

Investigating psychological variables for technologies promoting physical activity

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Abstract

Background: Many technological interventions designed to promote physical activity (PA) have limited efficacy and appear to lack important factors that could increase engagement. This may be due to a discrepancy between research conducted in this space, and software designers' and developers' use of this research to inform new digital applications.

Objectives: This study aimed to identify (1) what are the variables that act as barriers and facilitators to PA and (2) which PA variables are currently considered in the design of technologies promoting PA including psychological, physical, and personal/contextual ones which are critical in promoting PA. We emphasize psychological variables in this work because of their sparse and often simplistic integration in digital applications for PA.

Methods: We conducted two systematized reviews on PA variables, using PsycInfo and Association for Computing Machinery Digital Libraries for objectives 1 and 2.

Results: We identified 38 PA variables (mostly psychological ones) including barriers/facilitators in the literature. 17 of those variables were considered when developing digital applications for PA. Only few studies evaluate PA levels in relation to these variables. The same barriers are reported for all weight groups, though some barriers are stronger in people with obesity.

Conclusions: We identify PA variables and illustrate the lack of consideration of these in the design of PA technologies. Digital applications to promote PA may have limited efficacy if they do not address variables acting as facilitators or barriers to participation in PA, and that are important to people representing a range of body weight characteristics.

Keywords

Physical activity, exercise, psychology, barriers, facilitators, obesity, body weight, self-care technologies, behavior change

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Introduction

Physical inactivity is a serious problem: it is one of the main causes of death worldwide, causing 3.2 million deaths each year.¹ Globally, 23% of adults are not considered sufficiently active, and across Europe, one-third of the adult population is considered physically inactive.^{2–4} Physical inactivity in adults is a risk factor for obesity and many chronic diseases, including many cardiovascular and age-related diseases, diabetes, chronic pain, and some types of cancer; it increases the risk of depression and contributes to other negative health and psychosocial

outcomes.^{5–10} In turn, regular physical activity (PA)—

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150 minutes or more of moderate PA per week for adults—can reduce the prevalence of these conditions.¹¹

Technology often contributes to physical inactivity¹² but it also offers many cheap and widely accessible possibilities for increasing PA.¹³ Many technological interventions such as mobile apps, web interventions, activity trackers and visualizations of PA, social media, or videos^{14–18} are being designed to promote PA. While computer-based interventions were initially the primary approach to promote PA through technology,^{14,19,20} nowadays the main focus is on developing interventions using mobile devices.^{21,22} Moreover, wearable devices currently hold the first position in worldwide fitness trends²³ and are thus particularly relevant for PA interventions. However, merely focusing on rapid technology-driven development, without evaluating the impact of interventions can lead to important aspects being ignored. In fact, the effectiveness of technological interventions on PA has often been considered questionable or limited, as the reported PA increases are often small and transitory.^{24–26}

In the last decade, the Human-Computer Interaction research community, and more recently the commercial sector, have attempted to build on cognitive behavioral theories to design technologies to address the problem of physical inactivity. While a number of theories have been considered for explaining PA behavior, a systematic review of persuasive health technologies²⁷ reported that 55% of these technologies were not founded on any theory or do not specify it. Further, while most technologies claim to be based on a theoretical framework, it was not reported how the theory was integrated within the technological intervention. This is despite the fact that the effectiveness of the technology seems to be related to the behavioral theory that it relies on.²⁸ Some studies have suggested that PA interventions should also report which components of the theoretical framework/theory are used to make the intervention effective or are mediating variables for PA.²⁵ Especially when the intervention is based on multiple theories, where there is a risk of excluding potentially important variables.²⁹

A recent review³⁰ has highlighted important limitations of the approaches used for behavior change and called for reconsidering these works through the lens of critical but unaddressed factors, such as self-insight. Our paper aims to respond to this call by considering unaddressed factors in PA interventions. Another review about PA interventions recommends exploring other possible variables by using both inductive and deductive methods in addition to existing theories.²⁵ To that end, some studies have focused on gaining insight from looking at relevant aspects of the specific PA behavior by using an atheoretical approach. By atheoretical approach, we mean an approach not based on current theoretical models, which would allow investigating all mediating variables in PA-related behavior and not only those variables considered in existing theories. Taking this

approach is necessitated by the fact that the mediating variables obtained from current theoretical models do not account for substantial variability in the targeted outcomes.²⁵ In particular, different reviews and meta-analyses have reported only small to moderate effect sizes for theory-based interventions (e.g., in,³¹ effect sizes were in the range of 0.12–0.15, and in,³² were around 0.35). In this context, there is a debate on the appropriateness of using theory-based interventions for PA promotion.^{33–35} The main focus of studies using alternative, “atheoretical” approaches, has been to explore the barriers—obstacles found by people when trying to engage in PA- and facilitators-reasons found by people for doing PA—in specific populations.^{36–38} In addition, an atheoretical approach allows us to focus on recommendations on the importance of considering each component or potential variable affecting PA behavior and the fact that existent theories used in this context are not specifically designed for PA. In fact, some of the critical known affecting variables -barriers and facilitators- studied specifically for PA, are not taken into account in a number of studies.^{30,39–43}

Our paper addresses the identified need to support a more informed design of technology for promoting PA in two ways. First, we revisit the Psychology literature, focusing on barriers and facilitators to PA, to create a summary of the PA influencing variables. We will search for all the non-demographic variables critical for PA reported in this literature for adults. We specifically allude to non-demographic variables because demographic variables are not easy to handle for intervention purposes directly, as highlighted by.⁴⁴ The variables reported will be sorted according to three major levels: psychological, physical, and personal/contextual, based on.⁴⁵ We are mainly interested in psychological variables, and in how these are used to build potential interventions promoting PA. While physical and personal/contextual variables are also critical to app design for PA, the problem is that the psychological variables are generally ignored or addressed in a simplistic and narrow way (e.g. badges). Second, we revisit the Computing literature to better understand which of the variables identified in (1) are addressed and what is left out according to the well-established Psychology literature.

In this paper, we also consider body weight as a factor that is often implicated in physical inactivity.⁴⁶ The articles included in the literature review consider populations from all weight groups, that is, healthy weight, obese and overweight groups,⁴⁷ to be able to compare the variables across these groups. The promotion of PA seems to be of particular importance in the obese population to prevent health deterioration.⁴⁸ A deficient PA level, along with sedentary time, are among the fundamental causes of obesity in adults.^{5,7,10,48–50} People with obesity may experience/perceive more PA barriers than non-obese or the healthy-weight populations as shown in some studies with adolescents⁵¹ and women.⁵² It therefore seems crucial to assess the impact of

body weight when designing effective interventions for PA that consider specific barriers faced by the person.⁵³

The aim of this study was twofold. First, to review and to inform about the potential mediating non-demographic variables of PA. Second, to understand whether these potential variables are taken into account when developing technologies for PA. Two systematized reviews^{54,55} were conducted: one from the psychology field and one from the computing field. We conducted a systematized review as it is rigorous and encompasses several, but not all aspects of a full systematic review.⁵⁶ Like systematic reviews, the article search and selection, data extraction, and results synthesis for systematized reviews are determined a priori, fully documented, and systematic. However, a systematized review is often distinguished from a systematic review in that the former may not include a formal assessment of study quality, remove or weight study findings based on methodological quality, nor pool results to undertake meta-analysis.⁵⁴⁻⁵⁶ In addition, systematized literature reviews allow synthesizing qualitative evidence⁵⁴⁻⁵⁶ and provide the flexibility needed to consolidate the information about PA variables; since each article uses a different narrative to represent the same variable, for our study, this process entailed unifying the way in which the variables are expressed.

For the first review, we focus on the psychology field because our main focus is on psychological variables and they are more reported than contextual/personal or physical variables.⁵⁷⁻⁵⁹ While contextual variables related to PA exist, there is evidence that these explain less PA behavior than the internal or psychological variables to PA faced by individuals.⁶⁰⁻⁶⁶ Equally, we acknowledge physical variables to PA, especially among elderly people.⁶⁷ However, despite a statistical relationship with physical inactivity, there is less focus on reporting physical variables compared with psychological or contextual/personal ones by large epidemiological population-based studies.⁶⁸⁻⁷¹

Nevertheless, psychological variables are mostly overlooked in the design of technology, which generally focuses on addressing motivation rather than carrying out an in-depth analysis of the psychological barriers (beyond motivation) to undertaking PA (see for instance⁷²).

A recent review,⁷³ provides evidence of barriers to PA specific to obesity in the literature. The study refers to the importance of knowing whether being obese means people confront barriers that are additional to those faced by the non-obese population; however, the articles referred to in the study exclusively focus on obese individuals. Our aim is to build on this study and explore whether the barriers are the same in the non-obese and obese populations more broadly, and we believe that such a comparison can only be made if articles in the review include healthy-weight, overweight, and obese populations.

This paper is structured as follows: first, we present two systematized reviews, one from the psychology field and

another one from the computing field. We then discuss the results from both reviews and propose a rethink of PA technologies by considering psychological factors in the design process.

The contributions of this paper are an account of PA variables across populations differing in PA-level and body weight and an illustration of the lack of consideration of these in the design of PA technologies. In the Computing field, a literature review addressing this issue has not been carried out yet, to our knowledge.

Methods

Recruitment

The Psychology literature search—henceforth called Review 1—was conducted in June 2017. The Computing literature search—henceforth called Review 2—was conducted in July 2017 (for information on search dates and other details of the search strategy see “Search Strategy” section below).

Databases

The database used for Review 1 was PsycInfo, which includes scientific articles from the psychology and psychiatry fields provided by the American Psychological Association. This database is considered the most exhaustive database in its field globally.⁷⁴ Note that PsycInfo was selected because our main focus is on psychological variables, as explained above. It should further be noted that PsycInfo includes various medical journals and thus it also provides an understanding of that field.

For Review 2, we used the Association for Computing Machinery (ACM) digital library database, which contains the collection of all ACM publications.⁷⁵ ACM is considered the world’s largest educational and scientific computing society.⁷⁶

Search strategy

For both systematized reviews, the detailed search strategy implementation was as follows: [(“physical activity” OR “physically active” OR “physical inactivity” OR “physically inactive” OR “physical activities” OR “motor activity” OR “sedentary”)] had to appear on the title or abstract; ([“Needs” OR “barriers” OR “facilitators”]) in the article. In addition, for Review 1, the term “obesity” had to appear in the article. Note that for Review 2 the general terms “needs,” “barriers,” and “facilitators” were kept instead of searching for specific barriers to ensure barriers were not missed, as each article uses a different name or narrative to represent the same variable. Review 1 was restricted to peer-reviewed articles written in English and published from 2007 to 2017, on studies conducted with

adult human participants (18 years and older). Review 2 was restricted to conference proceedings and journal articles, published from 2007 to 2017. The reason for including gray literature,⁷⁷ and in particular conference proceedings, is because conference proceedings are one of the main means of publications in the field of computer science, differently from the psychology field. These differences in the restrictions are due to the search possibilities of the database.

Selection criteria

The resultant papers from each database search were revised to include only the relevant ones using the following exclusion criteria: PA not being relevant in the article; population under 18 years old; population with cognitive impairment; duplicate articles; systematic reviews, protocols, clinical cases, editors' letters, summary papers; articles not mentioning barriers or facilitators for PA; non-human subjects. While the term "obesity" had to appear in the article (see Search strategy), articles with any weight population were included according to our aim to understand whether the barriers are the same in the non-obese and obese populations.

Selection process

An Excel table including the publication name, authors, year, and journal of publication was created. The article screening consisted of three steps. At every step, articles meeting any of the exclusion criteria were excluded, and the unclear ones were treated as included articles until the next or final step. Three steps were: (1) we read titles and abstracts of all articles obtained through the search. Articles meeting any exclusion criteria were excluded. (2) We did a quick skim reading of the full text of the remaining articles, searching for relevant aspects mentioned in the search strategy. (3) The remaining articles were read completely and extensively. The relevant information regarding the population aspects, the methodology characteristics, and the aspects affecting PA from each article, was organized and placed in the table. Articles meeting any exclusion criteria were excluded from the final batch.

Data treatment

The articles identified through the systematized reviews were used to obtain information about the PA-reported variables (i.e. barriers and facilitators of PA). We worked to unify the way in which the variables are expressed, since each article uses a different narrative to represent the same variable. We organized the constructs, descriptions, sentences, or any type of quote used in the articles for expressing a variable in groups according to their similarity and gave a standardized name to each variable. Variables and quotes were

organized based on (a) the similarity of the quotes, (b) the similarity of the concepts or definitions underlying the quotes, and (c) whether the different quotes have been commonly presented together under the same concept or categorized as the same aspect. The classification of variables was conducted by one reviewer (first author of the paper) and revised by four other co-authors of this paper, all of them with experience in PA-related research.

Our intention is to classify the variables for standardized use when developing interventions. This would enable us to consider all the variables important for an intervention approach and to dismiss any irrelevant ones. The importance of an adequate classification system enabling a clear picture and selection of relevant aspects when choosing an intervention approach has been highlighted by Michie,²⁹ who developed a classification system for general behavior change techniques based on a review of the existing interventions. We follow this approach but make a classification in a more inductive way, drawing from the variables reported in the literature and organizing them into major levels, which can be useful when choosing an intervention approach. The particular way of organizing our variables is based on a framework presented in,⁴⁵ which fits with the variables we found in our work. Thus, the major levels used here for organizing the variables are the following:

1. *Psychological*: emotional, cognitive, motivational, affective, and behavioral aspects.
2. *Physical*: aspects related to the body nature and constitution and physiological processes.
3. *Personal/contextual*: utilitarian personal resources or environmental aspects.

Results

Review 1: PA influencing variables

The literature search yielded 470 articles. A flow diagram illustrating the three-step selection process followed and the reasons for the exclusion of the articles in each step is included in Figure 1. Through the reading of the title and abstract, 346 articles were excluded, and 124 remained. Through the quick full-text reading, 12 other articles were excluded. Finally, from the remaining articles, 62 other articles were excluded. The final sample comprises 50 articles (for a complete list, see Supplementary File 1).

From the final 50 articles, we extracted the population aspects related to body weight categories, obese, overweight, and healthy normal-weight (hereafter referred to as healthy-weight) based on⁴⁷. To classify the weight categories for each article, if most of the population from the article (near 80%) met one aspect (e.g. being overweight/obese), it was classified in that way. 16 (32%) of the articles were classified into the overweight/obese categories, 28

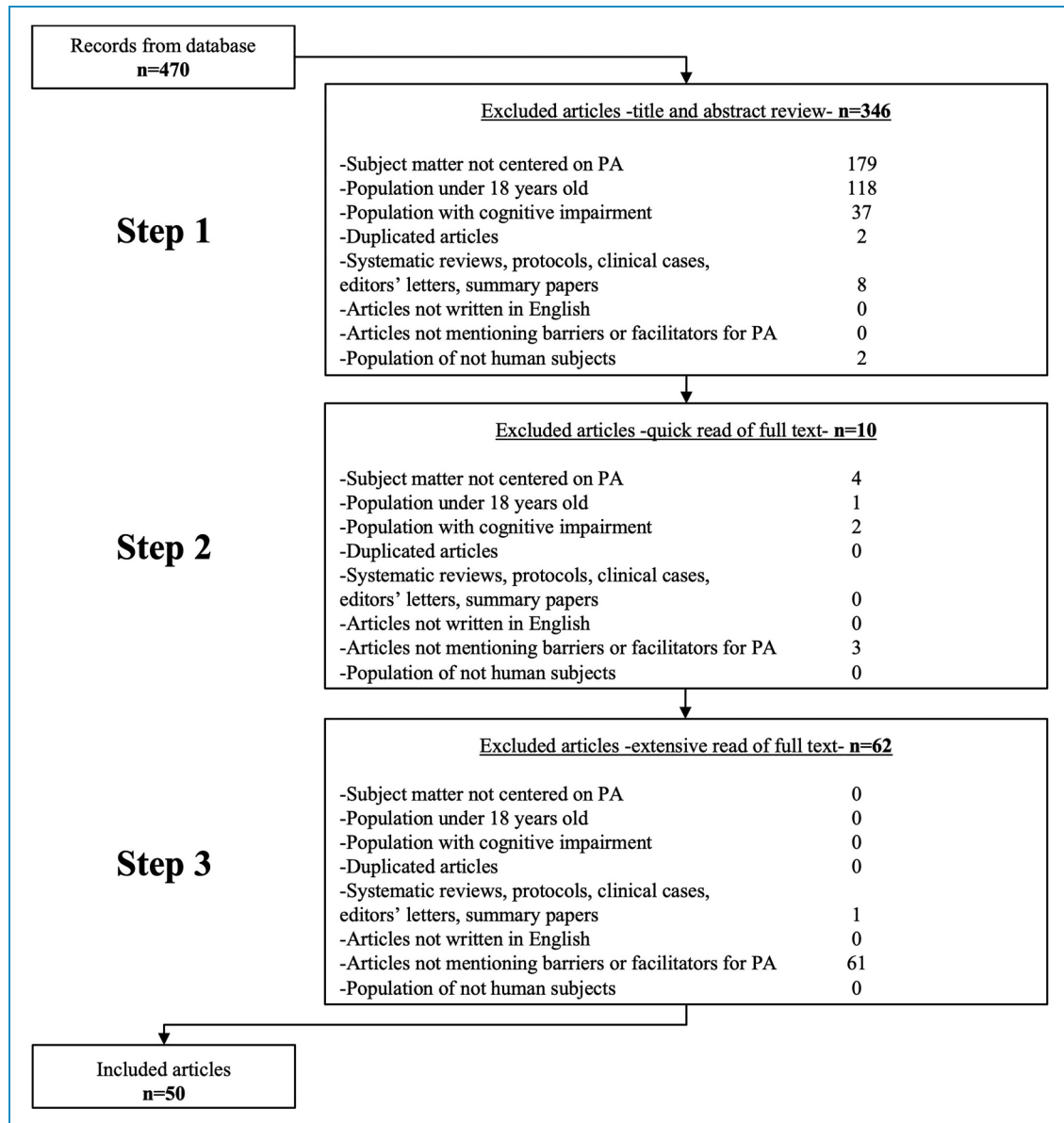


Figure 1. Flow diagram illustrating article selection strategy in Review 1.

(56%) into the healthy-weight category and the remaining 6 (12%) belonged to both categories. In addition, we extracted information related to whether the PA potential variables were measured in a qualitative (21 articles) or quantitative way (25 articles) or included both types of measures (4 articles). These classifications respond to the procedures/population regarding only PA variables in each article.

Review 2: Attention given to PA influencing variables in the Computing literature

The literature review from the ACM database yielded 123 articles. As for Review 1, we followed a three-step selection process (see Figure 2 with a flow diagram illustrating this

process and the reasons for the exclusion of the articles in each step). Through the reading of the title and abstract, 47 articles were excluded, leaving 76. Through the quick full-text reading, 33 other articles were excluded, leaving 43. Finally, from the remaining articles, 28 other articles were excluded. The final batch comprises 15 articles (for a complete list, see Supplementary File 2).

Evaluation Outcomes

As reported in the Methods section, the final batch of articles of Review 1 was used to identify the facilitators and barriers to PA. The aim of Review 2 was to evaluate if these variables were considered for technological

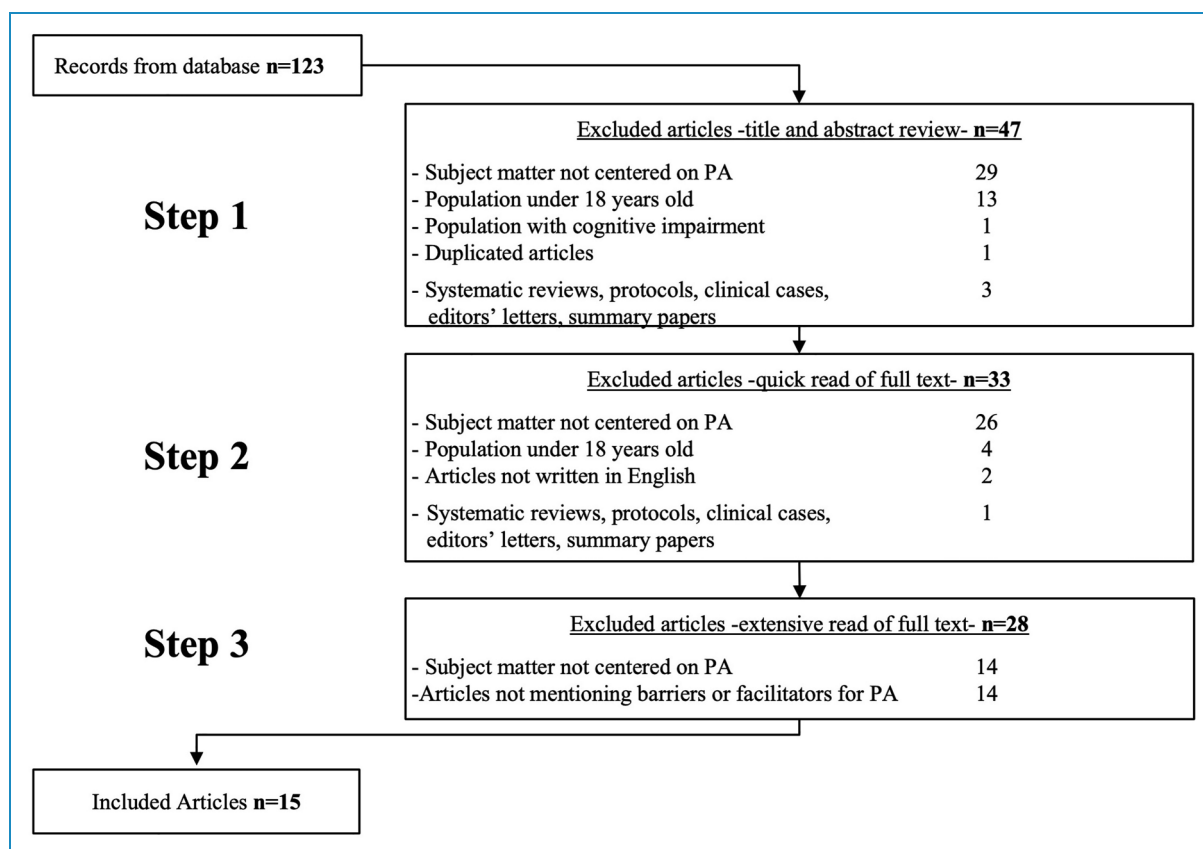


Figure 2. Flow diagram illustrating article selection strategy in Review 2.

interventions in the Computing literature. For Review 2, we report separately all the variables mentioned in the article, and the variables that were measured or evaluated (e.g., by means of questionnaires, as a theme topic in interviews or focus groups, with sensors or ad-hoc apps).

The criteria used to identify something as a barrier/facilitator was that the article explicitly mentioned that aspect as a barrier or facilitator for PA (e.g. “Lack of company acts as a barrier” or “company facilitates PA”), and in that sense, all variables were indeed associated in the articles to physical inactivity.

The variables are presented in Table 1, each classified according to one of the three main levels: psychological, physical, and personal/contextual levels, respectively. For each variable we present: (a) the general description, summarizing all mentions of a specific variable in relation to them acting as barrier or facilitator, without specifying specific populations to which these would apply, (b) a particular mention about the attention given to the relation to PA level in the article (e.g. people meeting PA guidelines vs not meeting them), (c) the specificities for the overweight/obese population, (d) the articles that raise the variable for both reviews, and the articles that evaluated the variables in the Review 2, and (e) a summary of the effects on PA of the factors included in the study design and

evaluated in Review 2. Figure 3 summarizes the percentage of articles in Review 1 that raise each variable, and the percentage of articles in Review 2 that raise and evaluate the variable. Supplementary Files 3–5 include Tables that present the number of articles that report each psychological variable organized by different aspects of the population (body weight group, place of residence, and specific population conditions, e.g. medical condition).

It should be noted that the column “Description” in Table 1 summarizes all mentions of specific variables as barriers or facilitators for PA. Then columns 3 and 4 include specific mentions of relation to PA levels and weight groups. Understanding the relationship of each variable with the PA level or with the weight group is important in order to consider their inclusion in the design of interventions aiming for behavior change. These aspects are presented in the different columns. The variables are presented by relevance, that is, in descending order, depending on the number of articles mentioning them.

To provide a more in-depth understanding of the focus of each study and its outcome, Table 2 summarizes the activities/interventions performed in the articles from Review 2 which evaluated psychological variables, as well as the populations under study, the measures employed, and the recommendations the authors made based on their findings.

Table 1. Psychological, physical and personal/contextual variables of PA obtained from Review 1, articles that raise each variable in Reviews 1 and 2 and that evaluate each variable in Review 2.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
Psychological					
Motivation	<ul style="list-style-type: none"> Lack of motivation is one of the biggest barriers to PA.^{78,84} Presence of motivation as a facilitator.⁸⁵ More often regarded as intrinsic (e.g. enjoyment^{86,89}). Conflict about the relevance of enjoyment as a barrier; some report it as highly prevalent,⁸⁷ in others it is less mentioned.⁸⁶ Some reported external motivation as facilitator.^{88,89} A particular example of an external motivator to PA is music.⁹⁰ 	Motivation is more reported in women not meeting PA guidelines than in women meeting PA guidelines. ⁹¹	Lack of motivation is more reported by overweight ⁹² and obese women. ^{92,95} A lower percentage of obese vs. non-obese women enjoy PA ^{90, 91} found no differences in enjoyment for different weight groups.	Raise: ¹⁰⁵⁻¹¹⁰ Evaluate: ^{106,107,109}	Greater levels of intrinsic (vs. extrinsic) motives are associated with more persistent PA engagement ¹⁰⁹ . E.g. enjoyable PA activities ^{106,107,109} .
Company	<p>References: ^{52,78-104}</p> <ul style="list-style-type: none"> Concerns about the passive presence of others while doing PA. Company facilitates PA.^{87,111} Lack of company acts as a barrier.^{81,94} Need for a company during PA can be due to many reasons, such as enjoyment¹¹¹, shyness⁹⁵, safety concerns.⁸⁸ Company of animals can have the same effect.⁸⁹ <p>References: ^{52,79-82,86-89,91,92,94-97,101,104,111-115}</p>	Company as a barrier was more likely to be reported by less active women. ⁹¹		Raise: ^{105,106,116} Evaluate: ^{105,108,116}	Company of others during PA acts as facilitator ^{105,108,116} .
Influence of others	<ul style="list-style-type: none"> Active intentional or unintentional manifestations by others. The intentional aspect includes the presence or absence of emotional support, or negative judgement and teasing. Emotional support or encouragement facilitates PA^{84,112} while its absence, or being intimidated or teased by the social environment are barriers.^{87,96,117} The unintentional aspect regards modeling: seeing people in the neighborhood or relatives doing PA,^{80,81} or recreational peers/professionals who lead by 	Lack of close active examples are a barrier for people not meeting PA recommendations. ⁹⁸ Higher social support is usually associated with people with higher rates of PA ^{113,119, 120} found no association between lack of social support and declines in PA.	Influence is reported as a significantly higher barrier in the obese population than the non-obese. ⁹¹ PA by social influence than in healthy-weight individuals. ^{99,121} Negative social influence can be higher for overweight/obese individuals, due to weight related teasing. ^{79,87}	Raise: ^{105,106,108, 124-128} Evaluate: ^{106,108,124,125,127,128}	Usually a facilitator of PA but can be a barrier in some cases. E.g. the effect of competitiveness can hamper or facilitate PA ^{82,84} .

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in Psycinfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor
	<p>example⁸⁷ can be facilitators. Illustrations of negative consequences of no PA¹¹² can be a facilitator.</p> <ul style="list-style-type: none"> Autonomy supportive behaviours are more effective than controlling support.¹¹⁸ The source of influence is relevant: being local and trusted⁹⁷; more value placed on family's advice over clinical advice.⁸⁸ <p>References: 79-81,83-85,87-89,91,96-99,112,113,117-123</p>			
Knowledge	<ul style="list-style-type: none"> Access to PA knowledge is a relevant variable,⁸⁰ although⁸⁶ reported a lack of concern for this variable in focus groups. Lack of knowledge,⁸⁷ misinformation or inconsistent information¹²⁹ are barriers to PA; information/knowledge is a facilitator.¹¹⁴ Many articles report general knowledge,⁸⁰ some are specific to the benefits of exercise,^{94,95,130} or to how/where to exercise.^{80,84,95} <p>References: 52,80,84,85,87,88,90,91,94,95,104,111,114,122,129-132</p>	Lack of education from health professionals has been associated with lower levels of PA. ¹³⁰	Tailored health messages seem to be a facilitator for obese women. ¹³¹	
Priorities	<ul style="list-style-type: none"> Time spent on PA depends on the level of priority.⁸⁹ Priorities other than PA,^{93,129} PA not a priority¹⁰⁰ and lack of time management^{83,99} are barriers to PA. Some reported activities prioritized before PA are Internet use,¹³³ TV use⁷⁹ and cognitive endeavors.¹³⁴ In some cases, prioritization is a perceived lack of time, which can sometimes be incongruent with a real lack of time.^{78,131} <p>References: 78,79,81-83,87,89,93,99-101,104,129,135</p>			Lack of energy seen as a priority; young adults related it to lack of time, or as if the priority was to rest ¹⁰⁵ .

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
Fear	<ul style="list-style-type: none"> Being afraid of injury during PA is a barrier.^{62,68} Fear that PA can worsen an illness/condition even when PA is recommended as having a positive effect, is a barrier.³⁵ <p>References:^{78,82,84,88,91,94-96,102,113,115,119,121,123,132,135}</p>	<p>Fear of injury more in low-to-moderate-active participants.⁹⁶ In Ref. 121, fear predicted PA during the first pregnancy trimester.</p>	<p>Fear of injury has been reported in a higher level by obese groups than by non-obese groups.⁹¹</p>	<p>Raise:^{106,109}</p>	
Discipline, initiative, willpower, and commitment	<ul style="list-style-type: none"> Lack of discipline, initiative, willpower, and commitment or laziness^{85,87,91} have been reported as barriers to PA. <p>References:^{52,81,83,85,87,91,95,96,117,119,121,123}</p>	<p>More likely to be reported by women with low PA.⁹¹ Feeling lazy predicts PA.¹²¹</p>	<p>More reported by overweight/obese women^{52,121}; but⁹¹ found no differences between weight groups</p>	<p>Raise:^{105,124,126,136} Evaluate:^{109,126,136}</p>	<p>Only specific goals with a high commitment level are good facilitators of PA^{109,136}. Commitment can act as a barrier if announced publicly¹²⁶.</p>
Self-consciousness	<ul style="list-style-type: none"> Concern with oneself or own looks in the presence of others. Feeling self-conscious/embarrassed,^{80,83,87,98} shy,¹⁰² or not wanting to exercise in front of others⁹³ are barriers to PA. Closely related to the later-presented variable self-confidence⁹⁵ but the classification of self-consciousness is made here in relation to the presence of others, while self-confidence is independent of presence. <p>References:^{52,79,80,83,84,87,88,93,96,102,135}</p>		<p>Reluctance toward PA in front of others due to weight or being uncomfortable with appearance/perceived size are barriers.^{73,93} Self-consciousness during PA is significantly higher in obese participants.⁵²</p>	<p>Raise:¹¹⁰</p>	
Self-efficacy	<ul style="list-style-type: none"> The self-perception of one's capability for doing PA. Lack of self-efficacy acts as a barrier to PA,⁸⁰ while the presence of self-efficacy can be a facilitator.⁸⁰ <p>References:^{80,84,86,87,90,103,115,119,120}</p>	<p>Correlates with PA level^{103,119,120,115} found self-efficacy did not predict PA adherence in either sex.</p>		<p>Raise:^{109,136} Evaluate:^{109,136}</p>	<p>Associated with persistent engagement in PA, if done with intrinsic motives.¹⁰⁹</p>
Emotional/psychological state	<ul style="list-style-type: none"> Emotional or psychological factors can affect PA. Depression,^{80,95} low mood,^{84,95} psychological distress,⁹⁹ anxiety,¹³⁷ traumatic life events (e.g. childhood sexual abuse, divorce)⁸⁰ are barriers. 			<p>Raise:^{105,138} Evaluate:^{105,106,109}</p>	<p>Mood affects PA levels^{105,106}, depression/sadness decreases PA¹⁰⁶, stress is a barrier^{106,109} but also a motivator to alleviate it¹⁰⁵.</p>

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
Self-confidence/self-esteem	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,81,83,87,89,93,94,101}</p> <ul style="list-style-type: none"> Not believing that PA is needed is a barrier⁸⁰; understanding exercise need due to a health problem^{114,133} can be a facilitator. Low importance given to PA if assuming that PA is only for losing weight; nutrition perceived as substitute for being active is a barrier.¹¹² 	<p>References: ^{78,86,96,100,112,114,133}</p> <ul style="list-style-type: none"> Health outcomes from PA, either already achieved e.g. seeing a reduction in weight due to PA⁸⁹ or expected e.g. wanting to live more¹¹³, are facilitators of PA. However, knowing that PA has health benefits is not a facilitator, but only seeing these health benefits after engaging in PA.^{79,112} 	<p>References: ^{79,80,84,87,89,99,112,113}</p> <ul style="list-style-type: none"> Concerns the role assumed by someone in their particular situation. PA and related aspects are considered inappropriate for women in some social groups.^{87,112}, in some populations, women 	
Perceived importance and need of exercise	<p>References: ^{80,81,83,87,89,93,94,101}</p> <ul style="list-style-type: none"> Not believing that PA is needed is a barrier⁸⁰; understanding exercise need due to a health problem^{114,133} can be a facilitator. Low importance given to PA if assuming that PA is only for losing weight; nutrition perceived as substitute for being active is a barrier.¹¹² 	<p>References: ^{80,81,83,87,89,93,94,101}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷
Health/weight benefits	<p>References: ^{78,86,96,100,112,114,133}</p> <ul style="list-style-type: none"> Health outcomes from PA, either already achieved e.g. seeing a reduction in weight due to PA⁸⁹ or expected e.g. wanting to live more¹¹³, are facilitators of PA. However, knowing that PA has health benefits is not a facilitator, but only seeing these health benefits after engaging in PA.^{79,112} 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷
Role compatibility	<p>References: ^{79,80,84,87,89,99,112,113}</p> <ul style="list-style-type: none"> Concerns the role assumed by someone in their particular situation. PA and related aspects are considered inappropriate for women in some social groups.^{87,112}, in some populations, women 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷ 	<p>References: ^{80,84,89,95,99,114,137}</p> <ul style="list-style-type: none"> Lack of self-confidence,^{81,89} body dissatisfaction,^{80,87} or discomfort with own looks⁹³ are barriers to PA; body image can be a facilitator.⁸⁰ Self-confidence can refer to body image and the self-concept; feelings of not deserving the time for PA is a barrier.⁸⁷

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in Psycinfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
	<p>undertaking activities unrelated to family are not well received.^{87,100,112}</p> <ul style="list-style-type: none"> Not being sporty,⁷⁸ or feeling PA is for other ages¹¹³ are barriers. <p>References:^{78,87,90,100,112,113}</p>				
Professional advice	<ul style="list-style-type: none"> Encouraging professional advice is a strong facilitator to PA⁹⁴; lack of professional advice⁸⁹ or conflicting advice⁸⁸ is a PA barrier. Trust in the advisor is important for the advice to be effective.⁸⁸ <p>References:^{80,87-89,94}</p>	Raise: ¹⁰⁸			
Challenge and difficulty	<ul style="list-style-type: none"> Perceived difficulty of a given activity can be a challenge, acting as a facilitator to PA,⁸³ or as an obstacle⁸⁶ functioning as a barrier. Not wanting to fail⁵² or having unrealistic goals are barriers.⁸⁵ <p>References:^{52,83,86,89,98}</p>	Reporting difficulty is significantly related to whether people meet PA recommendations. ³⁰		Raise: ¹³⁶ Evaluate: ¹³⁶	Difficult goals are PA facilitators. ¹³⁶
Cultural promotion	<ul style="list-style-type: none"> Refers to how the culture one feels belonging to promotes PA. Culture influences perceptions/ attitudes related to PA.⁸⁵ Cultures where social norms for inactivity dominate affect PA negatively.^{126,139} e.g. car culture⁸⁹ or preference for larger/curvaceous bodies⁷⁹ can reduce motivation for PA. <p>References:^{79,85,129,139}</p>				
Affective attitudes	<ul style="list-style-type: none"> Negative attitudes towards exercise, such as stigma/negative stereotypes attached to the gym, is a barrier to PA.^{80,83} Considering PA a luxury/guilt pleasure, can act as a barrier.⁸¹ 				

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Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
Awareness	<p>References:^{80,81,83,95}</p> <ul style="list-style-type: none"> Awareness about the body and activity is important to PA.⁸⁸ Poor or inconsistent self-monitoring is a barrier to PA⁹⁷; having a perceived internal locus of causality mediates exercise adherence.¹²² <p>References:^{88,89,122}</p>				
Appealing aesthetics	<ul style="list-style-type: none"> The natural and built environment aesthetics can be a facilitator to PA^{85,98,117}, while poor aesthetics were described as barriers.⁸⁵ <p>References:^{85,98,117}</p>			Raise: ^{105,107-110} Evaluate: ¹⁰⁷	Tracking both PA levels and contextual information supports reflection on their association ¹⁰⁷ .
Routine	<ul style="list-style-type: none"> A regular routine as an established habit is a PA facilitator.⁸⁹ <p>References:⁸⁹</p>				
Physical					
Pain or body sensations	<ul style="list-style-type: none"> Pain,^{80,82,89,95,99,101} and soreness⁸⁸ are barriers to PA. <p>References:^{52,80,83,88,89,93,95,99,101,115,121}</p>	In ¹²¹ , soreness (not pain) correlated with PA. In Ref. 115, higher body pain predicted greater PA in women and less in men.	Physical discomfort is a weight-related barrier. ⁹³ Pain is reported more by overweight/obese than healthy-weight women. ⁵²		
Medical status	<ul style="list-style-type: none"> Medical conditions/injuries are reported barriers to PA.^{87,96} Specific conditions reported are: chronic conditions,^{93,133} epilepsy,⁸² pregnancy complications,⁸⁴ or post-effects of bariatric surgery.⁸⁰ Side effects from medications are also a barrier.⁵² <p>References:^{52,80,82,84,87,91,93-96,120,133}</p>	There is a negative correlation between physical problems and PA level. ⁹⁵	Poor health or minor aches and pains are reported as bigger barriers by overweight and obese women in Ref. 52.	Raise: ^{105,106,108-110,124} Evaluate: ^{105,106,109-124}	Medical conditions (e.g. lack of sight) or decline in physical/health status are barriers. ^{106,108-110,124} . Adoption/maintenance of health doing PA are facilitators ^{105,109} .

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
Energy level	<ul style="list-style-type: none"> Low energy/tiredness is a barrier to PA⁸³; having energy a facilitator⁹⁴. Families and jobs are sometimes the cause of low energy.^{79,100} The lack of need for sleep are also barriers.^{88,135} <p>References: 79,88,89,194-96,100,121,135</p>	Energy level is correlated to the PA level. ^{95,121}	Tiredness ^{95,135} is a PA barrier related to weight.	Raise: ¹⁰⁵ Evaluate: ¹⁰⁵	Lack of energy is a barrier. ¹⁰⁵
Fitness status	<ul style="list-style-type: none"> Lack of good fitness status reported in the literature as a barrier.^{80,113,135} <p>References: 52,78,80,86,93,113,135</p>				
Skills	<ul style="list-style-type: none"> Lack of skills is a barrier to PA.^{22,97,112} while participation in previous activities is a facilitator.⁸⁵ <p>References: 52,85,87,91,98,122</p>	Lack of skills is a bigger barrier for those with low PA level. ⁹⁸		Raise: ^{105,109,126} Evaluate: ^{105,109,126}	Self-competition or prior PA level ¹⁰⁵ , performance ¹²⁶ and nimbleness (i.e., speed/accuracy in thoughts or movement) are facilitators. ¹⁰⁹
Personal/ contextual					
Facilities and access	<ul style="list-style-type: none"> Lack of facilities or having limited or no access to exercise facilities as a barrier to PA.^{87,89,86}; access to facilities is a facilitator.⁸⁰ Facilities can refer to indoors, including gyms, house size,^{90,111,112} or outdoors, including streets, parks, or neighborhoods.^{85,86,96,97} Distance from home to facilities can be a facilitator or a barrier, based on the walking distance or on the perception of it.⁸⁵ Facilities not addressing population needs are a barrier e.g. the lack of facilities adapted to cultural needs or to language is a barrier.^{87,133} <p>References: 80,82,83,85-87,90,94,97-99,111,112,133</p>	People meeting PA recommendations reported, in a greater level, having bicycle lanes around the house as a facilitator than those not meeting PA recommendations. ⁹⁸	The lack of access to facilities was especially discussed as a barrier by participants who had severe obesity. ⁸⁰	Raise: ^{106,108,140} Evaluate: ¹⁰⁶	Lack of facilities (e.g. gyms or stores), uneven pathways, noise, pollution, traffic or relocation to smaller homes reported as barriers. ¹⁰⁶
Costs	<ul style="list-style-type: none"> Costs, lack of affordable PA resources and insufficient money are barriers.^{88,93,112}; affordable PA options¹¹² or cost-free options⁸⁵ are facilitators.⁸⁸ 	High cost of PA is a significantly bigger barrier for those not meeting PA recommendations. ⁹⁸			

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
	<ul style="list-style-type: none"> Lack of money or poverty can make PA a low priority.¹²⁹ Economical barriers include indirect costs related to PA, like child-care,^{87,90,111} or equipment costs.^{95,115} <p>References:^{78,79,83,85,87,90,95,98,111,112,115,129}</p>			
Family/Social/Animal responsibilities	<ul style="list-style-type: none"> Family obligations,^{80,100} responsibilities of childcare,^{52,112,117} animals⁸⁹ and social demands⁵² like family visits,¹³³ caring for others' children⁷⁸ or other social demands are barriers to PA. Family responsibilities can be an opportunity for active living.⁸⁷ <p>References:^{52,78,80,87,89,94,96,100,112,117,121,133}</p>	Having family responsibilities predicts PA in healthy-weight women. ¹²¹	Raise. ¹⁰⁶ Evaluate. ¹⁰⁶	Caregiving duties can be a barrier ¹⁰⁶ .
Environment safety	<ul style="list-style-type: none"> Lack of environment safety as a barrier to PA^{79,129}; living in relatively safe neighborhoods reported as a facilitator to PA.¹¹² Communities with high rates of crime, traffic and stray animals can reduce active commuting.^{85,94,96} A particular case is racial exclusion, which acts as a PA barrier.^{97,129} <p>References:^{79,81,85,94,96,97,112,129}</p>	Neighbourhood safety is related to a person's PA level. ⁸¹		
Equipment	<ul style="list-style-type: none"> Ownership of equipment (bike, swimming pool, treadmill) facilitates PA⁸⁵; lack of equipment acts as a barrier.^{80,87,89,101} <p>References:^{80,85,87,89,91,96,101}</p>	Not finding appropriate clothing or equipment, discomfort in the clothes, ⁸⁰⁻⁸⁷ are barriers for overweight/obese people.		
Climate conditions	<ul style="list-style-type: none"> Hot,¹³³ or cold weather,^{100,117,141} 		Raise. ^{105,106} Evaluate. ^{105,106}	(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
	<p>pollution⁸⁵ or lack of snow removal⁸⁷ are rare barriers; pleasant weather is a facilitator.^{87,94}</p> <p>References:^{85,87,94,96,100,117,133,141}</p>	<p>Poor-weather correlates with PA level.⁹⁶</p>			<p>Inclement weather (e.g., extreme cold) reported as a barrier.^{105,106}</p>
Work/studies	<ul style="list-style-type: none"> Occupational—having long work hours or having multiple jobs - and educational demands are barriers to PA.^{80,100,135} Although work commitments are one of the most important perceived barriers to PA, being in paid work was associated with higher PA.⁷⁸ <p>References:^{78,80,100,121,135}</p>		<p>Having to work is a bigger barrier for healthy-weight than for overweight/ obese women.²¹</p>	<p>Raise:¹⁰⁶ Evaluate:¹⁰⁶</p>	<p>Work related time management is a barrier for elderly people.¹⁰⁶</p>
Transportation	<ul style="list-style-type: none"> Lack of transport is a barrier to PA.^{86,87,103,111} Active commuting is a means for doing PA. Other transport options, dependence on driving, or roads can act as barriers.^{97,112,139} <p>References:^{86,87,97,103,111,112,139}</p>			<p>Raise:^{108,140}</p>	
Instrumental social support	<ul style="list-style-type: none"> Child-care support is a facilitator¹¹²; lack of support a barrier^{100,132} <p>References:^{87,100,112,132}</p>				
Housework	<ul style="list-style-type: none"> Housework is both a barrier to PA^{112,133} and a source of PA.^{87,133} <p>References:^{87,112,133}</p>				
Policies	<ul style="list-style-type: none"> Insufficient funding for PA is a barrier; accessible subsidies a facilitator.⁸⁷ Other aspects are PA programming/promotion, government infrastructure support, local PA policies/regulations, rules 				

(continued)

Table 1. Continued.

Variable	Description and papers that raise the factor in PsycInfo	Specificities for groups differing in PA level	Specificities for weight groups	ACM papers that raise and evaluate the factor	Effects on PA as evaluated in ACM articles
	<p>affecting access to recreation areas, lack of partnership between health and recreation professionals and cash acceptance gyms.^{85,87,111}</p> <p>References:^{85,87,111}</p>				
Other/non-specified time demands	<ul style="list-style-type: none"> General daily life demands, busy lifestyles, or lack of time are PA barriers.^{7,81,93,98,101} In turn, having time is a PA facilitator.⁹⁴ Vacation, holidays, or celebrations are also mentioned as barriers.⁹⁹ <p>References:^{7,81,93,98,99,101,117,121}</p>	<p>Having no time is a bigger barrier for healthy-weight women than other weight categories.¹²¹</p>	<p>Raise:^{105,106} Evaluate:^{105,106}</p>	<p>Lack of time¹⁰⁶ or poor time management skills¹⁰⁵ are a barrier.</p>	

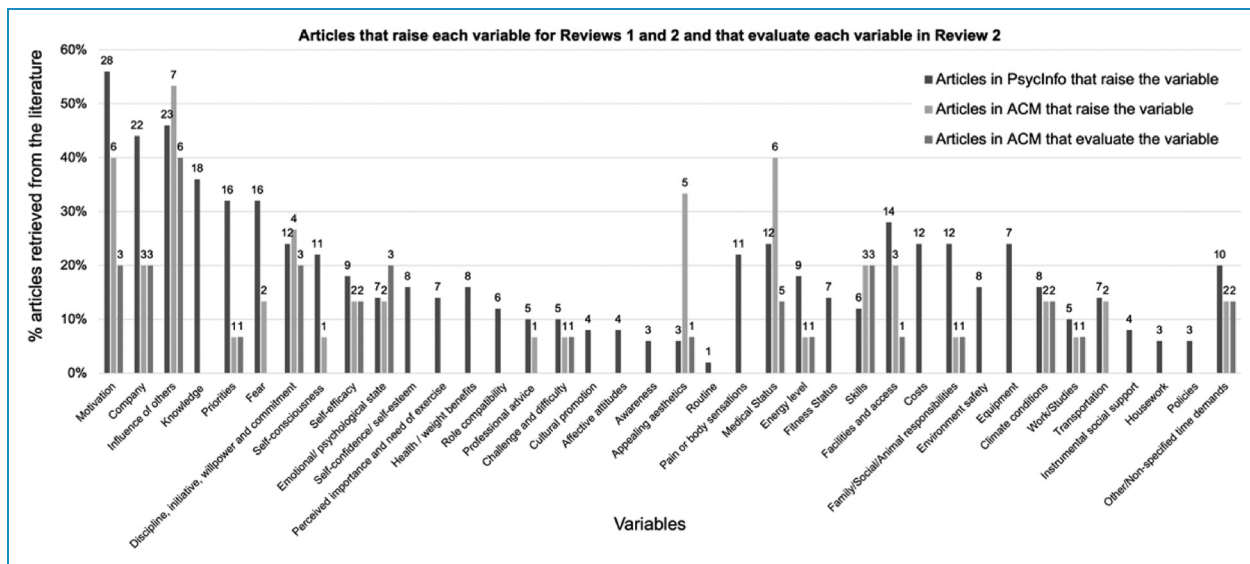


Figure 3. Percentage of articles that raise each variable in Reviews 1 and 2 and percentage of articles that evaluate the variable in Review 2. The numbers on top of the bars refer to the number of articles.

As it can be seen, only a few of the identified variables are taken into account in the development of technologies, according to Review 2. From 38 variables considered in the Psychology literature review, 21 are mentioned in the Computing literature review, and even less, 17, are actually considered in evaluations of the technology (see Table 1). In particular, the variables company; influence of others; initiative, willpower and commitment; emotional/psychological state; self-efficacy; medical status; skills; climate conditions; and other/non-specified time demands are taken into account and evaluated in articles about developing technologies. These articles report company of others during PA,^{105,108,116} self-efficacy¹⁰⁹ and skills (i.e. having a previous level of PA,¹⁰⁵ good performance,¹²⁶ and nimbleness¹⁰⁹) as facilitators to PA, while medical conditions or decline in physical/health status,^{106,108–110,124} inclement weather,^{105,106} and lack of time¹⁰⁶ or poor management skills¹⁰⁵ are reported as barriers. They also report that the influence of others is usually a facilitator of PA, but it could also be a barrier in some cases; for instance, the positive/negative effect of competitiveness in PA differs among people.¹²⁴ Similarly, specific goals with a high commitment level are usually good facilitators of PA^{109,136}, but can act as a barrier if announced publicly.¹²⁶ For emotional/psychological state, the mood was found to affect the level of PA^{105,106}: depression or sadness decreases PA¹⁰⁶; stress could be a barrier to PA^{106,109} but also a motivator to do PA to alleviate it.¹⁰⁵ Motivation is also mentioned in a number of studies, but evaluated in half of them; these studies found that greater levels of intrinsic (vs. extrinsic) motives, such as enjoyment of the PA,^{106,107,109} are associated with a more persistent engagement in PA.¹⁰⁹ Appealing aesthetics and facilities and access are

mentioned in some articles but just evaluated in one article, in which it was found that lack of facilities (e.g. gyms or stores), uneven pathways, noise, pollution, traffic or relocation to smaller homes act as barriers,¹⁰⁶ and that tracking PA and contextual information together supported users' reflection on the association between the environment and the PA level.¹⁰⁷ Priorities; challenges and difficulty; energy level; family/social/animal responsibilities; and work/studies are mentioned and evaluated in one article. These articles report difficult goals¹³⁶ as a facilitator to PA, while lack of energy,¹⁰⁵ caregiving duties,¹⁰⁶ and time management mistakes related to work¹⁰⁶ are mentioned as barriers for PA. Self-consciousness and transportation are barely mentioned and never evaluated. Fear is mentioned in two articles but also never evaluated. Finally, cultural promotion; role compatibility; health/weight benefits; routine; self-confidence/self-esteem; affective attitudes; knowledge; perceived importance and need of exercise; awareness; fitness status; pain or body sensations; environmental safety; policies; costs; equipment; instrumental social support; and housework are not mentioned, nor evaluated in the technological literature.

In addition to articles in Review 2, one Review 1 article also included a technology to promote PA.⁹⁶ This was a smartphone app to monitor the length and intensity of users' PA and to tell them when their goals had been reached. The aim was to assess the relation of users' PA behavior to self-reported PA barriers. While barriers were not considered in the technology employed in the article, the study also aimed to consider barriers for future technology design, as it collected users' opinions on the app to inform this. In particular, this article recommended that future interventions may provide financial incentives

Table 2. Summary of studies in Review 2.

First author/ Ref. nr.	Psychol. variables evaluated	Population	Activities/ Interventions performed	Measures employed	Findings/design implications. Technology should:
Capel ¹⁰⁵	<ul style="list-style-type: none"> Company Priorities Emotional/psychol. state 	Young adults	No intervention. 2-week user study with an exercise diary to inform technology for PA.	Interview Questionnaire	<ul style="list-style-type: none"> Facilitate scheduling workouts with others. This may facilitate making exercise a priority. Use music while exercising to adjust to the mood of users and motivate them.
Fan ¹⁰⁶	<ul style="list-style-type: none"> Motivation Influence of others Emotional/psychol. state 	Elderly	No intervention. Interview to evaluate concept storyboards to learn attitudes towards technology for PA interventions.	Interview	<ul style="list-style-type: none"> Address needs related to awareness of personal limitations, social connection, establishing and adapting to routines, and finding enjoyable activities. Interventions may be best suited to those who are currently inactive but motivated to change.
Li ¹⁰⁷	<ul style="list-style-type: none"> Motivation Appealing aesthetics 	Physically inactive	Two longitudinal studies with technology for monitoring/visualization of PA and context. 3 conditions compared: (1) control = no information; (2) information on PA only (step count); (3) information of PA and context.	Interview Questionnaire PA sensors Ad-hoc app	<p>Better integrate collection of/reflection on data:</p> <ul style="list-style-type: none"> Automatically collect PA and contextual information (directly through monitoring devices or indirectly through e.g. calendaring systems). Give access to users to the information; facilitate associating both types of information to increase awareness of opportunities for PA. Provide suggestions based on observed patterns of user activity (like a virtual coach).
Grosinger ¹⁰⁸	<ul style="list-style-type: none"> Influence of others Company 	Elderly	Think-aloud walkthrough with tablet-based prototype showing PA Information and Friends' PA activities and opportunities to join. 1-week study with technology probe and diary.	Interviews Questionnaire PA sensors Ad-hoc app	Promote PA by using social motivators to engage with close friends (e.g. promoting awareness of friends' activities and opportunities to join in).
Lacroix ¹⁰⁹	<ul style="list-style-type: none"> Motivation Discipline, initiative, willpower and commitment Self-efficacy Emotional/psychol. state 	Physically inactive	No intervention. PA was tracked with a wearable device for 10 days. PA analyzed together with questionnaire data on psychological variables.	Questionnaire PA sensors	<ul style="list-style-type: none"> Accommodate the variables of self-determined behavioral regulation, self-efficacy and experience of mainly health and well-being motivations. For inactive individuals aim to gradually induce and internalize these cognitions.
Chen ¹²⁴	<ul style="list-style-type: none"> Influence of others 	Healthy adults Diabetes Obese	2-month mix-method study; 1-month individual session + 1-month session with social fitness app allowing exercise in dyads with social incentives: (1) cooperation within dyads, (2) competition with other teams.	Interview PA sensors Ad-hoc app	<ul style="list-style-type: none"> Leverage existing social incentives to motivate people to exercise using fitness tracking tools. For unhealthy people, design social fitness applications which deemphasize competition to support normalization and strong ties between team members to facilitate completion.
Li ¹²⁵	<ul style="list-style-type: none"> Influence of others 	General population	No intervention. Surveys and interviews to understand how people use personal informatics systems.	Questionnaire Interview	<ul style="list-style-type: none"> Allow collecting information about oneself (e.g. inner thoughts, behavior, social interactions, environment), and use it to facilitate reflection and tailoring behaviors. Appropriately balance automated technology and user control. Support the association of multiple facets of people's lives (e.g. home/work life, social interactions, PA, etc.).

(continued)

Table 2. Continued.

First author/ Ref. nr.	Psychol. variables evaluated	Population	Activities/ Interventions performed	Measures employed	Findings/design implications. Technology should:
Munson ¹²⁶	• Discipline, initiative, willpower and commitment	People who are obese	Randomized field study with device for announcing PA commitments on social media. 3 conditions: (1) weekly commitments kept private (control); (2) public announcement of commitments; (3) public announcement of commitments and results (PA from sensors).	Sensors Ad-hoc app	<ul style="list-style-type: none"> For social support for health behavior change, allow public announcements of health/wellness commitments in social networks. Inherent trade-off: the prospect of social accountability may decrease the probability of making commitments (selection effect). To effectively use public accountability as a commitment device, the selection effect or its consequences needs to be reduced.
Turchani-nova ¹²⁷	• Influence of others	Mixed (healthy, overweight, obese)	1.5-month observational field study with an app that tracks PA and allows to follow other users.	Ad-hoc app	<ul style="list-style-type: none"> Track PA and integrate social features to follow others as effective role models (i.e. aspiring to be like them). Profile users into high/low persistence users, as the latter need additional motivational interventions, and to understand why they do not follow other users as effective role models.
Nakanishi ¹²⁸	• Influence of others	Runners	Field study with users with app to compete virtually with others running at different places and times. Users walked/ran under 3 conditions: (1) no competition; (2) one-to-one competition; (3) massive competition.	Ad-hoc app	<ul style="list-style-type: none"> Make users experience (virtual) competition to promote PA. Competition is more effective to promote PA than one-to-one or no competition schemes.
Leng ¹¹⁶	• Company	General population (Chinese immigrants)	No intervention. Surveys and interviews to learn about barriers to care towards intervention to promote access to cancer diagnosis/treatment.	Interview Questionnaire	<ul style="list-style-type: none"> Design information-based programs with information on financial/social assistance and general healthcare. Design in-person exercise programs in company with other patients.
Saini ¹³⁶	• Discipline, initiative, willpower and commitment • Self-efficacy • Challenge and difficulty	General population	10-day field study using a PA sensor. Users received feedback on their daily PA level and how common daily activities (e.g. household activities) contributed to it.	Questionnaire PA sensors	<ul style="list-style-type: none"> Make daily PA understandable: people tend to focus on vigorous PA at the cost of moderate PA. Provide goal setting support to guide users in setting concrete, challenging PA goals that accurately reflect behaviour change intentions. Use baseline measures of PA levels/patterns to ensure challenging but attainable goals.

(motivation), incorporate a social component (influence of others, company) and include different PA activities (e.g. walking; challenge, and difficulty) according to the user's PA level.

Overall, we consider that it is crucial to consider the potential variables when developing a PA intervention. Recommendations have been made to consider all possible mediating variables to PA when developing an intervention²⁵ and a relationship has been found between a technological intervention relying on a theoretical basis and the effectiveness of the technology.²⁷ Future work should aim to verify the importance of the identified variables to bring stronger support to their importance in considering them in the design of technology for PA.

Discussion

This study was conducted to address the need for considering the non-demographic variables of PA when developing technological interventions for the promotion of PA, and to investigate the relevance of these variables in relation to a person's PA level and body weight. We chose an atheoretical approximation due to the absence of specific theories explaining the PA behavior²⁹ and also to explore other possible variables.²⁵ By doing so, we can ensure that potentially important variables for PA are not excluded in studies. For the achievement of our goals, we have presented the variables appearing in the psychological/psychiatric literature in relation to PA and the effect of body weight on them; and we have highlighted the lack of consideration of these variables in the computing literature.

Non-demographic barriers to PA

PA seems to be affected by several variables. We have found 38 potential variables stated as barriers or facilitators to PA in the literature. It is advantageous to have all these variables compiled in one study to have a general view since none of the studies reviewed has considered all the variables presented here. Moreover, a previous study exploring the literature about barriers in the obese population reported 12 barriers.⁷³ We have considered a wider picture by including the facilitators in our review and including all weight categories (not only obese). In fact, while the aforementioned study included 17 studies for reviewing in the final sample, ours includes 50 studies from the Psychology literature and 15 from Computing. However, all of the barriers presented in⁷³ have also been identified in our review, which indicates a congruence of the findings. In our case, excess body weight is included within the variable fitness and perception of own body weight and includes stigma as social influence, self-esteem, and self-consciousness. In addition to this information, 21 articles measured PA potential variables through a qualitative methodology, 25 articles used a quantitative

methodology, and 4 articles a mixed approach. We have not analyzed if the variables showed any differences depending on the way in which they were measured, but this could be an interesting aspect to explore in the future.

The most reported variable is motivation, followed by company, influence of others, knowledge, priorities, and fear. The least reported variable is routine, followed by housework, policies, awareness, and appealing aesthetics. It is possible that some variables are reported more often in the reviewed studies than others because they are present in the existing tools rather than due to their prevalence in the population. In fact, when questioned about PA barriers, people report many more barriers than the ones in questionnaires.^{84,70} Since we aim to identify all the variables in the literature affecting PA, irrespective of their appearance in previous behavior theories, we suggest treating all the presented variables equally to avoid excluding potentially important variables by focusing only on those highlighted by Michie et al.²⁹ Indeed, many of the specific variables that we present here are not considered by the often-used behavior change theories for explaining PA behavior.^{142–144} While these theories focus on more general aspects that can affect different health behaviors, they do not consider specific aspects of PA. Yet, the individual components should be studied to understand which of them could make an intervention effective,²⁵ and breaking down each component into minor variables allows for studying the specific effects. Thus, interventions can be optimized by focusing only on the relevant aspects influencing PA. For example, engagement in health behaviors in the Health Belief Model (HBM).^{145,146} depends on how severe the health problem is perceived to be and how susceptible people feel themselves to be. However, in the case of PA, medical conditions are usually reported as barriers, not as facilitators.^{82,93,133}

Barriers according to PA level

Understanding the relationship of each variable with the PA level is fundamental for their inclusion in intervention design for behavior change. However, some reviewed studies evaluate the relationship of the variables presented with a person's PA level as they do not use an actual measure of PA levels. Our literature review shows the relation with a person's PA level for only a few variables (see the third column in Table 1), which should be prioritized over others for the inactive population. These are company, motivation, difficulty—only when regarded as a barrier but not as a facilitator—initiative, willpower and commitment, and knowledge. In some cases, such as for emotional/psychological state, the actual relation with PA level has been reported only in the technological literature. This means that while emotional/psychological state has been identified in the psychological literature as influencing PA, the studies reporting that influence do not actually

measure PA levels or examine differences between groups of the population differing in their PA level.

For other variables, we have not found consensus concerning whether there is any relation between them and PA level (e.g. influence of others, fear). This absence of consensus can be due to study methodological differences. For example, for self-efficacy there is a relation with the PA level in most cases, but¹¹⁵ does not find a correlation. This could be because in¹¹⁵ PA was measured within a particular long-term intervention involving a 12-month facility- and home-based exercise program, while most of the other studies^{80,84,86,87,90,120} did not have an intervention or had a shorter-term intervention involving more moderate PA (wear a pedometer for 8–9 weeks^{103,119}); this intervention type may not have the same effect as other PA kinds. Finally, while the relation with the PA level has not been mentioned in the literature for the majority of the variables, it is possible that in other medical fields, measures of PA are more commonly employed and studied in relation to PA barriers than the ones we studied from PsycInfo. It should however be noted that PsycInfo does include various medical journals and thus it also provides an understanding of that field.

Barriers according to body weight

We have also found that the effect of the identified variables over PA can be dependent on the population under study.^{78,91,94,96} A particularly relevant aspect influencing the effect of the variables is body weight. In our reviews, we further explored the specificities of the barriers to PA for the overweight/obese population. Though this population has the same barriers to PA as the healthy-weight population, some barriers were more important for them. In this population the effect of social influence is particularly important for several reasons: first, there is more reported reliance on social cues⁹⁹; second, lack of social support is reported as a barrier more often in the obese than non-obese population⁹¹; third, the influence of others is related to the PA level only in the overweight/obese population¹²¹; and finally, the incidence of negative social influence (e.g. teasing) can be higher for overweight/obese women.^{79,87} Thus, social influence should be especially considered in the development of interventions for PA for this population. Another relevant variable is lack of enjoyment, considered as the main cause of low exercise levels in obese women.⁹⁰ However,⁹¹ found no significant differences in lack of enjoyment as a barrier to PA between different weight groups of women. Since there are a few variables that are more reported by the overweight/obese than the healthy-weight population, it is important to study if the influence of enjoyment is mediated by other variables as a possible explanation. For example, one study found that obese women are more likely to agree that they only exercise when trying to lose weight.⁹³ Since the motives to exercise

are not usually intrinsic to activity in this group, it is expected to find motives more external to the activity in itself. Population specificity in certain studies can also lead to a greater homogeneity, and make other possible influences disappear. For example, the discrepancy about whether reporting initiative, willpower, and commitment as a barrier is dependent on weight groups can come from the fact that the only article finding no differences⁹¹ handles a population of African American breast cancer survivors, while those finding differences^{52,121} handle broader populations. Finally, in contrast, barriers related to time demands are reported to be lower for the overweight or obese population.¹²¹

In this work, we have only reviewed the variables reported in the articles that include the term “obesity,” but considered all body weights. Thus, based on our results we propose to prioritize the following factors in the development of interventions for PA for the overweight/obese populations: influence of others,^{79,87,91,99,121} fear of injury,⁹¹ self-consciousness,⁵² and self-confidence^{87,93} about one’s looks (leading to not wanting to exercise in front of others^{79,93}), knowledge (e.g. receiving health messages related to PA¹³¹), motivation, and potentially, initiative, willpower, and commitment (according to Refs. 52,121, although Ref. 91 reports no differences between weight groups). In relation to motivation, one study reported that the variable lack of enjoyment is the main cause of physical inactivity in obese women⁹⁰, although there is no consensus about it,⁹¹ perhaps as this variable may be mediated by other variables. Nevertheless, obese women seem to only find external (versus intrinsic) motives to exercise.⁹³ Nevertheless, we acknowledge the importance of considering individual differences in PA barriers.

Considering other individual factors

Given the above findings for the overweight or obese population, it is possible that a similar “barrier augmentation” effect takes place for other specific populations, that is, the barriers can be the same for the general population but can be bigger barriers to PA in the overweight/obese population or can have a different effect in them in some specific cases. Ideally, all the potential variables for the general and specific populations should be known, to be able to identify the relevant ones in each case and evaluate which aspects should be considered or prioritized in the development of PA-related interventions. Considering the different barriers faced by different populations would allow designing guidelines on factors to be prioritized for interventions for specific groups (e.g. with different PA levels or BMI). A general overview of the effects of these variables over PA is an important first step for designing PA interventions but a necessary second step includes evaluating their relevance in any given situation when

developing PA interventions, as the presence or influence of different variables could vary between populations. For example, ethnicity, age, and economic stability affect whether self-consciousness is reported as influencing PA⁹⁶; lack of willpower was not reported as a barrier by Hispanic students¹¹⁹; lack of self-confidence appears to be more likely reported as a barrier in younger adults than in older adults⁹⁴; and fear as a barrier appears to be higher in older adults than in younger adults,⁹⁴ in women than men,⁷⁸ and in non-college educated women.⁹¹

Design recommendations for technology addressing PA barriers

Literature Review 1 provided insights as to what needs should be addressed for facilitating adherence to PA overall, and about the prioritization of factors for people who are physically inactive or overweight/obese. While we recognize the importance of considering these factors influencing PA in the development of technological interventions that aim to increase participation in PA, Review 2 highlights that psychological barriers are mostly overlooked in the design of technology. Most work on technology to promote PA uses cognitive-behavioral approaches that are based on motivating, planning, and getting social support, but are not designed to support an analysis of the underlying problem; the focus is often placed on how to enhance positive emotions through intervention (e.g. with badges to mark achievements) but this approach falls short if motivation is not the barrier to PA.⁷²

We propose a rethink of PA technologies by considering psychological factors holistically and systematically in the design process. The conducted reviews provided valuable insights as to how technology could help address some of the psychological factors to promote higher participation in PA. Based on our reviews, we provide the following recommendations for technological interventions focused around three main topics: (i) integrating social features into the design, (ii) identifying opportunities for PA and helping to establish PA goals and routines, and (iii) regulating emotional/psychological state:

1. *Integrate social features into the design:* Our results show that technology should support the social aspect of PA, in four different ways. (1) By integrating features that facilitate scheduling workouts with others (e.g. with people they know or in person exercise programs), for instance by integrating a scheduler application shared with social media contacts that promotes awareness of friends' activities and opportunities to join in; this relates to company, but also, it may facilitate making exercise a priority.^{105,106,108,116} (2) By providing social incentives to motivate people to exercise, for instance by using fitness tracking tools,¹²⁴ or by making public

announcements of PA commitments in social networks,¹²⁶ which relate to the variables, influence of others and discipline, initiative, willpower, and commitment. Here it is important to profile users into low and high persistence users, as the latter may need additional motivational interventions, as well as to understand why they do not follow other users as effective role models.¹²⁷ Also, it is important to consider whether competition should be emphasized or de-emphasized for individual users: while competition seems to be effective for the average population,¹²⁸ for some individuals (e.g. obesity, diabetes) the focus should be on supporting strong ties between team members.¹²⁴ (3) By allowing following others as effective role models¹²⁷ which also relate to the influence of others. (4) By integrating social assistance¹²⁶ and professional advice.

2. *Identify opportunities for PA and help in establishing PA goals and routines:* personal informatics should allow tracking, collection, and integration of various types of information on PA and contextual information (using monitoring devices or calendaring systems) and allow linking multiple facets of people's life (at home, at work, daily social interactions, PA)^{107,125}, to increase awareness of personal limitations and of opportunities for PA. For instance, the system could provide users with detailed feedback on their PA and the contribution of common daily activities (e.g. household activities) to their PA level.¹³⁶ The system could also integrate a virtual coach, providing suggestions based on calendar and observed patterns,¹⁰⁷ and help to establish and adapt to routines,¹⁰⁶ as well as to set PA goals. PA goals should be concrete and challenging, but attainable, and conveyed in an easy and straightforward manner, which relates to challenges and difficulties.¹³⁶ For instance, according to the user's PA level, different PA activities could be suggested (e.g. walking or running).⁹⁶
3. *Regulate emotional/psychological state:* Related to the previous point, personal informatics could also help to apply self-regulatory mechanisms to drive motivation and goal attainment,¹³⁶ and to find enjoyable activities to support PA¹⁰⁶ and experience. One example¹⁰⁵ is the use of music while exercising by adjusting the music to the pace, workout type or mood of the users, to regulate their emotional state and motivate them.¹⁰⁵

Future research should study the integration of other factors in technology design to promote participation in PA, and especially to consider that while certain interventions may work for the general population or for a specific population, they may not work for other population groups. An example is when depression affects PA^{80,95}; while using music while exercising has been suggested as an effective tool to adjust the mood of users and motivate them,¹⁰⁵ the same type of intervention may not work to adjust the mood of people with depression. We acknowledge that none of the

reviewed technologies studies looked at the psychological consequences of using the wrong intervention. We suggest that, rather than thinking of a unique intervention, it may be more effective to think in terms of structured interventions, where different needs are addressed at different times; this requires first identifying the pre-requisites for applying specific interventions (e.g. enhancing positivity towards one's body prior to apply interventions integrating social features). A first and necessary step for this is to find out the most important barriers to PA for the targeted users, to then center the design and the evaluation of the interventions around the identified barriers.

Finally, we highlight the fact that all the interventions performed in the reviewed studies involve top-down cognitive-behavioral mechanisms, but recent works have started to demonstrate the potential of using bottom-up mechanisms. For instance, one can involve these mechanisms to change self-perception, bringing positivity to the perception of one's body and one's own physical capabilities, and in turn affect PA.^{60,42,147–151} Future works should investigate the combination of top-down and bottom-up mechanisms to address PA barriers in structured interventions.

Conclusion

In conclusion, our study has highlighted the importance of all the specific PA variables reported in the articles reviewed, in total 38 variables (21 psychological, 5 physical, 12 personal/contextual), which should be taken into account when developing interventions for the promotion of PA. Moreover, the body weight aspect must be also considered, as it can be associated with the variable effect. The Computing field should be particularly made cognisant of the importance of basing the intervention developments on the knowledge of the PA variables as a means of building on the literature and evidence and adding to it; our study has demonstrated a lack of enough consideration for such variables, which means that studies do not build on the existing evidence base efficiently and effectively. This paper is a step forward to building a tool for supporting designers in understanding the PA problem they are designed for and setting the measures they need to assess the efficacy of their technology-based design. In particular, our study can be used to develop systematic tools that could be used to explore the variables that affect PA and how PA-related applications are affected by them, to inform the design and the evaluation of new PA interventions.

Limitations

We acknowledge several limitations of this work. First, the systematized reviews were not pre-registered. Further, only one author reviewed the articles for their inclusion, the search period was limited to 10 years (2007–2017) and we used only one database per search; these elements could be

considered limitations but they are common and standard in the method followed in systematized reviews. Hence, there is a possibility of some barriers and facilitators being missed. However, our analysis suggests that the possibility of this is small as the principal variables are repeated several times across articles and just a small proportion of variables appear only once. Further, a quality assessment of the included articles was not performed, but at the same time adding specific quality criteria would have entailed the risk of biasing the selection process and ending up with a skewed sample or missing relevant barriers as noted e.g. by Snyder.⁶¹ In addition, the articles considered were all peer-reviewed and included in the PsycInfo/ACM databases implying an existing quality filter. Second, restricting the literature review by introducing the word “obese” prevents us from asserting that the variables presented represent all the potential variables for PA in the general population. Future work should gather and present information for a wider population sample.

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