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Thigh-worn accelerometry for measuring movement and posture across the 24-hour cycle: a scoping review and expert statement

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ABSTRACT

Introduction The Prospective Physical Activity Sitting and Sleep consortium (ProPASS) is an international collaboration platform committed to harmonise thigh-worn accelerometry data. The aim of this paper is to (1) outline observational thigh-worn accelerometry studies and (2) summarise key strategic directions arising from the inaugural ProPASS meeting.

Methods (1) We performed a systematic scoping review for observational studies of thigh-worn triaxial accelerometers in free-living adults (n≥100, 24 hours monitoring protocols). (2)Attendees of the inaugural ProPASS meeting were sent a survey focused on areas related to developing ProPASS: important terminology (Q1); accelerometry constructs (Q2); advantages and distinct contribution of the consortium (Q3); data pooling and harmonisation (Q4); data access and sharing (Q5 and Q6).

Results (1) Eighty eligible articles were identified (22 primary studies; n~17 685). The accelerometers used most often were the ActivPAL3 and ActiGraph GT3X. The most commonly collected health outcomes were cardiometabolic and musculoskeletal. (2) None of the survey questions elicited the predefined 60% agreement. Survey responses recommended that ProPASS: use the term physical behaviour or movement behaviour rather than 'physical activity' for the data we are collecting (Q1); make only minor changes to ProPASS's accelerometry construct (Q2); prioritise developing standardised protocols/tools (Q4); facilitate flexible methods of data sharing and access (Q5 and Q6).

Conclusions Thigh-worn accelerometry is an emerging method of capturing movement and posture across the 24 hours cycle. In 2020, the literature is limited to 22 primary studies from high-income western countries. This work identified ProPASS's strategic directions—indicating areas where ProPASS can most benefit the field of research: use of clear terminology, refinement of the measured construct, standardised protocols/tools and flexible data sharing.

What is known

- ► The use of thigh-worn accelereometry for measuring movement and posture is growing.
- ► The Prospective Physical Activity Sitting and Sleep consortium (ProPASS) is committed to harmonising thigh-worn accelerometry data to investigate longitudinal associations of physical activity, posture and sleep with long-term health outcomes and longevity.

What are the new findings

- ► This scoping review identified 22 primary studies (roughly 17 685 participants) with the potential to pool thigh-worn triaxial accelerometer data.
- ► This manuscript will guide and set the direction for ProPASS's contribution to the field of physical activity and health.

INTRODUCTION

Different aspects of movement and posture-defined physical behaviour—such as physical activity, sitting and sleep—are vital and modifiable determinants of health.[1 2] Traditionally, much of the research into physical behaviours has operated in subdisciplinary silos (eg, physical activity, exercise, sedentary behaviour, sleep) partially owing to variations in methodological paradigms, in particular differences in measurements.[3–5] Recent advances in wearable technology, such as accelerometers, provide the potential to concurrently quantify multiple aspects of such behaviours in free-living conditions continuously across a number of days or weeks.[6 7] This presents opportunities for a major breakthrough in our ability to understand how all these aspects of physical behaviour synergistically influence health and promote chronic disease prevention.[7]

One area of vigorous debate regarding the use of accelerometers is where they should be placed, with the aim to maximise feasibility and the breadth and depth of collected data. In the first generation of accelerometer studies, most large-scale studies focused on physical activity used devices worn on a belt around the waist/hip.[8–10] This location was initially chosen due to its simplicity (ease of setup and wear) and close proximity to a person's centre of gravity (minimising the effect of extraneous movement). However, due to it's interference with clothing (requiring removal of the device when changing, etc) and sleep, waist/hip-worn devices have often been used only for waking hours, or part thereof.

Waist/hip-worn devices are also limited regarding the aspects/constructs of physical behaviour that they can currently identify. For instance, although they have been extensively validated for measuring energy expenditure,[11] they have difficulty quantifying postures and distinguishing between different physical behaviours (eg, sitting vs standing, walking on a flat surface vs stair climbing).[12] Wrist-worn devices, traditionally favoured in sleep research, have also gained popularity for physical activity assessment. This 'watch-like' wrist attachment carries less burden for research participants, resulting in higher compliance, and thus, may be more feasible for complete monitoring of 24 hours daily cycles than waist/hip-worn methods.[13 14] However, similar to waist/hip-worn devices, wrist-worn accelerometers currently have difficulty distinguishing between basic aspects of physical behaviour, such as posture and activity type.[12 15]

An emerging accelerometer placement location is the thigh. Thigh-worn accelerometers are typically taped to the front of the thigh and can be worn under clothing 24 hours a day for multiple days.[16–18] In addition to energy expenditure outcomes,[19] thigh placement allows detection of the specific physical behaviours (ie, sitting/lying, standing, walking, running, stair climbing, cycling) with excellent accuracy.[20 21] As such, an increasing number of major international cohorts have recently adopted such methods to measure thousands of participants, such as the Maastricht Study (n~8000), HUNT4 (n~38 000) and the 1970 British Birth Cohort (n~6000).[22] The successful incorporation of thigh-worn accelerometry by these studies demonstrates that thigh-worn accelerometry is feasible for comprehensively quantifying physical behaviour across the 24 hours cycle in large-scale health research.

The Prospective Physical Activity Sitting and Sleep consortium (ProPASS) is a recent research collaboration platform[22] of investigators utilising observational studies of thigh-worn accelerometry. ProPASS's ultimate scientific objective is to produce longitudinal evidence on the associations of physical activity, posture and sleep with long-term health outcomes and longevity. To fulfil these aims, ProPASS will harmonise and integrate thigh-worn accelerometry and corresponding health outcomes data—including linkage to administrative health data such as mortality and cause-specific hospital admissions. Besides its function to harmonise previously collected data, a fundamental aspect of ProPASS is its prospective nature. As such, ProPASS will develop standards to support future population-based studies to collect preharmonised thigh-worn accelerometry data. Meeting these objectives and handling sensitive health-related data is complex and demands long-term planning.

In line with publications describing previous accelerometry consortia,[23] this paper had a dual aim:

- To identify studies potentially eligible for inclusion in ProPASS via a systematic scoping review to summarise observational studies that collected 24 hours thigh-worn triaxial accelerometery data in population or community-based adult samples.
- To guide the development of ProPASS by compiling and sumarising key discussions and decisions arising from the initial ProPASS collaborators meeting (held in October 2018 in Copenhagen, Denmark) into an expert collaborator statement.

OBJECTIVE 1: SCOPING REVIEW

Methods

We conducted a scoping review and reported it according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting standards[24] and the PRISMA Extension for Scoping Reviews.[25]

Search strategy and article selection

Systematic searches scanned the literature (initial: July 2018; updated: August 2020) in MEDLINE via Ovid and Embase via Ovid, with no date or language restrictions. The search included terms for accelerometers combined with terms for observational studies. Full details of the search strategy are provided in online supplemental appendix 1.

Articles identified during the search were screened for their eligibility for the study in two stages by two reviewers independently (MLS, TC, NG, EIE). The first stage involved screening articles by title and abstract and clearly ineligible articles were excluded at this stage. If there was doubt about the eligibility of an article or disagreement between the reviewers, the article was included in the full-text review. The second stage involved a full-text review; any disagreements at this stage were resolved by discussion between the two reviewers until consensus was reached. For each excluded full text article, the reason for exclusion was noted.

To be included in this review, articles had to meet the following criteria: full-text publication using an observational study design where community-based, free-living adult participants wore thigh-worn triaxial accelerometers that used 24 hours activity data monitoring protocols. Exclusion criteria were: studies with <100 participants; studies of institutionalised participants or specialised clinical cohorts (eg, undergoing or perioperative major treatments or surgery); validation and calibration studies and non-English language studies. If studies included some participants (<20%) under 18 years of age, we considered to include them on a case-by-case basis so

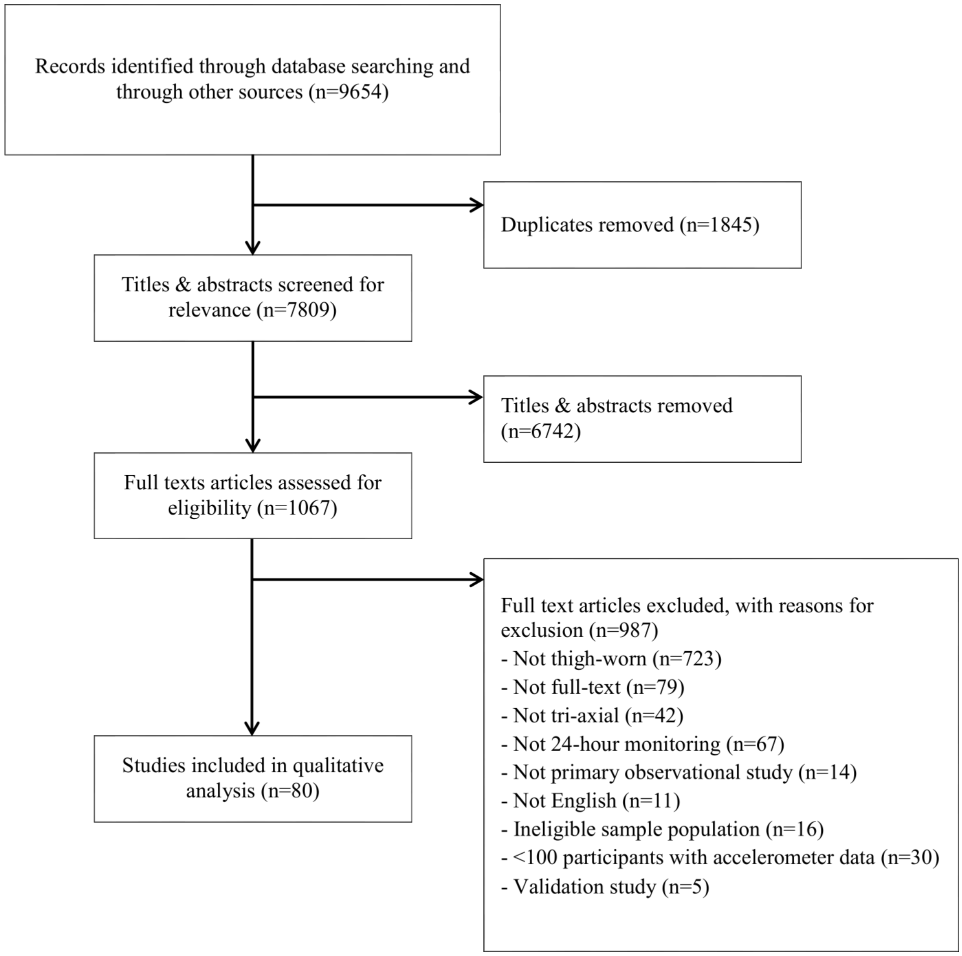

Figure 1 Flow diagram of study selection.

long as the participant range was close to adulthood (ie, older than 15).

Data extraction, outcomes and analysis

Data extraction, undertaken by a single author (EIE and MLS), included details of:

1. Study participants (eg, design, recruitment, sample criteria, size, location, age, sex, employment, whether the study belongs to a 'primary' study/cohort).
2. Accelerometry protocols (eg, device, placement, other sensors, days of wear, software used, variables created).
3. Physical behaviour information collected by other methods (eg, collected by questionnaire).
4. Health outcome variables (eg, cholesterol, fasting glucose, body mass index (BMI), back pain).
5. Data sharing policies.

The data extracted is presented and summarised.

Results

Of the 9654 articles identified through the search, 1845 were duplicates, leaving 7809 articles to be screened for eligibility. Of these 7809 articles, 6742 were excluded by title and abstract and another 987 were excluded after reading through the full text. This left 80 articles eligible for inclusion (figure 1). Full details of the data extracted from each study are provided in online supplemental appendix 2.

Studies design and participants

Of the 80 articles identified, 72 were cross-sectional,[6,26–96] leaving 8 articles that presented prospective data.[97–104] The 80 articles contained data from 22 different primary studies.[26,27,35,37,38,40,44,49,63,64,68,72,75,76,79,81,85,94,96,100,104] These 22 primary studies consisted of 18 longitudinal studies[26,27,37,38,40,49,63,68,72,75,76,79,81,85,96,100,104] and 4 cross-sectional studies.[35,44,64,94] The 22 different primary studies (~17 685 participants) were mainly from the Netherlands, UK and Denmark. The mean/median age range for participants was 20–79 years and all collected data in both men and women. Ten of the 22 primary studies recruited participants from their workplace[35,37,44,75,76,79,81,96,100,104]—such as healthcare, construction, manufacturing and cleaning. The remaining 12 studies recruited participants from the general population.[26,27,38,40,49,63,64,68,72,85,94]

Accelerometry protocols

The accelerometer used most often was the ActivPAL (10 primary studies),[26,38,44,49,63,64,68,76,94] followed by the ActiGraph GT3X (eight primary studies)[35,37,72,79,81,96,100,104] and MOX Accelerometry Monitor (two primary studies).[27,40]

Most studies processed accelerometry data using either ActivPAL software (four primary studies)[26 38 44 64] or custom Matlab software (11 primary studies; of which 9 used the custom Matlab Acti4 program).[27 35 37 49 72 75 79 81 96 100 104] All accelerometers were attached to the skin on the front of the thigh (roughly midway between the anterior superior iliac spine and the patella). Participants were asked to wear the accelerometer continuously for between 3 and 10 days with the most commonly requested wear time being 7 days (11 primary studies).[26 27 37 38 40 64 68 72 76 94]

Daily logs/diary data

Fourteen primary studies used diaries to supplement the information collected by accelerometry.[26 27 35 37 38 44 64 68 72 75 76 81 96] Mostly, diary-based information was used to identify participants' time in bed (11 primary studies)[26 27 35 37 38 63 72 76 81 96] non-wear time (8 primary studies)[26 27 35 37 44 72 81 96] and times at work (7 primary studies).[35 37 44 72 75 81 96]

Health outcomes

The most commonly reported health outcomes were cardiometabolic (11 primary studies),[26 35 40 49 63 72 75 79 81 85 96] followed by musculoskeletal (five primary studies).[26 81 96 100 104] Commonly reported cardiometabolic outcomes were insulin and cholesterol levels, fasting/2-hour postload glucose, blood pressure, body composition and BMI. The most commonly reported musculoskeletal outcome was low back pain, followed by neck/shoulder pain. Other identified health outcome fields were mental health (eg, depression, mental fatigue; three primary studies)[38 85] respiratory/cardiorespiratory (eg, forced expiratory volume, forced vital capacity, submaximal cycle ergometer; two primary studies)[40 49] and epigenetics (DNA methylation; one primary study).[38] We identified no prospective studies linked to mortality or incident disease outcomes.

Data sharing

Six primary studies mentioned the potential for datasharing.[38 68 72 81 85]

OBJECTIVE 2: EXPERT COLLABORATOR STATEMENT

Methods

In October 2018, 19 ProPASS collaborators (including all authors of this paper) met in Copenhagen for 2 days to discuss strategies relevant for the successful establishment, growth and management of the consortium. The meeting was structured around the following areas: (1) The main aims and purpose of ProPASS (including terminology); (2) the constructs that thigh-worn accelerometry can output; (3) the advantages and unique contribution that ProPASS can make to the health literature; (4) the optimal methods for data pooling, harmonisation and linkage with health administration data and (5) the data access and sharing model. To inform this discussion, the results from the above scoping review (initial search) were presented.

Following this meeting there were several key points—vital to the progression and goals of ProPASS—about which no clear decision had been made. Thus, we decided to conduct a formal survey of meeting participants regarding these key points. The purpose of the survey was to systematically consolidate ProPASS collaborators' views on the topics discussed during the 2-day meeting towards an expert collaborator statement as the blueprint for the next stages of the consortium's growth and its contribution to the field.

Participants

The attendees at the ProPASS Copenhagen meeting were associated with the participating ProPASS cohorts, members of the ProPASS advisory group, or scientists with expertise in one or more of the key ProPASS development priority areas. All who attended the 2018 ProPASS meeting were invited to participate in the survey (n=19).

Survey procedures

From the minutes of the ProPASS Consortium meeting in Copenhagen in 2018, we identified key areas that required further input and developed six questions to capture collaborators' views on these areas. Each question corresponded to one of the workshops at the meeting. All survey questions were multiple choice, but permitted 'other' responses and also provided space for unrestricted free comment. This allowed participants to elaborate on their answer and expand beyond the specific questions. These survey questions were:

1. What term best describes the data we aim to collect and analyse in ProPASS?
2. Do you agree with the ProPASS Accelerometry Construct? The ProPASS construct is an ideal set of accelerometer-based movement/posture variables that ProPASS will aim to extract and harmonise (figure 2).
3. What do you think is the main advantage of harmonising and pooling thigh-worn accelerometry data for epidemiological research?
4. What is the best approach for harmonising thigh-worn accelerometry data?
5. What is the best approach for managing access to ProPASS pooled accelerometry data (provided that regulatory and legal conditions are met)?
6. What should be the data sharing model for a thigh-based accelerometry pooled data resource?

In March/April 2019, all attendees of the ProPASS Copenhagen meeting were sent the survey. The survey was communicated by email, and contained the expert collaborator statement protocol and a link (SurveyMonkey (SurveyMonkey, California, USA; www.surveymonkey.com)) to the survey. All participants were asked to complete the survey within 2 weeks. Those not responding to the initial email were sent a single reminder email and given an additional week to respond.

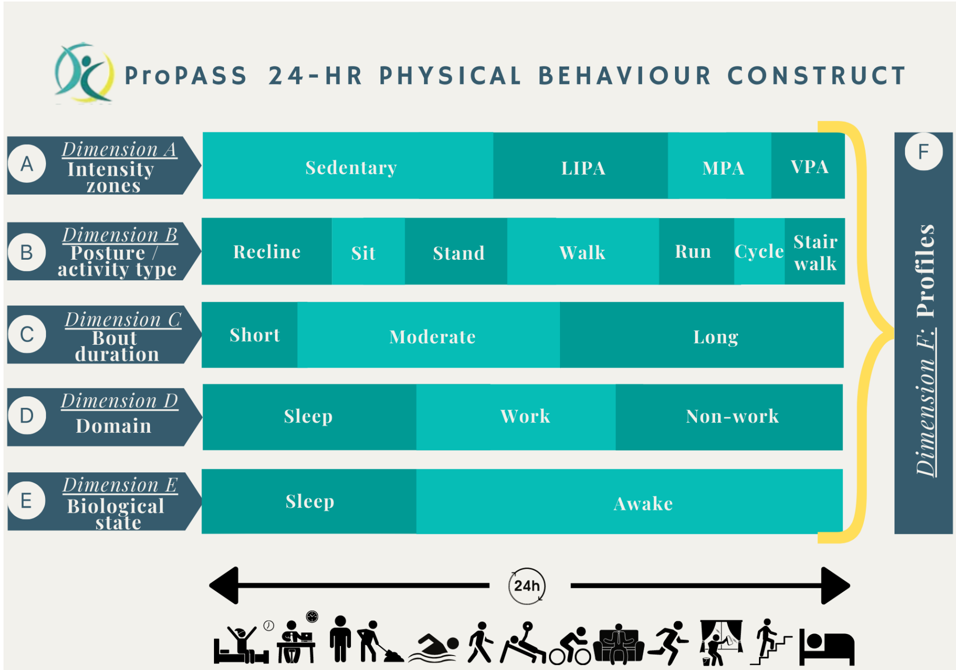

Figure 2 The dimensions of the proposed ProPASS Accelerometry Construct. Dimension A: the basic intensity-based dimension of the 24 hours physical activity (PA) construct stratified on sedentary behaviour, light physical activity (LIPA), moderate physical activity (MPA) and vigorous physical activity (VPA). Dimension B: information about both posture and physical activity types. Dimension C: information of time spent on various length of bouts with uninterrupted periods of physical activity types and posture. For example, short bouts (0–5 mins), moderate (>5–10 min) and long (>10 mins) bouts of standing; meaningful bouts length could be different for sitting and other activity types or postures Dimension D: domains where the physical activity components and posture occurs. Dimension E: Acknowledges that sleep is a different biological state. Dimension F: indicates that the profile is a combination of all other dimensions A–E. ProPASS, Physical Activity Sitting and Sleep consortium.

Data analysis

For each survey question, we calculated frequencies of endorsement for each response and summarised the open-ended responses using thematic analysis. Agreement for a particular response was indicated by an endorsement rating of 60%. Where 60% agreement was not reached, the leading responses (those within 20% of the lead response) were provided. Thematic analysis was performed by identifying the key idea(s) within each free-text field and then collating those ideas into themes that developed from the ideas identified within each question. The thematic analysis was conducted jointly by two authors (MLS/EIE) before being opened up to the whole author group for comment and feedback.

Results

Of the 19 attendees at the ProPASS meeting, 16 responded to the survey. Responders were from 11 different institutions (including government, academia and industry) distributed across seven countries. No question reached the predefined threshold for agreement of 60%. The percentage responses for each question are provided in table 1.

Question 1: what term best describes the data we aim to collect and analyse in ProPASS?

The overall term to describe the data that ProPASS aims to collect and analyse that was voted most highly was 'physical behaviour' with 50% of the votes, followed closely by 'movement behaviour' with 44% of votes. Analysis of the free-text indicated that although many respondents were in favour of the term 'movement behaviour', it missed important concepts such as sedentary time and/or sleep. No respondent voted for the use of 'physical activity'. The free-text suggests that this is because the term 'physical activity' is generally regarded as referring to data collected using accelerometry counts-based methods, a connotation that is not compatible with ProPASS objectives, and also misses sedentary behaviour, postures and sleep behaviours.

Question 2: do you agree with the ProPASS accelerometry construct?

The ProPASS Accelerometry Construct was designed to bring the research theories in physical behaviour research together with the variables to be used in ProPASS. It consists of several dimensions of the construct that are not necessarily hierarchical and can be combined to form new hybrid variables (figure 2). The dimensions are:

Dimension A: 'intensity zones'—containing the information on whether an individual is sedentary or conducting light physical activity, moderate physical activity or vigorous physical activity.

Dimension B: the 'posture/activity type'—consisting of lying, sit, stand, walk, run, cycling and stair climbing.

Table 1 ProPASS collaborator survey: questions and responses (%)

1. what term best describes the data we aim to collect and analyse in ProPASS?					
Physical activity		Physical behaviour	Movement behaviour	Other (please describe)	
0%		50%	44%	6%	
2. Do you agree with the ProPASS Accelerometry Construct? The ProPASS construct is an ideal set of accelerometer-based movement/posture variables that ProPASS will aim to extract and harmonise. (Please note that these dimensions are not mutually exclusive)					
I agree with the construct as it is		I have minor suggestions to improve the construct (describe below)		I have major suggestions (describe below)	
50%		44%		6%	
3. What do you think is the main advantage of harmonising and pooling thigh-worn accelerometry data for epidemiological research?					
Superior statistical power		Better ecological validity/generalisability	Opportunities for network building	Other (please describe)	
31%		25%	19%	25%	
4. What is the best approach for harmonising thigh-worn accelerometry data?					
Central processing—Collaborators send ProPASS the raw data to reprocess from scratch		ProPASS develops software tools, processes, and protocols to allow collaborators to reprocess their own accelerometry data from scratch	Make use of the variables collaborators have already extracted (this will limit the number of harmonised variables available)	Other (please describe)	
0%		56%	19%	25%	
5. What is the best approach for managing access to ProPASS pooled accelerometry data (provided that regulatory and legal conditions are met)?					
All/most data to be pooled/deposited centrally—Data are sent to data analysts when appropriate.		All/most data to be pooled/deposited centrally—analysts access data remotely through appropriate IT infrastructure	Federated data analyses (the data stay in each cohorts' servers)—data are accessed remotely by analysts	Other (please describe)	
13%		30%	44%	13%	
6. What should be the data sharing model for a thigh-based accelerometry pooled data resource?					
Fee to access for all users	Free to all bona fide researchers worldwide	Free to ProPASS collaborators, fee to access for all bona fide researchers	Closed, available to ProPASS collaborators only for a nominal fee	Closed, available to ProPASS collaborators only for free	Other (please describe)
13%	0%	50%	13%	0%	25%

IT, Information Technology; ProPASS, Prospective Physical Activity Sitting and Sleep consortium.

Dimension C: the 'bout duration' of physical behaviours—such as short, moderate and long duration patterns of various dimensions of physical behaviours.

Dimension D: the 'domains' of physical behaviours—such as being at work, commuting to work and non-work time.

Dimension E: the 'biological state'—relating to the condition of being asleep or awake.

Dimension F: the 'physical behaviour profile'—24 hours time spent on various dimensions of physical behaviours.

Nearly all (94%) respondents either agreed with the ProPASS Accelerometry Construct as presented (50%) or had only minor suggestions (44%). In summary, suggestions to improve the construct included: not to limit the construct to 24 hours cycles (eg, allow for diurnal cycles or cycles across weeks/years/life, etc); to avoid arbitrary intensity thresholds (eg, light/moderate/vigorous) and instead focus on other ways of grouping behaviours (eg, aerobic/anaerobic states); the addition of a construct that incorporates the time sequence/patterns of physical behaviour (ie, frequency, duration and order); and the addition of categories into some constructs (eg, slow/fast walking in dimension B (posture/activity types), transportation in dimension D (domain)). Some respondents also felt that it is not completely clear what the purpose of dimension C (bout duration) was, and suggested that it could be included as a vertical dimension that spans across all other dimensions.

Question 3: what do you think is the main advantage of harmonising and pooling thigh-worn accelerometry data for epidemiological research?

Votes for the primary value of harmonising thigh-worn accelerometry data were split between the four choices provided: 'superior statistical power' (31%), 'better ecological validity/generalisability' (25%), 'opportunities for network building' (19%) and 'other' (25%). Within the free-text fields related to 'other' was further mention of both concepts of statistical power and ecological validity. It was also mentioned that while 'opportunities for network building' in itself may not be as important as the other concepts, it is important because it leads to improved approaches to analysis.

Question 4: what is the best approach for harmonising thigh-worn accelerometry data?

Although not meeting the a priori requirements for agreement, there was support for ProPASS developing its own software tools, processes and protocols and allow collaborators to reprocess their own accelerometry data from scratch (56% of respondents). The open ended free-text responses showed support for the need to be flexible and allow for various methods (eg, central or dispersed processing of data) to be used depending on the constraints of collaborators. In line with this, there were also suggestions to focus on the outcomes of harmonisation rather than the process of harmonisation (ie, focus on the definitions and derivations of the outcome variables rather than where or by whom the data are processed).

Question 5: what is the best approach for managing access to ProPASS pooled accelerometry data (provided that regulatory and legal conditions are met)?

With reference to what the best approach to manage access to the ProPASS pooled accelerometry data would be, the most endorsed response was to use federated data analyses where the data remain on local servers hosted by collaborators which are remotely accessed by analysts (44%). This was followed by central pooling of data on ProPASS run servers which could still be accessed remotely for conducting analyses (31%). Free-text responses highlighted the importance of remaining flexible with suggestions for possible hybrid options.

Question 6: what should be the data sharing model for a thigh-based accelerometry pooled data resource?

Half (50%) of respondents endorsed free data access for ProPASS collaborators but combined with an access fee for external researchers. Open-ended responses also showed support for a differential pricing structure based on contribution (collaborators), need (researchers) and ability to pay (industry). Regardless of the pricing structure, responders mentioned the need for restricting access and having processes for research proposal evaluation and management.

DISCUSSION

The aim of this paper was to highlight the existing observational thigh-worn accelerometry literature and to capture and sumarise key discussions and decisions that arose at the initial ProPASS collaborators meeting. In this section, we discuss the main outcomes of the two paper components and their main implications for the immediate future of ProPASS.

Scoping review: key findings and future directions

The scoping review identified 22 primary studies with the potential to pool thigh-worn triaxial accelerometer data. These studies were primarily conducted in the Netherlands, UK and Denmark and contained participants recruited from both workplaces and the general population. However, the (likely) limited consent for some of these studies means that not all should be expected to be able to contribute to ProPASS. On the other hand, several additional cohorts (which are relatively new and thus were not identified in our scoping review due to a lack of published data) may also be included in the harmonised ProPASS data set.[22]

Although there have been many reviews of accelerometry methods,[11 23 105–108] to date none have focused specifically on thigh-worn accelerometry. Compared with our study, prior reviews have identified a much greater number of individual studies but with a wider variation in accelerometry protocols (including differences in the device used, its placement and processing method). For instance, one review (focused on the use of hip-worn ActiGraph accelerometers in youth studies) found that their included studies used 6 different epoch lengths, different definitions of non-wear time, 13 different definitions of a valid day, 8 different minimum wear day thresholds, 12 different cut points for moderate intensity physical activity and 11 different cut points for sedentary behaviour.[106] In contrast, the data from thigh-worn accelerometry were more homogeneous with 13 of the 22 identified primary studies using one of two primary methods. Moreover, in a recent study, we have shown that processing raw triaxial thigh-worn accelerometry data using a single software package (Acti4,[20]) produces consistent and accurate results across different accelerometer devices.[21] This supports the potential for thigh-worn accelerometer data to be harmonised retrospectively and prospectively across different studies. However, even though there may be less heterogeneity in the collection and processing of thigh-worn accelerometry compared with other wear-locations, there are still several areas for which standardised protocols would be of benefit to the field (eg, number of days of wear, definitions for a valid day, detection of non-wear time).[109]

From the results of our review, there are at least four important implications for ProPASS. The first is the opportunity for ProPASS to be a source of information and infrastructure for collecting and harmonising triaxial thigh-worn accelerometry data. The second can be seen in the relative youth of these studies—which only entered the scientific literature in 2015—and the small number of primary studies containing this data. This indicates the opportunity to collaborate in the development of standardised protocols (and outcome definitions) for collecting triaxial thigh-worn accelerometry data and associated health outcomes—setting the standard for prospective harmonisation. Third, there is currently a lack of studies investigating the prospective associations of physical behaviours with incident health outcomes. For example, despite the longitudinal nature of most of the primary studies identified (82%) only a very small proportion of all identified studies (10%) have used this prospective data. This is likely due to the relative youth of these studies which means that these studies may still be collecting data and/or are waiting to have enough events. Finally, there is also a lack of studies that collect repeated measures of physical behaviour using thigh-worn accelerometry.

ProPASS collaborator statement: responses and implications for moving forward

The responses regarding the terminology for ProPASS highlight its importance for achieving a clear identity and avoiding misunderstanding and confusion. Although there was no clearly favoured response, there was a desire to differentiate from terms that are generally used to describe counts-based measurements of physical activity. As both movement and physical behaviour were highly endorsed it seems that some combination of these ideas may be ideal (eg, movement and posture defined physical behaviour). However, the ability to quickly and simply reference an idea is important and as such a longer, more descriptive term would still require a shortened form (eg, physical behaviour).

The relative agreement around the physical behaviour constructs developed meant that collaborators generally agreed with the ProPASS constructs as defined. However, there is a need for continued refinement of the construct. The purpose of this construct is to provide guidance on the optimal set of accelerometry variables to be extracted and analysed in a framework for understanding the ways in which physical behaviours can be structured. Therefore, it is important to make sure its dimensions are clear and cover all important health-related aspects of physical behaviour.

Although not reaching our predefined agreement of 60%, the relative endorsement of both decentralised processing and federated analyses suggest that there is general agreement towards ProPASS collaborators maintaining control of and being responsible for their own data. This requires that ProPASS develops/adapts tools and processes that enable collaborators to easily manage and process their data in a consistent fashion. Such methods may be easier from a privacy perspective, but require more work on behalf of the collaborators to setup and maintain these systems. In contrast to this trend for ProPASS collaborators to maintain control and responsibility for their own data, the other major accelerometry database—the International Children's Accelerometry database—pooled and processed all data centrally.[110] These differences may be due to tightening privacy laws across Europe[109] and/or the prior lack of the technology required to conduct federated analyses, which were only recently introduced to large scale harmonisation studies with the Biobank Standardisation and Harmonisation for Research Excellence in the European Union project.[111]

With regard to the data sharing model and methods for accessing the data for conducting research, the option most favoured (although not reaching the predefined agreement level of 60%) was to restrict access and put in place an access fee for external researchers. Such a fee would help to offset the costs of developing and maintaining such a database while also rewarding those contributing data. However, it would be important that the fee is not so large as to deter researchers with fewer resources. As the implementation of a fee to access the data does not align with the principles of open access, ProPASS will carefully consider its implementation in the next few years. However, if sustained funding cannot be acquired through other means (grants etc) it may be a necessity.

CONCLUSION

This scoping review and systematically developed expert collaborator statement will guide ProPASS and set the direction for ProPASS's contribution to understanding the associations of physical activity, posture, and sleep with long-term health outcomes and longevity. Directions taken as a result of this work are currently being implemented and have led to positive outcomes in terms of consortium growth, funding and progress with the consirtium's aims. We are: (1) using the term physical behaviour to account for the full spectrum of movement and posture related physical behaviours that includes physical activity, sedentary behaviours and sleep; we encourage others to do the same for the reasons outlined above; (2) developing a comprehensive set of standardised protocols and tools for the collection of accelerometry and important health outcomes data (including fieldwork training materials); (3) developing tools for processing thigh-worn accelerometry data according to the ProPASS construct presented in this manuscript and (4) developing/adopting systems for conducting federated data analysis.

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