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Title:

Promoting physical activity in persons with type 2 diabetes mellitus: a systematic review of systematic reviews

Running head:

Promoting physical activity

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Abstract

Objective: There is a large amount of studies about interventions for promoting physical activity (PA) in persons with type 2 diabetes (T2D) as well as several systematic reviews referring to these studies. The objective of this contribution is to provide a systematic review of these systematic reviews.

Method: PubMed, PsychInfo and the Cochrane Library were searched for systematic reviews and/or meta-analyses regarding interventions for promoting PA in persons with T2D. The individual reviews and the relationships between the reviews were analysed.

Results: Eighteen reviews were included. Seventeen of these reviews contained references to included trials, amounting to 113 trials in total. Five of the reviews addressed PA interventions in general; six addressed specific devices for delivering the intervention; five addressed specific approaches for giving the participants feedback about their outcomes; and two addressed specific therapeutic approaches. Only 14 cross-references were found.

Conclusion: Giving feedback about outcomes and helping people to integrate PA in their daily lives seem to be the most effective intervention components. Basing intervention development on theories seems helpful.

Practical implications: Interventions should give feedback about outcomes and help to integrate PA in daily life. Intervention development should be theory-based.

Keywords

Type 2 diabetes, physical activity, intervention, health-related behaviour, exercise, self-care

1 Introduction

One very effective measure for delaying the progression of Type 2 Diabetes (T2D) and thus preventing the long-term complications of this disease is physical activity (PA) [1]. For this reason – and because of the tremendous and still further increasing prevalence of diabetes [2], mostly T2D [3] – a large amount of interventions addressing PA in persons with T2D have been developed and evaluated in the last three decades. The corresponding studies provide a huge body of empirical evidence about what might work for promoting PA in persons with T2D and what not. However, because this body of evidence is so huge, it is difficult to get an overview. In response to this problem, several systematic reviews regarding the promotion of PA in persons with T2D have already been presented. However, these systematic reviews only partially solve the problem of this lack of survey. Every one of these reviews provides a special view on the empirical evidence accrued to that point, while leaving other aspects unaddressed.

Presumably, the limitations of the individual reviews can best be overcome by subjecting the reviews to a higher order review, i.e. by performing a systematic review of the relevant systematic reviews. This is the general objective of the paper presented here: a systematic review of systematic reviews regarding the promotion of PA in persons with T2D. In detail, two specific objectives are pursued: (1) the core messages of the individual reviews are outlined; and (2) the relationships between the individual reviews are elaborated. As reviews are necessarily based on arbitrary decisions of the researchers, and as these decisions often depend on the prevailing zeitgeist, the chronology of the reviews is also considered.

2 Methods

2.1 Literature search

2.1.1 Inclusion criteria

To be included in this systematic review, publications had to fulfil seven criteria.

1) They had to be a review and/or a meta-analysis of original empirical research, i.e. publications that included reviews were excluded.
2) They had to contain clear criteria for the inclusion of original studies and had to be performed with the goal of identifying and including all original studies that fulfilled these criteria, i.e. publications that only discussed examples were excluded.
3) They had to refer exclusively to adult persons with T2D without further restrictions regarding demographic features, specific comorbidities or context, i.e. publications that included persons with type 1 diabetes or were restricted to a narrower age range than "adult persons", to a specific comorbidity or to a specific country were excluded.
4) They had to contain results regarding the effects of interventions on measures of PA, for example steps per day or hours of vigorous activity per week.
5) They had to focus on efficacy, i.e. publications addressing aspects of translation of interventions into practice were excluded.

6) They had to either provide a statistic describing the aggregated effect of the individual studies or at least state the numbers of trials with a positive, a negative and no effect.
7) They had to be written in English and to have been published in a peer-reviewed journal.

The search was restricted to English language papers to give each reader of this review a fair chance to retrace the review. The restriction to peer reviewed journals was meant as a measure of quality assurance. No time limit with regard to the past was set because one objective of the review was to show developments over time.

2.1.2 Search procedure

The search procedure consisted of two components. The first component served to identify a basic set of reviews to be included, the second component to identify further reviews based on already included reviews (see Figure 1).

The first component of the search procedure consisted in searching PubMed, PsychInfo and the Cochrane Library with the following text string:

> '((behaviour change) OR (behavior change) OR (behaviour modification) OR (behavior modification) OR (impact on behaviour) OR (impact on behavior)) AND (strategy OR strategies OR technique OR techniques OR intervention OR interventions) AND diabetes AND ((physical activity) OR exercise OR sports) AND (review OR meta)'.

The search with this text string was performed on 2020/10/28. Both authors searched the references produced by this text string for articles fulfilling the inclusion criteria (see 2.1.1). Disagreement was resolved by discussion.

The second component was an iterative procedure with each cycle based on the literature identified in the preceding cycle or, in case of the first cycle, based on the literature directly identified in the databases at start (see Figure 1). The newly identified reviews themselves and the original trials included in these reviews were considered. For each of them, three different sources were searched: (1) the reference lists of the articles, (2) the reference lists produced for these articles by the PubMed function 'cited by'; and (3) the reference lists produced for these articles by the PubMed function 'similar articles'. The latter two were restricted to ('reviews' OR 'systematic reviews' OR 'meta-analyses'. When an iterative cycle produced new eligible reviews, a new iterative cycle was performed with these reviews. Otherwise, the search was terminated (see Figure 1). Both authors performed each cycle separately and compared their results. Disagreement was resolved via discussion.

2.2 Literature analysis

Both authors judged the quality of the reviews identified using items 4, 9, 11, 13 and 15 of ALMSTAR 2 [4]. The remaining ALMSTAR items did not seem appropriate in this context. Disagreement was resolved via discussion. The first author grouped the reviews according to their objectives and analysed them. For each review, six aspects were considered: (1) the objective; (2) the inclusion and exclusion criteria; (3) the number of trials included; (4) the time interval in which the trials were published; (5) the designs of the trials actually included; and

(6) the basic results. The first author also analysed the cross-references between the reviews and the overlap between the trials included in the reviews.

3 Results

Altogether, 18 eligible reviews were identified [5-22], with 11 at the start of the search procedure and seven in the first iterative cycle. The second iterative cycle produced no further reviews. Nearly all of these reviews are based on a comprehensive literature search and in most of them the methodological quality of the included trials has been assessed (see Table 1). With one exception [7], the reviews contained references to the original studies. The 17 reviews with references referred to 113 different trials, some of which were described in more than one publication. Five of the 18 reviews referred to PA interventions in general [5,7,8,17,18]. Six reviews focused on specific devices for delivering the intervention [6,10-12,15,16,20], five on specific approaches for giving the participants feedback about their outcomes [9,14,19,22], and two on specific therapeutic approaches [13,21]. The publication dates of the reviews ranged from 2001 to 2020 with a large gap between the first and the second review, which was published in 2011 [20].

Insert Table 1 about here

3.1 Individual reviews

The results are presented for each group separately and within each group in the order of the publication dates.

3.1.1 Interventions in general

The first review focusing on interventions that address PA in general is the oldest review identified here. It was presented by Norris et al. in 2001 [18]. The objective of these authors was to review self-management education programmes in T2D, which they themselves refer to as training programmes in T2D. The authors considered a large set of possible outcomes including PA. The review of Norris et al. is discussed here at this stage because any kind of intervention aimed at promoting PA can be understood as a self-management education programme that addresses PA and vice versa. Norris et al. restricted their review to RCTs and found a total of 72 eligible discrete trials. PA was assessed in nine trials, published between 1985 and 1997. The intervention had a statistically significant positive effect on PA in four of these trials and no effect in the other five trials.

In 2012, Avery et al. [8] published the second review focusing on PA interventions in general. Specifically, these authors were concerned with how interventions aimed at promoting PA in persons with T2D affect HbA1c and PA. The review is confined to RCTs regarding interventions that exclusively targeted PA. Seventeen eligible trials, published between 1997 and 2011, were included. The authors performed one meta-analysis for trials with PA measured by step-counters, i.e. pedometers or accelerometers, and one for trials with self-reported PA. Trials using both kinds of measurement were entered in both meta-analyses. This procedure yielded 6 trials with step-counters and 14 trials with self-reported PA. When a trial referred to more than one intervention, the authors entered each intervention individually into these meta-

analyses. Moreover, the authors distinguished four points of measurement after baseline: 1) at least 1 month and less than 6 months; 2) 6 months; 3) 12 months; and 4) 24 months. The fourth point of measurement was only realised for self-reported PA. In both meta-analyses, the authors found a significant overall effect favouring the PA intervention. Moreover, the authors found statistically significant positive effects for the first three measurement points except for the first measurement point in the analysis referring to step-counters.

In 2015, Avery et al. – nearly the same authors as in the review of Avery et al. (2012) – published the third review focusing on interventions in general [7]. In this review, the authors intended to find those components of PA interventions that make these interventions effective. The review contains no references to the trials included. However, the text suggests that these are the same trials as analysed by Avery et al. (2012) [8]. When the same trial referred to more than one intervention, the authors treated these interventions separately. This amounted to 21 different interventions included in the analyses. Avery et al. categorised these 21 interventions with respect to 26 dichotomous characteristics. The authors compared the standardised mean differences (SMDs) between intervention and control for interventions possessing the particular characteristic with the corresponding SMDs for interventions without that characteristic. There was a statistically significant positive effect for the characteristics 'Prompt focus on past success', 'Barrier identification/problem-solving', 'Use of follow-up prompts', and 'Provide information on where and when to perform the behaviour'; but there was a statistically significant negative effect for the characteristic 'pedometer use'.

In 2017, Alothman et al. published the fourth review addressing PA interventions in general [5]. The authors intended to review those studies in which the PA outcome was assessed using technical devices like pedometers or accelerometers. The authors limited themselves to RCTs published between 2000 and 2016 and found 15 eligible studies, published between 2001 and 2013. The authors treated these studies as 15 discrete trials. However, in one case, three of the 15 publications [23-25] refer to one particular trial and, in a further case, two publications [26,27] both refer to another particular trial. Hence, the review is actually only based on 12 discrete trials. There was a positive effect in 10 of these 12 trials. According to a qualitative analysis of the authors, exercise consultation, behavioural/cognitive consultation, continuous glucose monitoring counselling, and motivational phone calls promoting PA were those intervention components that were especially effective.

In 2018, Mosalman Haghighi et al. published the fifth and most recent review addressing PA interventions in general [17]. The authors intended to review the long-term effects of PA interventions, which they categorised into structured exercise and behavioural programmes. The authors confined themselves to RCTs and found 23 eligible trials (five structured exercise and 18 behavioural programmes), published between 1997 and 2014. Several meta-analyses were performed. When a trial referred to more than one intervention, the authors entered the individual interventions separately into the meta-analyses. This resulted in seven structured exercise and 22 behavioural programmes. Three of the structured exercise programmes had a positive effect and four no effect. Of the behavioural programmes, 10 had a positive and 12 no effect. For the structured exercise programmes, the authors performed no statistical test for

the meta-analysis because the programmes were statistically too heterogeneous. For the behavioural programmes, the authors performed a test after removing one numerical outlier and obtained a statistically significant result favouring the intervention. The authors found that, when PA was measured with technical devices, the overall effect was the same as for all behavioural programmes together.

3.1.2 Specific devices for delivery

In 2011, Ramadas et al. [20] published the first review focusing on specific devices for delivery of the intervention. This review is also the second oldest of all the reviews included in this systematic review. The objective of Ramadas et al. was a 'descriptive discussion' of web-based interventions addressing health-relevant behaviour of persons with T2D. The authors confined themselves to RCTs and quasi-experimental trials published between 2000 and 2010. Moreover, the trials had to refer to interventions in which information was exchanged between a healthcare provider and a person with T2D via a website and in which physical activity, nutrition, self-monitoring or weight loss was addressed. Ramadas et al. found 13 trials fulfilling these criteria. PA was addressed in four trials, which were published between 2002 and 2009 and which were all RCTs. The intervention had a positive effect on PA in three of these four trials and no effect in the fourth trial.

In 2012, Cassimatis and Kavanagh published the second review addressing specific devices for delivery [10]. The authors intended to review the effects of telehealth interventions on HbA1c and several forms of health care behaviour including PA. The authors limited themselves to RCTs and found 13 eligible trials. PA was addressed in eight trials published between 2003 and 2011. The intervention had a positive effect on PA in five trials and no effect in the other three trials.

In 2013, Connelly et al. published the third review addressing specific devices for delivery [11]. The authors intended to review interventions in which technology was used to promote PA in people with T2D. Specifically, the authors focused on interventions where technology was the main method of delivery and where information regarding main outcomes was exchanged using this technology. The authors did not confine themselves to RCTs, but to all trials with a pre- and a post-measure of PA. Fifteen trials, published between 2001 and 2012 and all RCTs, were included. The intervention had a positive effect on PA in 14 trials and no effect in the remaining trial.

In 2013 (e-pub ahead), Cotter et al. published the fourth review addressing specific devices for delivery [12]. The authors focused on studies using internet-based interventions to promote lifestyle modification among adults with T2D. As the only eligibility criterion regarding study design, the authors required the study to contain an evaluation component. Nine eligible trials were identified. PA was addressed in eight trials, published between 2000 and 2011. Seven of these trials were RCTs. The eighth trial was a non-randomised control group trial with pre- and post-measurements. Cotter et al. reported positive results for three of the eight PA trials. However, in only one case does this positive result stem from comparing the internet-intervention with a similar intervention without internet [28]. In the other two cases, the

positive results stem either from a comparison with no intervention at all [29] or from a pre-post-comparison [30].

In 2016, Arambepola et al. [6] published the fifth review focusing on specific devices for delivery. The authors intended to examine the effectiveness of interventions addressing healthy eating and/or PA in persons with T2D and performed with messages automatically delivered via mobile devices like mobile phones, smart-phones or hand-held computers. The authors distinguished unidirectional messaging, i.e. messages only sent from the intervention givers, and bidirectional messaging, i.e. messages exchanged between intervention givers and participants. The authors limited themselves to RCTs, non-randomised controlled trials and crossover studies. Fifteen separate eligible trials were included. However, PA outcomes were only reported for five trials, published between 2011 and 2014. Four of these trials referred to unidirectional and one to bidirectional messaging. For unidirectional messaging, the intervention had a positive effect in two trials and no effect in the other two trials. In the trial with bidirectional messaging, the intervention had no effect.

In 2020, Howland and Wakefield [15] published the sixth and most recent review regarding specific devices for delivery. The authors focused on interventions using telehealth to influence PA and/or sedentary behaviour in persons with T2D. There were no restrictions regarding study design, but the trials had to be published within the 10 years prior to the review and had to have PA, sedentary behaviour or HbA1c as outcomes. Seventeen trials published between 2009 and 2019 were included. In all of these trials, PA was considered as an outcome. Fourteen trials were RCTs and 3 quasi-experimental trials. Ten of these trials showed significant improvements in PA. The results of the remaining trials were not completely reported.

3.1.3 Specific approaches for giving feedback

In 2013, Funk and Taylor published the first review addressing specific approaches for giving the participants feedback regarding their outcomes [14]. The objective of this review was to determine the effect of pedometer-based interventions on PA and health outcomes in persons with T2D. Funk and Taylor explicitly focused on pedometers, i.e. devices that only count steps, and excluded accelerometers, i.e. devices that measure additional parameters. The authors formulated no inclusion criteria regarding study design. Ten trials published between 2004 and 2011 were included. In all these trials, PA was monitored and assessed as an outcome. The authors classified nine of these studies as RCTs and one as a quasi-experimental design. The authors adopted the latter classification from the original publication [31]. However, according to the further information given in this publication, this study was also an RCT. Nine of the trials were two-armed, one three-armed. The intervention had a statistically significant positive effect on PA in four of the nine two-armed trials and no effect in the remaining five two-armed trials. In the three-armed trial, one intervention arm had a statistically significant positive effect on PA in comparison with the control group, whereas the other intervention arm had no effect.

In 2014, Qiu et al. published the second review addressing special approaches for giving feedback. The authors intended to perform meta-analyses regarding the impact of using step-

counters, i.e. pedometers and accelerometers, for outcome monitoring on PA and HbA1c in persons with T2D. The authors focused on RCTs with PA and/or HbA1c as outcomes. The authors found 11 eligible trials. Viable PA data for the meta-analyses were reported for seven trials, published between 2004 and 2013. A meta-analysis for all seven trials together provided a statistically significant positive effect for the interventions. However, there was a lot of heterogeneity between the studies. A large part of the heterogeneity could be explained by grouping the trials into those in which a goal was set for the participants (four trials) and those in which no goal was set (three trials). There was a huge statistically significant positive effect in the with-goal group, whereas the increase in the no-goal group was not statistically significant. Further sub-group analyses showed that step diary use had a positive effect, too.

In 2017, Baskerville et al. published the third review addressing special approaches for giving feedback [9]. Like Qiu et al.[19], Baskerville et al. performed meta-analyses for investigating the impact of pedometer or accelerometer use on PA and HbA1c. Eligible studies were RCTs, non-randomised controlled trials and crossover studies. The authors identified 12 trials. Ten of these trials, published between 2004 and 2013, included PA measurements that could be applied for the meta-analyses. Nine of these PA trials were RCTs and one was a non-randomised controlled trial. Accelerometers were applied in three of these trials and pedometers in seven. The meta-analyses yielded two main results: (1) the intervention had a positive overall effect on PA; and (2) the results of accelerometers and pedometers were virtually identical.

In 2018, Taylor et al. published the fourth review addressing special approaches for giving feedback [22]. In this case, the focus was on continuous glucose monitoring. The authors were interested in the impact of this kind of monitoring on HbA1c and on lifestyle variables including PA. Eligible studies were RCTs and observational studies. The authors found 11 separate eligible trials. PA was assessed as an outcome in four trials, published between 2008 and 2016. Three of these were RCTs; the other one a one-group study with pre- and post-measurements. The intervention had a statistically significant positive effect on PA in three trials and no effect in the remaining one.

In 2019, Kongstad et al [16] published the fifth review concerned with interventions regarding specific approaches for giving feedback. The authors were concerned with PA interventions for persons with T2D in which remote feedback given via telephone, mobile phone, smartphone, tablet, computer or personal digital assistant was applied. The authors confined themselves to RCTs and found 27 eligible trials published between 2001 and 2015. Using a meta-analysis, the authors found a highly significant effect favouring the intervention. There was, however, a high heterogeneity. The authors investigated whether length of intervention, number of contacts per month, study size, delivery of feedback (telephone or textbased), preliminary face-to-face session (yes or no) and role of remote feedback (part of intervention or complete intervention) could explain parts of the heterogeneity. Only study size could do so, with a larger effect size in smaller studies.

3.1.4 Specific therapeutic approaches

In 2015 (e-pub ahead), Ekong and Kavookjian published the first review that focused on a special therapeutic approach applied to promote PA in persons with T2D [13]. These authors investigated the impact of motivational interviewing [32] on diabetes-relevant forms of lifestyle behaviour including PA. They limited themselves to RCTs and found a total of 14 eligible trials. PA was investigated in six trials, published between 1997 and 2013. The intervention had no statistically significant effect on PA in any of these trials.

In 2017, Soderlund published the second review addressing a special therapeutic approach [21]. She was also concerned with the use of motivational interviewing for promoting PA in persons with T2D. Her inclusion criterion regarding study design was that 'quantitative experimental research was used' [21]. She found nine eligible trials, published between 2004 and 2015. Seven of these trials were RCTs, one a non-randomised controlled trial, and one a one-group study with pre- and post-measurement. The intervention had a statistically significant positive effect on PA in four of the nine trials and no effect in the remaining five trials. Additionally, Soderlund tried to elaborate those characteristics of the interventions that are associated with a positive effect. She found: (1) the intervention should address only a small number of forms of behaviour, optimally only one; (2) the motivational interviewing sessions within the intervention should either be frequent, i.e. more than two and at least one per month, or have a duration of at least 30 minutes; and (3) the persons conducting the sessions should be proficient in motivational interviewing.

3.2 Relationships between the reviews

There are only 14 cross-references between the reviews from a set of possible cross-references of 153. Nine of the 17 reviews that could have had references to preceding reviews have no such reference at all (see Table 2). The trials included by the different reviews overlap to a varying extent. The trials included by Norris et al. do not overlap with trials of any other review presented here. On the other hand, the trials included by Kongstad et al. overlap with the trials of all other reviews except for those of Norris et al. and Taylor et al. (see Table 3).

Insert Tables 2 and 3 about here

4 Discussion and Conclusion

4.1 Discussion

4.1.1 Strengths and weaknesses

In addition to the direct search in three databases and the inspection of the reference lists of the reviews and the reviewed original articles, the search presented here also takes advantage of the PubMed functions 'similar articles' and 'cited by'. This should guarantee that all relevant reviews are found. However, the cross-references in PubMed are not perfect. Therefore, one or more than one relevant review might have been missed. Moreover, the overall approach applied here has an inherent limitation with regard to the objective of providing an overview of all of the hitherto accrued empirical evidence. This approach depends on the reviews

provided so far. Consequently, original studies not included in any of these reviews will not have found their way into the review presented here.

4.1.2 Discussion of results

There are only a few cross-references between the reviews presented here (see Table 2). Some of these reviews refer to such differing issues that references between these reviews would not make much sense. On the other hand, sometimes there are no references between closely related reviews. For example, there is only one cross-reference among the five reviews addressing PA interventions for persons with T2D in general, and this reference is from Avery et al. (2015) to Avery et al. (2012), i.e. a self-reference. This scarcity of cross-references between the reviews can be taken as an indication of the difficulty involved in getting an overview of the relevant research. The review presented here might help authors of future reviews to find those reviews that are most relevant for their particular issue and/or to identify those issues for which a review is still missing.

There is no overlap between the trials included in the first review, i.e. Norris et al. (2001), and all other reviews (see Table 3). This can be explained by an extreme change in the development of interventions addressing persons with T2D. Prior to 2000, most of these interventions were primarily educational and targeted all aspects of diabetes self-care, with PA being only one of several targets. Accordingly, Norris et al. (2001) could only review interventions of this kind. After 2000, interventions were increasingly developed that intervened in a targeted manner in the participants' daily life and focused on PA. Hence, later reviews do refer to interventions of this kind. The trials included by Arambepola et al. and by Taylor et al. each overlap with the other trials only with regard to one trial. The explanation for this is that these reviews addressed very special kinds of intervention. A similar situation exists for the reviews of Ekong and Kavookjian and of Soderlund, which both addressed motivational interviewing. As a result, the trials included by these reviews overlap, but only one of these trials [33] is included by the other reviews. There is, however, a large overlap between the remaining reviews. This indicates that the findings produced by these reviews are not independent of each other. Some of these reviews can be understood as partial repetitions of preceding reviews; others to some extent as considerations of the same object from different perspectives.

The most prominent finding supported by all reviews is that PA interventions have either a positive or no effect. More specifically, the reviews give some evidence that getting participants to monitor their success might be a very effective intervention component. This is corroborated by three reviews focusing on interventions in which the participants obtained feedback via step-counter [9,14,19], one review focusing on interventions in which feedback was given via continuous glucose monitoring [22], and one review focusing on remote feedback [16]. One of the reviews concerned with step-counter use [19] additionally shows that giving feedback via step-counters is especially effective when this is combined with goal-setting. However, in two other reviews in which interventions with step-counter use and interventions without step-counter use were compared, interventions without step-counter

use had the better results [7,17]. Unfortunately, these reviews give no indication as to the reasons for this larger success.

The reviews concerning specific devices for delivering the intervention provide, with one exception, rather moderate results. Sometimes the intervention had a positive effect, sometimes no effect. The exception is the review of Connelly et al. [11], in which the intervention had a positive effect in 14 of the 15 included trials. An explanation for this result might be that eight of the included trials are also included in the review of Kongstad et al. [16] (see Table 3), i.e. the interventions investigated in these trials also encompassed giving feedback. An explanation for the mixed results in the other reviews might be that the device of delivery is not the programme component that makes the difference, but the manner in which this device is applied. The reviews concerning motivational interviewing provide only weak evidence for the use of this approach. More detailed information as to what makes PA interventions effective is provided by the review of Avery et al. (2015) [7]. According to this review, the most effective components are 'Prompt focus on past success', 'Barrier identification/problem-solving', 'Use of follow-up prompts', and 'Provide information on where and when to perform the behaviour', i.e. measures that help the participants to integrate PA into their daily life.

4.2 Conclusion

The reviews suggest two intervention components that seem especially effective for promoting PA in persons with T2D. One component is giving feedback to these persons. The other component is enabling them to integrate PA in their daily lives. However, apart from this, the reviews only give rough clues as to what might be effective. This is not surprising because nearly all interventions consist of several components that can be combined with each other very differently and because each combination of components might have a different effect. Hence, further development of interventions will require some ingenuity as to how to combine these components and as to what new components might be tried additionally. Previous empirical results can give hints as to what might work. Well-functioning theories might help to assess in advance the expected efficacy of new interventions. This recommendation of theory-based intervention development is completely in line with those reviews that also address the subject of theory use in intervention development [7,8,12,15,20].

4.3 Practice implications

1) Give feedback.
2) Help to integrate PA in daily life.
3) Base intervention development on well-functioning theories.

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Table 1: Quality assessment

First author	Protocol registered before start of the review	Comprehensive literature search strategy[a]	Satisfactory technique for assessing risk of bias (RoB)	Appropriate statistical methods in meta-analysis	Accounting for RoB when interpreting results of individual trials	Adequate investigation and discussion of publication bias
Alothman	No	Partial Yes	Yes	No meta-analysis	Yes	No
Arambepola	Yes	Yes	Yes	No meta-analysis for PA	Yes	Yes
Avery (2012)	Yes	Yes	Yes	Yes	Yes	Yes
Avery (2015)[b]	No	No	No	No	No	No
Baskerville	Yes	Yes	Yes	Yes	Yes	Yes
Cassimatis	No	Yes	Yes	No meta-analysis	Yes	No
Connelly	No	Partial Yes	Yes	No meta-analysis	Yes	No
Cotter	No	No	No	No meta-analysis	No	No
Ekong	No	Yes	Yes	No meta-analysis	No	No
Funk	No	Partial Yes	No	No meta-analysis	No	No
Howland	No	Yes	Yes	No meta-analysis	No	No
Kongstad	Yes	Yes	Yes	Yes	Yes	No[c]
Mosalman H.	No	Yes	No	Yes	No	No[d]
Norris	No	Yes	Yes	No meta-analysis	No	No
Qiu	Yes	Yes	Yes	Yes	Yes	Yes
Ramadas	No	Yes	Yes	No meta-analysis	Yes	No
Soderlund	No	Yes	No	No meta-analysis	No	No
Taylor	No	Yes	No	No meta-analysis	No	No

[a] In contrast to the recommendations for the AMSTAR 2 guidance instrument, search in trial registries and consultation with experts of the field were not applied as crucial criteria for judging the literature search because this was not deemed to be relevant in this research context.

[b] The quality assessment is only based on the information given in the article. However, according to a communication with the first author the review presented by Avery et al. 2015 seems to refer to the same original trials as Avery et al. 2012. In this case, the first four criteria would be fulfilled.

[c] In the methods part, the authors state that they use publication bias as a criterion of judging quality of evidence and, in their meta-analyses, they found an effect that suggests publication bias, i.e. there are larger effect sizes for smaller studies. However, the authors do not perform analyses aimed at detecting publication bias and they do not diagnose the result of their meta-analyses as an indication of publication bias.

[d] The authors announce an adequate procedure for investigating publication bias in their methods part, but they neither report the results, nor refer to the results in their discussion.

Table 2: Cross-references

Citing Review[a]			Cited reviews[b]															
	Pub.-date																	
First author	Year	Month	Nor.	Ram	Av12	Cas.	Funk	Con.	Cot.	Qiu	Av15	Eko.	Ara.	Alo.	Bas.	Sod.	Tay.	Mos.	Kon.
Ramadas	2011	6	-																
Avery (2012)	2012	12	-	-															
Cassimatis	2012	12	-	-	-														
Funk	2013	11	-	-	-	-													
Connelly	2013	12	-	X	-	-	-												
Cotter	2013	12	-	X	-	-	-	-											
Qiu	2014	2	-	-	-	-	-	-	-										
Avery (2015)	2015	4	-	-	X	-	-	-	-	-									
Ekong	2015	12	-	-	-	-	-	-	-	-	-								
Arambepola	2016	4	-	-	X	X	-	-	X	-	-	-							
Alothman	2017	2	-	-	-	X	-	-	X	-	-	-	-						
Baskerville	2017	3	-	-	X	-	X	-	-	X	-	-	-	-					
Soderlund	2017	5	-	-	-	-	-	-	-	-	-	-	-	-	-				
Taylor	2018	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Mosalman H.	2018	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Kongstad	2019	1	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	
Howland	2020	10	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	X

[a]Listed in chronological order according to the publication dates. When there was an e-publication ahead, the date of this publication was chosen.

[b]Same order as the citing reviews. 'Nor' stands for Norris; 'X' means that the respective review was cited by the review described in the first three cells of the row.

Table 3: Overlap of trials included in the reviews[a]

	Nor.	Ram.	Av12	Cas.	Funk	Con.	Cot.	Qiu	Eko.	Ara.	Alo.	Bas.	Sod.	Tay.	Mos.	Kon.	How.
Norris	9 100	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ramadas	---	4 100	1 25.0	---	1 25.0	4 100	4 100	---	---	---	---	---	---	---	---	2 50.0	1 25.0
Avery (2012)	---	1 5.9	17 100	---	3 17.6	1 5.9	1 5.9	5 29.4	---	---	6 35.3	2 11.8	---	---	9 52.9	4 23.5	---
Cassimatis	---	---	---	8 100	---	---	---	---	---	---	---	1 12.5	---	---	---	4 50.0	1 12.5
Funk	---	1 10.0	3 30.0	---	10 100	1 10.0	1 10.0	3 30.0	---	---	4 40.0	4 40.0	---	---	3 30.0	2 20.0	---
Connelly	---	4 26.7	1 6.7	---	1 6.7	15 100	6 40.0	---	---	---	---	---	---	---	---	8 53.3	4 26.7
Cotter	---	4 50.0	1 12.5	---	1 12.5	6 75.0	8 100	---	---	---	---	---	---	---	---	4 50.0	3 37.5
Qiu	---	---	5 71.4	---	3 42.9	---	---	7 100	---	---	6 85.7	4 57.1	---	---	5 71.4	3 42.9	---
Ekong	---	---	---	---	---	---	---	---	6 100	---	---	---	2 33.3	---	1 16.7	1 16.7	---
Arambepola	---	---	---	---	---	---	---	---	---	5 100	---	---	---	---	---	1 20.0	---
Alothman	---	---	6 50.0	---	4 33.3	---	---	6 50.0	---	---	12 100	3 25.0	---	1 8.3	7 58.3	4 33.3	---
Baskerville	---	---	2 20.0	1 10.0	4 40.0	---	---	4 40.0	---	---	3 30.0	10 100	---	---	4 40.0	3 30.0	---
Soderlund	---	---	---	---	---	---	---	---	2 22.2	---	---	---	9 100	---	1 11.1	1 11.1	---
Taylor	---	---	---	---	---	---	---	---	---	---	1 25.0	---	---	4 100	---	---	---

Mosalman H.	---	---	9 39.1	---	3 13.0	---	---	5 21.7	1 4.3	---	7 30.4	4 17.4	1 4.3	---	23 100	6 26.1	1 4.3
Kongstad	---	2 7.7	4 15.4	4 15.4	2 7.7	8 30.8	4 15.4	3 11.5	1 3.8	1 3.8	4 15.4	3 11.5	1 3.8	---	6 23.1	26 100	4 15.4
Howland	---	1 5.9	---	1 5.9	---	4 23.5	3 17.6	---	---	---	---	---	---	---	1 5.9	4 23.5	17 100

[a] Reviews are ordered chronologically as in Table 1. Avery et al. 2015 was omitted due to lacking references to the trials. The first number in each cell is the number of trials that the review heading the row and the review heading the column have in common. The second number in each cell is the percentage of trials included in the review heading the row that is also included in the review heading the column. No overlap at all is represented by '---'.

Supporting File 1

Orig_Stud	Alothman	Arambepo	Avery_201	Avery_2015	Baskerville	Cassimatis	Connelly_	Cotter_20	Ekong_20	Funk_201	Howland_	Kongstad_	Mosalmar	Norris_20	Qiu_2014	Ramadas_	Soderlund	Taylor_2018
Agurs-Collins et al. (1997)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Akinci et al. (2018)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Allen, Fain et al. (2008)	1	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Allen, Whittemore et al. (2011)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Anderson et al. (2010)	0	0	0	#NULL!	1	1	0	0	0	0	0	1	0	0	0	0	0	0
Andrews et al. (2011)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Araiza et al. (2006)	1	0	0	#NULL!	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Armstrong et al. (2013)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Arora et al. (2014); Burner et al. (2014)	0	1	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balducci et al. (2010) 'Anti-inflammatory...'	0	0	1	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balducci et al. (2010) 'Effect...'	0	0	1	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Björgaas et al. (2005)	1	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Björgaas et al. (2008)	0	0	0	#NULL!	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Calhoun et al. (2010)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Carter et al. (2011)	0	0	0	#NULL!	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cheung et al. (2009)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chang et al. (2018)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Chlewbowy et al. (2015)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Christian et al. (2008)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Church et al. (2010)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Cinar & Schou (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Clark et al. (2004)	0	0	0	#NULL!	0	0	0	0	1	0	0	1	1	0	0	0	1	0
Connelly et al. (2017)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Cox et al. (2016)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	1
De Greef, Deforche, Ruige, et al. (2011); van Dyck et al. (2011); van Dyc	1	0	1	#NULL!	1	0	0	0	0	1	0	1	1	0	1	0	0	0
De Greef, Deforche, Tudor-Locke et al. (2010)	1	0	1	#NULL!	0	0	0	0	0	0	0	0	1	0	1	0	0	0
De Greef, Deforche, Tudor-Locke et al. (2011)	1	0	1	#NULL!	0	0	0	0	0	1	0	1	0	0	1	0	0	0
de Weerdt et al. (1989)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0
di Loreto et al. (2003); di Loreto et al. (2005)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Diedrich et al. (2010)	0	0	0	#NULL!	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Dunston et al. (2002)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Dyson et al. (2010)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Eakin et al. (2013); Eakin et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Edelman et al. (2015)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Engel & Lindner (2006)	0	0	0	#NULL!	1	0	0	0	0	1	0	0	1	0	0	0	0	0
Estabrooks et al. (2005)	0	0	0	#NULL!	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Falkenberg et al. (1986)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Faridi et al. (2008)	0	0	0	#NULL!	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Frosch et al. (2011)	0	0	0	#NULL!	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Furber et al. (2008)	0	0	0	#NULL!	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Glasgow, Boles et al. (2003); Feil et al. (2000); McKay, Glasgow et al. (2	0	0	0	#NULL!	0	0	1	1	0	0	0	0	0	0	0	1	0	0
Glasgow et al. (2006)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Glasgow, Kurz et al. (2010, 2012); Glasgow, Strycker et al. (2010); Glasg	0	0	0	#NULL!	0	0	1	1	0	0	1	1	0	0	0	0	0	0
Glasgow, Toobert et al. (1992)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Goodarzi et al. (2015)	0	1	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gram et al. (2010)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hanefeld et al. (1991)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hansel et al. (2017)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Heinrich et al. (2010)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Holbrook et al. (2009)	0	0	0	#NULL!	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Holmen et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Jansink et al. (2013)	0	0	0	#NULL!	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Jennings et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Johnson et al. (2009)	0	0	0	#NULL!	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Keyserling et al. (2002)	1	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Khan et al. (2011)	0	0	0	#NULL!	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Kim CJ & Kang (2006)	0	0	1	#NULL!	0	0	1	1	0	0	0	1	0	0	0	1	0	0
Kim H & Oh (2003)	0	0	0	#NULL!	0	1	0	0	0	0	0	1	0	0	0	0	0	0
King et al. (2006)	0	0	0	#NULL!	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Kirk, Barnett er al. (2009)	1	0	1	#NULL!	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Kirk, Higgins et al. (2001)	1	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirk, Mutrie et al. (2003); Kirk, Mutrie et al. (2004)	1	0	1	#NULL!	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Kooiman et al. (2018)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Liebreich et al. (2009)	0	0	0	#NULL!	0	0	1	1	0	0	1	1	0	0	0	1	0	0		
Ligtenberg et al. (1997)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Look AHEAD research group (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Lorig et al. (2010)	0	0	0	#NULL!	0	0	1	1	0	0	1	1	0	0	0	0	0	0		
Lorig et al. (2016)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0		
Lynch et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0		
Mash et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
McIlhenny et al. (2012) (wrong citation)	0	0	0	#NULL!	0	0	0	1	0	0	0	0	0	0	0	0	0	0		
McKay, King et al. (2001)	0	0	0	#NULL!	0	0	1	0	0	0	0	1	0	0	0	0	0	0		
Moczulski & Kempny (2005)	0	0	0	#NULL!	1	0	0	0	0	0	0	0	0	0	0	#NULL!	0	0		
Muller et al. (2017)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0		
Nesari et al. (2010)	0	0	0	#NULL!	0	1	0	0	0	0	0	1	0	0	0	0	0	0		
Osborn et al. (2010)	0	0	0	#NULL!	0	0	0	0	1	0	0	0	0	0	0	0	0	0		
Paschali et al. (2005)	0	0	0	#NULL!	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
Piette et al (2011)	0	0	0	#NULL!	1	0	0	0	0	0	0	0	0	0	1	0	0	0		
Plotnikoff, Eves et al. (2010)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Plotnikoff, Karunamuni et al. (2013)	1	0	0	#NULL!	1	0	0	0	0	0	0	1	1	0	1	0	0	0		
Plotnikoff, Pickering et al. (2011)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Poppe et al. 2019	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0		
Quinn et al. (2008)	0	0	0	#NULL!	0	0	1	0	0	0	0	0	0	0	0	0	0	0		
Richardson, Buis et al. (2010)	0	0	0	#NULL!	0	0	1	0	0	0	1	0	0	0	0	0	0	0		
Richardson, Mehari et al. (2007)	0	0	0	#NULL!	0	0	1	1	0	1	0	0	0	0	0	1	0	0		
Rubak et al. (2011)	0	0	0	#NULL!	0	0	0	0	1	0	0	0	0	0	0	0	1	0		
Sacco et al. (2009)	0	0	0	#NULL!	0	1	0	0	0	0	0	1	0	0	0	0	0	0		
Samaras et al. (1997)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Sazlina et al. (2015)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0		
Shetty et al. (2011)	0	1	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Smith et al. (1997)	0	0	0	#NULL!	0	0	0	0	1	0	0	0	0	0	0	0	0	0		
Sung & Bae (2012)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Tamban et al. (2013)	0	1	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Toobert et al. (2007)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Trief et al. (2011)	0	0	0	#NULL!	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
Tudor-Locke, Bell et al. (2004)	1	0	1	#NULL!	1	0	0	0	0	1	0	0	1	0	1	0	0	0		
Uusitupa (1996)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0		
van der Wegen et al. (2015)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0		
Varney et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0		
Verwey et al. (2014)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0		
Vincent (2009)	0	0	0	#NULL!	0	0	0	0	0	1	0	0	0	0	0	0	0	0		
Waki et al. (2014)	0	1	0	#NULL!	0	0	0	0	0	0	0	1	0	0	0	0	0	0		
Walker et al. (2011)	0	0	0	#NULL!	0	1	0	0	0	0	0	0	0	0	0	0	0	0		
Wattanakorn et al. (2013)	0	0	0	#NULL!	0	0	0	0	1	0	0	0	0	0	0	0	0	0		
Whittemore et al. (2004)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
Wierenga (1994)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0		
Wing et al. (1984)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0		
Wisse et al. (2010)	0	0	1	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Wolever et al. (2010)	0	0	0	#NULL!	0	1	0	0	0	0	1	0	0	0	0	0	0	0		
Wood (1989)	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	1	0	0	0	0		
Yom-Tov et al. (2017)	0	0	0	#NULL!	0	0	0	0	0	0	1	0	0	0	0	0	0	0		
Yoo et al. 2008	0	0	0	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
Zolfaghari et al. (2009); originally Zolfaghari et al. (2012) RETRACTED	0	0	0	#NULL!	0	0	1	0	0	0	0	1	0	0	0	0	0	0		

Supporting File 2

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