Posture variation among office workers when using different information and communication technologies at work and away-from-work

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Abstract

Office workers perform tasks using different information and communication technologies (ICT) involving various postures. Adequate variation in postures and muscle activity is generally believed to protect against musculoskeletal complaints, but insufficient information exists regarding the effect on postural variation of using different ICT. Thus, this study among office workers aimed to determine and compare postures and postural variation associated with using distinct types of ICT. Upper arm, head and trunk postures of 24 office workers were measured with the Physiometer® over a whole day in their natural work and away-from-work environments. Postural variation was quantified using two indices; $APDF_{(90-10)}$ and $EVA_{(sd)}$. Various ICT had different postural means and variation. Paper-based tasks had more non-neutral, yet also more variable postures. Electronics-based tasks had more neutral postures, with less postural variability. Tasks simultaneously using paper- and electronics-based ICT had least neutral and least variable postures. Tasks without ICT usually had the most posture variability. Interspersing tasks involving different ICT could increase overall exposure variation among office workers and may thus contribute to musculoskeletal risk reduction.

Keywords: ICT, posture, exposure variation analysis, APDF

Practitioner Summary: This study in office workers assessed posture variation, believed to protect against musculoskeletal complaints. Electronics-based tasks had more neutral upper body postures but less posture variation than other tasks. Combining tasks based on different technologies could increase postural variation in and outside the job for office workers.

1. Introduction

Physical risk factors associated with the development of musculoskeletal disorders (MSDs) include constrained and awkward postures (van der Windt et al. 2000; Keyserling 2000; Gerr, Marcus, and Monteilh 2004) and duration of exposure to computer use (Griffiths, Mackey, and Adamson 2007; Katz et al. 2000; Korpinen, Pääkkönen and Gobba 2013; Village 2005). Amid the debate regarding thresholds for acceptable exposure amplitudes or durations of use, there is general emphasis on the importance of securing adequate variation in the postures associated with information and communication technology (ICT) use (Straker and Mathiassen 2009), based on the presumption that office work, and in particular computer-intensive tasks, are at great risk of not offering sufficient variation (Arvidsson, Hansson, Mathiassen and Skerfving,2006).

Variation refers to changes in exposures with respect to time (Mathiassen 2006). Postures with small or slow rates of change within a task or given time period lack variation and are sometimes referred to as 'static postures' (Briggs, Straker, and Greig 2004; Forde, Punnett, and Wegman 2002; Szeto, Straker, and O'Sullivan 2005). 'Static' postures have been linked to the development of musculoskeletal complaints (Wærsted, Bjørklund, and Westgaard 1991; Evans and Patterson 2000). Diversity relates to differences in postures used across subsequent tasks or time periods. Combining tasks with large diversity and/or large within-task variability can create a time line with substantial exposure variation (Mathiassen 2006), although the physiological effects of doing this are yet to be adequately characterised.

Various ergonomics interventions to reduce the risks associated with lack of postural variation have been discussed and trialed including; workstation redesign (Aarås et al. 2001; Liao and Drury 2000), job rotation (Fernström and Åborg 1999;

Richter et al. 2009) and changed work-rest schedules (Balci and Aghazadeh 2003; McLean et al. 2001); however, there have been a limited number of studies to date that have documented the effects of such initiatives in terms of metrics quantifying postural variation (Delisle et al. 2004).

Some studies have reported on within-subject, within-day variability of postures in different occupations, but rarely in office settings (Arvidsson et al., 2012; Arvidsson et al., 2006; Mathiassen, Moller, & Forsman, 2003; Mathiassen & Paquet, 2010; Paquet, Punnett, Woskie & Buchholz, 2005; Svendsen, Mathiassen, & Bonde, 2005; van der Beek et al., 1995; Wahlstrom et al., 2010). Only a few studies have assessed postural diversity among the different tasks within a job, despite this being necessary to determine the result of interspersing different tasks to provide exposure variation (Hye-Knudsen et al. 2004; Möller et al. 2004; Wahlström et al. 2010). Additionally, there are a limited number of studies that have considered after-work (Mork and Westgaard 2005) or non-occupational (Azar et al. 2010) exposures despite the importance of including non-work related tasks in determining the risk of musculoskeletal disorders (Vroman and MacRae 2001; Cole and Rivilis 2004; Fredriksson et al. 2000). Consequently, little is known about the postural diversity among individuals in response to the demands of a range of tasks over the full course of the day, and particularly so among office workers.

This study aimed to quantify the variation in a sample of university office workers' upper body postures when using different ICT over the course of one week day, including non-work time, and determine if there was a difference in posture variation associated with using different ICT.

2. Method

2.1. *Study design*

In this observational study, upper body postures adopted by office workers during the normal tasks they performed using different types of ICT, i.e. *Old-*, *New-*, *Combined-* and *Non-ICT* tasks - see classification definitions below – were measured for up to 12 hours during one week day. Tasks included those performed in naturalistic work locations and away-from-work locations, including the participants' community and home environments.

2.2. *Participants*

A convenience sample of 24 (12 female and 12 male) right-handed office workers at a public university with a mean (SD) age 38.5(8.4) years was recruited. Eligibility criteria included self-reported daily use of computer-based ICT at their workplace. Those with a congenital or acquired musculoskeletal disorder, or who wore bi-focal lenses, were excluded. The Curtin University Human Research Ethics Committee approved the study and participants provided written informed consent prior to data collection.

2.3. *Data collection*

Participants' dominant upper arm, head and upper trunk postures were recorded for up to a maximum of 12 hours (9am-9pm) during one week day; their standard work day was eight hours. Participants' tasks and type of ICT used were recorded at a one minute resolution by a trained observer in a HP Jornada 565™ personal data assistant (Hewlett Packard, Palo Alto, USA) using customised database software (PocketCreations™, OT International, Perth, Australia). Tasks were categorized as productive, self-care, leisure and instrumental activities of daily living, and use of ICT was noted in four categories (c.f. section 2.4). The task results are reported in detail elsewhere (Ciccarelli et al. 2011b). Postures were recorded (c.f.

section 2.5) simultaneous to task observations, which enabled calculation of posture amplitudes and variation for each ICT type used.

2.4. Measurement of ICT used

Observations recorded the nature of the task, task location and the types of ICT used in real time. Types of ICT were categorized as being *Old-, New-, Combined-* or *Non-ICT* (Ciccarelli et al. 2011b). Examples of paper-based *Old ICT* tasks included reading a book or writing with a pen. *New ICT* included electronic interfaces that were computer-based, e.g., involving a desktop, laptop or hand held computer, or non-computer based, e.g., using a telephone or watching television. *Combined ICT* included tasks involving simultaneous use of both *New* and *Old ICT,* such as using a keyboard/monitor to compose a document while referring to hard copy notes (i.e., a computer-based *Combined ICT* task) or talking on the telephone while handwriting notes (i.e., a non-computer-based *Combined ICT* task). *Non-ICT* tasks involved no form of paper- or electronic-ICT and examples include face-to-face meetings, eating a meal, playing sport, or driving a vehicle.

The resulting observation data file consisted of a continuous time-line of categorized ICT tasks registered at a minute-to-minute resolution, which could then be synchronized with posture measurements.

2.5. Kinematic measurement

Bi-planar electronic inclinometers (Physiometer PHY-400®, Premed A/S, Oslo, Norway) measured the position of the dominant upper arm, head and upper trunk relative to gravity, in the frontal and sagittal planes. The inclinometers were strapped in place on the lateral surface of the dominant upper arm midway between the elbow and shoulder, to the back of the head, and between the third and fifth thoracic vertebrae. Output was sampled at 10Hz, and stored temporarily in a small portable computer (HP 200LX Palmtop®, Hewlett Packard, Palo Alto, USA), worn in a pouch around the participant's waist.

The inclinometers had functional ranges of 120º and were adjusted to cover 90º flexion and 30º extension for arm, head and trunk, 90º arm abduction and 30º arm adduction, and 60º left and right lateral bending of the head and trunk. Postural calibration was performed with each participant standing upright facing forwards, with both arms hanging by the side. Some crosstalk between planes was observed; however, a validation study found the inclinometers were accurate to an acceptable level, in comparison to optical and electromagnetic motion analysis systems for movements of moderate velocity and range (Straker et al. 2010). Arm elevation angles with respect to the line of gravity were calculated from the quality controlled recordings of arm abduction and arm flexion values using spherical geometry algorithms. This procedure also reduced the effect of Physiometer crosstalk (Straker et al. 2010).

2.6. Data processing

Postural data from the entire 12 hour observation period for each participant were processed to create a line graph representation of the frontal and sagittal plane postures of the arm, head and trunk. Postures were calculated over the whole day, and also for each task stratified by ICT type using the time-coded text file describing the participant's tasks and ICT use throughout the day (cf. section 2.4.).

For each ICT type, mean postures and standard deviations were determined, as well as the cumulative amplitude probability distribution function (APDF). From this, the range between the 10th and 90th percentiles ($APDF_{(90-10)}$) was calculated as one index of variation. A higher $APDF_{(90-10)}$ indicates larger posture variation.

A second variation index based on exposure variation analysis (EVA) (Mathiassen and Winkel 1991) was calculated for posture variables within each ICT type to characterize the duration of uninterrupted periods spent in different posture categories. The EVA matrix comprised seven time period classes on a logarithmic scale (0-1, 1-3, 3-7, 7-15, 15-31, 31-63, 63+seconds). For the exposure amplitude in the EVA matrix, ten equidistant amplitude intervals across the 120º physiological range of movement were formed for each posture (upper arm, head, trunk). The standard deviation of the cell values of the EVA matrix ($EVA_{(sd)}$) was calculated to provide a crude, overall index of exposure variation. Low $EVA_{(sd)}$ values represent a broad dispersion of posture amplitudes and/or a broad range of durations that postures were kept within the same amplitude class and thus higher variation. High $EVA_{(sd)}$ values represent a limited spread of amplitude and/or durations and thus lower variation.

2.7. Statistical Analyses

Overall differences in mean, $APDF_{(90-10)}$ and $EVA_{(sd)}$ of the dominant upper arm, head and trunk postures between the four ICT types were determined using one-way repeated measures analysis of variance (RANOVA). Planned-pairwise comparisons compared each pair among the four ICT task categories for posture mean values, and for posture variation expressed by $APDF_{(90-10)}$ and $EVA_{(sd)}$. A $p < .05$ was used as the limit of significance, with probabilities between .10 and .05 noted as trends. No adjustment for multiple comparisons was used, to balance Type I and Type II errors (Bland and Altman 1995; Perneger 1998; Feise 2002). Sphericity was determined using Mauchly’s Test, prior to calculating within-participant tests. Where sphericity could not be assumed, results were adjusted using the Huynh-Feldt correction. Analyses were performed using the Statistical Package for the Social Sciences (SPSS; v.20).

3. Results

3.1. Time spent using different ICT across the day

In total, a mean (SD) of 642 (40) minutes of task observations and postural recordings were made per participant. This is less than the intended duration of 720 minutes, reflecting the time required to complete procedural tasks related to the study that were not part of the participant's daily routine, including changing batteries in the portable computer, saving data from the morning collection period, and checking the position and fixture of the postural monitoring equipment.

About two thirds of the observation time (mean (SD) = 432 (48) minutes) were spent at the participants' workplace, and one third (210 (28) minutes) of observations were in other locations including community and home environments. Observation data identified that the dominant combinations of ICT and location were *computer-based New ICT* tasks performed at work (mean 173 minutes), *Non-ICT* tasks at work and other locations (mean 135 minutes and 154 minutes respectively), and *Old ICT* tasks at work (mean 83 minutes). *Combined ICT* was used very briefly in all locations, with the highest mean of 19 minutes observed using paper and computer simultaneously at work.

3.2. Mean postures when using different ICT types

The mean (SD) of postures (in degrees) when using different types of ICT, and the RANOVA statistics are shown in Table 1. *Old ICT* had less neutral mean head and trunk postures than *New ICT* and *Non-ICT*. For example mean head flexion during *Old ICT* was 8.8º more than *New ICT* ($p<.001$) and 9.4º more than *Non-ICT* ($p<.001$). Similarly mean trunk flexion during *Old ICT* was 4.3º more than *New ICT* ($p=.007$) and 5.9º more than *Non-ICT* ($p<.001$). *New ICT* mean postures were not different to *Non-ICT* postures. *Combined ICT* mean head flexion was equally non-neutral as *Old ICT.*

Insert Table 1 about here

3.3. APDF$_{(90-10)}$ of postures when using different ICT types

Descriptive statistics of APDF$_{(90-10)}$ for the 'whole day' upper arm, head and trunk postures and during the different ICT tasks, with RANOVA summary statistics are reported in Table 2. *New ICT* tasks and *Combined ICT* tasks had least or equal least postural range, i.e. least variation, for all kinematic variables. For example, the mean range in arm elevation during *New ICT* tasks was 12.2º less than *Non-ICT* tasks ($p < .001$). The mean range of head flexion during *New ICT* tasks was 15.0º less than in *Old ICT* tasks ($p < .001$) and 10.4º less than *Non-ICT* tasks ($p < .001$). Trunk flexion during *New ICT* had a mean range 7.9 º less than during *Non-ICT* tasks ($p = .005$). The range of trunk lateral bending during *New ICT* was 13.8º less than during *Old ICT* ($p = .001$) and 15.3º less than during *Non-ICT* tasks ($p < .001$). *Old ICT* tasks had the greatest postural range for head postures; otherwise *Non-ICT* tasks had the greatest ranges.

Insert Table 2 about here

3.4. Standard deviation of Exposure Variation Analysis (EVA$_{(sd)}$) of postures

Descriptive statistics of $EVA_{(sd)}$ of upper arm, head and trunk postures for the 'whole day' recording period and during the different ICT tasks, with RANOVA summary statistics are in Table 3.

New ICT tasks and *Combined ICT* tasks often had greatest $EVA_{(sd)}$; i.e., least variation, for arm, head and trunk kinematic variables. For example, arm abduction during *New ICT* tasks had an $EVA_{(sd)}$ that was 0.8 %time more than *Old ICT* tasks (p = .035) and 1.6%time more than *Non-ICT* tasks (p <.001). Head flexion $EVA_{(sd)}$ during *New ICT* tasks was 0.5%time more than *Old ICT* tasks (p = .001) and *Non-ICT* tasks (p <.018). Trunk flexion $EVA_{(sd)}$ during *New ICT* tasks was 1.0%time more than during *Non-ICT* tasks (p <.011). Head posture variation was greatest according to $EVA_{(sd)}$ during *Old ICT* tasks, otherwise $EVA_{(sd)}$ showed greatest variation during *Non-ICT* tasks.

Insert Table 3 about here

4. Discussion

Our study demonstrated upper arm, head and trunk posture differences between ICT types, both in terms of mean postures used and with respect to within-task postural variation. Thus, interspersing ICT types represents a potential for enhanced overall postural variation for office workers.

4.1 Old vs New ICT tasks

Interestingly, the potentially beneficial task characteristics of neutral mean postures and greater postural variation typically did not co-occur within the same ICT task type. For example, head and trunk postures were often more neutral, but also less variable during *New ICT* tasks, compared with *Old ICT* tasks. This finding is consistent with a prior study on the impact of display height on posture when using different types of ICT (Straker et al. 2008) and suggests that the lower postural variability during *New ICT* tasks may reduce the benefits of the more neutral upper body postures associated with this ICT. There is a paucity of studies that have measured postural variability among office workers within workplace settings, against which we can compare our findings. A recent field study by Bruno Garza and colleagues (2012) measured variability of posture and muscle activity among computer operators performing their typical work duties in the workplace for durations of up to three hours. They identified that idle activities during computer work produced the largest variability in all upper body postures measured; however, in our study we did not differentiate periods of active keyboard and mouse use from idle periods where the hands either hovered over the keyboard or rested on the mouse.

The less neutral head postures during mainly computer-based *New ICT* tasks in our study were similar to the reported postures of other computer operators (Bruno Garza et al. 2012; Sommerich, Joines, and Psihogios 2001; Seghers, Jochem, and Spaepen 2003; Psihogios et al. 2001; Szeto, Straker, and O’Sullivan 2005; Arvidsson et al. 2006). Others have found that the most head extension and least postural variation in the neck or trunk of computer users during keyboarding tasks; while mouse use resulted in the least postural variability of the head (Bruno Garza et al. 2012).

We had anticipated less neutral arm postures, in addition to less neutral head and trunk postures, during *Old ICT* tasks compared to *New ICT* tasks but this was not the case. Examination of the recorded task observations suggested that similarities in mean arm elevations during *Old ICT* and *New ICT* tasks were a result of close positioning of the mouse to the keyboard, and stabilisation of the forearm on the desktop during both reading/writing and keyboard/mouse tasks. Bruno Garza et al (2012) reported small variability of the shoulder occurred during both mouse and keyboard use; a finding consistent with the stabilisation of the forearm to allow for neutral arm postures as observed in our study.

4.2 Combined ICT tasks

Whilst the potentially beneficial task characteristics of more neutral mean postures combined with greater variability did not co-occur, the potentially detrimental task characteristics of less neutral postures and less variability where both observed during *Combined ICT* tasks using paper and electronic interfaces simultaneously. Examination of the recorded task data suggested the poorer *Combined ICT* task postures were due to placement of the respective paper and electronic components. For example, when participants did perform *Combined ICT* tasks, the paper components were frequently placed on the desk, lateral to the keyboard and participants leaned laterally to the left to read from the paper copy, while their right hand remained anchored to the mouse or the keyboard. Although *Combined ICT* tasks showed both less neutral postures and less postural variation, the overall duration office workers were exposed to *Combined ICT* tasks was small over the whole day suggesting that for these workers *Combined ICT* tasks may only make a small contribution to MSD risk.

4.3 Non-ICT tasks

Non-ICT tasks were different from the other ICT types in terms of mean postures, and were thus a source of whole day postural variation for these office workers. Tasks such as toileting or consuming refreshments during scheduled or discretionary breaks, and walking between task locations involved mean arm elevation and head flexion values that were significantly different to *Old* and

Combined ICT tasks; and trunk flexion values different to the posture during *Old ICT* tasks. *Non ICT* tasks also often had the greatest within task variation.

Thus, according to the $APDF_{(90-10)}$ and $EVA_{(sd)}$ indices postural variation across the whole day increased for several posture variables when all tasks were included in the analysis as compared to using either type of ICT alone, due to both the diversity of *Non-ICT* task mean postures compared to other ICT tasks and the variability of postures within *Non-ICT* tasks.

Elevated arm postures during *Non-ICT* tasks related mainly to the handling of objects at a range of heights, including above shoulder. *Non-ICT* tasks observed thus included retrieving binders from above-shoulder height shelving in the office, or retrieving food preparation items during meal times from overhead kitchen cupboards. Low trunk flexion during *Non-ICT* tasks was associated with sitting or standing during meetings and self-care tasks, and when walking during, and between, tasks.

4.4 The trade-off between neutral and variable postures

Our finding that *New ICT* tasks were associated with more neutral mean postures but at the same time less variable postures, and that in contrast *Old ICT* and *Non-ICT* tasks were associated with less neutral mean postures but at the same time more variable postures, highlights the need to be cautious when attempting to classify the risk of MSDs based solely on mean postures. A review of workplace interventions aimed at reducing musculoskeletal symptoms among computers operators, found moderate evidence that workstation adjustments, and rest breaks combined with exercise, had no effect on musculoskeletal health (Brewer et al 2006). Future studies investigating the risk of MSDs associated with “awkward” postures or the efficacy of interventions to reduce MSDs, therefore need to measure both the mean and variability of postures throughout and after the work day.

4.5 Metrics of postural variation

Two metrics were used to quantify posture variation in our study. The $APDF_{(90\text{-}10)}$ range describes how much amplitude varies, and similar approaches have previously been used to measure postural variation (Arvidsson et al. 2006; Maslen and Straker 2009; Kazmierczak et al. 2005; Wahlström et al. 2010). The EVA method has been used in prior studies of postures of the upper arm (Möller et al. 2004), head (Bao, Mathiassen, and Winkel 1996; Straker et al. 2008), and trunk (Torgén, Nygård, and Kilbom 1995; Vi 2006; Jansen, Burdorf, and Steyerberg 2001); however, $EVA_{(sd)}$, is a relatively new index proposed to represent variation (Delisle et al. 2006; Maslen and Straker 2009; Ciccarelli et al. 2011a). $APDF_{(90\text{-}10)}$ considers variability in terms of the amplitude range only, whereas the $EVA_{(sd)}$ quantifies variability of both amplitude and the time spent at specific amplitude categories. For example, if there is variability in the duration of periods spent without interruption within different posture categories, the $EVA_{(sd)}$ index will be sensitive to this; whereas the $APDF_{(90\text{-}10)}$ index will not. However, $EVA_{(sd)}$ does not discriminate if the posture is across high amplitude or long duration cells of the matrix; both of which may present as a heightened risk for MSDs. Thus, the two indices describe different expressions of variation, but in our data they generally supported each other when determining variability. Further use of the two indices to quantify risk of developing MSDs requires investigation and validation in epidemiology studies to determine whether they can, indeed, be used as indicators of risk for MSDs, and if so, what range of postural risk thresholds would apply.

4.6 Limitations and strengths of the study

The Physiometer PHY-400® inclinometers on the upper arm had a linear response up to 73º relative to vertical above which there was a sudden drop in values (to 0º) as the inclinometer approached horizontal. Therefore postural values for arm abduction and arm flexion above 73º were underestimated leading to a potential underestimate of mean posture and posture variation. However, based on other studies among office workers we believe that these “extreme” upper arm angles did not occur much (Fernström and Ericson, 1996; Delisle et al. 2006; Szeto et al. 2005), and thus that our data were only marginally effected. Some cross talk was present between arm flexion and abduction which is why arm elevation was also determined based on previously reported methods that reduce the impact of this crosstalk (Bao, Mathiassen, and Winkel 1996; Hansson et al. 2006) and thus provide greater confidence in the findings related to arm elevation.

Direct observation *in situ* was necessary to capture information about tasks performed and ICT used and presence of the observer may have influenced participants’ postures and activities. However, throughout the observation and recording period participants adopted postures that were less than ideal, suggesting they were using their typical postures. Workers are likely to over-estimate durations of computer work (Heinrich, Blatter and Bongers 2004, IJmker et al. 2008), leading to under-estimation of a valid dose-response relationship between computer use and musculoskeletal symptoms (IJmker et al. 2010). In investigations of exposure and variation over long durations and/or where effects of the environment are to be considered, a field study is preferential to laboratory studies in order to increase representativeness of typical postures (Bruno Garza et al. 2012) or to self-reports of exposures in order to improve reliability of measurements (IJmker et al. 2010). However the labour intensiveness of this data collection method limited feasible monitoring to one day of direct posture measurement per participant. This limits the precision of estimates of individual participants' postures, and also implies that what seems to be variability between subjects may, to some extent, be variability between days of observation within subjects (Hansson et al. 2006; Mathiassen et al. 2006). Further, this study only examined 24 right-handed office workers at one organisation in one industry, and thus differences observed may not be generalisable to office workers irrespective of occupational setting.

The use of touch screen tablet computers was not observed during the data collection performed for this study in 2003, however these devices are likely to have an important impact on posture which should be investigated given the rapid growth in their occupational and leisure use.

Strengths of the study include the objective measures of posture simultaneously with task classification, the measure of both work and away-from-work 'whole day' postures and tasks in the natural environment of a considerable number of office workers, and the use of two novel indices to quantify postural variation.

5. Conclusion

The 24 office workers in our study used distinct ICT types to perform tasks at work and other locations over the course of one week day. Mean postures and posture variation differed between some of them.

New ICT tasks involved upper body postures that were more neutral than paper-based *Old ICT* tasks, although *Old ICT* tasks had greater posture variation. *Non-ICT* tasks often had the greatest postural variation and *Combined ICT* tasks involving simultaneous use of paper and electronic technology were often associated with the least neutral postures and the least variation. Interspersing tasks involving distinct ICT, in particular *Non-ICT* tasks, could increase overall whole-day exposure variation among office workers and may therefore be a useful strategy to reduce their risks for developing musculoskeletal complaints.

Acknowledgements

The authors thank Paul Davey for writing the LabVIEW™ software program used in data processing, and James Lyra for assistance with observations. A National Health and Medical Research Council of Australia Public Health Scholarship and a research grant from the Western Australian Occupational Therapists' Registration Board supported this study.

References

Aarås, A., G. Horgen, H. Bjørset, O. Ro, and H. Walsøe. 2001. "Musculoskeletal, Visual and Psychosocial Stress in VDU Operators Before and After Multidisciplinary Ergonomic Interventions. A 6-years Prospective Study - Part II." *Ergonomics* 32: 559-571.

Arvidsson, I., I. Balogh, I., G.-Å. Hansson, K. Ohlsson, I. Åkesson, & C. Nordander, 2012. "Rationalization in Meat Cutting - Consequences on Physical Workload." *Applied Ergonomics,* 43: 1026-1032.

Arvidsson, I., G-Å. Hansson, SE. Mathiassen, and S. Skerfving. 2006. "Changes in Physical Workload with Implementation of Mouse-Based Information Technology in Air Traffic Control." *International Journal of Industrial Ergonomics* 36: 613-622.

Azar, N. R., C.A. Godin, D.M. Andrews, and J.P. Callaghan. 2010. "Three-Dimensional Peak and Cumulative L4/L5 Spine Loads and Trunk Postures During Non-Occupational Tasks." *Occupational Ergonomics* 9: 127-139.

Balci, R., and F. Aghazadeh. 2003. "The Effect of Work-Rest Schedules and Type of Task on the Discomfort and Performance of VDT Users." *Ergonomics* 46: 455-465.

Bao, S., SE. Mathiassen, and J. Winkel. 1996. "Ergonomic Effects of a Management-Based Rationalization in Assembly Work - A Case Study." *Applied Ergonomics* 2789-99.

Bland, J., and D. Altman. 1995. "Multiple Significance Tests: The Bonferroni Method." *British Medical Journal* 310: 170.

Brewer, S., D Eerd, B.C. Amick III, E Irvin, K Daum, F Gerr, J Moore, K Cullen, and D Rempel. 2006. “Workplace Interventions to Prevent Musculoskeletal and Visual Symptoms and Disorders Among Computer Users: A Systematic Review. *Journal of Occupational Rehabilitation*, 16: 317-350.

Briggs, A., L. Straker, and A. Greig. 2004. "Upper Quadrant Postural Changes of School Children in Response to Interaction with Different Information Technologies." *Ergonomics* 47: 790-819.

Bruno Garza, J., B Eijckelhof, P Johnson, S Raina, P Rynell, M Huysmans, J van Dieën, A van der Beek, B Blatter, and J Dennerlein. 2012. “Observed Differences in Upper Extremity Forces, Muscle Efforts, Postures, Velocities and Accelerations Across Computer Activities in a Field Study of Office Workers.” *Ergonomics* 55: 670-681.

Ciccarelli, M., L. Straker, SE. Mathiassen, and C. Pollock. 2011a. "ITKids Part II: Variation of Postures and Muscle Activity in Children Using Different Information and Communication Technologies." *Work* 38:413-427.

Ciccarelli, M., L. Straker, SE. Mathiassen, and C. Pollock. 2011b. "Diversity of Occupations and Technologies Used by Office Workers At and Away From Work." *Ergonomics* 54: 1017-1028.

Cole, D., and I. Rivilis. 2004. "Individual Factors and Musculoskeletal Disorders: A Framework for Their Consideration." *Journal of Electromyography & Kinesiology* 14: 121-127.

Delisle, A., D Imbeau, B Santos, A Plamondon, and Y Montpetit. 2004. “Left-Handed Versus Right-Handed Computer Mouse Use: Effect on Upper-Extremity Posture.” *Applied Ergonomics 35*: 21-28.

Delisle, A., C. Larivière, A. Plamondon, and D. Imbeau. 2006. "Comparison of Three Computer Office Workstations Offering Forearm Support: Impact on Upper Limb Posture and Muscle Activation." *Ergonomics* 10: 139-60.

Evans, O., and K. Patterson. 2000. "Predictors of Neck and Shoulder Pain in Non-Secretarial Computer Users." *International Journal of Industrial Ergonomics* 26: 357-365.

Feise, R. 2002. "Do Multiple Outcome Measures Require P-Value Adjustment?" *BMC Medical Research Methodology* 2: 8.

Fernström, E., and C. Åborg. 1999. "Alterations in Shoulder Muscle Activity Due to Changes in Data Entry Organisation." *International Journal of Industrial Ergonomics* 23: 231-40.

Fernström, E., and M. Ericson. 1996. "Upper-arm elevation during office work." *Ergonomics*, 39: 1221-1230.

Forde, M., L. Punnett, and D.H. Wegman. 2002. "Pathomechanisms of Work-Related Musculoskeletal Disorders: Conceptual Issues." *Ergonomics* 45: 619-630.

Fredriksson, K., L. Alfredsson, C. Thorbjörnsson, L. Punnett, A. Toomingas, M. Torgén, and Å. Kilbom. 2000. "Risk Factors for Neck and Shoulder Disorders: A Nested Case-Control Study Covering a 24-Year Period." *American Journal of Industrial Medicine* 38: 516-528.

Gerr, F., M. Marcus, and C. Monteilh. 2004. "Epidemiology of Musculoskeletal Disorders Among Computer Users: Lesson Learned From the Role of Posture and Keyboard Use." *Journal of Electromyography & Kinesiology* 14: 25-31.

Griffiths, K., M. Mackey, and B. Adamson. 2007. "The Impact of a Computerized Work Environment on Professional Occupational Groups and Behavioural and Physiological Risk Factors for Musculoskeletal Symptoms: A Literature Review." *Journal of Occupational Rehabilitation* 17: 743-765.

Hansson, G-Å., I. Arvidsson, K. Ohlsson, C. Nordander, SE. Mathiassen, S. Skerfving, and I. Balogh. 2006. "Precision of Measurements of Physical Workload During Standardised Manual Handling. Part II: Inclinometry of Head,Upper Back, Neck and Upper Arms." *Journal of Electromyography & Kinesiology* 16: 125-136.

Heinrich, J., B. Blatter, and P. Bongers. 2004. "A Comparison of Methods for the Assessment of Postural Load and Duration of Computer Use." *Occupational and Environmental Medicine*, 61:1027-1031.

Hye-Knudsen, C., B. Schibye, N. Hjortskov, and N. Fallentin. 2004. "Trunk Motion Characterstics During Different Patient Handling Tasks." *International Journal of Industrial Ergonomics* 33: 327-337.

IJmker, S., M Huysmans, A van der Beek, D Knol, W van Mechelen, P Bongers, and B Blatter. 2010. "Software-Recorded and Self-Reported Duration of Computer Use in Relation to the Onset of Severe Arm-Wrist-Hand Pain and Neck-Shoulder Pain." *Occupational and Environmental Medicine* 68, 502-509.

Ijmker, S., J Leijssen, B Blatter, A van der Beek, W van Mechelen, and P Bongers. 2008. "Test-Retest Reliability and Validity of Self-Reported Duration of

Computer Use at Work.” *Scandinavian Journal of Work, Health & Environment* 34: 113-119.

Jansen, J.P., A. Burdorf, and E. Steyerberg. 2001. "A Novel Approach for Evaluating Level, Frequency and Duration of Lumbar Posture Simultaneously During Work." *Scandinavian Journal of Work, Environment and Health* 27: 373-380.

Katz, J., B.C. Amick, B. Carroll, C. Hollis, A. Fossel, and C. Coley. 2000. "Prevalence of Upper Extremity Musculoskeletal Disorders in College Students." *American Journal of Medicine* 109: 586-588.

Kazmierczak, K., SE. Mathiassen, M. Forsman, and J. Winkel. 2005. "An Integrated Analysis of Ergonomics and Time Consumption in Swedish 'Craft-Type' Car Disassembly." *Applied Ergonomics* 36: 263-273.

Keyserling, W. 2000. "Workplace Risk Factors and Occupational Musculoskeletal Disorders, Part 1: A Review of Biomechanical and Psychophysical Research on Risk Factors Associated with Low-Back Pain." *AIHAJ: Journal for the Science of Occupational and Environmental Health and Safety* 61: 39-50.

Korpinen, L., R Pääkkönen, and F Gobba. 2013. “Self-Reported Neck Symptoms and Use of Personal Computers, Laptops and Cell Phones Among Finns Aged 18-65.” *Ergonomics* 56: 1134-1146.

Liao, M-H., and C.G. Drury. 2000. "Posture, Discomfort and Performance in a VDT Task." *Ergonomics* 43: 345-359.

Maslen, B., and L. Straker. 2009. "A Comparison of Posture and Muscle Activity Means and Variation Amongst Young Children, Older Children and Young Adults Whilst Working with Computers." *Work* 32: 311-320.

Mathiassen, SE. 2006. "Diversity and Variation in Biomechanical Exposure: What is it, and Why Would We Like to Know?" *Applied Ergonomics* 37: 419-427.

Mathiassen, SE., T. Möller, and M. Forsman. 2003. "Variability in Mechanical Exposure Within and Between Individuals Performing a Highly Constrained Industrial Work Task." *Ergonomics* 46: 800-824.

Mathiassen, SE., and V. Paquet. 2010. "The Ability of Limited Exposure Sampling to Detect Effects of Interventions that Reduce the Occurrence of Pronounced Trunk Inclination." *Applied Ergonomics* 41: 295-304.

Mathiassen, SE., and J. Winkel. 1991. "Quantifying Variation in Physical Load Using Exposure-Vs-Time Data." *Ergonomics* 34: 1455-1468.

McLean, L., M. Tingley, R. Scott, and J. Rickards. 2001. "Computer Terminal Work and the Benefit of Microbreaks." *Applied Ergonomics* 32: 225-237.

Möller, T., SE. Mathiassen, H. Franzon, and S. Kihlberg. 2004. "Job Enlargement and Mechanical Exposure Variability in Cyclic Assembly Work." *Ergonomics* 47: 19-40.

Mork, P., and R. Westgaard. 2005. "Long-Term Electromyographic Activity in Upper Trapezius and Low Back Muscles of Women with Moderate Physical Activity." *Journal of Applied Physiology* 99: 570-578.

Paquet, V, L Punnett, S Woskie, and B Buchholz. 2005. "Reliable Exposure Assessment Strategies for Physical Ergonomics Stressors in Construction and Other Non-Routinized Work." *Ergonomics* 48: 1200-19.

Perneger, T. 1998. "What's Wrong with Bonferroni Adjustments?" *British Medical Journal* 316: 1236–1238. .

Psihogios, J , C Sommerich, G Mirka, and S Moon. 2001. "A Field Evaluation of Monitor Placement Effects in VDT Users." *Applied Ergonomics* 32: 313-25.

Richter, J, S Mathiassen, H Slijper, E Over, and M Frens. 2009. "Differences in Muscle Load Between Computer and Non-Computer Work Among Office Workers." *Ergonomics* 52: 1540-1555.

Seghers, J, A Jochem, and A Spaepen. 2003. "Posture, Muscle Activity and Muscle Fatigue in Prolonged VDT Work at Different Screen Height Settings." *Ergonomics* 46: 714-730.

Sommerich, C, S Joines, and J. Psihogios. 2001. "Effects of Computer Monitor Viewing Angle and Related Factors on Strain, Performance, and Preference Outcomes." *Human Factors* 43: 39-55.

Straker, L., R. Burgess-Limerick, C. Pollock, K. Murray, K. Netto, J. Coleman, and R. Skoss. 2008. "The Impact of Computer Display Height and Desk Design on 3D Posture During Information Technology Work by Young Adults." *Journal of Electromyography and Kinesiology* 18: 336-349.

Straker, L., A. Campbell, J. Coleman, M. Ciccarelli, and W. Dankaerts. 2010. "In Vivo Laboratory Validation of the Physiometer: A Measurement System for Long Term Recording of Posture and Movements in the Work Place." *Ergonomics* 53: 672-684.

Straker, L., and SE. Mathiassen. 2009. "Increased Physical Work Loads in Modern Work – A Necessity for Better Health and Performance?" *Ergonomics* 52: 1215-1225.

Svendsen, S., SE. Mathiassen, and J. Bonde. 2005. "Task Based Exposure Assessment in Ergonomic Epidemiology: A Study of Upper Arm Elevation in the Jobs of Machinists, Car Mechanics, and House Painters." *Occupational and Environmental Medicine* 62: 18-27.

Szeto, G., L. Straker, and P. O'Sullivan. 2005. "A Comparison Of Symptomatic and Asymptomatic Office Workers Performing Monotonous Keyboard Work—2: Neck and Shoulder Kinematics." *Manual Therapy* 10: 281-291.

Torgén, M., C-H. Nygård, and Å. Kilbom. 1995. "Physical Work Load, Physical Capacity and Strain Among Elderly Female Aides in Home-Care Service." *European Journal of Applied Physiology* 71: 444-452.

van der Beek, A., J. Kuiper, M. Dawson, A. Burdorf, P. Bongers, and M. Frings-Dresen. 1995. "Sources of Variance in Exposure to Nonneutral Trunk Postures in Varying Work Situations." *Scandinavian Journal of Work, Health & Environment* 21: 215-22.

van der Windt, D., E. Thomas, D. Pope, A. de Winter, G. MacFarlane, L. Bouter, and A.J. Silman. 2000. "Occupational Risk Factors for Shoulder Pain: A Systematic Review." *Occupational and Environmental Medicine* 57: 422-442.

Vi, P. 2006. "A Field Study Investigating The Effects of a Rebar-Tying Machine on Trunk Flexion, Tool Usability and Productivity." *Ergonomics* 49: 1437-1455.

Village, J. 2005. "Musculoskeletal Disorders of the Upper Extremity Associated with Computer Work: A Systematic Review." *Occupational Ergonomics* 5: 205.

Vroman, K., and N. MacRae. 2001. "Non-Work Factors Associated with Musculoskeletal Upper Extremity Disorders Among Women: Beyond the Work Environment." *Work* 17: 3-9.

Wærsted, M., R. Bjørklund, and R. Westgaard. 1991. "Shoulder Muscle Tension Induced By Two VDU-Based Tasks of Different Complexity." *Ergonomics* 34: 137-150.

Wahlström, J., SE. Mathiassen, P. Liv, P. Hedlund, C. Ahlgren, and M.Forsman. 2010. "Upper Arm Postures and Movements in Female Hairdressers Across Four Full Working Days." *Annals of Occupational Hygiene* 1-11

Table captions

Table 1. Group mean (SD between participants) of individual mean postures across the whole day and when using different ICT types.

Table 2**.** Group mean (SD between participants) of individual $APDF_{(90\text{-}10)}$ range of postures across the whole day and when using different ICT types

Table 3. Group mean (SD between participants) of posture EVA standard deviations ($EVA_{(sd)}$) across the whole day and when using different ICT types

Table 1. Group mean (SD between participants) of individual mean postures (degrees with respect to calibrated neutral [zero] posture) across the whole day and when using different ICT types.

Posture	Whole day	ICT Type: Old	New	Combined	Non	RANOVA
Arm Abduction	13.4 (5.0)	12.3 (5.0)[a]	13.0 (6.0)[a]	12.5 (6.7)[a]	13.6 (5.6)[a]	$F_{2.5, 55.0}$ = 0.46; p = .674
Arm Flexion	10.4 (3.5)	7.0 (5.6)[a]	10.0 (6.3)[a,b]	7.9 (9.1)[a,b]	11.6 (4.7)[b]	$F_{2.1, 46.5}$ = 3.09; p = .053
Arm Elevation	18.8 (3.7)	16.8 (4.4)[a]	18.1 (5.3)[a,b]	16.8 (6.7)[a]	20.0 (4.5)[b]	$F_{2.0, 44.4}$ = 2.88; p = .066
Head Flexion	9.7 (6.1)	17.6 (8.6)[a]	8.8 (6.7)[b]	16.6 (12.3)[a]	8.2 (6.2)[b]	$F_{2.3, 50.9}$ = 15.23; p <.001
Head Lateral Bending	-0.5 (4.2)	2.2 (5.8)[a]	-0.8 (3.9)[b,c]	1.6 (8.7)[ac]	-1.2 (4.5)[b]	$F_{1.9, 41.2}$ = 4.98; p = .013
Trunk Flexion	11.8 (5.7)	16.7 (7.0)[a]	12.2 (6.9)[b]	12.1 (7.0)[b]	10.8 (5.6)[b]	$F_{3, 66.0}$ = 9.46; p < .001
Trunk Lateral Bending	0.7 (3.8)	1.7 (6.0)[a]	0.4 (3.6)[ab]	1.1 (4.2)[ab]	0.6 (4.2)[b]	$F_{1.6, 35.3}$ = 0.86; p = .411

Negative values for head and trunk lateral bending indicate bending to the left.

[a,b,c] ICT type categories sharing the same letter were not significantly different; (planned contrast, p ≤ .05).

Table 2. Group mean (SD between participants) of individual $APDF_{(90-10)}$ range of postures (degrees with respect to calibrated neutral [zero] posture) across the whole day and when using different ICT types

		ICT Type				RANOVA
Posture	Whole Day	Old	New	Combined	Non	
Arm Abduction	28.6 (8.8)	24.1 (8.0)^{a}	21.9 (8.7)^{a}	20.1 (9.4)^{a}	33.0 (11.0)^{b}	$F_{2.5, 55.7}$ = 9.78; p < .001
Arm Flexion	45.4 (8.9)	37.7 (7.6)^{a}	36.0 (10.4)^{a}	32.9 (11.0)^{a}	51.8 (11.0)^{b}	$F_{3,66}$ = 20.18; p < .001
Arm Elevation	34.4 (7.4)	27.5 (6.7)^{a}	26.2 (8.7)^{a,b}	22.1 (8.9)^{b}	40.3 (9.5)^{c}	$F_{3,66}$ = 20.46; p < .001
Head Flexion	40.7 (7.5)	46.6 (10.0)^{a}	31.6 (9.8)^{b}	35.2 (16.4)^{b,c}	42.0 (8.2)^{a,c}	$F_{2.1, 47.1}$ = 11.08; p < .001
Head Lateral Bending	24.9 (5.5)	30.5 (6.7)^{a}	18.3 (6.3)^{b}	20.1 (8.0)^{b}	26.3 (5.8)^{c}	$F_{3,66}$ = 22.61; p < .001
Trunk Flexion	33.7 (11.0)	30.0 (9.8)^{a}	27.1 (9.4)^{a}	22.8 (10.9)^{b}	35.0 (12.5)^{c}	$F_{3,66}$ = 9.35; p < .001
Trunk Lateral Bending	17.8 (10.7)	17.3 (9.9)^{a}	3.5 (1.5)^{b}	12.4 (6.0)^{c}	18.8 (10.9)^{a}	$F_{1.6, 36.2}$ = 23.00; p < .001

$APDF_{(90-10)}$ values increase when variation increases.

[a,b,c] ICT type categories sharing the same letter were not significantly different; (planned contrast, p ≤ .05).

Table 3. Group mean (SD between participants) of posture EVA standard deviations of the cells in the EVA matrix ($EVA_{(sd)}$) across the whole day and when using different ICT types

	Whole Day	ICT Type				RANOVA
		Old	New	Combined	Non-ICT	
Arm Abduction	3.2 (0.7)	3.6 (0.8)^a	4.4 (1.5)^b	4.9 (1.6)^b	2.8 (0.5)^c	$F_{2.4, 53.4} = 16.84; p < .001$
Arm Flexion	2.2 (0.4)	2.9 (0.8)^a	2.9 (1.0)^a	3.7 (1.3)^b	2.2 (0.3)^c	$F_{3, 66} = 17.55; p < .001$
Arm Elevation	1.8 (0.3)	2.3 (0.5)^a	2.2 (0.7)^a	3.3 (1.5)^b	2.0 (0.3)^a	$F_{1.7, 36.6} = 11.66; p < .001$
Head Flexion	2.3 (0.3)	2.3 (0.4)^a	2.8 (0.4)^b	3.2 (0.9)^c	2.5 (0.2)^a	$F_{1.7, 37.2} = 14.38; p < .001$
Head Lateral Bending	2.7 (0.3)	2.6 (0.4)^a	3.0 (0.3)^b	3.4 (0.6)^c	3.0 (0.3)^b	$F_{2.5, 54.7} = 15.84; p < .001$
Trunk Flexion	2.7 (0.8)	3.0 (0.7)^a	3.7 (1.6)^a	4.7 (1.8)^b	2.7 (0.8)^c	$F_{2.2, 48.3} = 14.33; p < .001$
Trunk Lateral Bending	3.2 (0.9)	3.3 (0.7)^a	3.7 (1.5)^{a,b}	4.6 (2.1)^b	3.0 (0.4)^c	$F_{1.9, 41.2} = 7.96; p = .001$

$EVA_{(sd)}$ values decrease when variation increases.

^{a,b,c,d} ICT type categories sharing the same letter were not significantly different; (planned contrast, $p \leq .05$).