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Title

Barriers and facilitators of physical activity participation in adults living with type 1 diabetes:

A systematic scoping review.

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Abstract

To identify and map barriers and facilitators of physical activity (PA) in adults living with type 1 diabetes (T1D) in any care setting or environment.

A scoping review was conducted in accordance with the PRISMA-ScR guidelines to address the aim of this review. Exclusion / inclusion criteria were determined a priori. Articles captured in the search were subject to title and abstract screening before full text articles were assessed for eligibility against the exclusion / inclusion criteria. Included articles underwent critical appraisal before being charted, mapped, and discussed.

Forty-six articles were included in the final synthesis. Most commonly, articles reported cross-sectional survey studies (46%), then qualitative designs (17%), and opinion or text (17%). Experimental studies accounted for 13% of included articles. *Fear of hypoglycaemia / hypoglycaemia* was the most commonly reported barrier and *patient education* the most commonly discussed facilitator. Quality appraisal revealed methodological issues among included articles.

Higher quality research with theoretically sound behaviour change interventions combined with targeted patient education is needed to address fear of hypoglycaemia / hypoglycaemia as a barrier to PA.

Novelty bullets

- Hypoglycaemia and fear of hypoglycaemia were the most commonly reported barriers to physical activity in adults with T1D
- Powered RCTs are required to establish efficacy of behaviour change interventions targeting these barriers to physical activity

Keywords: Adult; Barriers; Exercise; Facilitators; Scoping review; Type 1 diabetes

Introduction

Physical Activity (PA) has long been recommended to people living with type 1 diabetes (T1D), owing to its positive effects on HbA1c, cardiovascular health, and insulin-dose requirements (Yardley, Hay, Abou-Setta, Marks, & McGavock, 2014). Physical activity is included as an essential management strategy in recommendations by various international bodies (Colberg et al., 2016; Craig et al., 2011; Diabetes Canada Clinical Practice Guidelines Expert Committee, 2018; National Institute for Health and Care Excellence, 2018). It is recommended people living with T1D engage in at least 150 minutes per week of moderate intensity PA, participate in resistance training on two days per week, and limit sitting time (Colberg et al., 2016).

Despite the benefits of PA, rates of inactivity in the T1D population are higher than those found in the general population. Internationally, studies have acknowledged 65% to 82% of T1D study participants did not meet national PA guidelines, compared to between 48% to 61% in the general population (Bohn et al., 2015; Clarke, Norris, & Schiller, 2017; McCarthy, Whittemore, & Grey, 2016; Plotnikoff et al., 2006; Speight et al., 2011; World Health Organisation, 2016). Both groups are likely to share similar barriers to PA, however the reported higher rates of inactivity for people living with T1D suggest there may be additional considerations.

Physical activity is a challenging aspect of diabetes management as it can result in dramatic fluctuations of blood glucose levels during and up to at least 24 hours after activity. The rate of blood glucose rise, or fall will depend on the duration, intensity, and type of activity. Without careful adjustment of insulin and / or carbohydrate in response to these factors, rapid fluctuations in blood glucose can occur, often resulting in hyper or hypoglycaemia (Michael

C. Riddell et al., 2017). This complex adjustment requires knowledge, well developed self-management skills, and planning from the person living with T1D. It is conceivable that people living with T1D may choose to avoid PA to obviate the unpleasant extremes of hyper and hypoglycaemia. These unique challenges are not addressed by generic, whole population PA campaigns, nor programs targeting non-specific diabetes cohorts.

Systematic reviews in the area of T1D and PA participation in the past decade have largely focused on child and adolescent populations (Pillay et al., 2015). We identified one systematic review that examined diabetes self-management education programs, targeting several self-management behaviours and outcomes in T1D participants of all ages (Pillay et al., 2015). The review concluded there was insufficient strength of evidence to comment on PA outcomes in the adult population. We did not locate any systematic reviews synthesising literature on barriers to PA and facilitators specifically targeting PA behaviour in the adult T1D population.

Our scoping review aims to systematically map the literature on barriers and facilitators of PA in T1D. We elected to conduct a scoping review due the emerging nature of this field as well as the heterogeneity among a small number of studies identified in previous limited searches of the literature (Brennan & Brown, 2019). This review will provide initial insights into the source and quality of existing evidence as well as identify gaps in the evidence. We aim to provide a better understanding of the issues faced by people living with T1D in order to guide future research and interventions to support PA in the T1D population.

Review question

What are the barriers and facilitators of PA participation in adults aged 18 years and over, living with T1D in any environment or care setting?

A preliminary search of PROSPERO, the Cochrane Database of Systematic Reviews and the Joanna Briggs Institute (JBI) Database of Systematic Reviews and Implementation Reports was conducted, and no current or planned scoping reviews or systematic reviews exclusively exploring physical activity participation in T1D were found. Subsequently, this review was registered with the JBI database in February 2019 and has been executed in accordance with the protocol, JBISRIR-D-19-00219R1 (Brennan, Brown, Ntoumanis, & Leslie, 2020).

Methods

This review was conducted and reported in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) checklist (Tricco, Lillie, Zarin, & et al., 2018) (reported in Supplementary Table S1) and the JBI methodology for scoping reviews (Peters et al., 2020). The PRISMA-ScR checklist explains that critical appraisal of included articles is an optional item of the checklist; a view shared by JBI (Peters et al., 2020; Tricco et al., 2018). We have opted to include critical appraisal in order to provide the reader with a better understanding of the reliability, rigour, and overall standing of included articles.

Selection criteria

Concepts

Articles that explored *barriers to PA participation* and / or *facilitators of PA participation* were considered for inclusion in this review. *Barriers to PA* as a concept incorporated articles exploring problems, issues, challenges, and/or difficulties with PA participation. The concept

facilitators of PA referred to programs, interventions, or factors that may improve PA participation.

We acknowledge there is literature examining effective methods to manage blood glucose levels for PA however, these are outside the scope of this review. Our focus was on barriers to and facilitators of participation in PA rather than to achieve glycaemic control. Our review included articles that examined PA participation or intention to participate in PA as outcomes. Where fitness or glycaemic biomarkers (for example, glycated haemoglobin) were the only reported outcome measures, the study was excluded.

Context

Studies or articles that sampled from all care settings, including in-patient, out-patient, primary care, and or community settings were considered in this review. Articles were not excluded based on geographical location.

Population

Articles sampled participants of any gender, over the age of 18 years, living with T1D. Further clarification was sought from authors where details, specific to these participant features, could not be extracted and interpreted independently. If such clarification could not be obtained, the article was excluded. By way of example, for a study with a sample including participants with both type 1 and type 2 diabetes, we sought to obtain details specific to the T1D participants.

Types of sources

Articles reporting research using quantitative, qualitative, and mixed methods study designs were considered for inclusion, as were systematic reviews and text and opinion papers. Articles were limited to those published in English between 1996 to March 2020, as the first

analogue insulin was approved in 1996 which subsequently changed the course of T1D management (Quianzon & Cheikh, 2012). Every attempt was made to source full text copies of articles by searching the University library catalogue, journal archives, Google and Google Scholar, as well as contacting authors where contact details were provided. Articles were excluded when full text copies could not be obtained.

Search strategy and article selection

An experienced university health librarian was consulted during the search phase. Using key words from the review question (type 1 diabetes; PA; barriers; correlates; facilitators), an initial limited search of MEDLINE (Ovid) and CINAHL full text (EBSCO) was undertaken. Text words contained in the titles and abstracts of relevant records found in MEDLINE and CINAHL and the index terms were used to develop a full search strategy (Supplementary Table S2). The search strategy was adapted for each of the following searched information sources; CINAHL full text (EBSCO); MEDLINE (Ovid); Web of Science (Clarivate Analytics); Scopus (Elsevier); PsychINFO (Ovid), and PubMed (NCBI). Guided by the Canadian Agency for Drugs and Technologies in Health (CADTH) Checklist (Canadian Agency for Drugs and Technologies in Health, 2018), sources of unpublished literature and grey literature were searched. Additional sources searched, that did not appear on the CADTH Checklist, included government health websites (Australian National Diabetes Strategy), The Australian Centre for Behavioural Research in Diabetes, Exercise and Sports Science Australia, and the Australian Diabetes Educator publication. The reference lists of all articles selected for critical appraisal were screened for additional articles meeting the inclusion criteria.

Following the search, all identified articles were collated and uploaded into EndNote X9 1.1 (Clarivate Analytics, PA, USA), and duplicates removed. As per the PRISMA-ScR checklist (Moher, Liberati, Tetzlaff, Altman, & The Prisma Group, 2009), titles and abstracts were then screened by two independent reviewers for assessment against the inclusion / exclusion criteria for the review. Remaining articles were then retrieved in full and their citation details imported into the Joanna Briggs Institute System for the Unified Management, Assessment and Review of Information (JBI SUMARI) (Joanna Briggs Institute, Adelaide, Australia) (Munn et al., 2019). These full text articles were assessed for eligibility by the same two independent reviewers (author initials to be added following blind, peer review). Corresponding authors were contacted when clarification was necessary. Reasons for exclusion of full text articles that did not meet the inclusion criteria were recorded and reported; any disagreements that arose between the reviewers at each stage of the article selection process were resolved through discussion or referral to a third reviewer if required.

Assessment of methodological quality

Eligible articles were critically appraised by two independent reviewers for methodological quality using standardised critical appraisal instruments from the JBI for observational, review, text and opinion pieces, qualitative, experimental, and quasi-experimental studies (Joanna Briggs Institute, 2017). Questions within each critical appraisal tool attracted a score of one (reflecting the criterion was met) or zero (reflecting either the criterion was not met, or it was unclear to the reviewers). The maximum score corresponds to the number of questions excluding those marked *not applicable* (N/A). Disagreement resolution followed the process explained in article selection. A constellation of critical appraisal tables can be viewed in

Supplementary Tables S3.1-S3.6. A minimum quality threshold for article inclusion was not enforced.

Data extraction and presentation

Data were extracted from included papers using a customised extraction instrument we developed (Supplementary Table S4). The review team trialled the data extraction tool detailed in the review protocol (Brennan et al., 2020) on six articles to ensure all relevant results were extracted (Peters et al., 2020). Modifications included adding 'study aims', 'recruitment methodology', and 'intervention / control' (where appropriate), while definitions of each of these headings were refined.

The extracted data is presented in tabular and diagrammatic (mind map) form in a manner that aligns with the aim of this scoping review. Characteristics of each article including study design, sample size, concepts explored, and critical appraisal score are described in Table 1. Individual sources of evidence are presented (Supplementary Table S5), describing the aims, design, participants or population, intervention and or control, and key findings of each article. The mind map synthesises the literature by grouping barriers and facilitators of PA (Tricco et al., 2018). Included articles may have examined one or a combination of these concepts, therefore the totals included in the mind map may not equate to the number of articles included. All individually reported barriers and facilitators of PA were listed prior to establishing and grouping like list items within each concept. For each barrier and facilitator group, the size of the mind map bubble is influenced by the number of articles that identified this group. An indication is provided for each barrier group as to the portion of articles using quantitative, qualitative or opinion outputs, or in the case of *facilitators*, themes that were

trialled versus suggested. Trialled facilitators used experimental designs to empirically derive efficacy and suggested facilitators were proposed by authors as potential facilitators.

Results

Article inclusion

Databases were searched on 3rd February 2020 and identified 4,792 records – see adapted PRISMA flow diagram in Figure 1. The corresponding authors of seven individual papers were contacted to request missing or additional data for clarification. Three authors replied to this request, none of whom provided information sufficient for inclusion. We were unable to contact the remaining four authors. A total of 46 articles were included in the final synthesis.

Characteristics of included articles

Of the 46 articles included in this review, all were placed in the community setting, 11 (24%) of which were more specific in detailing their location as community out-patient clinics. Most were located in the United Kingdom (n=11, 24%), Canada (n=10, 22%) and the USA (n=9, 20%). Table 1 shows most commonly, articles reported cross-sectional survey studies (46%), followed by qualitative designs (17%), and opinion or text (17%). For those studies that included research participants, sample size ranged from 4 to 1104. Studies of experimental design (three randomised control trials and three quasi-experimental) had an average sample size of 34. A total of 37 (80%) articles focused on *facilitators* and 24 (52%) articles examined *barriers* to PA. Full details of included individual sources of evidence are provided in Supplementary Table S5.

Critical appraisal

The results of the critical appraisal are tabulated to show each criterion met by the included article (Supplementary Tables S3.1-S3.6). The critical appraisal tables are sequenced to reflect a hierarchy of evidence from *systematic reviews* to *text and opinion*. Higher scores within each table correspond to greater methodological quality within the hierarchical category.

Included within the highest level of evidence, systematic reviews (Supplementary Table S3.1), were two studies (Kavookjian, Elswick, & Whetsel, 2007; Pillay et al., 2015) that scored 8/11 and 10/11 respectively. Randomised control trials followed (Supplementary Table S3.2), where three included studies (Brazeau et al., 2014; Hasler, Fisher, Macintyre, & Mutrie, 2000; Narendran et al., 2017), scored 3/13 (Hasler et al., 2000), and two studies 9/13 (Brazeau et al., 2014; Narendran et al., 2017). There were three quasi-experimental studies (Dyck et al., 2018; Ruiz-González et al., 2016; Scott et al., 2019) that scored 3/6, 7/9, and 3/6 respectively (Supplementary Table S3.3). The majority (21) of included studies were cross-sectional survey designs (Ahola et al., 2012; Ahola et al., 2016; Brazeau, Rabasa-Lhoret, Strychar, & Mircescu, 2008; Delmonte et al., 2013; Duarte, Almeida, Merker, Brauer, & Rodrigues, 2012; Kebede & Pischke, 2019; Keshawarz et al., 2018; Kneckt, Keinanen-Kiukaanniemi, Knuuttila, & Syrjala, 2001; Lloyd, Pambianco, & Orchard, 2010; Martyn-Nemeth et al., 2017; McCarthy, Whittemore, Gholson, & Grey, 2017; Pinsker et al., 2016; Plotnikoff et al., 2006; Plotnikoff, Karunamuni, & Brunet, 2009; Plotnikoff , Lippke, Courneya, Birkett, & Sigal, 2010; Plotnikoff, Lippke, Courneya, Birkett, & Sigal, 2008; Plotnikoff et al., 2007; Plotnikoff et al., 2010; Raaijmakers et al., 2015; Stuij, Elling, & Abma, 2017; Thomas, Alder, & Leese, 2004) (Supplementary Table S3.4) and scored between 2/8 (Ahola et al., 2016; Stuij et al., 2017; Thomas et al., 2004) and 7/8 (Lloyd et al., 2010; Plotnikoff et al., 2006). Studies using qualitative design (Supplementary Table S3.5)

totalled eight (Balfe et al., 2014; Dizon, Malcolm, Rowan, & Keely, 2019; Kennedy et al., 2018; Kilbride et al., 2011; Kime, Pringle, Rivett, & Robinson, 2018; Lascar et al., 2014; Martyn-Nemeth, Duffecy, Fritschi, & Quinn, 2019; Oser et al., 2019) and scored between 6/10 (Balfe et al., 2014; Kennedy et al., 2018; Kilbride et al., 2011; Lascar et al., 2014) and 8/10 (Kime et al., 2018; Martyn-Nemeth et al., 2019). Ranked lowest in the hierarchy were eight text and opinion pieces (Supplementary Table S3.6) (Colberg, Laan, Dassau, & Kerr, 2015; Greener, 2017; Kime & Pringle, 2018, 2019; Narendran & Andrews, 2018; National Institute for Health and Care Excellence, 2018; Riddell, Gallen, & Rabasa-Lhoret, 2017; Sundberg, 2018) and a single narrative review (Klaprat, MacIntosh, & McGavock, 2019).

Review findings

Like items found within each concept (barriers and facilitators) were compiled into 13 groups (Table 2). The mind map (Figure 2) conceptualises the distribution and nature of the literature while exposing synergies and inconsistencies between groups.

The following narrative refers to details of individual studies (see also Table 1 and Supplementary Table S5).

Measures of physical activity

Of the 24 studies measuring PA, six used device-based measures of PA participation (Brazeau et al., 2014; Keshawarz et al., 2018; Martyn-Nemeth et al., 2017; McCarthy et al., 2017; Narendran et al., 2017; Scott et al., 2019); two studies utilised SenseWear Armbands (HealthWear Bodymedia, Pittsburgh, Pa, USA) (Brazeau et al., 2014; Martyn-Nemeth et al., 2017), two used ActiGraph models (ActiGraph LLC, Pensacola, FL, USA) (Keshawarz et al., 2018; Narendran et al., 2017), McCarthy et al. (2017) used the Yamax digi-walker pedometer (Yamasa Tokei Keiki Co., Ltd., Tokyo, Japan), and Scott et al. (2019) monitored heart rate remotely using the Polar Beat phone application (www.polar.com/beat/uk-en). All studies

employing device-based PA measures collected data over a period of one to two weeks, with the exception of Scott et al. (2019) who monitored PA over the course of six weeks. Half (n=12) used questionnaires including the Godin Leisure-time Exercise Questionnaire (Plotnikoff et al., 2006; Plotnikoff et al., 2009; Plotnikoff et al., 2010; Plotnikoff et al., 2008; Plotnikoff et al., 2007; Plotnikoff et al., 2010), the Summary of Diabetes Self-care Activities Questionnaire (Kebede & Pischke, 2019; Raaijmakers et al., 2015; Ruiz-González et al., 2016), the Scottish PA questionnaire (Hasler et al., 2000), the Kuopio Ischemic Heart Disease 12 month leisure time PA history (Ahola et al., 2012), and the International PA Questionnaire – long form (Duarte et al., 2012). The remaining six studies used researcher developed questionnaires or PA diaries (Ahola et al., 2016; Delmonte et al., 2013; Kneckt et al., 2001; Lloyd et al., 2010; Pinsker et al., 2016; Thomas et al., 2004). Two studies used a combination of both device-based and self-reported measures (McCarthy et al., 2017; Narendran et al., 2017).

Measures of barriers to physical activity

Fifteen studies measured barriers to PA for the purposes of describing perceived barriers. The most frequently used quantitative measure (n=5) was the validated Barriers to PA in Diabetes – Type 1 (Dubé, Valois, Prud'homme, Weisnagel, & Lavoie, 2006) (BAPAD1) tool (Brazeau et al., 2008; Brazeau et al., 2014; Dyck et al., 2018; Keshawarz et al., 2018; McCarthy et al., 2017). Other quantitative measures included the Diabetes Care Profile (Ruiz-González et al., 2016) and a researcher developed questionnaire (Stuij et al., 2017). Over half of the studies (n=8) used qualitative methods to explore barriers to PA. These methods included focus groups (Martyn-Nemeth et al., 2019), one-on-one interviews (Balfe et al., 2014; Lascar et al., 2014), a combination of both focus groups and one-on-one interviews (Kennedy et al., 2018; Kime et al., 2018), and open questions in researcher-developed questionnaires (Duarte et al.,

2012; Scott et al., 2019). One study used a combination of one-on-one interviews, participant journaling, and existing material on T1D blogs (Oser et al., 2019). Two studies using one-on-one interviews utilised a mixture of phone interviews as well as face-to-face interviews (Balfe et al., 2014; Kennedy et al., 2018).

Barriers

Of the 13 mapped barrier groups, *fear of hypoglycaemia (FoH) / hypoglycaemia* was detailed most frequently (n=14) (Brazeau et al., 2008; Colberg et al., 2015; Duarte et al., 2012; Dyck et al., 2018; Greener, 2017; Kennedy et al., 2018; Keshawarz et al., 2018; Kime et al., 2018; Martyn-Nemeth et al., 2019; Martyn-Nemeth et al., 2017; McCarthy et al., 2017; Narendran & Andrews, 2018; Oser et al., 2019; Scott et al., 2019), followed by *time / energy / motivation / work* (n=11) (Balfe et al., 2014; Brazeau et al., 2008; Duarte et al., 2012; Dyck et al., 2018; Kennedy et al., 2018; Kime et al., 2018; Lascar et al., 2014; Martyn-Nemeth et al., 2019; McCarthy et al., 2017; Oser et al., 2019; Scott et al., 2019). *Limited health professional support or advice* (Greener, 2017; Kennedy et al., 2018; Kime & Pringle, 2019; Narendran & Andrews, 2018; Oser et al., 2019; M. C. Riddell et al., 2017; Stuij et al., 2017) and *psychosocial factors* (Duarte et al., 2012; Kennedy et al., 2018; Kime et al., 2018; Lascar et al., 2014; Lloyd et al., 2010; Narendran & Andrews, 2018; Sundberg, 2018) were the next most frequently reported barrier groups (each n=7). The barriers reported least frequently (n=1) were *hyperglycaemia (Keshawarz et al., 2018)* and *difficulties with ADLs (Plotnikoff et al., 2007).*

Facilitators

The largest portion of articles investigating facilitators of PA participation fell within the *patient education* category (n=15) (Brazeau et al., 2014; Dyck et al., 2018; Hasler et al.,

2000; Kavookjian et al., 2007; Kennedy et al., 2018; Kime & Pringle, 2018; Kime et al., 2018; Klaprat et al., 2019; Narendran & Andrews, 2018; Narendran et al., 2017; Pillay et al., 2015; Plotnikoff et al., 2009; M. C. Riddell et al., 2017; Ruiz-González et al., 2016; Sundberg, 2018). The next largest facilitator group was *psychosocial factors* with 14 articles in this group (Ahola et al., 2012; Balfe et al., 2014; Brazeau et al., 2008; Dizon et al., 2019; Hasler et al., 2000; Kilbride et al., 2011; Kime et al., 2018; Kneckt et al., 2001; Lascar et al., 2014; Narendran & Andrews, 2018; Oser et al., 2019; Plotnikoff et al., 2010; Plotnikoff et al., 2008; Plotnikoff et al., 2010). *Health professional training and engagement* was reported on eight occasions (Dizon et al., 2019; Kime & Pringle, 2019; Kime et al., 2018; Narendran & Andrews, 2018; National Institute for Health and Care Excellence, 2018; Oser et al., 2019; Plotnikoff et al., 2009; M. C. Riddell et al., 2017). *Positive biomarkers* (Keshawarz et al., 2018; Narendran et al., 2017), *less perceived disability / ADL difficulties* (Plotnikoff et al., 2006; Plotnikoff et al., 2007), *reduce FoH* (Kilbride et al., 2011; Sundberg, 2018), *and environment (Balfe et al., 2014; Lascar et al., 2014)* were the least reported facilitator groups. *Patient education* and *exercise programs* were the only groups to include studies that trialled a facilitator. Five studies trialled *patient education* (Brazeau et al., 2014; Dyck et al., 2018; Hasler et al., 2000; Narendran et al., 2017; Ruiz-González et al., 2016) and three studies trialled *exercise programs* (Brazeau et al., 2014; Dyck et al., 2018; Scott et al., 2019). Two studies that trialled *exercise programs* also included *patient education* within the program (Brazeau et al., 2014; Dyck et al., 2018).

Discussion

This scoping review aimed to identify and map barriers and facilitators of PA in adults living with T1D. Forty-six articles published between 1996 and January 2020 were included in the scoping review. Research and opinion articles have steadily increased in this area over the

last few years, with 21 of the included articles published between 2017 to 2019. Our review established that many of the included articles exhibited issues with methodological quality. Figure 2 (also see Table 2) identify pertinent barriers and facilitators of physical activity within the literature. The review supports the notion that 'diabetes-specific' barriers, and in particular FoH / hypoglycaemia, are the most commonly reported barriers to PA in this population. The review also reveals a disparity between what is known about barriers to PA, and what is done to facilitate participation in PA. Although many facilitators have been suggested, very few have been trialled using robust study designs. The review does, however, identify some congruence within the literature. There is agreement that patient education should be provided to those living with T1D, psychosocial factors need to be addressed, and greater health professional knowledge and training is required in order for this support to be given. Coordinated and meaningful interpretation of barriers and facilitators of PA is required to engage the T1D community and improve activity rates.

Fifteen articles discussed barriers to PA using quantitative methods, and the most popular tool was the BAPAD1 (Dubé et al., 2006). This tool is currently the only validated instrument specific to measuring barriers to PA in the T1D population. Using a Likert scale (1, extremely unlikely to 7, extremely likely), participants indicate the likelihood that each listed barrier (11) will keep them from exercising (Dubé et al., 2006). Although it does provide a platform for consistent and valid reporting of barriers, it may not capture or allow the researcher to understand the full breadth of issues experienced by this population. This might explain the large contribution of qualitative methods to explore barriers to PA.

Barriers identified in this review are a mix of 'diabetes-specific' barriers and common barriers experienced by the general population. Of the six top ranking barriers to PA, four are

'diabetes specific': *FoH / hypoglycaemia; limited health professional support or advice; BGL variation / loss of control,* and *lack of knowledge.* The dominance of 'diabetes-specific' barriers identified in this review is consistent with and explains lower activity rates in the T1D population. *Time / energy / motivation / work* was however, the second most frequently reported barrier to PA. Time and lack of enjoyment are identified as the most salient barriers to PA in the general population (Australian Institute of Health and Welfare, 2018; Hoare, Stavreski, Jennings, & Kingwell, 2017), so it is not surprising to see these barriers prominent in this review. The recommended management strategies for T1D and PA require meticulous planning (Michael C. Riddell et al., 2017), therefore, the additional tasks involved for the person living with T1D may accentuate *time, energy, and motivation* as a barrier. Seemingly 'common' barriers may be experienced differently by those living with T1D and will need to be considered along with 'diabetes-specific' barriers. General community PA initiatives will fall short of the needs of adults living with T1D, given their unique experience of barriers to PA. This population requires specifically tailored interventions before confidently participating in general community initiatives.

Given PA is a known precipitant of hypoglycaemia (Michael C. Riddell et al., 2017), it is conceivable that episodes of hypoglycaemia or a *fear* of hypoglycaemia, is the most frequently described barrier to participating in PA (Brazeau et al., 2008; Colberg et al., 2015; Duarte et al., 2012; Dyck et al., 2018; Greener, 2017; Kennedy et al., 2018; Keshawarz et al., 2018; Kime et al., 2018; Martyn-Nemeth et al., 2019; Martyn-Nemeth et al., 2017; McCarthy et al., 2017; Narendran & Andrews, 2018; Oser et al., 2019; Scott et al., 2019). The experience of a hypoglycaemic episode, either lived or vicarious can be extremely unpleasant and may result in cessation of an activity or task (Frier, 2008). Despite the clarity surrounding barriers to PA, only two articles *suggested* that addressing FoH may act as a facilitator to PA

and no articles *trialled* an intervention explicitly targeting FoH (Kilbride et al., 2011; Sundberg, 2018). The dominance of *FoH / hypoglycaemia* as a barrier should direct health professionals and future research to prioritise and understand FoH / hypoglycaemia when aiming to improve PA participation in adults living with T1D.

Upon scoping the literature for facilitators of PA, *patient education* emerged as a clear focus, followed by *psychosocial factors* and *health professional training and engagement.* The strong focus on *patient education* is consistent with *lack of knowledge* being among the most reported barriers to PA (Brazeau et al., 2014; Dyck et al., 2018; Hasler et al., 2000; Kavookjian et al., 2007; Kennedy et al., 2018; Kime & Pringle, 2018; Kime et al., 2018; Klaprat et al., 2019; Narendran & Andrews, 2018; Narendran et al., 2017; Pillay et al., 2015; Plotnikoff et al., 2009; M. C. Riddell et al., 2017; Ruiz-González et al., 2016; Sundberg, 2018). A modest number of articles also suggested *guidelines / increase patient knowledge* as a facilitator (Brazeau et al., 2008; Greener, 2017; Kilbride et al., 2011; Kime et al., 2018; Lascar et al., 2014; National Institute for Health and Care Excellence, 2018) which, along with *patient education* may also address other, less obvious barriers. Knowledge and skills provided by patient education or guidelines may lead to confidence and competence in avoiding hypoglycaemia and BGL variation, therefore working to address the barriers of *BGL variation / loss of control* and *fear of hypoglycaemia / hypoglycaemia*. Despite their dominance, *patient education* and *guidelines / increase patient knowledge* were predominately *suggested* (as opposed to *trialled*) as facilitators. This review found many possible facilitators were *suggested* at the conclusion of articles as a way to address issues identified in the article. Very few proceeded to *trial* the feasibility or efficacy of these possible facilitators (Brazeau et al., 2014; Dyck et al., 2018; Hasler et al., 2000; Narendran et al., 2017; Ruiz-González et al., 2016). General diabetes self-management education is

already recommended by diabetes authorities for people living with T1D (Craig et al., 2011; National Institute for Health and Care Excellence, 2018), so it is plausible to see authors suggesting *patient education* as a facilitator of PA (Kavookjian et al., 2007; Kennedy et al., 2018; Kime & Pringle, 2018; Kime et al., 2018; Klaprat et al., 2019; Narendran & Andrews, 2018; Pillay et al., 2015; Plotnikoff et al., 2009; M. C. Riddell et al., 2017; Sundberg, 2018). It is widely accepted however, that behaviour change, including increasing PA requires more than just knowledge and skill, the hallmarks of patient education (Knight, Dornan, & Bundy, 2006). This is particularly true for those living with T1D who may be exposed to 'diabetes-specific' burden and diabetes distress, further complicating behaviour change efforts (Knight et al., 2006; Speight et al., 2011). Behaviour change theories that propose psychosocial concepts such as self-efficacy and self-determined motivation, need to be embedded within education programs to facilitate behaviour change (Knight et al., 2006; Ntoumanis et al., 2020).

Of the five trialled *patient education* facilitators, only three were trialled with interventions based on behaviour change theories (Brazeau et al., 2014; Hasler et al., 2000; Narendran et al., 2017). A finding consistent with general diabetes education interventions (Knight et al., 2006). Behaviour change theories can describe how, when and why change occurs or does not occur and are crucial in developing effective behaviour change interventions (Michie & Johnston, 2012). Having a theoretical basis to an intervention has been shown to improve efficacy and is emphasised in key frameworks for developing behaviour change interventions (Craig et al., 2008; Dombrowski, Sniehotta, Avenell, MacLennon, & Arau`jo-Soares, 2012; Taylor, Conner, & Lawton, 2012). The three studies to trial theory driven behaviour change interventions were all pilot RCTs. The theories described were the Transtheoretical Model (Hasler et al., 2000), Goal Orientated Motivational Interviewing (Narendran et al., 2017),

Theory of Planned Behaviour (Brazeau et al., 2014), and Social Cognitive Theory (Brazeau et al., 2014). Furthermore, none of the included studies reported the use of any behaviour change techniques. Consistent reporting of behaviour change techniques or the 'active ingredients' of interventions is essential for fidelity, replication, and synthesis of interventions (Michie & Johnston, 2012; Teixeira et al.).

In order to develop effective *patient education*, training of health professionals and improving their engagement with the T1D community is essential. *Health professional training and engagement* was suggested as a (potential) facilitator to PA on eight occasions (Dizon et al., 2019; Kime & Pringle, 2019; Kime et al., 2018; Narendran & Andrews, 2018; National Institute for Health and Care Excellence, 2018; Oser et al., 2019; Plotnikoff et al., 2009; M. C. Riddell et al., 2017), making it the third most discussed facilitator. This echoes the literature exploring barriers to PA, where *limited health professional support or advice* was the third most commonly reported barrier to PA. The review demonstrates agreement in the literature among experts and people living with T1D, that health professionals do not possess adequate knowledge or confidence to assist people living with T1D in the area of PA (Dizon et al., 2019; Greener, 2017; Kennedy et al., 2018; Kime & Pringle, 2019; Kime et al., 2018; Narendran & Andrews, 2018; National Institute for Health and Care Excellence, 2018; Oser et al., 2019; Plotnikoff et al., 2009; M. C. Riddell et al., 2017; Stuij et al., 2017). Although a prominent *suggested* facilitator, this review has revealed no formal examination or discussion of an effective way to improve *health professional training and engagement.*

Psychosocial factors was prominent as both a barrier and suggested facilitator of PA. It is logical to expect negative psychosocial factors to act as barriers (for example: diabetes distress, depression, embarrassment, low confidence) and positive psychosocial factors as

facilitators (for example: greater social support, well-being, enjoyment, self-efficacy, self-esteem, motivation) (Table 2). Among psychosocial facilitators, social support was suggested most frequently (n=7), a finding that juxtaposes with the most frequently reported psychosocial barriers: low confidence / overwhelmed and embarrassment / discouragement (each n=3) (Balfe et al., 2014; Brazeau et al., 2008; Dizon et al., 2019; Duarte et al., 2012; Kennedy et al., 2018; Kime et al., 2018; Lascar et al., 2014; Narendran & Andrews, 2018; Oser et al., 2019; Sundberg, 2018). Self-efficacy (a predictor of PA behaviour change) and social support are highly correlated (McAuley, Jerome, Elavsky, Marquez, & Ramsey, 2003). Using social support in intervention design may improve self-efficacy, enjoyment, and motivation towards PA, hence increasing the likelihood of PA behaviour change (Ntoumanis, Thøgersen-Ntoumani, Quested, & Chatzisarantis, 2018; Plotnikoff et al., 2008). Although theoretically sound, these strategies are yet to be explored beyond small pilot studies in the area of PA and T1D (Brazeau et al., 2014; Dyck et al., 2018).

Gap in the literature

Technology in T1D management is developing rapidly and becoming more accessible (Atkinson, Eisenbarth, & Michels, 2014), yet it did not feature heavily in this review. Devices such as insulin pumps, continuous glucose monitoring (CGM), T1D and activity-specific phone applications as well as closed loop systems (artificial pancreas or automated insulin delivery) are already having a dramatic impact on general T1D management (Atkinson et al., 2014). It is surprising we only found two barriers related to access/use of technology and only five facilitators linked to technology, many of which were from the same opinion piece (Colberg et al., 2015; Dizon et al., 2019; Kebede & Pischke, 2019; Keshawarz et al., 2018; Pinsker et al., 2016; Scott et al., 2019). Adding to the ambiguity in this area, insulin pumps

and CGM were identified as both barriers and facilitators of PA (Colberg et al., 2015; Dizon et al., 2019; Keshawarz et al., 2018; Pinsker et al., 2016). In the opinion of health professionals and athletes with T1D, insulin pumps and CGM may facilitate PA (Colberg et al., 2015; Dizon et al., 2019). However, two articles found those using CGM and or insulin pumps experienced more barriers to PA and or participated in less activity than those not using this technology (Keshawarz et al., 2018; Pinsker et al., 2016). Articles were excluded if PA participation was not an outcome of the study, as such, a number of articles exploring efficacy of using technology in relation to glycaemic control were excluded. The low quality and small number of articles examining technology as either a barrier or facilitator, indicates a need for further research to examine the role of technology in overcoming barriers and increasing participation in PA.

Technology should also be a consideration in the design of future studies where PA participation is an outcome. Despite their availability, the use of PA tracking devices was extremely limited. Only five studies utilised accelerometry to measure PA (Brazeau et al., 2014; Keshawarz et al., 2018; Martyn-Nemeth et al., 2017; McCarthy et al., 2017; Narendran et al., 2017), while others relied on validated and non-validated questionnaires. Self-reported PA levels obtained via questionnaires are known to be subject to bias and over-reporting of activity (Kapteyn et al., 2018).

Limitations

Although an optional component of a scoping review (Tricco et al., 2018), we included critical appraisal of the reviewed studies. Given the type and aim of the review, a minimum quality threshold was not enforced, and all articles were included. In doing so, we discovered substantial variation in methodological rigour (Supplementary Tables S3.1-S3.6). The small

number of rigorous studies in the area explains why there were no recent systematic reviews solely focused on barriers and / or facilitators of PA participation in the T1D population. Only three review articles were identified, one of which was a narrative review with substantial methodological issues (Klaprat et al., 2019). The average sample size (n=34) of the six experimental studies included in this review was very low (Brazeau et al., 2014; Dyck et al., 2018; Hasler et al., 2000; Narendran et al., 2017; Ruiz-González et al., 2016; Scott et al., 2019). The three included RCTs were all pilot studies, also of varying quality (Brazeau et al., 2014; Hasler et al., 2000; Narendran et al., 2017). The remaining three experimental studies were of quasi-experimental design (Dyck et al., 2018; Ruiz-González et al., 2016; Scott et al., 2019), leaving the bulk of the included articles in the lower half of the evidence hierarchy (Joanna Briggs Institute, 2017).

Conclusions

The available literature examining barriers and facilitators of PA participation for people with T1D is limited and is dominated by articles possessing methodological concerns. Evidence relating to issues influencing participation in PA in this population is growing, pointing to 'diabetes-specific' barriers as the prominent concerns for people living with T1D. *Patient education* was the most commonly suggested or trialled facilitator of PA. The dominance of *patient education* as a suggested and trialled facilitator addresses 'diabetes-specific' barriers to PA, while *psychosocial factors* as both barriers and facilitators need to be considered in future intervention designs. The need for greater *health professional support and advice* has been met with frequent suggestions that this factor is likely to facilitate PA in this population. Major inconsistencies in the literature were also established. The most frequently identified barrier, *FoH / hypoglycaemia* was rarely explicitly targeted when exploring facilitators to PA.

A major limitation of the research to date is the extremely small number of studies trialling behaviour change interventions in this area. Despite a considerable number of suggested facilitators, very few studies trialled interventions to increase PA. Of those that did, the majority were pilot studies trialling group or one-on-one interventions. Finally, the role of technology in overcoming barriers and increasing participation in PA was considerably underrepresented in this review, given the large role it plays in daily management of T1D. The current state of evidence is insufficient to confidently inform future practice among diabetes health professionals.

Fully powered randomised controlled trials are required to establish efficacy of behaviour change interventions targeting FoH / hypoglycaemia and other psychosocial factors. Researchers are called to consider device-based measures of PA and complement quantitative findings with qualitative assessment of acceptability. These trials should include interventions based on sound theoretical foundations, using and reporting appropriate behaviour change techniques.

In addition to developing behaviour change interventions for those living with T1D, systematically designed and evaluated training programs for health professionals are needed in the area of T1D and PA. Researchers should strive for better dissemination to health professionals of the latest evidence-based approaches to T1D management for PA. Consistent and reputable information communicated by health professionals, using motivationally supportive language is an important part of improving activity levels in this population (Ntoumanis, Quested, & Reeve, 2018).

Continued exploration of barriers to PA is required within local T1D communities. Using a quantitative measure of barriers to PA, such as the BAPAD1 tool (Dubé et al., 2006) is useful

in synthesising evidence in this area. However, in an era of rapidly evolving management strategies and devices, barriers to PA may change, thus continued exploration of the problems faced by local T1D communities will be important. To provide future balanced and insightful representation of the barriers faced by the T1D population, a mixed method approach is recommended; this might include using a validated quantitative tool such as the BAPAD1, together with qualitative focus group interviews.

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Conflicts of interest

MB is an employee of Diabetes Western Australia, however the organisation had no influence on the conceptualisation, operationalisation, or conclusions of this review.

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Table 1 – Article characteristics

Author	Design	Sample Size or Number of Studies (reviews only)	Concepts		Critical Appraisal Score
			Barriers	**Facilitators**	
Kavookjian et al. (2007)	Systematic review	41	-	Patient education (unspecified)	8/11
Klaprat et al. (2019)	Narrative review	NR	-	Patient education (unspecified)	3/11
Pillay et al. (2015)	Systematic review	36	-	Patient education (unspecified)	10/11
Brazeau et al. (2014)	RCT	48	-	Patient education (group) Exercise programs (group)	9/13
Hasler et al. (2000)	RCT	34	-	Patient education (1:1) Psychosocial factors (stage of change)	3/13
Narendran et al. (2017)	RCT	58	-	Patient education (1:1) Positive biomarkers (VO_{2max})	9/13
Dyck et al. (2018)	Quasi-experimental	12	FoH/Hypo Time/Energy/Motivation/Work Low fitness/Tired BGL variability/Loss of control	Patient education (group) Exercise programs (group)	3/6
Ruiz-Gonzalez et al. (2016)	Quasi-experimental	40	-	Patient education (group)	7/9
Scott et al. (2019)	Quasi-experimental	11	FoH/Hypo Time/Energy/Motivation/Work	Technology (phone app) Exercise programs (1:1)	3/6
Ahola et al. (2012)	Cross-sectional	1104	-	Psychosocial factors (sense of coherence)	6/8
Ahola et al. (2016)	Cross-sectional	615	FoH/Hypo (not significant)	FoH/Hypo (not significant)	2/8
Brazeau et al. (2008)	Cross-sectional	100	FoH/Hypo Time/Energy/Motivation/Work Low fitness/Tired BGL variability/Loss of control	Psychosocial factors (well-being; social support) Guidelines/Increase patient knowledge	5/8
Delmont et al. (2013)	Cross-sectional	33	Islet cell transplant (not significant)	Islet cell transplant (not significant)	5/7
Duarte et al. (2012)	Cross-sectional	107	FoH/Hypo Time/Energy/Motivation/Work Psychosocial factors (discouragement)	-	5/8
Kebede and Pischke (2019)	Cross-sectional	1,052	-	Technology (phone app)	6/8
Keshawarz et al. (2018)	Cross-sectional	44	FoH/Hypo BGL variability/Loss of control Hyperglycaemia Technology (CGM) Demographics (younger age)	Positive biomarkers (high HDL; lower diastolic blood pressure)	5/8
Kneckt et al. (2001)	Cross-sectional	149	-	Psychosocial factors (self-esteem)	6/8
Lloyd et al. (2010)	Cross-sectional	264	Psychosocial factors (diabetes distress)	-	7/8
Martyn-Nemeth et al. (2017)	Cross-sectional	35	FoH/Hypo	-	5/8

Author	Design	Sample Size or Number of Studies (reviews only)	Concepts		Critical Appraisal Score
			Barriers	**Facilitators**	
McCarthy et al. (2017)	Cross-sectional	83	FoH/Hypo Time/Energy/Motivation/Work Environment (weather)	Demographics (full-time work)	6/8
Pinsker et al. (2016)	Cross-sectional	244	Technology (pump)	-	3/8
ALEXANDRA Study - Plotnikoff et al. (2010)	Cross-sectional	697	-	Psychosocial factors (perceived behavioural control)	6/7
ALEXANDRA Study - Plotnikoff et al. (2009)	Cross-sectional	695	Diagnosis of T1D	Patient education (unspecified) HP training and engagement Overcoming barriers/Trial and error	6/7
ALEXANDRA Study - Plotnikoff et al. (2007)	Cross-sectional	510	Difficulties with ADLs Demographic factors (older age)	Less perceived disability/ADL difficulties Demographic factors (younger age at diagnosis)	5/7
ALEXANDRA Study - Plotnikoff et al. (2010)	Cross-sectional	697	-	Psychosocial factors (intention; self-efficacy)	6/7
ALEXANDRA Study - Plotnikoff et al. (2006)	Cross-sectional	697	-	Less perceived disability/ADL difficulties Demographic factors (younger age; single; higher income)	7/8
ALEXANDRA Study - Plotnikoff et al. (2008)	Cross-sectional	697	-	Psychosocial factors (self-efficacy) Time management/Goal setting	6/7
Raaijmakers et al. (2015)	Cross-sectional	143	Demographic factors (higher education)	-	6/8
Stuij et al. (2017)	Cross-sectional	71	Limited HP support or advice	-	2/8
Thomas et al. (2004)	Cross-sectional	77	Age or weight (not significant)	Age or weight (not significant)	2/8
Balfe et al. (2014)	Qualitative	32	Time/Energy/Motivation/Work Low fitness/Tired Environment (bad weather)	Psychosocial factors (social support; motivation) Environment (good weather)	6/10
Dizon et al. (2019)	Qualitative	21	-	HP training and engagement Psychosocial factors (social support) Technology (phone app) Overcoming barriers/trial and error	8/10
Kennedy et al. (2018)	Qualitative	15	FoH/Hypo Time/Energy/Motivation/Work Limited HP support or advice Lack of knowledge Psychosocial factors (low confidence) Diagnosis of T1D	Patient education (group) Exercise programs (group) Time management/Goal setting	6/10
Kilbride et al. (2011)	Qualitative	4	-	Psychosocial factors (locus of control) Guidelines/Increase patient knowledge Overcoming barriers/Trial and error Reduce FoH	6/10
Kime et al. (2018)	Qualitative	67	FoH/Hypo	Patient education (group)	8/10

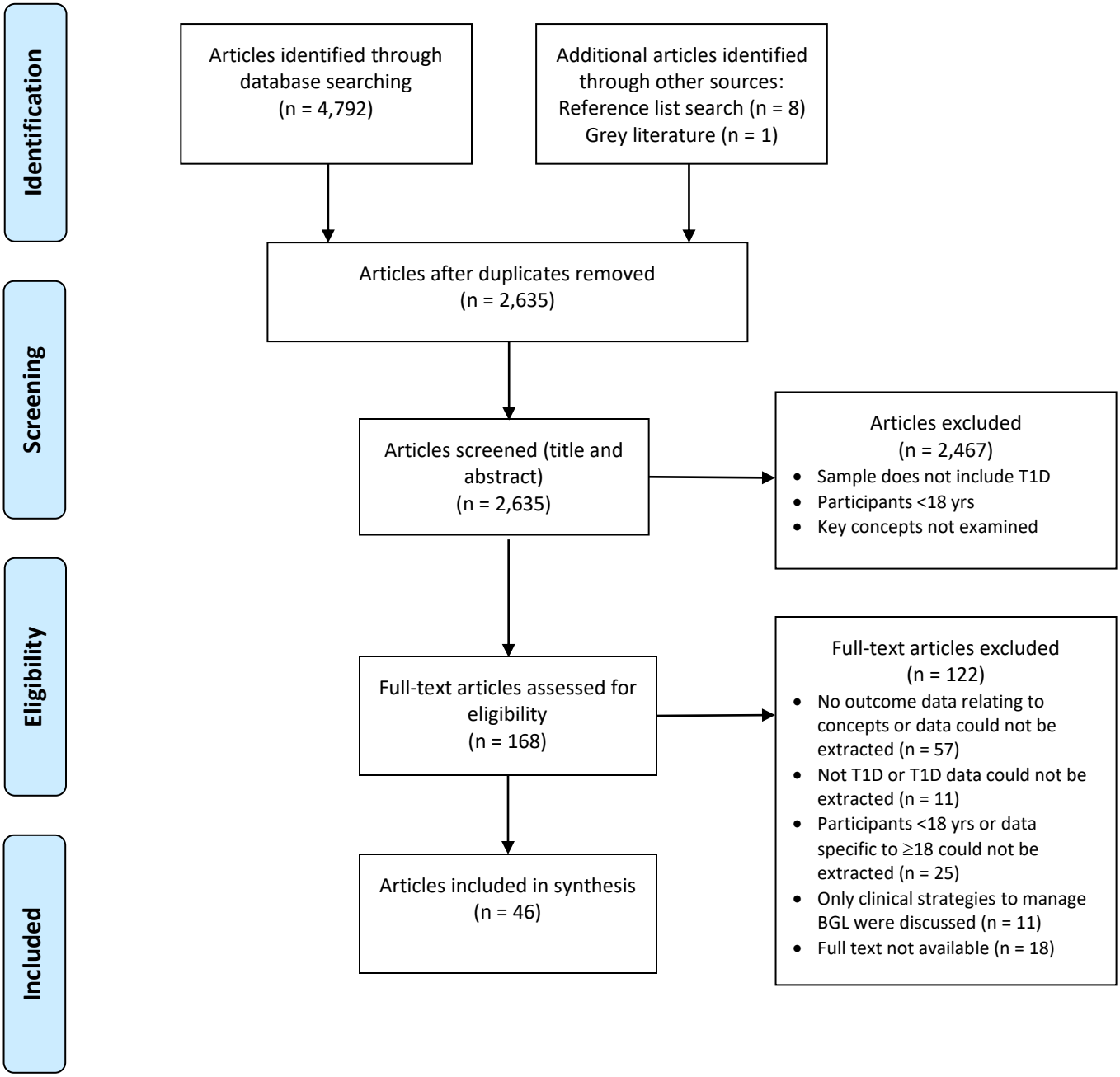
Author	Design	Sample Size or Number of Studies (reviews only)	Concepts		Critical Appraisal Score
			Barriers	**Facilitators**	
			Time/Energy/Motivation/Work Psychosocial factors (embarrassment)	HP training and engagement Psychosocial factors (social support; enjoyment) Guidelines/Increase patient knowledge Exercise programs (group)	
Lascar et al. (2014)	Qualitative	26	Time/Energy/Motivation/Work Lack of knowledge Psychosocial factors (embarrassment) Environment (weather)	Psychosocial factors (social support; enjoyment) Guidelines/Increase patient knowledge Time management/Goal setting Environment (free/reduced admission to gyms/pools)	6/10
Martyn-Nemeth et al. (2019)	Qualitative	30	FoH/Hypo Time/Energy/Motivation/Work	Overcoming barriers/Trial and error	8/10
Oser et al. (2019)	Qualitative	67 blog posts + 10 participants	FoH/Hypo Time/Energy/Motivation/Work Limited HP support or advice	HP training and engagement Psychosocial factors (social support) Exercise programs (unspecified)	7/10
Colberg et al. (2015)	Text and Opinion	Nil	FoH/Hypo Lack of knowledge	Technology (activity trackers; pumps; glucose monitors; CGM; artificial pancreas; social integration)	5/5
Greener (2017)	Text and Opinion	Nil	FoH/Hypo Limited HP support or advice BGL variability/Loss of control Lack of knowledge	Guidelines/Increase patient knowledge Time management/Goal setting	5/6
Kime and Pringle (2018)	Text and Opinion	Nil	-	Patient education (unspecified)	5/6
Kime and Pringle (2019)	Text and Opinion	Nil	Limited HP support or advice	HP training and engagement	4/6
Narendran and Andrews (2018)	Text and Opinion	Nil	FoH/Hypo Time/Energy/Motivation/Work Limited HP support or advice BGL variability/Loss of control Lack of knowledge Psychosocial factors (overwhelmed; low confidence)	Patient education (unspecified) HP training and engagement Psychosocial factors (social support)	6/6
National Institute for Health and Care Excellence (2018)	Text and Opinion	Nil	-	HP training and engagement Guideline/Increase patient knowledge	5/5
M. C. Riddell et al. (2017)	Text and Opinion	Nil	Limited HP support or advice	Patient education (group) HP training and engagement Overcoming barriers/Trial and error	6/6
Sundberg (2018)	Text and Opinion	Nil	Psychosocial factors (low confidence)	Patient education (unspecified) Reduce FoH	5/5

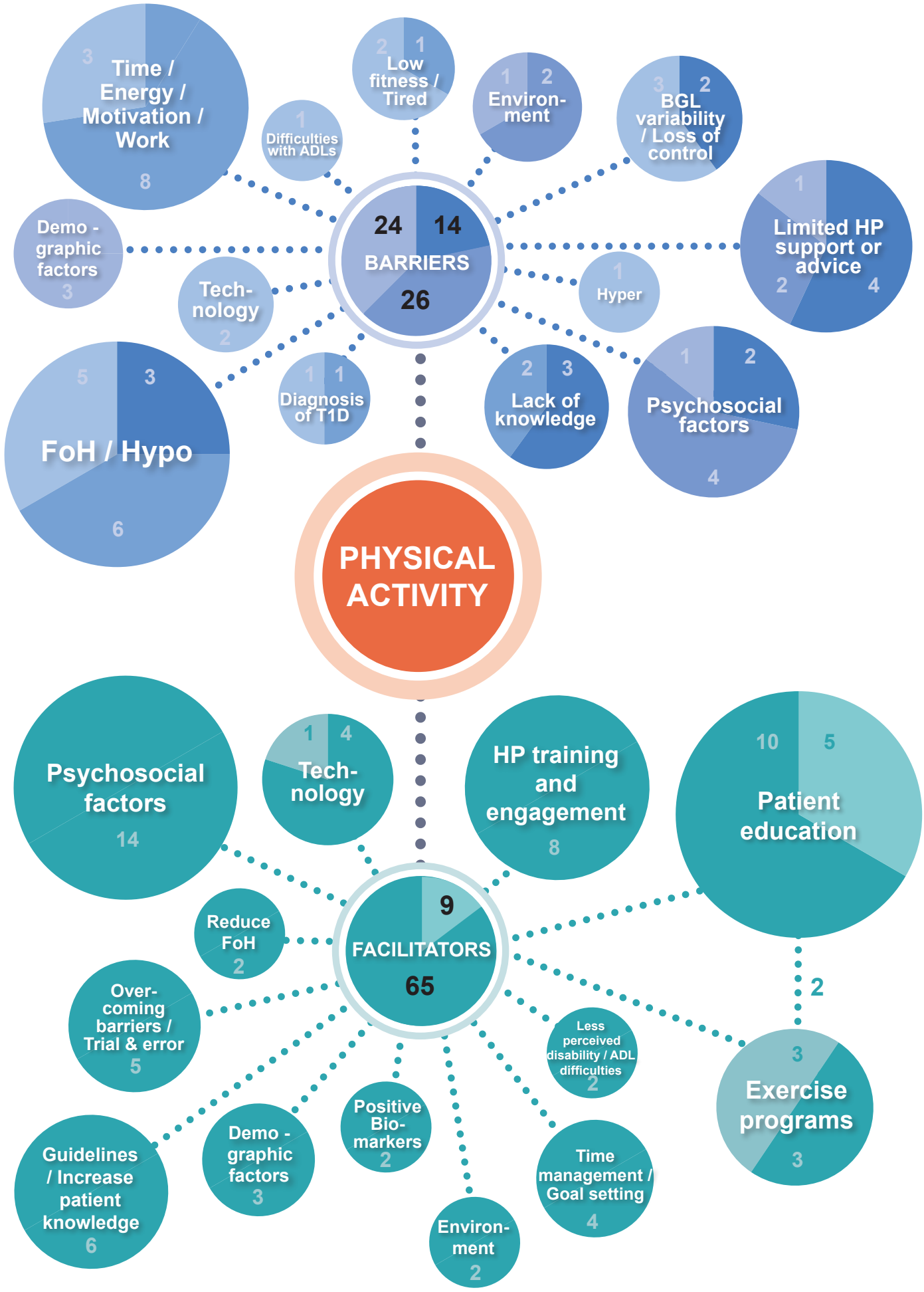
NR – Not reported; Unspecified – unspecified mode of delivery; Group – delivered in a group setting; 1:1 – one on one delivery; PA - Physical activity; FoH – Fear of hypoglycaemia; Hypo – hypoglycaemia; BGL – Blood glucose level; HDL – high-density lipoprotein; HP – Health professional; ADL – Activities of daily living; CGM – continuous glucose monitor

Table 2 – Concept group descriptions

Concept Groups	Item Description
Barrier Groups	
Time / energy / motivation / work	Time and energy involved in preparing for PA; lack of time; work; low motivation; general dislike of exercise
Environment	Difficulties accessing facilities; the burden of carrying supplies; weather or seasonality
Psychosocial factors	Embarrassment/discouragement to engage in PA by those around them; low confidence/overwhelmed by managing blood glucose levels for PA; diabetes distress; depression
Blood glucose level variability / loss of control	Exercise inducing loss of control of diabetes or blood glucose levels.
Lack of knowledge	Lack of knowledge surrounding T1D management for PA
FoH / hypoglycaemia	Fear of experiencing hypoglycaemia; actual episodes of hypoglycaemia
Limited HP support or advice	Limited HP support or advice available to those with T1D
Low fitness / tired	Low fitness levels; feeling tired or fatigued
Hyperglycaemia	Episodes of hyperglycaemia
Technology	Use of insulin pump; use of CGM
Demographic factors	Younger age; higher education; older age
Diagnosis of T1D	Being diagnosed/living with T1D
Difficulties with ADLs	Experiencing difficulties with ADLs
Facilitator Groups	
Environment	Weather; access to facilities
Guidelines / increase patient knowledge	Availability of information and guidelines on insulin and nutrition adjustments and the effect of PA on blood glucose levels
Psychosocial factors	Sense of coherence; intention; self-esteem; self-efficacy; locus of control; self-motivation; stage of change (contemplators, preparers, maintainers); social/peer support; family support; enjoyment; well-being; perceived behavioural control
Positive biomarkers	VO_{2max}; higher HDL; lower diastolic blood pressure
Less perceived disability/ADL difficulties	Lower level of perceived disability and less perceived difficulties with ADLs
Patient education	Structured education, workshops or courses - delivered in a group, one on one or unspecified mode of delivery.
Exercise programs	Programs, workshops or classes where exercise was performed by participants - delivered in a group, one on one or unspecified mode of delivery.
Technology	Activity tracking devices; insulin pumps; glucose monitors; continuous glucose monitors; artificial pancreas systems; social integration; phone applications
HP training and engagement	Need for HP training in the area of PA and T1D; HP to emphasise benefits of PA on T1D management; HP to engage with T1D patients and community sport; HP to encourage PA
Overcoming barriers / trial and error	Overcoming or addressing barriers to PA; trial and error of strategies to manage T1D with PA
Time management / goal setting	Improve time management; set goals
Reduce FoH	Address or reduce FoH
Demographic factors	Younger age (total and at diagnosis); full-time work; single; higher income

PA – physical activity; FoH – fear of hypoglycaemia; HP – health professional; T1D – type 1 diabetes; ADL – activities of daily living; HDL – high-density lipoprotein

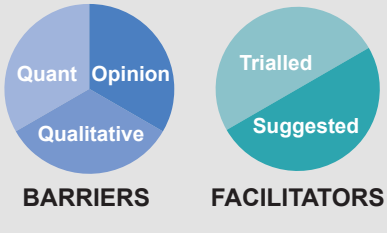

Identification
Screening
Eligibility
Included
Articles identified through database searching (n = 4,792)
Additional articles identified through other sources: Reference list search (n = 8) Grey literature (n = 1)
Articles after duplicates removed (n = 2,635)
Articles screened (title and abstract) (n = 2,635)
Articles excluded (n = 2,467)
Sample does not include T1D
Participants <18 yrs
Key concepts not examined
Full-text articles assessed for eligibility (n = 168)
Full-text articles excluded (n = 122)
No outcome data relating to concepts or data could not be extracted (n = 57)
Not T1D or T1D data could not be extracted (n = 11)
Participants <18 yrs or data specific to ≥18 could not be extracted (n = 25)
Only clinical strategies to manage BGL were discussed (n = 11)
Full text not available (n = 18)
Articles included in synthesis (n = 46)



KEY

Abbreviations

ADL = Activities of daily living
BGL = Blood glucose levels
FoH = Fear of hypoglycaemia
HP = Health professional
Hyper = Hyperglycaemia
Hypo = Hypoglycaemia
Quant = Quantitative
T1D = Type 1 diabetes



Supplement 1 – PRISMA-ScR Checklist

Section	Item	PRISMA-ScR Checklist Item	Reported on Page #
Title			
Title	1	Identify the report as a scoping review.	1
Abstract			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
Introduction			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	5-6
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	6-7
Methods			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	6
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	8-9
Information sources	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	8-9
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Supp 2
Selection of sources of evidence	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	8-9
Data charting process	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	10-11
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	p. 10 Supp 4
Critical appraisal of individual sources of evidence	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	9-10
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	10-11
Results			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	11 Fig 1.
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	11 Table 1

Section	Item	PRISMA-ScR Checklist Item	Reported on Page #
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	12-13 Supp 3
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	13-17 Supp 5
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	13-17 Figure 2
Discussion			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	17-23
Limitations	20	Discuss the limitations of the scoping review process.	23
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	25-26
Funding			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	27

PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

Supplement 2 - Sample search strategy - CINAHL full text (EBSCO)

Search	Query	Records Retrieved
S1	(MH "Diabetes Mellitus, Type 1")	22,426
S2	(MH "Physical Fitness+") OR (MH "Sports+") OR (MH "Leisure Activities+") OR (MH "Exercise+") OR (MH "Physical Activity")	226,538
S3	(MH "Health Education") OR (MH "Diabetes Education") OR (MH "Learning Methods+") OR "client education" OR "education" OR "health promotion" OR "structured education" OR "group education" OR "group program" OR "group intervention" OR "program*" OR "counsel#ing" OR "strateg*" OR "facilitators" OR "method" OR "motivators" OR "enablers" OR "barriers to PA" OR "barriers" OR "problems" OR "challenges" OR "issue*" OR "difficult*" OR "compliance" OR "non#compliance" OR "associations" OR "correlations" OR "links" OR "predictors"	1,985,495
S4	S1 AND S2 AND S3	416
Limiters - Published date: 01/01/1996 – 03/02/2020; English language; Human		186

Search conducted on 3rd February 2020

Supplement 3 - Critical appraisal

Table 1

Systematic Review and Research Syntheses

Citation	**Q1** **Is the review question clearly and explicitly stated?** It was agreed that a clearly and explicitly stated review question would be formulated around PICO elements	**Q2** **Were the inclusion criteria appropriate for the review question?** It was agreed that if inclusion criteria were adequately described, even in the absence of a PICO statement, this criterion would be met	**Q3** **Was the search strategy appropriate ?** It was agreed that if a search strategy was not explicitly detailed, *uncertain* would be assigned	**Q4** **Were the sources and resources used to search for studies adequate?** It was agreed that if a search strategy was not explicitly detailed, *uncertain* would be assigned	**Q5** **Were the criteria for appraising studies appropriate ?** It was agreed that if critical appraisal was not explicitly detailed, this criterion was not met	**Q6** **Was critical appraisal conducted by two or more reviewers independentl y?** It was agreed that if critical appraisal processes were not explicitly detailed, *uncertain* would be assigned	**Q7** **Were there methods to minimize errors in data extraction?** It was agreed that if specific tools to guide data extraction were not used, this criterion would not be met	**Q8** **Were the methods used to combine studies appropriate?** It was agreed that in order to meet this criterion, the synthesis must be appropriate for the review question and the stated type of review	**Q9** **Was the likelihood of publication bias assessed?** It was agreed that if the search strategy was not comprehensive and or statistical tests to assess bias were not used, this criterion would not be met	**Q10** **Were recommendati ons for policy and/or practice supported by the reported data?** It was agreed that if there was evidence the strength and quality of the findings were considered in formulating recommendatio ns, this criterion would be met	**Q11** **Were the specific directives for new research appropriate?** It was agreed that if the review considered and reported gaps in research or knowledge base, this criterion would be met	**Score**
Kavookjia n et al. (2007)	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	8/11
Klaprat et al. (2019)*	N	Y	U	U	N	U	U	U	N	Y	Y	3/11
Pillay et al. (2015)	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10/11
%	33.33	100.0	66.66	66.66	66.66	66.66	33.33	33.33	33.33	100.0	100.0	

*This narrative review is positioned here to align with the JBI instrument used to critically appraise it and is not reflective of its position in the evidence hierarchy

Table 2

Randomised Controlled Trials

Citation	Q1 **Was true randomisation used for assignment of participants to treatment groups?** It was agreed that if a detailed description of the randomisation procedure was not provided, *unclear* would be assigned	Q2 **Was allocation to treatment groups concealed?** It was agreed that concealment of allocation referred to the personnel allocating participants into groups	Q3 **Were treatment groups similar at the baseline?** It was agreed that if participant characteristics (particularly those that may explain the effect in the absence of the cause) were not similar, this criterion would not be met	Q4 **Were participants blind to treatment assignment?** It was agreed that if not explicitly described, *unclear* would be assigned	Q5 **Were those delivering treatment blind to treatment assignment?**	Q6 **Were outcomes assessors blind to treatment assignment?**	Q7 **Were treatment groups treated identically other than the intervention of interest?**	Q8 **Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?** It was agreed that incomplete follow up was defined as incomplete information on all participants	Q9 **Were participants analysed in the groups to which they were randomised?** It was agreed that this item was related to intention to treat analysis	Q10 **Were outcomes measured in the same way for treatment groups?**	Q11 **Were outcomes measured in a reliable way?** It was agreed that if a valid and reliable measure existed and was available but not used, this criterion was not met	Q12 **Was appropriate statistical analysis used?**	Q13 **Was the trial design appropriate, and any deviations from the standard RCT design accounted for in the conduct and analysis of the trial?**	**Score**
Brazeau et al. (2014)	Y	Y	Y	N	N	U	Y	Y	Y	Y	Y	N	Y	9/13
Hasler et al. (2000)	U	U	U	U	N	U	U	U	U	Y	Y	N	Y	3/13
Narendran et al. (2017)	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	9/13
%	66.66	66.66	33.33	0.0	0.0	0.0	66.66	66.66	66.66	100.0	100.0	66.66	100.0	

Table 3

Quasi-Experimental Studies

Citation	Q1 **Is it clear in the study what is the 'cause' and what is the 'effect'?** It was agreed that if the *cause* (independent variable) did not occur before the *effect* (dependent variable), this criterion would not be met	Q2 **Were the participants included in any comparisons similar?** It was agreed that if there was no comparison, this criterion was deemed *not applicable* (N/A)	Q3 **Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?** It was agreed that if there was no comparison, this criterion was deemed *not applicable* (N/A)	Q4 **Was there a control group?** It was agreed that to satisfy this criterion, the control group should be an independent, separate control group, not pre-test group in a pre-post test design	Q5 **Were there multiple measurements of the outcome both pre and post the intervention/exposure?** It was agreed that if there were multiple post-test measurements of the outcome, this criterion would be met	Q6 **Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?** It was agreed that incomplete follow up was defined as incomplete information on all participants	Q7 **Were the outcomes of participants included in any comparisons measured in the same way?** It was agreed that if there was no comparison, this criterion would be deemed *not applicable* (N/A)	Q8 **Were outcomes measured in a reliable way?** It was agreed that if a valid and reliable measure existed and was available but not used, this criterion would not met	Q9 **Was appropriate statistical analysis used?**	**Score**
Dyck et al. (2018)	Y	N/A	N/A	N	N	N	N/A	Y	Y	3/6
Ruiz-Gonzalez et al. (2016)	Y	Y	Y	N	Y	N	Y	Y	Y	7/9
Scott et al. (2019)	Y	N/A	N/A	N	N	U	N/A	Y	Y	3/6
%	100.0	33.33	33.33	0.0	33.33	0.0	33.33	100.0	100	

Table 4

Analytical Cross-Sectional Studies

Citation	Q1 **Were the criteria for inclusion in the sample clearly defined?** It was agreed that if these details were described in earlier referenced, studies, this criterion was met	Q2 **Were the study subjects and the setting described in detail?** It was agreed that if these details were described in earlier referenced, studies, this criterion was met	Q3 **Was the exposure measured in a valid and reliable way?** It was agreed that if a valid and reliable measure existed and was available but not used, this criterion was not met	Q4 **Were objective, standard criteria used for measurement of the condition?** It was agreed patient-report does not constitute objective, standard criteria	Q5 **Were confounding factors identified?** It was agreed that this may have occurred in study design, data analysis or limitations section of the study	Q6 **Were strategies to deal with confounding factors stated?** It was agreed that if there were no identified confounding factors, this criterion would be marked not applicable (N/A)	Q7 **Were the outcomes measured in a valid and reliable way?** It was agreed that if a valid and reliable measure existed and was available but not used, this criterion was not met	Q8 **Was appropriate statistical analysis used?**	Score
Ahola et al. (2012)	U	U	Y	Y	Y	Y	Y	Y	6/8
Ahola et al. (2016)	U	U	N	Y	N	N	N	Y	2/8
Brazeau et al. (2008)	N	Y	Y	Y	N	N	Y	Y	5/8
Delmonte et al. (2013)	Y	Y	Y	Y	N	N/A	U	Y	5/7
Duarte et al. (2012)	Y	Y	Y	Y	N	N	N	Y	5/8
Kebede and Pischke (2019)	N	Y	Y	U	Y	Y	Y	Y	6/8
Keshawarz et al. (2018)	N	N	Y	U	Y	Y	Y	Y	5/8
Kneckt et al. (2001)	Y	Y	Y	Y	N	N	Y	Y	6/8
Lloyd et al. (2010)	Y	Y	Y	Y	Y	Y	U	Y	7/8
Martyn-Nemeth et al. (2017)	Y	Y	Y	U	U	N	Y	Y	5/8

McCarthy et al. (2017)	Y	Y	Y	Y	U	U	Y	Y	6/8
Pinsker et al. (2016)	Y	Y	U	N	U	N	U	Y	3/8
ALEXANDRA Study - Plotnikoff et al. (2010)	Y	Y	Y	Y	N	N/A	Y	Y	6/7
ALEXANDRA Study – Plotnikoff et al. (2009)	Y	Y	Y	Y	N	N/A	Y	Y	6/7
ALEXANDRA Study – Plotnikoff et al. (2007)	Y	Y	U	Y	N	N/A	Y	Y	5/7
ALEXANDRA Study – Plotnikoff et al. (2010)	Y	Y	Y	Y	N	N/A	Y	Y	6/7
ALEXANDRA Study – Plotnikoff et al. (2006)	Y	Y	Y	Y	U	Y	Y	Y	7/8
ALEXANDRA Study – Plotnikoff et al. (2008)	Y	Y	Y	Y	N	N/A	Y	Y	6/7
Raaijmakers et al. (2015)	N	Y	Y	U	Y	Y	Y	Y	6/8
Stuij et al. (2017)	N	Y	U	U	U	U	N	Y	2/8
Thomas et al. (2004)	N	Y	U	N	N	N	N	Y	2/8
%	61.9	85.71	76.19	66.66	23.8	28.57	66.66	100.0	

Table 5

Qualitative Research

Citation	Q1 **Is there congruity between the stated philosophical perspective and the research methodology?** It was agreed that if a specific philosophical perspective was not stated, evidence of a sound qualitative approach would satisfy this criterion	Q2 **Is there congruity between the research methodology and the research question or objectives?** It was agreed that if the study design was congruent with the interpretive paradigm this criterion was met	Q3 **Is there congruity between the research methodology and the methods used to collect data?** It was agreed that if the study methods were congruent with the interpretive paradigm, this criterion was met	Q4 **Is there congruity between the research methodology and the representation and analysis of data?** It was agreed that if the representation and analysis of data were congruent with the interpretive paradigm, this criterion was met	Q5 **Is there congruity between the research methodology and the interpretation of results?** It was agreed that if the interpretation of results were congruent with the interpretive paradigm, this criterion was met	Q6 **Is there a statement locating the researcher culturally or theoretically ?** It was agreed that statements relating to the influence of the researcher's beliefs or values would satisfy this criterion	Q7 **Is the influence of the researcher on the research, and vice-versa, addressed?** It was agreed that any attempt at describing this relationship would satisfy this criterion	Q8 **Are participants, and their voices, adequately represented?** It was agreed that inclusion of participant quotes would satisfy this criterion	Q9 **Is the research ethical according to current criteria or, for recent studies, and is there evidence of ethical approval by an appropriate body?**	Q10 **Do the conclusions drawn in the research report flow from the analysis, or interpretation, of the data?** It was agreed that this criterion was met if the conclusions drawn were based on the data collected	**Score**
Balfe et al. (2014)	U	Y	Y	Y	U	N	N	Y	Y	Y	6/10
Dizon et al. (2019)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	8/10
Kennedy et al. (2018)	U	Y	Y	Y	U	N	N	Y	Y	Y	6/10
Kilbride et al. (2011)	U	Y	N	Y	Y	N	N	Y	Y	Y	6/10
Kime et al. (2018)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	8/10
Lascar et al. (2014)	U	Y	Y	Y	U	N	N	Y	Y	Y	6/10
Martyn-Nemeth et al. (2019)	Y	Y	Y	Y	Y	N	N	Y	Y	Y	8/10

Oser et al. (2019)	U	Y	Y	Y	Y	N	N	Y	Y	Y	7/10
%	37.5	100.0	87.5	100.0	62.5	0.0	0.0	100.0	100.0	100.0	

Table 6

Text and Opinion Articles

Citation	**Q1** **Is the source of the opinion clearly identified?** It was agreed if there was a named author, this criterion was met	**Q2** **Does the source of opinion have standing in the field of expertise?** It was agreed that authors without diabetes related qualifications, appointments or affiliations did not satisfy this criterion	**Q3** **Are the interests of the relevant population the central focus of the opinion?** It was agreed that if the author's purpose of writing the article did not align with the intended audience, this criterion was not met	**Q4** **Is the stated position the result of an analytical process, and is there logic in the opinion expressed?** It was agreed that if the main points of the article have not been argued, supported and presented in a logical way, this criterion was not met	**Q5** **Is there reference to the extant literature?** It was agreed that if extant literature was referenced with bias or was inconclusive, this criterion was not met	**Q6** **Is any incongruence with the literature/sources logically defended?** It was agreed that if the article did not explicitly express an opinion, *not applicable* (N/A) was assigned	**Score**
Colberg et al. (2015)	Y	Y	Y	Y	Y	N/A	5/5
Greener (2017)	Y	N	Y	Y	Y	Y	5/6
Kime and Pringle (2018)	Y	Y	Y	N	Y	Y	5/6
Kime and Pringle (2019)	Y	Y	Y	Y	N	N	4/6
Narendran and Andrews (2018)	Y	Y	Y	Y	Y	Y	6/6
National Institute for Health and Care Excellence (2018)	Y	Y	Y	Y	Y	N/A	5/5
M. C. Riddell et al. (2017)	Y	Y	Y	Y	Y	Y	6/6
Sundberg (2018)	Y	Y	Y	Y	Y	N/A	5/5
%	100.0	87.5	100.0	87.5	75.0	50.0	

Supplement 4 - Data extraction tool

Scoping Review Details	
Scoping Review title:	
Review objective/s:	
Review question/s:	
Inclusion/Exclusion Criteria	
Population	
Concept	
Context	
Types of Study	
Article Details and Characteristics	
Article citation details (e.g. author/s, date, title, journal, volume, issue, pages)	
Article/review type	
Country	
Context	
Participants (details e.g. age/sex and number)	
Details/Results extracted from article (in relation to the concept of the scoping review)	
Aim / Hypothesis / Objectives	
Recruitment methods (or search strategy for reviews)	
Barriers to physical activity participation	
Tools used to measure barriers	
Associations or correlations (with physical activity / barriers to physical activity)	
Measure of physical activity participation	
Facilitator of physical activity	
Key Findings	

Adapted from JBI data extraction instrument (Peters et al., 2020)

Supplement 6 - Individual sources of evidence

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
Kavookjian et al. (2007)	To assess and summarise evidence and gaps in the literature regarding the intervention for being active among individuals with diabetes	Systematic review	T1D Adults	Included interventions involved any type of PA, individual or group, delivered via didactic communication or collaborative effort and using written, computer-based, or visual materials	More research required to determine if exercise consultation results in sustained PA Very little research exists on learning/behavioural outcomes or on clinical outcomes
Klaprat et al. (2019)	An updated overview of: • What we know about PA for persons with T1D • Gaps in the literature that could guide future research programs • Explore the benefits of patient engagement and co-development of a research agenda	Narrative review	T1D Adults	Behavioural trials that motivate individuals to adopt a more active lifestyle	Lack of adequately powered clinical trials of PA on health-relate outcomes Lack of optimal theoretical model for long term adherence to PA Lack of optimal delivery model for increasing PA
Pillay et al. (2015)	To determine the effects of behavioural programs for patients with T1D on behavioural, clinical, and health outcomes and to investigate factors that might moderate effect	Systematic review	T1D Adults Mean age ranged from: 30 - 49 yrs Mean HbA1c ranged from: 7.7% - 9.6%	Behavioural programs	Insufficient evidence to suggest behavioural programs significantly change PA (intensity/duration) when compared to usual care

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
Brazeau et al. (2014)	To examine the efficacy of a physical exercise promotion program to improve total energy expenditure in adults with T1D	RCT	T1D Adults Mean age: Intervention: 45.1 ±14.5 yrs Control: 44.2 ±12.5 yrs Mean duration of diabetes: Intervention: 20.3 ±12.9 yrs Control: 24.4 ±13.6 yrs	Group program of PA promotion and exercise activities / Information leaflet	No significant improvement to TEE or PAL. 14% improvement of VO2peak in intervention group from baseline to 3 months: Baseline: 24.6 (22.0-27.2) ml/kg/min 3 months: 28.2 (24.9-31.3) ml/kg/min (p = 0.003)
Hasler et al. (2000)	To evaluate the effectiveness of 1:1 exercise consultation in increasing PALs	RCT	T1D Adults Mean age: 33.1 ±9.2 yrs	Exercise consultation (1:1) / Information leaflet	64.8% increase in LTPA in intervention pre to post (3 weeks) (p = 0.045). No significant change in control Intervention participants identified as 'contemplators' or 'preparers' at baseline associated with higher percentage participating in sport and exercise after intervention Intervention participants identified as 'maintainers' at baseline associated with higher percentage participating in overall LTPA after intervention

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
Narendran et al. (2017)	A pilot trial to address the key uncertainties in designing a definitive trial to test whether exercise preserves beta-cell function	RCT	T1D Adults Mean age: 32.3 ±10.5 yrs Mean duration of diabetes: 12 ±27 months Mean HbA1c: 9 ±2.3%	Exercise training (goal-oriented motivational interviewing, graded unsupervised exercise program, PA log) plus usual care / Usual care alone	Participants meeting 150 min/week moderate intensity PA (self-reported) increased from 16% to 61% in intervention compared to 21% to 12% in control (baseline – 6 months) Intervention increased from 243 ±141 min MVPA/wk to 285 ±40 min/wk at 6 months and 273 ±34 min/wk at 12 months. Control decreased MVPA/wk at 6 months MVPA/wk correlated with VO2max
Dyck et al. (2018)	To use education sessions and exercise classes to improve exercise self-efficacy in individuals with T1D	Quasi-experimental	T1D Adults Mean age: 44.1 yrs Duration of diabetes: >1 year HbA1c: <10%	4 boot camp sessions (once per week) Each weekly session: 30-minute education session + group exercise class / No control	Barriers to PA (BAPAD1): "Loss of control over diabetes" – rated highest (3.00 ±2.04) "Your work/school schedule" (2.83 ±1.77) "Fear of being tired" (2.42 ±1.85) "Risk of hypoglycaemia" (2.25 ±1.69) Positive correlation between number of hypoglycaemic events and BAPAD1 scores ($r = 0.82$, $p = 0.001$) No significant change to BAPAD1 score pre-post

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
Ruiz-Gonzalez et al. (2016)	To implement an intensive and practical diabetes education program and evaluate long-term effects and impact on psychosocial variables	Quasi-experimental	T1D Adults Mean age: 32.8 ±14.16 yrs	Educational program (group) – 3 sessions delivered by a diabetes educator / Participants are their own controls	Self-care barriers including exercise significantly decreased after the educational program ($p < 0.01$) Pre = 2.56 ±1.71 6 months post = 1.92 ±1.49 1year 2.15 ±1.36 (All scores out of 10) No significant change to frequency of physical exercise.
Scott et al. (2019)	To evaluate virtually monitored home-based high intensity interval training (Home-HIT) in people with T1D	Quasi-experimental	T1D Adults Mean age: 30 ±3 yrs Mean duration of diabetes: 10 ±2 yrs Mean HbA1c: 8 ±0.6%	Six-week virtually monitored Home-HIT program / No control	95% adherence to unsupervised Home-HIT Home-HIT increased VO_{2peak} by 7% (p=0.017) Positives about HOME-HIT: Convenience Time efficiency More stable BGLs Virtual monitoring improved motivation Use of remotely monitored heart rate suggested to improve uptake, adherence, compliance to exercise Top three barriers to Home-HIT: Lack of time (91%) FoH (27%) Lack of motivation (18%)
Ahola et al. (2012)	To study the associations between sense of coherence and self-care practices in patients with T1D	Cross-sectional	T1D Adults Median age: 44 (35-53) yrs Median duration of diabetes: 27.2 (17.3-37.1)	N/A	Sense of coherence scores correlated with observed weekly LTPA (MET hours) r = 0.098 p = 0.004 Sense of coherence score predicted MET hour values in men but not women

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
Ahola et al. (2016)	To study the association between FoH and various diabetes self-management practices	Cross-sectional	T1D Adults with FoH Mean age: Women: 47.2 ±13.6 yrs Men: 48.6 ±13.3 yrs Mean duration of diabetes: Women: 31.2 ±13.3 yrs Men: 30.8 ±14.1 yrs	N/A	No differences observed in levels of reported PA by FoH status. Median MET hours/number of journal days: Men FoH: 4.3 (2.5-8.4) No FoH: 5 (2.4-8.6) $p = 0.901$ Women FoH: 5.3 (3.2-8.3) No FoH: 4.5 (2.7-8) $p = 0.242$
Brazeau et al. (2008)	To determine, in an adult population with T1D, barriers to regular PA using a 'diabetes-specific' barriers measure and factors associated with these barriers	Cross-sectional	T1D Adults Mean age: 43.5 ±11.6 yrs Mean duration of diabetes: 23.3 ±13.2 yrs Mean HbA1c: 7.7 ±1.1%	N/A	Barriers to PA (BAPAD1): FoH 3.58 ±2.02 Work schedule 3.05 ±1.98 Loss of control over diabetes 2.83 ±1.80 Low levels of fitness 2.83 ±1.95 Correlates of barriers: Perceived well-being, knowledge of insulin pharmacokinetics, implementation of strategies to reduce the probability of exercise-induced hypoglycaemia, greater social support and having someone to perform PA with were associated with fewer barriers.
Delmont et al. (2013)	To investigate how islet transplantation influenced diet, exercise habits, and body composition during 10 years after transplantation	Cross-sectional	T1D Adults who have undergone islet transplant Mean age: 45.8 ±8 yrs	Islet transplant / No control	No significant change in average hours/week of voluntary PA during the 10-year follow-up (average 5.3 ±5.6 hours/wk)

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
			Mean duration of diabetes: 37 ±11 yrs		
Duarte et al. (2012)	To compare PAL and care related to exercise in patients with diabetes mellitus	Cross-sectional	T1D Adults Mean age: 37 ±11 yrs Mean duration of diabetes: 17 ±9 yrs Mean HbA1c: 9.2 ±2.2%	N/A	Reasons for not exercising: Lack of time 43.9% Discouragement 17.5% Patient does not like exercise 8.8% Hypoglycaemia 8.8% (p<0.001)
Kebede and Pischke (2019)	To investigate the association of diabetes app use and other factors with self-care behaviour (including PA)	Cross-sectional	T1D Adults Mean age: 39 ±12.9 yrs	N/A	Using a diabetes app associated with greater PA (self-care score – PA 3.43 ±2.09) when compared to non-app users (2.93 ±2.07) (p = 0.0001)
Keshawarz et al. (2018)	To compare planned LTPA levels in adults with and without T1D using an accelerometer. To examine ‘‘diabetes-specific’’ barriers to PA and explored how barriers and hypoglycaemic episodes impacted PA in people with T1D	Cross-sectional	T1D Adults Mean age: 49 ±9 yrs Mean duration of diabetes: 36 ±8 yrs Mean HbA1c: 7.7 ±1.4%	N/A	% of participants scoring a BAPAD1 item >4: Risk of Hypoglycaemia (25%) Fear of loss of control over diabetes (21%) Risk of hyperglycaemia (14%) Participants reporting barriers spent significantly less time in MVPA bouts/wk (p = 0.047) and engaged in significantly fewer bouts of MVPA/wk than participants who did not report barriers (p = 0.005) ‘Diabetes-specific’ barriers to PA were associated with less MVPA across all outcomes, while reporting no barriers to PA was associated with higher levels of MVPA

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
					Men reporting frequent hypoglycaemia spent less time in MVPA bouts/wk (p = 0.003*)* and had significantly fewer MVPA bouts/wk compared to men who reported infrequent hypoglycaemia (p = 0.02) Participants experiencing barriers were younger (p = 0.0001) Participants using CGM experienced more barriers (p = 0.04) Participants with higher HDL and lower diastolic blood pressure experienced less barriers (p = 0.03, p = 0.02)
Kneckt et al. (2001)	To evaluate whether self-esteem can determine diabetes adherence and oral health behaviour	Cross-sectional	T1D Adults Mean age: 34 ±12 yrs Mean duration of diabetes: 16 ±10 yrs Mean HbA1c: 8.5 ±1.8%	N/A	58% of those having high self-esteem had good exercise adherence, while 34% of those with low self-esteem had poor exercise adherence (p = 0.005)
Lloyd et al. (2010)	To examine the relationship between depressive symptomatology, diabetes-related distress and aspects of diabetes selfcare in a cohort of individuals with T1D	Cross-sectional	T1D Adults Mean age: 45 ±7.5 yrs Mean duration of diabetes: 36.7 ±7.1 yrs Mean HbA1c: 7.5 ±1.4%	N/A	All four PA variables were significantly and negatively correlated with the BDI (r between -0.20 and -0.27; p < 0.01) CESD scale (r between -0.16 and -0.33; p < 0.01) PAID scale (r between -0.14, p < 0.05, and -0.23, p< 0.01)
Martyn-Nemeth et al. (2017)	To examine the association of FoH with self-management behaviours	Cross-sectional	T1D (all using insulin pump) Adults (18-35 years) Mean age: 26 ±4 yrs Mean duration of diabetes: 13 ±8.1 yrs Mean HbA1c: 7.2 ±1%	N/A	FoH was associated with less PA (light activity, r = -0.341, p = 0.045)

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
McCarthy et al. (2017)	To examine patterns of PA and to identify the biological and psychosocial factors associated with PA To examine the self-management strategies employed to engage in PA	Cross-sectional	T1D Adults Mean age: 45 ±17 yrs Mean duration of diabetes: 20 ±15 yrs Mean HbA1c: 7.8 ±1.2%	N/A	Barriers to PA (BAPAD1): Work schedule (3.75 ± 2.24) Weather conditions (3.54 ± 2.06) Individuals who worked full-time had high step counts compared to other categories of employment 55,193 versus 38,295 steps (p = 0.001) Total BAPAD1 score negative correlated with weekly step counts
Pinsker et al. (2016)	To determine whether use of differing diabetes technologies affects health-related behaviours	Cross-sectional	T1D Adults Mean age: 41.4 ±16.5 yrs Mean duration of diabetes: 22.8 ±14.7 yrs	N/A	Pump users (with and without CGM) exercised less (3.8 ±1.6 days/wk) than those who did not use pump (4.54 ±1.6 day/wk; p<0.001) Participants using pump (with and without CGM) were more likely to disagree with the statement "fear of low blood glucose levels keeps me from exercising" (p<0.01) than those who did not use any devices or CGM alone
ALEXANDRA Study - Plotnikoff et al. (2010)	To investigate the utility of the Theory of Planned Behaviour in understanding PA in an adult population with T1D or T2D	Cross-sectional	T1D Adults Mean age: 51.1 ±17.1 yrs	N/A	Perceived behavioural control had a direct impact on 6-month PA in T1D group β = 0.10 (model 1) and β = 0.12 (model 2)
ALEXANDRA Study - Plotnikoff et al. (2009)	To compare PA related, key social-cognitive constructs from major health behaviour theories/models between large samples of adults with either T1D or T2D, and those without diabetes	Cross-sectional	T1D Adults Mean age: 51.1 ±17.1 yrs	N/A	T1D group reported greater cons for PA than those with T2D or without diabetes (p<0.05). "Generic population-based, theoretically driven interventions operationalizing [social-cognitive] constructs should have equal salience

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
					to adults with T1D, T2D and those without diabetes" Lower reported response efficacy (perceived benefits) scores compared to those without diabetes – suggests emphasis on the benefits of PA is required for programs targeting individuals with T1D. Greater cons in T1D group suggests emphasis should be placed on overcoming barriers to PA
ALEXANDRA Study - Plotnikoff et al. (2007)	To examine the predictors of PA and activity change for individuals with T1D or T2D	Cross-sectional	T1D Adults Mean age: 51.88 ±16.75 yrs Mean duration of diabetes: 21.34 ±12.89 yrs	N/A	Older age (β = -0.11 p<0.05) and difficulties performing tasks of daily living (β = -0.12, p<0.05) significantly associated with less PA Individuals diagnosed >1 yr: Higher level of PA associated with younger age at diagnosis (β = -0.11, p<0.05) and less perceived difficulties in tasks of daily living (β = -0.12, p<0.05)
ALEXANDRA Study - Plotnikoff et al. (2010)	To investigate the utility of the Protection Motivation theory for explaining PA in an adult population with T1D or T2D	Cross-sectional	T1D Adults Mean age: 51.1 ±17.1 yrs	N/A	Intention and PA behaviour were highly interrelated cross-sectionally (β = 0.30) and longitudinally (β = 0.19) Self-efficacy predictive of PA behaviour cross-sectionally (β = 0.26) and longitudinally (β = 0.20)

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
ALEXANDRA Study - Plotnikoff et al. (2006)	To identify key demographic and health factors associated with PA participation in adults with T1D or T2D	Cross-sectional	T1D Adults Mean age: 51.1 ±17.1 yrs	N/A	Combined model: Higher levels of PA were correlated with: Younger age (β = -0.12, p<0.01) Being single (β = -0.11, p<0.01) Higher income (β = 0.11, p<0.01) Lower level of perceived disability (β = -0.19, p<0.001)
ALEXANDRA Study - Plotnikoff et al. (2008)	To test the social cognitive theory for explaining PA in a large population sample of adults with T1D and T2D	Cross-sectional	T1D Adults Mean age: 51.1 ±17.1 yrs	N/A	Self-efficacy associated with PA (β = 0.22, p<0.01) Goals associated with PA (β = 0.17, p<0.01)
Raaijmakers et al. (2015)	To determine whether T1D and T2D patients' perceived autonomy support from their primary care provider, as well as their perceived competence and treatment self-regulation, are associated with their diabetes self-care activities and general diabetes control	Cross-sectional	T1D Adults	N/A	Highly educated participants engaged significantly less often in 30 min of PA than those with lower education (β = -0.73, p<0.05) Perceived competence was NOT significantly correlated with PA
Stuij et al. (2017)	To explore and describe how people with T1D and T2D in the Netherlands experience sports and PA counselling from their medical professionals in general	Cross-sectional	T1D Adults	N/A	62% disagree with this statement: "I was guided properly in taking up sports and PA (again) after my diagnosis" 38% agree / 39% disagree with this statement: "There hardly is/was any attention for sports and PA during my treatment" 37% disagree with this statement: "I find it pleasant that my HCP exert pressure on me to do more sports and PA"

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Thomas et al. (2004)	To explore how much PA patients with diabetes need to perform and what are the perceived factors that prevent patients from doing more PA	Cross-sectional	T1D Adults Mean age: Active participants: 31.9 ±9.8 yrs Inactive participants: 35.9 ±6.9 yrs	N/A	Activity was not significantly associated with age or weight
Balfe et al. (2014)	To determine how and why workplace environments impact diabetes management for adults people with T1D	Qualitative	T1D Adults Age range: 23-30 yrs Mean duration of diabetes: 11.5 ±5.6 yrs	N/A	Barriers to PA: Commute time to/from work Exhausted after work Pressure to be at their desk while at work Seasonality Associated with PA: Commuting, "exhausted" after work and commute, seasonality Facilitators of PA: Good weather Partner Self-motivation
Dizon et al. (2019)	To understand patient perspectives on managing T1D during exercise	Qualitative	T1D (athletes >10 hrs/wk of PA) Adults Mean age: 41 Mean duration of diabetes: 22 yrs	N/A	Facilitators/preferred resources: Trial and error Peer-support Support from HCP Pumps, CGM and phone applications
Kennedy et al. (2018)	To explore attitudes and barriers to exercise in adults with new-onset T1D	Qualitative	T1D Adults Median age: 29 (18-53) yrs Median duration of diabetes: 66 days	N/A	Medical barriers to PA: Most frequently cited was hypoglycaemia – related to actual experience and worry about hypoglycaemia. Lack of knowledge or confidence in managing diabetes around exercise. Influence of HCP: 4 participants said HCP had advised

Author	Aims	Design	Population/Participants	Intervention / Control	Key Findings
					them not to exercise Work commitments Family and other time commitments Around a half of participants reported a decline in activity levels around the time of diagnosis. Participants suggested education, supervised or group activity sessions, a programme of gradually increasing exercise, help with goal setting and a fitness advisor may improve activity levels
Kilbride et al. (2011)	To explore the experience of participating in exercise among people with T1D who exercise regularly	Qualitative	T1D Adults Mean age: 48.5 ±2.5 yrs Mean HbA1c: 7.35 ±0.5 %	N/A	Facilitators of PA: Trial and error Overcome FoH Understand effect of PA on their bodies Spend time adjusting insulin, food intake, monitoring and then reviewing strategies Locus of control

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Kime et al. (2018)	To investigate the needs of adults with T1D around PA and the challenges they face	Qualitative	T1D Adults Age range: Women: 26-84 yrs Men: 33-91 yrs Duration of diabetes range: 2-57 yrs	N/A	Barriers to PA: Hypoglycaemia (FoH) Motivation Embarrassment Facilitators to PA: Health promotion Enjoyment To learn how PA affected their diabetes Change in culture amongst health professionals Tailored information with guidelines and instructions on how to manage activity with T1D Peer support – talking Workshops/courses PA weekend
Lascar et al. (2014)	To explore attitudes, barriers and facilitators to exercise in patients with T1D	Qualitative	T1D Adults Age range: Women: 21-62 yrs Men: 21-65 yrs Duration of diabetes range: 2 wks-50 yrs	N/A	Barriers to PA: Lack of knowledge of the management of diabetes for exercise Time and work Access to facilities Embarrassment, body image, fear of failure Lack of motivation Weather Facilitators to PA: Free or reduced admission gyms/pools Better time management Support and encouragement Advice and information Motivators: Health benefits Body image

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					Enjoyment Social Aspects
Martyn-Nemeth et al. (2019)	To gain knowledge about the challenges imposed by hypoglycaemia and how FoH may influence diabetes self-management behaviours	Qualitative	T1D Adults Age range: 20-57 yrs Mean duration of diabetes: 16 yrs	N/A	Barriers to PA: Hypoglycaemia High degree of planning and time required to participate in exercise Facilitators of PA: Trial and error
Oser et al. (2019)	To broaden the understanding of barriers and facilitators to exercise among adults living with T1D	Qualitative	T1D Adults Age range: 19-63 yrs 40% HbA1c >9%	N/A	Barriers to PA: Hypoglycaemia Burden of carrying supplies Universal barriers such as time and motivation Lack of exercise instruction from HCP Facilitators of PA: Family Online peer support Organised T1D activities Support from HCP

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Colberg et al. (2015) (Colberg et al., 2015)	An overview of technology in T1D and PA	Text and Opinion	Nil	Technology eg wearables, pumps, monitors, calculators, artificial pancreas, pattern recognition and learning, and social integration	The overriding barrier to PA: Fear of severe hypoglycaemia, and a lack of knowledge of effective strategies for hypoglycaemia avoidance. Facilitators of PA: Technology – Activity tracking devices, insulin pumps, glucose monitors, continuous glucose monitors, artificial pancreas systems, social integration. "While technological advances have allowed exercisers with diabetes to progress toward more effectively managing their blood glucose levels during various types of PA, technology is still far from fully removing the FoH that is the strongest impediment to undertaking regular exercise with T1D"
Greener (2017)	The author explores the latest advice, including that of a recent consensus statement, and highlights areas where more input is needed	Text and Opinion	Nil	N/A	Barriers to PA: FoH during and after PA Concerns about losing glycaemic control Inadequate knowledge around managing diabetes when they exercise A lack of evidence about the optimal frequency, duration and intensity of exercise that improves glycaemic control Facilitators of PA: NICE guidelines for PA in T1D Consider patient's goals Further research is needed to define

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					factors that can improve uptake and persistence in people with T1D
Kime and Pringle (2018)	Commentary: Exercise and PA in people with T1D: The importance of behaviour change	Text and Opinion	Nil	N/A	Health professionals should consider the use of behaviour theory and effective intervention strategies Programmes to have greater applicability for the average person with T1D who just wants to increase activity around daily active living and recreation
Kime and Pringle (2019)	This article outlines the importance of the role of healthcare professionals in providing advice to patients to become more physically active, and the training that could be provided to support this.	Text and Opinion	Nil	N/A	HCP need support and training around PA and T1D and behaviour change techniques

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Narendran and Andrews (2018)	To outline the origins of EXercising for Type One Diabetes (EXTOD), a summary of what has been achieved so far, and a brief overview of future plans.	Text and Opinion	Nil	N/A	Barriers to PA: New-onset T1D: Hypoglycaemia (actual and fear of) Lack of knowledge/confidence in managing diabetes Advice from HCP to stop exercising Planning Feeling overwhelmed by diagnosis Established T1D: Loss of control of diabetes Lack of knowledge on the management of diabetes when exercising Facilitators of PA: Education program for people with T1D Peer support Engagement with patients and public to support local sporting events

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National Institute for Health and Care Excellence (2018)	NICE guidelines are evidence-based recommendations for health and care in England	Text and Opinion	Nil	N/A	Advise adults with T1D that PA can reduce their enhanced cardiovascular risk in the medium and longer term. Give adults with T1D information about: Appropriate intensity and frequency of PA Role of self-monitoring of changed insulin and/or nutritional needs Effect of activity on blood glucose levels (likely fall) when insulin levels are adequate Effect of exercise on blood glucose levels when hyperglycaemic and hypoinsulinaemic Appropriate adjustments of insulin dosage and/or nutritional intake for exercise and post-exercise periods, and the next 24 hours Interactions of exercise and alcohol Further contacts and sources of information.
M. C. Riddell et al. (2017)	Author's reply to remarks by Matthew Campbell and colleagues on the consensus statement on exercise management in T1D	Text and Opinion	Nil	N/A	Barriers to PA: HCP have poor knowledge of PA and T1D Support for PA and exercise management is scarce Facilitators of PA: Health-care providers to equip themselves with knowledge to advise patients, confidently HCP to question the type and frequency of PA and any barriers to PA at each clinic visit Use of behavioural science to

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					overcome barriers Motivational interviewing PEAK programme and EXTOD educating health professionals and patients
Sundberg (2018)	Discussion surrounding unawareness of low PA in people with T1D	Text and Opinion	Nil	N/A	Is lack of PA another social complication of diabetes? Could it be that if you are less active already from childhood, then you are less skilled in activities and thus perform them less often? Facilitators of PA: Support people with diabetes to recognise their lack of PA and identify strategies to increase PA If FoH is a major barrier to PA but not experienced hypoglycaemia, shall interventions then be targeting FoH or glycaemic variability to be most efficient?

T1D – type 1 diabetes; PA – physical activity; TEE – total energy expenditure; PAL – physical activity levels; $VO_{2peak\ or\ max}$ - maximum rate of oxygen consumption; LTPA – leisure time physical activity; MVPA – moderate to vigorous physical activity; BAPAD1 – barriers to physical activity in diabetes – type 1; MET – metabolic equivalent; HDL – high density lipoprotein; BDI – Beck Depression Inventory; CESD – Centre for Epidemiological Studies of Depression; PAID – Problem Areas in Diabetes; FoH – fear of hypoglycaemia; CGM – continuous glucose monitor; HCP – healthcare professional; NICE – National Institute for Health and Care Excellence; EXTOD – exercise for type 1 diabetes; PEAK – performance in exercise and knowledge

± standard deviation