anything that kept me from getting on with what I was doing				
15. I felt I was close to panic				
16. I was unable to become enthusiastic about anything				
17. I felt I wasn't worth much as a person				
18. I felt that I was rather touchy				
19. I was aware of the action of my heart in the absence of physical exertion (e.g. sense of heart rate increase, heart missing a beat)				
20. I felt scared without any good reason				
21. I felt that life was meaningless				

End of survey. Thank you!

Appendix V Percentage of higher socioeconomic status (SES) for housing type, parents' education and academic level for each category of schools in stratified sampling matrix

School level	Location of school/ class streaming		Government schools	Government-aided schools
Primary 5	Schools located in planning area of top 50th percentile of median household income	Higher SES (housing)	39.0%	69.6%
		Higher SES (father's education)	25.2%	55.3%
		Higher SES (mother's education)	28.8%	61.7%
	Schools located in planning area of bottom 50th percentile of median household income	Higher SES (housing)	28.5%	38.4%
		Higher SES (father's education)	20.7%	27.1%
		Higher SES (mother's education)	26.7%	27.1%
Secondary 1	Express stream	Higher SES (housing)	38.5%	65.1%
		Higher SES (father's education)	40.7%	68.5%
		Higher SES (mother's education)	33.3%	69.9%
		Higher academic	61.2%	84.6%
	Normal stream	Higher SES (housing)	31.5%	44.5%
		Higher SES (father's education)	20.0%	22.8%
		Higher SES (mother's education)	16.9%	25.6%
		Higher academic	32.3%	27.4%
Secondary 3	Express stream	Higher SES (housing)	42.9%	66.3%
		Higher SES (father's education)	45.1%	68.5%
		Higher SES (mother's education)	41.1%	71.7%
		Higher academic	43.4%	51.1%
	Normal stream	Higher SES (housing)	29.9%	40.2 %
		Higher SES (father's education)	21.2%	23.6%
		Higher SES (mother's education)	20.4%	31.7%
		Higher academic	20.3%	19.7%

Higher SES (housing) refers to 5 room/ executive HDB or private housing, higher SES (parents' education) refers to post-secondary education and above, higher academic refers to "mostly B's", "mostly A's and B's" or "mostly A's" from the answer options listed in questionnaire

Appendix W Percentage of adolescents with technology ownership by gender and school level

	Total (n=1884)	Boys (n=935)	Girls (n=949)	Primary 5 (n=516)	Secondary 1 (n=530)	Secondary 3 (n=693)	Junior college 1 (n=145)
Smartphone	88.9	86.2	91.6***	70.2	94.7	96.3	99.3***
Tablet	47.9	49.2	46.7	46.3	51.9	47.5	41.4
TV	49.6	52.7	46.5**	33.7	50.2	59.7	55.2***
Desktop	32.0	36.0	28.0***	27.1	31.1	35.4	36.6*
Laptop	61.2	62.9	59.4	50.8	56.2	67.2	86.9***
Handheld games	28.3	31.2	25.4**	18.8	31.7	31.5	34.5***
Non-active console games	26.9	36.7	17.2***	20.2	29.6	30.0	25.5**
Active console games	23.6	27.7	19.6***	22.1	26.2	22.9	22.8

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between boys and girls and among all the school levels using chi-square test*

Appendix X Percentage of adolescents using technology in bedroom by gender and school level

	Total (n=1884)	Boys (n=935)	Girls (n=949)	Primary 5 (n=516)	Secondary 1 (n=530)	Secondary 3 (n=693)	Junior college 1 (n=145)
Smartphone	83.1	79.5	86.6***	60.5	88.7	93.1	95.2***
Tablet	40.2	40.0	40.4	40.3	44.2	38.7	32.4
TV	24.0	25.8	22.2	24.2	24.5	25.0	16.6
Desktop	19.1	22.5	15.8***	16.7	21.1	19.8	17.2
Laptop	48.8	49.2	48.4	35.9	46.2	55.1	73.8***
Handheld games	18.4	22.6	14.3***	10.1	21.0	21.9	22.1***
Non-active console games	13.1	19.3	7.0***	8.7	17.4	13.4	11.0***
Active console games	10.4	12.8	7.9***	10.3	12.1	9.8	6.9

*Significance values ***p<.001 for differences between boys and girls and among all the school levels using chi-square test*

Appendix Y Technology use by polytechnic students

Percentage of polytechnic students using technology in the last 12 months, mean (standard deviation) and median (interquartile range) daily minutes of technology use across whole week, mean (standard deviation) daily minutes of technology use on weekdays and weekend days

	Last 12 months usage (%) *(n=123)*	**Mean (SD) use across whole week** (mins/day)	**Median (IQR) use across whole week** (mins/day)	**Weekday** (mins/day)	**Weekend** (mins/day)
Smartphone	96.8	478 (236)	527 (270-720)	474 (240)	480 (248)
Tablet	56.1	48 (133)	0 (0-11)	47 (143)	50 (133)
TV	95.9	89 (131)	32 (0-137)	81 (128)	113 (166)
Desktop	67.5	36 (100)	0 (0-9)	34 (100)	38 (117)
Laptop	99.2	153(137)	129 (51-223)	141 (137)	181 (195)
Handheld games	17.1	3 (22)	0 (0-0)	2 (17)	6 (38)
Non-active game consoles	20.3	5 (29)	0 (0-0)	5 (29)	5 (31)
Active game consoles	15.5	1 (3)	0 (0-0)	0 (2)	1 (7)
[#]Total technology use	NA	742 (354)	714 (506-1003)	731 (484)	787 (531)

[#]Obtained by summing technology use for all the devices; NA: not applicable

Appendix Z Musculoskeletal symptoms among polytechnic students

Number (percentage) of polytechnic students reporting musculoskeletal symptoms in the last month by body regions, gender and school levels, and in those with symptoms the number (percentage) reporting high frequency symptoms in the last month of "Often or always", mean (standard deviation) of discomfort intensity (out of 10) and interference with daily activities (out of 10), as well as mean (standard deviation) for number of visual symptoms, number (percentage) of polytechnic students reporting wearing glasses/ contact lenses and in those wearing glasses/contact lenses reporting trouble seeing far (myopia) or near (hyperopia) or both, across school levels

		Total (n=96)
Neck/shoulders	Last month prevalence	54 (56.3%)
	Often or always	19 (35.2%)
	Intensity	3.6 (1.8)
	Interference	2.9 (2.2)
Upper back	Last month prevalence	26 (27.1%)
	Often or always	5 (19.2%)
	Intensity	3.4 (2.1)
	Interference	3.1 (2.2)
Low back	Last month prevalence	35 (36.5%)
	Often or always	12 (34.3%)
	Intensity	4.3 (2.0)
	Interference	3.8 (2.5)
Arms	Last month prevalence	35 (36.5%)
	Often or always	10 (28.6%)
	Intensity	3.0 (2.1)
	Interference	2.5 (2.0)
Wrist/hand	Last month prevalence	23 (24.0%)
	Often or always	11 (47.8%)
	Intensity	3.4 (2.1)
	Interference	2.6 (2.3)
Visual symptoms		3.1 (1.8)
Wearing glasses/ contact lenses		70 (72.9%)
Far (myopia)		61 (87.1%)
Near (hyperopia)		3 (4.3%)
Both		0 (0%)

Appendix AA Mean (standard deviation) and median (interquartile range) daily minutes of technology use across whole week, mean (standard deviation) daily minutes on weekdays and weekend days, and for boys and girls (across whole week usage)

	N for whole week	**Mean (SD) use across whole week (mins/day)**	**Median (IQR) use across whole week (mins/day)**	**Weekday (mins/day)**	**Weekend (mins/day)**	**Boys**	**Girls**
Smartphone	1836	264 (243)	180 (51-429)	254 (245)	287 (258)***	230 (233)	297 (249)***
Tablet	1848	53 (124)	2 (0-39)	47 (121)	67 (147)***	56 (129)	49 (118)
TV	1847	106 (138)	56 (17-137)	97 (138)	128 (168)***	109 (143)	103 (133)
Desktop	1855	33 (92)	0 (0-17)	28 (87)	44 (125)***	46 (115)	20 (60)***
Laptop	1834	63 (114)	15 (0-73)	56 (110)	82 (151)***	70 (126)	56 (100)
Handheld games	1870	7 (48)	0 (0-0)	6 (47)	9 (57)***	11 (63)	3 (24)***
Non-active game consoles	1851	18 (73)	0 (0-0)	15 (69)	27 (99)***	30 (94)	7 (40)***
Active game consoles	1857	8 (43)	0 (0-0)	6 (41)	11 (56)***	11 (57)	5 (21)*
#Total technology use	1746	537 (471)	411 (208-746)	503 (482)	638 (568)***	542 (513)	532 (426)

#Obtained by summing technology use for all the devices

*Significance values *p<.05 or ***p<.001 for differences between weekday and weekend days using Wilcoxon signed-rank test, and between boys and girls using Mann-Whitney U test*

Appendix BB Number (percentage) of students reporting multitasking some or most of the time during technology use, by gender and school level

	N for total	Total	Boys	Girls	Primary 5 (n=516)	Secondary 1 (n=530)	Secondary 3 (n=693)	Junior college 1 (n=145)
Smartphone	1866	1294 (69.4%)	615 (66.8%)	679 (71.9%)*	273 (53.2%)	371 (70.4%)	541 (79.1%)	109 (76.8%)***
Tablet	1839	567 (30.8%)	288 (31.5%)	279 (30.1%)	177 (44.6%)	160 (43.2%)	198 (45.4%)	32 (23.0%)*
TV	1859	1066 (57.3%)	487 (52.8%)	579 (61.9%)***	267 (52.1%)	287 (54.9%)	422 (62.0%)	90 (63.4%)**
Desktop	1840	425 (23.1%)	221 (24.2%)	204 (22.0%)	92 (18.0%)	98 (19.0%)	188 (27.8%)	47 (34.6%)***
Laptop	1855	775 (41.8%)	367 (40.1%)	408 (43.5%)	144 (28.1%)	196 (37.6%)	337 (49.5%)	98 (70.0%)***
Handheld game consoles	1864	104 (5.6%)	79 (8.5%)	25 (2.7%)***	23 (4.5%)	34 (6.5%)	37 (5.4%)	10 (7.0%)
Non-active game consoles	1860	212 (11.4%)	157 (17.0%)	55 (5.9%)***	40 (7.8%)	72 (13.7%)	86 (12.7%)	14 (10.0%)*
Active game consoles	1847	127 (6.9%)	73 (8.0%)	54 (5.8%)	31 (6.1%)	47 (9.0%)	40 (5.9%)	9 (6.5%)

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between boys and girls and differences among all the school levels using chi-square test*

Appendix CC Mean (standard deviation) and median (interquartile range) minutes of typical bout length of technology use, and mean (standard deviation) minutes for each gender and school level

	N for total	Mean (SD)	Median (IQR)	Boys	Girls	Primary 5	Secondary 1	Secondary 3	Junior college 1
Smartphone	1866	191 (221)	120 (30-300)	182 (216)	200 (216)	118 (176)	215 (227)	239 (239)	128 (173)***
Tablet	1806	69 (127)	15 (0-60)	75 (139)	63 (114)	81 (138)	77 (134)	62 (121)	28 (59)***
TV	1854	101 (133)	60 (30-120)	104 (140)	98 (125)	107 (136)	109 (141)	102 (133)	48 (49)***
Desktop	1805	58 (120)	5 (0-60)	74 (143)	42 (91)**	43 (105)	64 (134)	67 (127)	44 (70)
Laptop	1831	100 (148)	60 (5-120)	110 (164)	89 (129)	65 (125)	97 (151)	125 (160)	115 (121)***
Handheld games	1842	19 (79)	0 (0-0)	24 (88)	13 (68)***	19 (90)	21 (84)	19 (72)	9 (33)
Non-active console games	1834	42 (111)	0 (0-30)	65 (138)	20 (69)***	36 (107)	54 (129)	43 (107)	19 (49)*
Active console games	1812	29 (92)	0 (0-5)	34 (104)	23 (78)*	34 (107)	36 (108)	21 (68)	17 (55)

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between boys and girls using Mann-Whitney U test, and differences among all the school levels using Kruskal Wallis test*

Appendix DD   Number (percentage) of adolescents reporting each visual symptom

Visual symptoms	Total n=1860 n (%)
Eye strain	668 (35.9%)
Tiredness of eyes	1045 (56.2%)
Watering of eyes	407 (21.9%)
Redness of eyes	204 (11.0%)
Itching of eyes	439 (23.6%)
Blurring of vision	338 (18.2%)
Dry eyes	247 (13.3%)
Double vision	153 (8.2%)
Headache	562 (30.2%)

Appendix EE Unadjusted prospective associations between MTSD usage, bout length, types of activities and multitasking (at baseline) and musculoskeletal symptoms in the last 12 months (at follow-up)

	Smartphone					Tablet				
	Musculoskeletal symptoms in last 12 months (at follow-up)									
	Neck/ shoulder	**Upper back**	**Low back**	**Arms**	**Wrist/ hand**	**Neck/ shoulder**	**Upper back**	**Low back**	**Arms**	**Wrist/ hand**
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
MTSD usage										
Yes[a]	**1.68****	1.37	**2.24****	**1.51***	1.35	1.03	0.97	1.08	1.09	1.12
	(1.15-2.46)	(0.92-1.04)	**(1.39-3.62)**	**(1.03-2.22)**	(0.89-2.04)	(0.83-1.29)	(0.78-1.20)	(0.86-1.34)	(0.88-1.36)	(0.90-1.40)
Use duration	**1.07*****	**1.06*****	**1.05*****	**1.06*****	**1.04****	0.97	1.00	0.98	0.95	1.02
(hrs/day)	**(1.04-1.10)**	**(1.04-1.09)**	**(1.03-1.08)**	**(1.03-1.09)**	**(1.01-1.07)**	(0.92-1.03)	(0.95-1.05)	(0.93-1.04)	(0.90-1.00)	(0.97-1.07)
Bout length										
≥ 1 hour	**1.38****	**1.47****	1.14	**1.40****	**1.33***	1.13	1.11	**1.31***	1.22	1.20
	(1.11-1.72)	**(1.18-1.83)**	(0.91-1.43)	**(1.13-1.74)**	**(1.06-1.67)**	(0.92-1.40)	(0.90-1.36)	**(1.05-1.65)**	(1.00-1.50)	(0.98-1.48)
Types of activities										
Homework	**1.39****	**1.26***	**1.49*****	**1.38****	1.06	0.94	0.93	0.94	0.89	0.96
Yes[a]	**(1.12-1.74)**	**(1.02-1.57)**	**(1.19-1.86)**	**(1.11-1.70)**	(0.85-1.32)	(0.73-1.20)	(0.73-1.19)	(0.73-1.20)	(0.70-1.13)	(0.75-1.23)
Duration	1.01	1.03	1.04	1.00	1.01	1.03	1.01	1.05	0.94	1.06
(hrs/day)	(0.96-1.07)	(0.98-1.08)	(0.99-1.10)	(0.95-1.06)	(0.96-1.07)	(0.91-1.18)	(0.89-1.14)	(0.93-1.19)	(0.83-1.07)	(0.94-1.20)
Social activities	**2.44*****	**1.60****	**2.09*****	**2.12*****	**1.40***	1.10	1.08	1.12	1.08	0.98
Yes[a]	**(1.83-3.25)**	**(1.19-2.15)**	**(1.50-2.91)**	**(1.59-2.84)**	**(1.04-1.90)**	(0.86-1.41)	(0.85-1.38)	(0.87-1.43)	(0.85-1.38)	(0.76-1.25)
Duration	**1.05****	**1.05****	**1.06*****	**1.03***	**1.04***	0.99	1.01	1.03	1.00	1.06
(hrs/day)	**(1.02-1.09)**	**(1.01-1.08)**	**(1.03-1.10)**	**(1.00-1.07)**	**(1.00-1.07)**	(0.92-1.07)	(0.94-1.09)	(0.96-1.11)	(0.93-1.08)	(0.98-1.14)

Appendix EE Unadjusted prospective associations between MTSD usage, bout length, types of activities and multitasking (at baseline) and musculoskeletal symptoms in the last 12 months (at follow-up)

	Smartphone					Tablet				
	Musculoskeletal symptoms in last 12 months (at follow-up)									
	Neck/ shoulder	**Upper back**	**Low back**	**Arms**	**Wrist/ hand**	**Neck/ shoulder**	**Upper back**	**Low back**	**Arms**	**Wrist/ hand**
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
Games	1.03	1.11	1.23	1.16	1.07	0.90	0.94	0.80	0.99	0.98
Yes[a]	(0.81-1.31)	(0.88-1.41)	(0.97-1.57)	(0.92-1.46)	(0.84-1.36)	(0.72-1.13)	(0.71-1.16)	(0.63-1.01)	(0.80-1.24)	(0.78-1.23)
Duration	1.03	**1.06****	1.02	1.03	1.03	0.98	1.03	1.02	0.96	1.00
(hrs/day)	(0.98-1.07)	**(1.02-1.11)**	(0.98-1.06)	(0.99-1.08)	(0.99-1.07)	(0.91-1.05)	(0.96-1.10)	(0.95-1.10)	(0.90-1.03)	(0.93-1.08)
Watching videos	**1.48****	1.13	**1.77*****	**1.50****	1.06	1.02	0.97	0.97	1.09	1.09
Yes[a]	**(1.12-1.94)**	(0.86-1.48)	**(1.32-2.38)**	**(1.14-1.96)**	(0.80-1.40)	(0.81-1.28)	(0.78-1.21)	(0.78-1.22)	(0.88-1.36)	(0.87-1.37)
Duration	1.04	**1.06****	1.02	1.03	**1.04***	0.98	1.02	1.01	0.96	1.01
(hrs/day)	(1.00-1.08)	**(1.02-1.10)**	(0.98-1.06)	(0.99-1.07)	**(1.01-1.08)**	(0.92-1.04)	(0.96-1.08)	(0.96-1.07)	(0.91-1.02)	(0.95-1.07)
General use	**1.78*****	**1.59*****	**2.15*****	**1.89*****	**1.71*****	1.05	1.06	1.11	0.97	1.24
Yes[a]	**(1.41-2.23)**	**(1.26-2.00)**	**(1.68-2.75)**	**(1.51-2.37)**	**(1.35-2.17)**	(0.82-1.33)	(0.84-1.34)	(0.87-1.40)	(0.77-1.21)	(0.98-1.57)
Duration	1.05	**1.06***	1.02	1.02	1.01	1.03	1.05	1.04	1.02	1.01
(hrs/day)	(1.00-1.10)	**(1.01-1.10)**	(0.98-1.07)	(0.98-1.07)	(0.97-1.06)	(0.95-1.12)	(0.98-1.14)	(0.96-1.12)	(0.94-1.10)	(0.93-1.09)
Multitasking										
Yes[a]	**1.93****	1.50	**1.74***	**1.73***	1.36	1.17	1.00	1.06	1.22	0.92
	(1.25-2.99)	(0.98-2.31)	**(1.10-2.73)**	**(1.13-2.64)**	(0.88-2.11)	(0.78-1.75)	(0.68-1.48)	(0.71-1.58)	(0.83-1.79)	(0.62-1.38)
Extent of multitasking[b]	1.05	1.04	1.08	1.052	1.05	1.02	1.07	1.08	0.97	1.11
	(0.90-1.21)	(0.90-1.19)	(0.94-1.25)	(0.91-1.21)	(0.91-1.21)	(0.85-1.22)	(0.90-1.27)	(0.90-1.29)	(0.81-1.15)	(0.93-1.33)

*[a]ORs obtained from prevalence of smartphone/tablet use, participation in the types of activities and multitasking yes/no (with binary exposure variables); [b]among the categories of extent of multitasking (i.e. never; a little, some, or most of the time); *p<.05, **p<.01 or ***p<.001, significant findings in bold*

Appendix FF Unadjusted prospective associations between MTSD usage (at baseline) and visual health outcomes (at follow-up)

	Smartphone			Tablet		
	Visual health outcomes					
	Presence of visual symptoms	Wearing glasses/contact lenses	Myopia	Presence of visual symptoms	Wearing glasses/contact lenses	Myopia
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
MTSD usage						
Yes[a]	1.09 (0.70-1.70)	**1.53* (1.04-2.25)**	1.44 (0.97-2.12)	1.07 (0.82-1.39)	0.89 (0.71-1.11)	0.85 (0.68-1.07)
Use duration *(hrs/day)*	**1.05** (1.01-1.09)**	0.99 (0.96-1.01)	0.99 (0.96-1.01)	1.00 (0.93-1.06)	0.95 (0.90-1.00)	0.95 (0.90-1.00)

*[a]ORs obtained from prevalence of smartphone/tablet use yes/no model; *p<.05, **p<.01 or ***p<.001, significant findings in bold*

Appendix GG Minutes per day (median (IQR)) of MTSD usage and patterns of MTSD use at baseline and follow-up

Independent variables	Smartphone		Tablet	
	Baseline	Follow-up	Baseline	Follow-up
MTSD usage				
Use duration *(median (IQR))*	180 (51-420)	214 (86-420)	2 (0-39)	0 (0-17)
Bout length *(median (IQR)*	120 (30-300)	120 (30-240)	15 (0-60)	5 (0-60)
Types of activities				
Homework				
Duration *(median (IQR))*	11 (0-51)	15 (0-60)	0 (0-2)	0 (0-0)
Social activities				
Duration *(median (IQR)*	60 (11-197)	60 (17-197)	0 (0-3)	0 (0-0)
Games				
Duration *(median (IQR)*	26 (0-87)	26 (0-77)	0 (0-15)	0 (0-0)
Watching videos				
Duration *(median (IQR)*	60 (11-176)	77 (28-180)	0 (0-26)	0 (0-7)
General use				
Duration *(median (IQR)*	15 (0-60)	30 (1-77)	0 (0-4)	0 (0-0)

Appendix HH Change in severity index of musculoskeletal symptoms from baseline to follow-up

	Smartphone					Tablet				
Musculoskeletal symptoms	Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand	Neck/ shoulder	Upper back	Low back	Arms	Wrist/ hand
△ Severity index *(mean (SD))*										
Subgroup only[a]	+0.9 (7.6)	+0.6 (7.1)	+0.6 (6.9)	+0.8 (8.0)	+0.3 (7.1)	+0.8 (8.0)	+0.7 (7.1)	+0.8 (7.0)	+0.7 (7.8)	+0.4 (7.1)

△ changes in; [a]among participants who used smartphone/tablet at both baseline and follow-up

Appendix II Mean (standard deviation) daily minutes of smartphone/tablet use for each type of activities at baseline

		Across the whole week (mins/day)	**Weekday** (mins/day)	**Weekend** (mins/day)	**Boys** (mins/day)	**Girls** (mins/day)
Smart-phone	Homework	54 (117)	53 (119)	57 (129)	45 (109)	63 (124)***
	Social	150 (201)	145 (202)	161 (213)***	114 (173)	184 (221)***
	Videos	130 (174)	125 (176)	146 (188)***	120 (165)	141 (182)*
	Games	85 (152)	81 (153)	93 (163)***	106 (162)	63 (139)***
	General	75 (146)	73 (147)	79 (155)***	66 (139)	84 (153)***
Tablet	Homework	15 (53)	14 (54)	17 (64)***	15 (50)	14 (56)
	Social	24 (89)	24 (92)	27 (96)***	23 (87)	25 (91)
	Videos	45 (116)	41 (114)	55 (133)***	46 (117)	43 (115)
	Games	32 (95)	29 (95)	40 (111)***	43 (110)	21 (78)***
	General	23 (87)	22 (88)	26 (96)***	25 (96)	22 (78)

*Significance values *p<.05, **p<.01 or ***p<.001 for differences between weekday and weekend use and between boys and girls*

Appendix JJ Statement of contribution from co-authors

Curtin University

To: Whom It May Concern

For papers of joint authorship, the author attests to having completed the following aspects for each paper. I, Siao Hui TOH, contributed to conception, design, execution, data processing and analysis, and original manuscript writing and subsequent editing for the papers/publications entitled:

1. Toh SH, Coenen P, Howie EK, Straker LM (2017) The associations of mobile touch screen device use with musculoskeletal symptoms and exposures: A systematic review. *PloS One* 12: e0181220.

2. Toh SH, Howie EK, Coenen P, Straker LM (2019) "From the moment I wake up I will use it...every day, very hour": A qualitative study on the patterns of adolescents' mobile touch screen device use from adolescent and parent perspectives. *BMC Pediatrics* 19: 30.

3. Toh SH, Coenen P, Howie EK, Mukherjee S, Mackey DA, Straker LM (2019) Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents. *Ergonomics* 62: 778-793.

4. Chapter 4 - Study A2: Qualitative study on the discomfort and postures during MTSD use by adolescents (prepared for submission)

5. Chapter 6 - Study C: Prospective longitudinal associations of MTSD use with musculoskeletal symptoms and visual health (under journal review)

Siao Hui TOH

I, as Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

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To: Whom It May Concern

For papers of joint authorship, the author attests to having completed the following aspects for each paper. I, Siao Hui TOH, contributed to conception, design, execution, data processir and analysis, and original manuscript writing and subsequent editing for the papers/publications entitled:

1. Toh SH, Coenen P, Howie EK, Mukherjee S, Mackey DA, Straker LM (2019) Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents. *Ergonomic* 62: 778-793.

2. Chapter 6 - Study C: Prospective longitudinal associations of MTSD use with musculoskeletal symptoms and visual health (under journal review)

____ Siao Hui ___

Siao Hui TOH

I, as Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

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	10 June 2019
______David Mackey____________	________________________________
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Sent: 08/06/2019 09:25
To: plosone@plos.org
Subject: Request for permission to use article for PhD Thesis

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Correspondence with Springer Nature publisher

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From: noreply@salesforce.com on behalf of "Neil Castil" <neil.castil@springernature.com> <neil.castil@springernature.com>
Sent: Sunday, June 9, 2019 1:34 PM
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Neil Castil
Global Open Research Support Specialist
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Look forward to hearing from you soon, and thank you in advance for your consideration of my request.

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