Sports Medicine

Determinants of Change in Physical Activity in Children 0-6 years of age: A Systematic Review of Quantitative Literature

--Manuscript Draft--

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Abstract:	Background: Understanding the determinants of children's health behaviours is important to develop successful behaviour-change interventions. Objective: We aimed to synthesise the evidence around determinants ('preceding predictors') of change in physical activity (PA) in young children (0-6 years of age). Methods: As part of a suite of reviews, prospective quantitative studies investigating change in physical activity in children aged 0-6 years were identified from eight databases (to October 2015): MEDLINE; Embase; CINHAL; PsycINFO; Web of Knowledge; British Nursing Index; Applied Social Sciences Index and Abstracts; and Sociological Abstracts. Determinants and direction of association were extracted, described and synthesised according to the Socio-ecological model (individual; interpersonal; organisational; community; policy). Results: Forty-four determinants, predominantly in the interpersonal and organisational domains, were reported across 44 papers (6 prospective cohort, 38 intervention); 14 determinants were assessed in four or more papers. Parental monitoring showed a consistent positive association with change in PA; provider training was positively association with change in children's moderate-to-vigorous PA only. Five (sex; parental goal setting; social support; motor skill training; and increased time for PA) showed no clear association. A further seven (child knowledge; parental knowledge; parental motivation; parenting skills; parental self-efficacy; curriculum materials; portable equipment) were consistently not associated with change in children's PA. Maternal role-modelling was positively associated with change in PA in all 3 studies in which it was examined. Conclusions: A range of studied determinants of change in young children's PA were identified, but only parental monitoring was found to be consistently positively associated. More evidence in community and policy domains, from low/middle-income countries, and lesser-explored modifiable family- and childcare-related determinants is required.
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Author Comments:	MRC Epidemiology Unit and Centre for Diet and Activity Research, University of Cambridge, Cambridge, UK 29 September 2016 Dear Dr Olney, Thank you for providing us with the opportunity to revise our systematic review "Determinants of Change in Physical Activity in Children 0-6 years of age: A Systematic Review and Synthesis of Quantitative Literature", which we hereby re-submitted for publication in Sports Medicine. As noted by reviewers, using a rigorously-applied methodology, this is the first paper to systematically synthesise both prospective and intervention evidence regarding determinants of change in physical activity in children 0-6 years old. Conducted as part of a suite of reviews that aimed to explore the determinants of obesogenic behaviours in young children, it makes an important contribution to the current limited literature about (longitudinal) influences on physical activity in children during early life and the preschool period. We therefore believe it will be of interest to your Sports Medicine readership. We would like to thank you and the reviewers for the detailed reviews and helpful suggestions provided. In the text in the response to review document we have responded in detail to each of the specific points raised by the reviewers. We have also highlighted all changes made in the manuscript. We have also made all of the editorial changes requested (highlighted in the text where relevant); any relevant responses to those comments can be found below. The authors are responsible for the content presented in this manuscript and have approved it for submission to Sports Medicine. The authors have no conflict of interest and full access to all aspects of the research and writing processes will be at your disposal. I accept full and final responsibility for the paper and thank you for re-considering it. We hope you agree that enclosed revisions strengthen the paper, and we look forward to your final decision, Sincerely, Kathryn Hesketh, PhD Corresponding Author

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Editor's comments:

Thank you for providing these detailed amendments - we apologise for errors made in formatting the article for Sports Medicine. Although we have not responded to each of the comments in turn here (i.e. when simple amendments were required), we have made each of the changes as per your suggestion and we have highlighted all changes in the manuscript text as instructed.

4/8/16 (RO): Editorial notes to author:
1. Title - please add 'of Age' after '0-6 Years'.
2. Key Points - please provide 2 or 3 short, stand-alone sentences on separate lines summarizing the key findings/implications of the article. These should be provided before the abstract under the heading 'Key Points'.
These have now been included as follows:
*Forty-four determinants of change in young children's physical activity were assessed across 44 papers, predominately in the intrapersonal, interpersonal and organisational domain.
*Although 14 determinants were assessed in 4 or more studies, only parental monitoring was consistently positively associated with change in physical activity and provider training associated with change in moderate-to-vigorous physical activity.
*Evidence in community and policy domains, and from low/middle-income countries, is required.

3. Abstract: ALL AMENDMENTS MADE
* Background, final sentence - please add 'of age' after '0-6 years'.
* Objective - please insert an 'Objective' section after the 'Background' section which states the objective of your review.
* Methods - please change 'Medline' to 'MEDLINE', 'Cinhal' to 'CINAHL', and 'Socio-Ecological Model' to 'socio-ecological model'.
* Conclusion, final sentence - 'Evidence in the community and policy domains, from low/middle-income countries, and lesser-explored modifiable family- and childcare-related determinants necessitate future consideration.' I'm not sure I quite followed this sentence as written. Would the following rewording be acceptable: 'More evidence concerning determinants in community and policy domains, low/middle-income countries, and in relation to other lesser-explored modifiable family- and childcare factors is required.'

Apologies that this was not clear - we have now changed the sentence as per your suggestion.

4. Please delete the key words.
5. Methods, final sentence - I didn't understand what was meant by '…smaller teams led on the specific behaviours of interest.' Please clarify your meaning/reword.

We have now amended this section as follows:
One search (led by HM) was conducted to identify studies across all reviews; at the data extraction stage, smaller teams led each of the reviews focusing on specific behaviours of interest (i.e. physical activity (Review lead: KH), fruit and vegetable consumption (COM), sugar sweetened beverages (VP)). KH also conducted the search update specific to physical activity in October 2015.

ALL FOLLOWING CHANGES MADE
6. Section 2.1.1 - please change 'Medline' to 'MEDLINE', 'Cinhal' to 'CINAHL', 'Psychinfo' to 'PsycINFO', 'Ebsco' to 'EBSCO', and 'Proquest' to 'ProQuest'.
7. Section 2.1.1, sentence 1 - I wasn't sure what was meant by 'review leads'. Please clarify your meaning/reword.
8. Section 2.2.1, sentence 1 - please change 'randomized control trial' to 'randomized controlled trial'.
9. Section 2.2.2, sentence 1 - please change 'Supplementary material; S1' to 'Electronic Supplementary Material Table S1'.
10. Section 2.2.2, final sentence - please change 'High' to 'high', 'Medium' to

'medium', and 'Low' to 'low'.
11. Section 3, paragraph 2 - please change 'Range' to 'range' ((x2)).
12. Please define CLAN at first mention in the text.
13. Please delete the list of abbreviations.

THE FOLLOWING SECTIONS HAVE BEEN REFORMATTED AS REQUESTED
14. Acknowledgements and Compliance with Ethical Standards section - please move this to immediately before the References section and reformat/reword it under the heading and subheadings as set out below:
Compliance with Ethical Standards
Funding
This independent research was funded by the ((Author - please state the country here, presumably UK)) National Institute of Health Research, School for Public Health Research (NIHR SPHR). The views expressed are those of the author(s) and not necessarily those of the National Health Service, the NIHR or the Department of Health. The National Institute for Health Research's School for Public Health Research is a partnership between the Universities of Sheffield, Bristol, Cambridge, UCL; The London School for Hygiene and Tropical Medicine; The Peninsula College of Medicine and Dentistry; the LiLaC collaboration between the Universities of Liverpool and Lancaster and Fuse; and The Centre for Translational Research in Public Health (a collaboration between Newcastle, Durham, Northumbria, Sunderland and Teesside Universities).
This work was also supported by the Medical Research Council [Unit Programme numbers MC_UU_12015/7, MC_UU_12015/2 and MC_UU_12015/4], and undertaken under the auspices of the Centre for Diet and Activity Research, a United Kingdom Clinical Research Collaboration (UKCRC) Public Health Research Centre of Excellence, which is funded by the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, the National Institute for Health Research, and the Wellcome Trust (RES-590-28-0002). Kathryn Hesketh is a Sir Henry Wellcome Fellow (Wellcome Trust Grant 107337/Z/15/Z).
Conflicts of Interest
Kathryn Hesketh, Claire O'Malley, Veena Mazarello Paes, Helen Moore, Carolyn Summerbell, Ken Ong, Rajalakshmi Lakshman and Esther van Sluijs declare that they have no conflicts of interest relevant to the content of this review.

REFERENCES NOW FORMATTED AS INSTRUCTED
15. References:
* With respect to author names, if there is one author, please state Smith AB. If there are two authors, please state Smith AB, Brown CD. If there are three authors, please state Smith AB, Brown CD, Jones EF. If there are more than three authors, please state Smith AB, Brown CD, Jones EF, et al.
All references have now been amended as per suggestions above and below, thank you.
* Reference 2 - please change the journal name to 'JAMA.'
* Please delete all full stops within journal name abbreviations (but retain the full stop at the end), e.g. change 'Int. J. Pediatr. Obes.' to 'Int J Pediatr Obes.' etc.
* Please change all unnecessarily upper case letters in journal article titles to lower case letters. For example, please change the article title in reference 3 to: 'Childhood obesity.' Please make the same changes to references 8, 22, 25, 43, 49, 50, 52, 66, 67, 74, 77, 82, 83, 88 and 89.
* References 41, 47 and 68 - please delete 'Journal of Behavioral Nutrition and Physical Activity' (only the abbreviated version is needed).
* References 53 and 85 - please check the third author's initials.
* References 57, 58, 88 and 93 - please change 'Heal.' to 'Health.'
* Reference 64 - please delete 'Society for Nutrition Education and Behavior'.
* Reference 76 - please only use upper-case letters for the first letter of each name and the initials.
* Reference 77 - please check the second author's initials.
* Reference 90 - please delete the space between 'parents' and the subsequent apostrophe.

WE HAVE NOW CHANGE THE TABLES AS PER YOUR COMMENTS BELOW. IN ADDITION, DUE TO THE TWO DIFFERENT WAYS WEEKS WERE REPRESENTED (wk and w) WE HAVE TAKE THE 'w' ABBREVIATION THROUGHOUT.

16. Table 1:
* Please unbold all bold text.
* Please change the superscript '1' after the heading to a superscript 'a'.
* Please change 'Sample Characteristic' to 'Sample characteristic', 'Total Sample Size' to 'Total sample size', and 'High Quality' to 'High quality'.
* Column 2 heading - please change 'Paper ID' to 'Reference'.
* Column 1 - please write out PA in full.
* Column 1 - please change 'Country' to 'Region' or 'Continent' or something similar.
* Column 1 - please change the asterisk to a superscript 'b'.
* Please change the footnotes denoted by '1' and '*' beneath the table to superscript 'a' and 'b', respectively.

17. Table 2:
* Please unbold all bold text.
* Please combine columns 1 and 2 into a single column entitled 'Reference'. The first entry in this column should then be formatted as 'Alhassan et al. (2007) [37], USA', and so on. Please note that all studies should be listed as the name of the author if there is only one author (e.g. Smith (2000) [1]), both names if there are two authors (e.g. Smith and Jones (2001) [2]), and the first name then 'et al.' if there are three or more authors (e.g. Smith et al. (2003) [3]).
* Column 5 heading - please change to 'Age at start (mean ± SD, and/or range)'.
* Column 9 heading - please change to 'Intervention duration (or follow-up)'.
* Column 13 heading - please change the asterisk to a superscript, lower-case 'a'.
* Please change 'Male' to 'M' throughout the table.
* Please change 'Hispanic' to 'H' throughout the table (or use 'Hispanic' throughout the table).
* Please change 'other' to 'O' throughout the table (or use 'other' throughout the table).
* Please change 'incl.' to 'including' throughout the table.
* Please change 'freq.' to 'frequency' throughout the table.
* Please give only the first word in each cell an upper-case initial letter (except where proper nouns, the names of exercise programs etc that require upper-case initial letters are used, of course). Examples where upper-case initial letters do not need to be used include 'Cohort' in column 2, 'Low', 'Classrooms', 'Stratified', 'Childcare', 'Migrant', 'Higher' in column 3, and so on (all columns). Please give all of these words (and all other instances were upper-case initial letters are used unnecessarily) an initial lower-case letter.
* Please change 'nb' to just 'n' throughout the table (readers will take this number to be a baseline population without having to explain this). Where numbers for both baseline and follow-up are provided for a study these can be labeled accordingly (see below).
* Alhassan [50] row, column 4 - please change to '2 preschools; n (baseline) = 75; n (follow-up) 67 (57% M)'. Presumably, '57% M' applies to the follow-up population; if not, please move these data to immediately after '75'.
* Cottrell [39] row, column 4 - please change to '29 preschools; n (baseline) = 203 (49% M; 93% W); n (follow-up) = 50.'
* Davison [70] row, column 4 - please change to '5 Headstart centres; n (baseline) = 117 (45% M; 68% W, 22% AA, 6% non-H, 4% O); n (follow-up) = 57'.
* De Bock [46] row, column 4 - please change to '37 preschools; n (baseline) = 809 (52% M; low income25%, middle income 55%); n (follow-up) = 467'.
* De Coen [71] row, column 4 - please change to '31 schools across high, medium and low SES; n (baseline) = 1589 (I: 1032; C:557); n (2-year follow-up) 694 (I: 396; C: 298)'.
* Fitzgibbon [52] row, column 4 - should 'C:' precede '6.5% AA, 89.4% H, 4.0% O'?
* Fitzgibbon [53] row, column 4 - please change to '18 Headstart centres; n (baseline) = 223 (44% M; I: 97% AA, 1% H, 2% O; C: 91% AA, 5% H, 4% O); n (baseline) = 190'.
* Fitzgibbon [67] row, column 4 - please change to '4 centres; n (baseline) = 146 (50% M; 94% H, 2% AA, 4% O); n (follow-up) = 190'. ((Author - please check - the follow-up number is greater than the baseline number?))
* Jones [76] row, column 4 - please change to 'Overweight preschool children and parents; n (baseline) = 46 (~80% parents had degree/ technical trade certificate); n (follow-up) = 40'.

* Taylor [61] row, column 4 - please change '11% M' to '11% Maori'.
* Whaley [54] row, column 4 - please change to 'Low-income mothers; n (baseline) = 821; n (follow-up) = 589 (94% H; 50% mothers of boys)'. Presumably, '(94% H; 50% mothers of boys)' applies to the follow-up population; if not, please move these data to immediately after '821'.
* Column 5 - please change 'yrs' to 'y' throughout the column and ensure that all entries in this column state whether the data are 'y' or 'mo'.
* Annesi [55] and [43] rows, column 5 - what do the data in brackets signify?
* De Craemer [68] row, column 7 - please change 'ws' to 'wks'.
* Eliakim [65] row, column 7 - please change 'spilt' to 'split'.
* O'Dwyer [42] row, column 7 - what does '6and' mean?
* Trost [35] row, column 7 - please change 'move and learn' to 'Move and Learn'.
* Column 9 - please use the abbreviations 'd', 'w', 'mo' and 'y' throughout this column.
* Klohe-Lehman [55] row, column 10 - please close the bracket.
* Please change 'Randomised control trial' to 'Randomised controlled trial' beneath the table.
* Please define (where these are acronyms or abbreviations) cRCT, M (as male), KAN-DO, SPARK, SPARKLE, LAUNCH, FLAME, IA, ICSEA, PRECEDE-PROCEED, OSRAP, OSRAC-P, MI, w/e, w/d, LMVPA, TEE and the symbol '–' (see Saakslahti row, column 12) beneath the table.
* Please delete the definitions of nb, nfu, M (as Maori) and GMS beneath the table.
* Please change the footnote denoted by '*' beneath the table to superscript 'a'.

THESE HAVE BEEN FORMATTED AS BELOW; AS PER OUR PREVIOUS CORRESPONDENCE, THE INTERVENTION AND PROSPECTIVE STUDIES HAVE BEEN DIFFERENTIATED USING ITALIC FORMATTING IN THE TABLE.

18. Table 3:
* Please unbold all bold text.
* Column 5 heading - please clarify in the heading what the numbers in this column mean, e.g. 'Studies showing positive association'.
* Column 1 - please change all asterisks to a superscript 'a'.
* Please de-italicize all italicized headings and remove the underlining.
* Column 1 - only the first word in each cell requires an upper-case initial letter please.
* When listing reference numbers, please 'collapse' sequences of numbers wherever possible and insert commas at the bottom of the square bracket rather than half-way up the bracket. Please also remove the colour from the text (this is not journal style for tables) - subheadings within cells can be used to categorize references. Thus, for example, please change to:

0	+
Motor/skills Total activity/cpe: [47,48,63]	
MVPA: [49]	MVPA: [43,44,51]
Steps/pedometer: [64]	Steps/pedometer: [65,66]
Knowledge Total activity/cpe: [47,53,63,67]	
MVPA: [68-70]	
Questionnaire: [11,52,71]	
Steps/pedometer: [39]	

etc.
* Please define cpe, SES, PA and MVPA beneath the table.
* Please change the footnote denoted by '*' beneath the table to superscript 'a'.
19. Figure 1:
* Please unbold all bold text.
* Please change 'Medline' to 'MEDLINE' ((x2)), 'Cinahl' to 'CINAHL' ((x2)), and 'Psychinfo' to 'PsycINFO' ((x2)).
* Please be consistent with use of commas in numbers with 4 or more digits (whichever convention you prefer is fine but currently some figures have commas and some don't).
* Please be consistent with formatting of 'n = x' data, i.e. please insert a letter space before and after the equals symbol on all occasions.
* Top left-hand box - the total number of records listed for the individual databases should equal the number at the top of the box (i.e. 37, 686) but doesn't. Perhaps it is because the numbers for each database are pre de-duplication. In any case, can you

	please rectify this. * Top right-hand box - I think it would be helpful if you could make it a little clearer what this search was for, i.e. 'Additional PA records...' does not seem to provide a very complete description of what you were looking for in this search. (Journal figures should stand alone in terms of their meaning as much as possible.) * Top right-hand box - as with the top left-hand box, the total number of records listed for the individual databases should equal 3,652 but doesn't. Again, can you please rectify this. * Please change 'Title and Abstract screened' to 'Title and abstract screened' ((x2)). * The figure doesn't make arithmetic sense after the 'Full texts retrieved and read in full n = 164' box, i.e. 164 - 123 + 1 = 42 (not 43). Furthermore, the numbers of articles that were excluded based on full text on this side of the figure total 124 (not 123) if one adds up the n values for the different reasons for exclusion. Please check and revise as appropriate. * Final box - 6 + 38 = 44 (not 43). Can you please reconcile this difference. * Final box - I don't understand what the bottom line means (or why it is necessary - can it be deleted?). If not, please de-italicize the italicized text and change 'Refereences' to 'references'. * Legend - please define ASSIA, PA and BMI at the end of the figure legend. CHANGES MADE AS REQUESTED 20. Electronic Supplementary Material: * Please change the heading for the first table to 'Electronic Supplementary Material Table S1. Quality assessment criteria by study design'. * Please change the heading for the second table to 'Electronic Supplementary Material Table S2. Search strategy for full review and physical activity-specific update[a]'. * Please provide a cross-reference to 'Electronic Supplementary Material Table S2' at an appropriate point in the text.
Response to Reviewers:	Please see uploaded document for Response to Reviewers.
Suggested Reviewers:	Russell Jago russ.ago@bristol.ac.uk Professor working in the field of children's physical activity
	Rebecca Stanley rstanley@uow.edu.au Focus on physical activity in young children
	Ellen De Decker ellen.dedecker@ugent.be Researcher working in field of physical activity epidemiology (in young children)
	Ian Janssen ian.janssen@queensus.ca Researcher familiar with systematic reviews and a physical activity focus

Dear Dr Olney,

We would like to thank you and the reviewers for the reviews and helpful suggestions provided. In the text below we have responded in detail to the specific points raised by each of the reviewers. We have also highlighted all changes made in the manuscript. We hope you agree that these revisions strengthen the paper, and we look forward to your decision.

Yours,

Kathryn Hesketh, PhD
Corresponding Author

Reviewer #2:
Thank you for the opportunity to review this systematic review of physical activity change in very young children. I commend the authors on an extremely well-written paper, with a very clear and rigorously-applied methodology. While I do not see any major issues with the execution of the study nor the reporting of the findings, I do have one larger concern, and several other points that I believe the authors can address to improve the readability of the manuscript. I would outline these below.

We thank the reviewer for their kind comments – we are glad that they feel the paper is well written, and that our methods were appropriately rigorous. We have responded to the specific points raised below.

It may be important to rationalize and to provide explicit comments comparing findings from the prospective studies to the intervention studies. While intervention studies are likely intended to increase PA levels among the young children, this isn't necessarily the case for prospective studies - and understanding the relationship between correlates and PA over time seems to me slightly different. Determinants of activity should not be discounted only for the fact that PA did not change over time; is it not possible that a determinant is highly predictive of stable PA patterns? Perhaps separating the results by design may be of value, and could potentially yield more positive results.
We explored whether splitting out the Tables by study type was informative (please see at split tables at the end of this document) but felt that this did not add anything over and above the text outlined above. This is partly due to the limited number of prospective studies included, and furthermore due to the lack of overlap between the factors extracted from the prospective and intervention studies. We have therefore chosen to retain one combined table, but have more clearly indicated in Table 3 which of the study results are from prospective vs. intervention studies.

We agree with the reviewer that it is equally of interest whether a factor predicts stable PA patterns. We stress that we are not studying whether a factor predicts increases in PA over time, but whether different level of a factor predicts differences in change in PA over time. As an example, for sex, this could mean that boys' PA increases over time whereas girls' activity stays stable, or that boys' PA remains stable whereas girls' activity decreases. The data available to us do not allow us to explore the actual direction of change, so we are unable to comment on this. We have however included this as a consideration for future research in the Discussion.

We also highlight more clearly in the text how the findings from the prospective and intervention studies differ, and we have now included the following in the Results (Pg 10):

1.1 Overview of prospective and intervention studies

A total of 44 potential determinants of change were reported (Table 3) across papers. The same cohort study (Children Living in Active Neighborhoods (CLAN) [59]) was described in three[60–62] of the six prospective papers. One paper describing this study contributed all 16 determinants identified across prospective studies in

intrapersonal, interpersonal and temporal domains. This paper predominantly reported on determinants relating to parental influence on change in physical activity.

The 38 intervention studies targeted 28 potential (modifiable) determinants at intrapersonal (n=6), interpersonal (n=10), organisational (n=10) and community levels (n=1). No determinants at the policy level were identified across included studies. Of the 38 intervention studies, 27 (68%) were classified as multi-level;[11,42,44,47,48,50–52,55,56,58,63–77] these most commonly targeted individual/ interpersonal (i.e. children, parents, teachers) and organisational (i.e. preschool/ home environment) factors. Of these, 11 multi-level interventions (42%) effected a positive change in children's physical activity,[42,44,47,48,56,58,63–67] though no clear effective combinations of components emerged. Across all prospective studies, positive effect sizes were generally small, with increases of less than 10% in total activity or MVPA from relatively low baseline levels.

1.2 Determinants identified in four or more studies

Fourteen determinants were assessed in four or more studies. One, sex, was reported in five prospective papers [60,61,78–80] (from 4 study samples: the association between sex and two different outcome measures were assessed within the same CLAN study sample). The remaining 13 determinants, reported four or more times, were all intervention components, including at the intrapersonal level: motor/skills training[46,47,50–52,54,66,67,76,81] and child knowledge[11,42,50,55,56,65,72,74,76,77,82], and at the interpersonal level: parental monitoring[42,44,67,70,71,73]; parental motivation [49,57,73,83]; goal setting[70,73,77,84]; parental knowledge [11,42,44,48–50,55,56,58,65,67,70–74,76,77,81–84]; general parental skills[49,51,77,82–85]; parent self-efficacy[57,67,71,83]; parental social support[70,73,76,84,85]; and provider training[38,44–47,49–54,65,67,73,76,81]. Those determinants at the organisational level included: more physical activity opportunities[11,38,40,45,53,55,56,66,67,74,76]; use of portable equipment [37,41,48,50,76]; and supplying curriculum materials[11,49,50,53,55,56,65,72,74,76,81].

And Discussion (Pg 17)

Finally, determinants may be time or situation specific. Very few prospective observational studies have assessed determinants of physical activity change in young children. Including both prospective and intervention studies (and treating intervention components as determinants in the latter) allowed us to identify a wider range of factors that have been posited to effect change in physical activity. This review also indicates that determinants may differ within the same cohort depending on measurement method and follow-up period (i.e. in the CLAN study, there was no association between sex and counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]). Prospective studies allow assessment of change in behaviour over relatively long periods of time; interventions, with generally much shorter follow-up periods than prospective studies, may be able to capture more short-term fluctuations in behaviour. Both types of study also tend to assess differing types of determinants. Prospective studies have focused on child's sex, parental psychosocial and temporal factors, whereas intervention studies target child skill and knowledge, parental knowledge and behaviour, and elements in the preschool environment including care-provider training and provision of curriculum materials. Both types of study are therefore beneficial to establish whether a determinant is associated with behaviour change, and whether

change is sustained over time. In combination, a more comprehensive picture of the determinants landscape in children 0-6 years of age can emerge; this will ensure future research focuses on where gaps in the current evidence exist, whilst focusing work on areas where potential positive gains in changing young childrens' physcial activity are most likely to be made.

- *Page 10, 2nd paragraph: From this paragraph forward, it was somewhat difficult to follow the findings at times. I would suggest that the authors break the results into subheadings based on the SEM as way to improve the organization of the findings being presented.*

We are sorry that elements of the results were difficult to follow, and agree that restructuring the results would aid clarification of our findings. In response to your comments, we have now included a number of subheadings to structure the findings reported in the results section and have clearly highlighted the domains that each of the determinants come from (Pg 10 onwards):

1.3 Determinants identified in four or more studies

Fourteen determinants were assessed in four or more studies. One, sex, was reported in five prospective papers [60,61,78–80] (from 4 study samples: the association between sex and two different outcome measures were assessed within the same CLAN study sample). The remaining 13 determinants, reported four or more times, were all intervention components, including at the intrapersonal level: motor/skills training[46,47,50–52,54,66,67,76,81] and child knowledge[11,42,50,55,56,65,72,74,76,77,82], and at the interpersonal level: parental monitoring[42,44,67,70,71,73]; parental motivation [49,57,73,83]; goal setting[70,73,77,84]; parental knowledge [11,42,44,48–50,55,56,58,65,67,70–74,76,77,81–84]; general parental skills[49,51,77,82–85]; parent self-efficacy[57,67,71,83]; parental social support[70,73,76,84,85]; and provider training[38,44–47,49–54,65,67,73,76,81]. Those determinants at the organisational level included: more physical activity opportunities[11,38,40,45,53,55,56,66,67,74,76]; use of portable equipment [37,41,48,50,76]; and supplying curriculum materials[11,49,50,53,55,56,65,72,74,76,81].

Of these 14 more frequently studied determinants, parental monitoring was consistently shown to be positively associated with change in young children's physical activity across intensities, with four of six study samples reporting a positive association. Provider training was also positively associated with change in children's MVPA in six of nine studies[38,44,46,47,53,54] but showed no clear association with physical activity overall (positive association in 8/16 studies), suggesting that determinants may be intensity specific.

Five determinants, across the intra- and interpersonal domains, namely sex (positive association in 2/5 studies); motor skill training (5/10); parental goal setting (2/4); parental social support (2/5); and increased time for physical activity (usually within the care setting; 4/11) showed no consistent association with change in physical activity. In the case of sex, evidence from the CLAN study served to highlight how determinants may differ within the same sample depending on the outcome used and time of follow up (i.e. no association with counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]). For motor skills training[46,47,54,66,67] and increased time for physical activity [38,53,66,67] the majority of intervention studies that found a positive association with change in physical activity used objective measures.

The remaining seven determinants assessed in four or more studies, i.e. child knowledge (positive association in 2/12 studies); parental knowledge (7/22); parenting skills (2/7); parental motivation (1/4); parental self-efficacy (1/4); curriculum materials (2/11); and portable equipment (1/5), consistently showed no association with change in young children's physical activity (i.e. >67% of studies reported no association).

1.4 Determinants identified in fewer than four studies

Determinants assessed in three study samples in the intra/interpersonal domains included child monitoring,[42,71,83] parental role-modelling [71,77,83] and maternal role modelling,[44,58,61], with only the latter shown to be positively associated with change in physical activity in all three studies (one using proxy-reported physical activity[58]). In the organisational domain, increasing the number of care providers within the childcare setting was found to be positively associated with change in two (out of three) intervention studies.[49,66] Community awareness showed no association with change in children's physical activity.[72,73,82] Positive associations with change in physical activity were also found for providing additional opportunities for play within the home (two studies)[44,58] and sibling co-participation (one study)[61], and with structured physical activity[53] and lowering playground density[43] in one study each within the organisational domain.

- *Discussion 1st paragraph: While the authors do a good job of summarizing the quantitative findings, I'm left with the question of what it means - specifically with the lack of consistency.*

We now include a short overview of what we believe the review's overall messages are, including that a lack of consistency appears to be an important finding in and of itself:

This review is the first to synthesise evidence from longitudinal studies relating to the determinants of change in physical activity in preschool-aged children. Forty-four determinants were identified; determinants at the interpersonal and organisational levels were most commonly evaluated. Fourteen determinants were identified in four or more quantitative studies: parental monitoring showed a consistent positive association with change in physical activity. Provider training was positively associated with change in MVPA, but showed no clear association with physical activity overall. Of the remaining 12 determinants, a further five showed no clear association, and seven were consistently not associated with change in children's physical activity. Moreover, maternal role modelling was positively associated with physical activity in three studies.[44,58,61] A range of modifiable family- and childcare-related elements also showed positive associations with change in young children's activity in fewer studies. Where positive effects on change in physical activity were seen, they were often small in magnitude, particularly in studies reporting accelerometer-measured outcomes. Despite identifying a range of determinants that have been assessed, there appears to be little evidence of what results in positive change in preschoolers' physical activity. Where determinants have shown no positive effect (e.g. child/ parental knowledge) researchers should divert emphasis instead to other potentially influential determinants. Both parental monitoring and maternal role modelling may provide feasible and effective determinants of change; given the lack of longitudinal evidence from the community and policy domains, and with no evidence to date from developing countries, further exploration of possible determinants of change in these areas is also required.

- *Given the saliency of maternal and familial influences, I believe that the authors should be providing more details in terms of the studies related to this (what did the interventions study do, what did the prospective studies measure).*

We agree with the reviewer that this is important, and have now included the following in the Discussion to highlight specific maternal/ familial influences on children's physical activity (Pg 14):

Determinants in the interpersonal domain were most frequently assessed. Only one determinant, parental monitoring, was consistently positively associated with change in physical activity in both prospective and intervention studies this age group. This was operationalized in a range of ways by increasing parental awareness of the child's physical activity,[67,70] including using log books[44] and pedometers.[42] Although evidence of parental monitoring effecting a positive change in physical activity prospectively in older children is sparse,[86,87] cross-sectional evidence from a small sample of US children (n=99) suggests that where parenting is permissive, parental monitoring may lead to increases in MVPA in children.[88] Evidence tends to suggest that parents tend to over-estimate their children's physical activity in general.[89] Yet conscious parental monitoring of the target behaviour may increase its salience, resulting in a greater number of prompts to be active and therefore higher subsequent physical activity.

Three further studies reported a positive effect of maternal role modelling on children's activity;[7,15,3] this ranged from assessing mothers' own physical activity[3] to increasing maternal awareness and encouraging increased physical activity within families, with or without her child so as to model activity behaviour.[7,15] These findings are supported by qualitative literature, with parents consistently suggesting that active parents and parents as role models were important facilitators of children's activity.[54–59] Positive associations between parents' and children's activity have also been reported previously in cross-sectional studies.[60–62] Intervention studies targeting other interpersonal factors such as increasing parental knowledge[5–7,9,38,10,13–15,18,20,23–27,29,30,36,37,40,41] or social support,[23,26,29,41,42] and improving parenting skills[38,11,30,37] showed indeterminate associations; both high and lower quality studies reported both positive[6,7,38,15,20,23,41] and no associations[5,9–11,13,14,18,24–27,29,30,36,37,40,42] for these intervention components. It may therefore be that it is parental awareness and their own activity behaviours that are important for their child's activity. Further research is needed to explore how objectively measured physical activity in preschool-aged children and their parents are associated longitudinally.

- *Similarly, in the multi-faceted interventions studies, I question whether or not there were certain characteristics or similarities in the studies that found positive effects to those that did not see any change in physical activities (ie, similar determinants being focused, similar sample compositions or study designs?)*

We agree that it would be of interest to consider similarities and differences between the intervention studies in the review. Though we believe that full explanation of these differences would be more appropriate in a review focussed on intervention effectiveness and therefore beyond the scope of the review, where possible, we have included a consideration regarding the importance of sample and context for the associations observed (please see the revised Discussion text in the response to the following comment).

- *Page 13: The authors should comment on the how studies have differed in terms of studies exclusively looking at care providers and those looking at the care environment. This is particularly relevant for the intervention studies and understanding the implications of studies that did not find changing PA levels targeting both care providers and the environment, and what it means in the context of understanding individual determinants.*

The distinction between studies focusing on care providers and those looking at the care environment is an important one. Although there have been a number of reviews explicitly exploring how interventions conducted in the childcare environment influence children's physical activity (e.g. Finch et al 2016; Ward et al 2009), and we aimed to identify determinants of change in physical activity, we have integrated the following into the Discussion (pg 15):

Several reviews conducted previously suggest that elements in the preschool environment may be positively associated with children's activity.[27,99] Many intervention studies here specifically targeted the childcare environment, providing curriculum materials or modified elements within childcare settings, but no clear determinants were identified. [11,37,39,41,43,48–50,53,55,56,65,72,74,76,81] Four of the intervention studies used

variations of the same 'Hip-Hop-to-Health' intervention,[11,55,56,74] targeting a range of elements in the childcare setting: only one[56] showed a positive sustained effect on accelerometer-measured activity in a predominantly African American population. This highlights that even with a consistent core intervention, factors including cultural variability, differing reported outcomes and intervention fidelity likely influence intervention success.

Yet although environmental childcare determinants showed inconclusive results, of 16 intervention studies incorporating provider training, eight noted positive increases in children's activity[38,44,46,47,49,53,54,67], and MVPA in particular. Interestingly, those interventions showing positive effects often incorporated few additional environmental elements, including providing additional curriculum materials;[49,53] they did however tend to include motor skill training, [46,47,54,67] parental elements[44,67] and/or allocate additional time for physical activity.[38,53,67] Introducing additional providers also led to increased physical activity in two out of three high quality intervention studies, where external gym trainers[49] and professional coaches[66] led physical activity sessions.

Given the increasing amount of time children now spend in childcare, care providers feasibly to play an important role in shaping children's health behaviours. It is not possible here to disentangle which elements of training resulted in positive physical activity change, but encouraging care providers to build on their skill-base and/or confidence in multi-component interventions may be important. Moreover, qualitative literature suggests that care providers perceive themselves to be both a positive[100–102] and negative[100,103,104] influence on children's physical activity, yet no quantitative studies to date have specifically focused on care-providers own behaviour as a potential determinant. Doing so may be timely given providers believe they can influence children's activity and that young children should be active, but many are not aware of how much physical activity young children require.[105]

References:

Ward DS, Vaughn A, McWilliams C, Hales D. Physical activity at child care settings: Review and research recommendations. Am. J. Lifestyle Med. 2009;3:474.

Finch M, Jones J, Yoong S, Wiggers J, Wolfenden L. Effectiveness of centre-based childcare interventions in increasing child physical activity: A systematic review and meta-analysis for policymakers and practitioners. Obes. Rev. 2016;17:412–28.

Very minor details:

- *I would consider changing the title to "very young children" and not specify from 0-6 years - particularly given that there were very few studies focused on children under 2 or 3?*

As this was performed as part of a suite of reviews, we have chosen to keep our nomenclature consistent across all reviews and have retained our original title, adding in '0-6 years of age' as per the suggestion of the editor.

- *Page 4, line 52 - could add in the 60 minutes of activity at a moderate to vigorous intensity*
- *Page 4, line 53 - remove hyphen from psycho-social (to be consistent above)*

Amended, thank you.

- *Page 9 Australia was mis-spelled*

We have included 'Australasia' as the region encompassing Australia, New Zealand, the island of New Guinea, and neighbouring islands in the Pacific Ocean.

Reviewer #3: Thank you for the opportunity to review the manuscript entitled "Determinants of change in physical activity in children 0-6 years: A systematic review of quantitative literature". This manuscript is interesting, well-written and carefully prepared. The authors should be commended on the high quality research conducted. Nonetheless, I do have a few comments and questions that I think the authors should address prior to publication.

We thank the reviewer for their commendation and encouraging comments; we have addressed their comments below.

General comment:

Can the authors please comment on their decision to include both observational (longitudinal) and intervention studies in the review? In longitudinal studies the 'determinant' would be directly assessed at one time point and compared to physical activity at a later time point. However, for intervention work, the 'determinants' identified were those factors in the intervention that authors tried to target (e.g., parent/childcare provider skills, knowledge), though this association between the 'determinant' and physical activity wouldn't necessarily have been statistically tested. If this is the case, I'm not sure combining these two study designs in one review is appropriate. In one instance (longitudinal) the relationship is directly assessed, in the other (intervention) an assumption is being made that the 'determinant' is related to the outcome (change in PA).

Thank you for raising this issue. As this review highlights, there are very few prospective studies that assess determinants of change in PA in young children. Including both prospective and intervention studies (and treating the latter intervention components as determinants) allowed us to identify a range of factors, which may result in behaviour change. As the reviewer points out, the association between the specific determinant and physical activity wouldn't necessarily have been statistically tested in interventions. Indeed, the study of mediation is uncommon in youth physical activity promotion in general, and in young children specifically. However, as also highlighted in this reviewer's later comments, including information about the types of factors that have been assessed to date to affect change in children's physical activity is likely to be very informative for those developing prospective /intervention studies. Indeed, as we hope is now clear from the revised Table 3, there is relatively little overlap between the types of determinants assessed in prospective studies and those targeted in intervention studies. In addition, whilst prospective studies provide long-term information about determinants of behaviour change, interventions, with their much shorter follow-up periods, likely capture more short-term fluctuations in activity behaviour. By including both study types, we are better able to highlight these elements of the evidence base, which we believe to be both relevant and important for people working in young children's physical activity promotion, providing a holistic view of the current determinants landscape. We have discussed this, along with why we have included both types of study, in the Discussion as you suggest (please also see below):

Finally, determinants may be time or situation specific. Very few prospective observational studies have assessed determinants of physical activity change in young children. Including both prospective and intervention studies (and treating intervention components as determinants in the latter) allowed us to identify a wider range of factors that have been posited to effect change in physical activity. This review also indicates that determinants may differ within the same cohort depending on measurement method and follow-up period (i.e. in the CLAN study, there was no association between sex and counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]). Prospective studies allow assessment of change in behaviour over relatively long periods of time; interventions, with generally much shorter follow-up periods than prospective studies, may be able to capture more short-term fluctuations in behaviour. Both types of study also tend to assess differing types of determinants. Prospective studies have focused on child's sex, parental psychosocial and temporal factors, whereas intervention studies target child skill and knowledge, parental knowledge and behaviour, and elements in the preschool environment including care-provider training and provision of curriculum materials. Both types of study are therefore beneficial to establish whether a determinant is associated with behaviour change, and whether change is sustained over time. In combination, a more comprehensive picture of the determinants landscape in children 0-6 years of age can emerge; this will ensure future research focuses on where gaps in the current evidence exist, whilst focusing work on areas where potential positive gains in changing young childrens' physcial activity are most likely to be made.

Introduction:

I understand that this review is part of a suite of reviews focused on obesity prevention, however I found that there was a strong emphasis on the relationship between physical activity and obesity in the introduction, but then the discussion was focused only on physical activity (not linked back to obesity prevention). I would recommend that the authors either: a) expand the introduction to focus on the other benefits of PA in addition to obesity, or b) link the discussion back to how your findings relate to obesity. Given the focus of the present journal, I would probably suggest the former.

Thank you for pointing this out. We have now toned down the obesity focus in the Introduction whilst increasing the section focusing on the benefits of physical activity in young children [pg 4] as follows:

In addition to consuming a balanced nutritious diet, children up to the age of 5 years are recommended to engage in 180 minutes of physical activity daily.[19,20] In addition to higher levels of physical activity being associated with decreased adiposity in preschool-aged children, it is positively associated with motor skill development, psychosocial health, and with decreased cardio-metabolic risk prospectively.[13] Cross-sectional studies in older preschool-aged children (2 years and over) also indicate that increased physical activity is linked to better gross motor control[21] and improved social skills.[22] Yet despite the importance of physical activity for young children's health and development,[13] studies suggest that young children do not engage in sufficient levels of physical activity.[23]

In order to specifically increase physical activity in targeted interventions, it is important to establish which factors influence activity behaviour.[24] A number of systematic reviews have been conducted to examine the associations between cross-sectional factors ('correlates') and young children's physical activity.[16,25,26]…

Results:

How were papers from the same study dealt with? Please clarify in the results section (page 9, line 12) and also in the methods section. Based on the comment on page 10, line 12, it seems as though multiple papers from each study were included if they met the inclusion criteria, but I found the description of the number of studies reporting determinants difficult to follow at times (specifically paragraph 3 and 4 in the results section). Perhaps modifying the terminology from 'different studies' to 'different sample groups' might be helpful?

We apologise that is was not clear how multiple papers from the same study were dealt with/described in the paper. We have modified terminology as suggested and have amended the Methods and Results sections to refer to study samples and papers (also see below):

Methods (Pg 8):

For longitudinal studies, the latest data available before the children were 6 years old was included; where two or more papers reported on the same study sample, both were included if they reported determinants associated with different outcome measures.

On this note, I'm not sure it is appropriate to include 'sex' from the CLAN study in Table 3 twice. Given the result has come from the same sample group it isn't a 'new' finding, but rather one that has just been published twice.

As you mention above, multiple papers from one study were included if they met the inclusion criteria. In the case of the CLAN study, the findings for sex were included twice as different papers reported different outcome measures (counts per epoch vs. MVPA) and follow-up prospectively (i.e. 3 and 5 years post baseline). We believe that this highlights an important finding that change may differ within the same cohort depending measurement and follow-up used. We have clarified this in the methods (which also relates to your query above):

The influence of sex on change in physical activity was reported in five papers[60,61,78–80] (from 4 study samples: the association between sex and two different outcome measures were assessed within the same CLAN study sample)…

Here, evidence from the CLAN study served to highlight how findings may differ within the same sample depending on the outcome used and time of follow up (i.e. no association with counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]).

And have also highlighted this in the Discussion (Pg17):

This review also indicates that determinants may differ within the same cohort depending on measurement method and follow-up period (i.e. in the CLAN study, there was no association between sex and counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]). Prospective studies allow assessment of change in behaviour over relatively long periods of time; interventions, with generally much shorter follow-up periods than prospective studies, may be able to capture more short-term fluctuations in behaviour. Both types of study also tend to assess differing types of determinants. Prospective studies have focused on child's sex, parental psychosocial and temporal factors, whereas intervention studies target child skill and knowledge, parental knowledge and behaviour, and elements in the preschool environment including care-provider training and provision of curriculum materials. Both types of study are therefore beneficial to establish whether a determinant is associated with behaviour change, and whether change is sustained over time.

Had the included studies reported on the same findings (i.e. both reported on sex using the same outcome and time period), the study using the latest data available before the children were 6 years old (or as close to 6 years if only available afterwards) would have been included, as per the study protocol (Methods; Pg 8, as above).

Table 3 - I think parent role-modelling should be listed under 'parent behaviours' rather than 'parent psycho-social' since it would be a behaviour (physical activity) that a child sees a parent do.

Although we appreciate that role-modelling may involve children seeing their parents be physically active, it can also encompass a number of elements around a behaviour (i.e. seeing a parent in sports clothes, leaving the house to go to the gym) and we have therefore decided to leave role-modelling within the psycho-social category. To clarify this determinant more clearly, we now include a brief overview of what studies including maternal role modelling described it as (Pg 14):

Three further studies reported a positive effect of maternal role modelling on children's activity;[3,7,15] this ranged from assessing mothers' own physical activity[3] to increasing maternal awareness and encouraging increased physical activity within families, with or without her child so as to model activity behaviour.[7,15]

The authors considered any intensity of physical activity which is appropriate given the current recommendations. However, I am wondering if any different findings emerged if LPA and MVPA were examined separately? For example, perhaps provider training might have shown a more conclusive result if studies examining changes in children's MVPA were examined on their own (or vice versa for LPA).

We agree that the determinants of physical activity in pre-schoolers may differ depending on their intensity, and have published evidence of this cross-sectionally. To address this comment, and also to fulfil formatting requirements stipulated by the Editor, we have now partitioned out the outcomes in Table 3 according to intensity/measurement. This shows that even when PA outcomes are partitioned out by intensity, only the finding for provider training differs, as it is associated with positive change in preschoolers' MVPA in 6/9 studies. We have now made reference to this throughout the paper, in the Abstract (Pg 3):

Parental monitoring showed a consistent positive association with change in PA; provider training was positively association with change in children's moderate-to-vigorous PA only. Five (sex; parental goal setting; social support; motor skill training; provider training and increased time for PA) showed no clear association.

Results (Pg 11):

Of these 14 more frequently studied determinants, parental monitoring was consistently shown to be positively associated with change in young children's physical activity across intensities, with four of six study samples reporting a positive association. Provider training was also positively associated with change in children's MVPA in six of nine studies[38,44,46,47,53,54] but showed no clear association with physical activity overall (positive association in 8/16 studies), suggesting that determinants may be intensity specific.

Discussion (Pg 15):

Yet although environmental childcare determinants showed inconclusive results, of 16 intervention studies incorporating provider training, eight noted positive increases in children's activity[38,44,46,47,49,53,54,67], and MVPA in particular[38,44,46,47,53,54]. Interestingly, those interventions showing positive effects often incorporated few additional environmental elements, including providing additional curriculum materials;[49,53] they did however tend to include motor skill training, [46,47,54,67] parental elements[44,67] and/or allocate additional time for physical activity.[38,53,67] Introducing additional providers also led to increased physical activity in two out of three high quality intervention studies, where external gym trainers[49] and professional coaches[66] led physical activity sessions.

And Conclusion (Pg 19)

This review identified a range of predominantly interpersonal and organisational determinants of change in young children's physical activity; however, only parental monitoring of their child's physical activity emerged as a consistent positive determinant of change, with provider training positively associated with change in children's MVPA.

Discussion:
Since parental monitoring was the only consistent determinant observed, it would be nice for the authors to discuss why they think this might be. Is there any literature that shows that is the case in older children that you could draw on?

Thank you for this suggestion. As per this reviewer's comment and that of Reviewer 2 we have now included the following information in the Discussion (Pg 14):

Only one determinant, parental monitoring, was consistently positively associated with change in physical activity in both prospective and intervention studies this age group. This was operationalized in a range of ways by increasing parental awareness of the child's physical activity,[67,70] including using log books[44] and pedometers.[42] Although evidence of parental monitoring effecting a positive change in physical activity prospectively in older children is sparse,[86,87] cross-sectional evidence from a small sample of US children (n=99) suggests that where parenting is permissive, parental monitoring may lead to increases in MVPA in children.[88] Evidence tends to suggest that parents tend to over-estimate their children's physical activity in general.[89] Yet conscious parental monitoring of the target behaviour may increase its salience, resulting in a greater number of prompts to be active and therefore higher subsequent physical activity.

I think it would be nice if the authors could comment on the scope of the research regarding determinants of physical activity conducted to date. You can quite clearly see that the parent knowledge has been examined in a considerable

number of studies. Comparatively fewer studies have assessed many of the other determinants (e.g., goal setting) and virtually none have been assessed in the community/policy domain. I see that there is a sentence on page 12, line 14, briefly mentioning this latter point, but I think it should be emphasized more in the review - perhaps as its own separate paragraph. Given many people who are designing longitudinal studies or intervention programs will read this paper, I think that highlighting this finding will bring attention to this issue, and hopefully shape the design of future research studies.

We agree that it would be beneficial to draw out the limited range of determinants assessed across the socio-ecological model, and have amended the Discussion (Pg 16) as follows:

This review also highlights where research evidence and gaps exist. A large number of (intervention) studies have targeted determinants such as child motor/skills training; child and parental knowledge; provision of extra time for physical activity or curriculum materials; and provider training, with the studies overall showing no or indeterminate effects. Comparatively few studies have assessed a wide range of other determinants such as child/parent goal setting, and provider monitoring or social support. There is also a lack of studies assessing paternal determinants, and where this information is provided, studies tend to use maternal report. Only one determinant has been assessed in the community domain and none in the policy domain; no studies have been conducted to assess determinants in developing countries. Focusing research were such gaps exist will yield novel evidence, potentially prevent wastage of resources and promote physical activity change.

The authors mention that few studies have focused on children aged 2 years or younger. If space permits, they might like to discuss some of the challenges associated with research in this age group. For example, it is challenging to determine true 'change' in physical activity when children are not yet walking at baseline.

Thank you for this suggestion. Again, in response to this and Reviewer 2's comments, we have now included the following in the Discussion (Pg 17):

Moreover, little work has been conducted to explore how children's activity levels change from infancy to the preschool period, with only 6 studies including children aged 2 years or younger.[57,58,70,71,84,85] Questions remain about the optimal method for assessing physical activity in infants and toddlers.[106] Moreover, assessing physical activity across developmental periods may necessitate different measurement and processing protocols, complicating the assessment of change in physical activity. Nevertheless, given the early years represent a period of rapid development and a crucial window for positive habit formation, it is important to determine for whom, how, and why physical activity may change *throughout early childhood,* and whether behaviour and potential inequalities in health manifest and remain in later years.

Reviewer #4: This article was clearly and logically presented, making it easy to read and understand the findings of the review. I believe this makes a significant contribution to the field, by focussing on the best available evidence for the target age group. I have no changes to suggest.
We thank the reviewer for their positive comments and are pleased that the reviewer thinks this paper will make a significant contribution to the field, being clear and logical in presentation.

N.B. The Tables on the following pages are included in their original pre-revision format to illustrate our response to reviewer comments. The Tables in the revised document have been fully formatted according to Editor/ Reviewer comments.

Determinants assessed in Prospective Studies

	Association with change in physical activity				
Determinant	**-**	**0**	**+**	**Studies**	**Outcome**
Intrapersonal (child)					
Sex (boys)	(Saakslahti et al., 2004)	(Ball et al., 2009), (Taylor et al., 2009)	(Reilly et al., 2004), (Verity Cleland et al., 2011)	2/5	??
Interpersonal					
Family demographics					
Maternal SES		(Ball et al., 2009)		0/1	0
Sibling PA level		(Verity Cleland et al., 2011)		0/1	0
Parental psychosocial					
Maternal reinforcement		(Verity Cleland et al., 2011)		0/1	0
Paternal reinforcement		(Verity Cleland et al., 2011)		0/1	0
Maternal Role-modelling*			(Verity Cleland et al., 2011)	1/1	+
Paternal Role-modelling		(Verity Cleland et al., 2011)		0/1	0
Maternal co-participation		(Verity Cleland et al., 2011)		0/1	0
Paternal co-participation		(Verity Cleland et al., 2011)		0/1	0
Siblings co-participation			(Verity Cleland et al., 2011)	1/1	+
Family participation		(Verity Cleland et al., 2011)		0/1	0
Maternal direct support		(Verity Cleland et al., 2011)		0/1	0
Paternal direct support		(Verity Cleland et al., 2011)		0/1	0
Temporal					
Time of the day		(V Cleland et al., 2008)		0/1	0
Time of the week		(V Cleland et al., 2008), (Taylor et al., 2009)		0/2	0
Season		(V Cleland et al., 2008)		0/1	0

*Intervention components. For 1-3 studies: 0: 0-33% of papers support positive/negative association; ?: 34-59% support positive/negative association; +/ -: 60-100% support positive or negative association. For ≥4 studies: 00: 0-33% of papers support positive/negative association; ??: 34-59% support positive/negative association; ++/--: 60-100% support positive or negative association. Total activity/ counts per epoch; MVPA; steps/ pedometer; questionnaire

Determinants assessed in Intervention Studies

	Association with change in physical activity				
Determinant	**-**	**0**	**+**	**Studies**	**Outcome**
Intrapersonal (child)					
Motor/ Skills*		(Bonvin et al., 2013), (Jones et al., 2011), (Puder et al., 2011), (Sofiya Alhassan et al., 2012), (L. Bellows & Anderson, 2013)	(Annesi et al., 2013a, 2013b, 2013d), (Eliakim et al., 2007), (Yin et al., 2012)	5/10	??
Knowledge*		(Bonvin et al., 2013), (M. M. L. Fitzgibbon et al., 2013), (M. L. Fitzgibbon et al., 2011), (Puder et al., 2011), (Marieke De Craemer et al., 2014), (Stark et al., 2011), (K. Davison et al., 2013), (De Coen et al., 2012), (M. Fitzgibbon et al., 2005), (M. L. Fitzgibbon et al., 2006)	(Cottrell et al., 2005)	1/11	00
Goal setting*		(Stark et al., 2011)		0/1	0
Monitoring*		(Verbestel et al., 2013), (Østbye et al., 2013)	(Cottrell et al., 2005)	1/3	0
Fitness*		(Puder et al., 2011)		0/1	0
Interpersonal					
Maternal Role-modelling*			(Mareesa V O'Dwyer et al., 2012), (Klohe-Lehman et al., 2007)	2/2	+
Parental Role-modelling*		(Stark et al., 2011), (Østbye et al., 2013), (Verbestel et al., 2013)		0/3	0
Parental monitoring*		(Elder et al., 2014), (Verbestel et al., 2013)	(Mareesa V O'Dwyer et al., 2012), (Cottrell et al., 2005), (Yin et al., 2012), (Davis et al., 2013)	4/6	++
Parental motivation*		(Elder et al., 2014), (Østbye et al., 2013), (Whaley et al., 2010)	(De Bock et al., 2013)	1/4	00

Parental goal setting*		(Elder et al., 2014), (Stark et al., 2011)	(JONES et al., 2011), (Davis et al., 2013)	2/4	??
Parental knowledge*		(Engelen et al., 2013), (Bonvin et al., 2013), (Puder et al., 2011), (M. L. Fitzgibbon et al., 2011), (M. M. L. Fitzgibbon et al., 2013), (Elder et al., 2014), (Marieke De Craemer et al., 2014), (K. Davison et al., 2013), (Stark et al., 2011), (Østbye et al., 2013), (L. Bellows & Anderson, 2013), (De Coen et al., 2012), (M. Fitzgibbon et al., 2005), (M. L. Fitzgibbon et al., 2006), (Verbestel et al., 2013)	(De Bock et al., 2013), (Mareesa V O'Dwyer et al., 2012), (Cottrell et al., 2005), (Yin et al., 2012), (JONES et al., 2011), (Klohe-Lehman et al., 2007), (Davis et al., 2013),	7/22	00
Parent skills*		(Jones et al., 2011), (K. Davison et al., 2013), (Stark et al., 2011), (Østbye et al., 2013), (Li Ming Wen et al., 2015)	(De Bock et al., 2013), (JONES et al., 2011)	2/7	00
Parental self efficacy*		(Østbye et al., 2013), (Verbestel et al., 2013), (Whaley et al., 2010)	(Yin et al., 2012)	1/4	00
Parental social support*		(Puder et al., 2011), (Elder et al., 2014), (Li Ming Wen et al., 2015)	(JONES et al., 2011), (Davis et al., 2013)	2/5	??
Parental Behaviour					
Parental co-participation*		(Puder et al., 2011)		0/1	0
Opportunities for play*			(Mareesa V O'Dwyer et al., 2012), (Klohe-Lehman et al., 2007)	2/2	+
Organisational					
Preschool Environment					
Provider training*		(Bonvin et al., 2013), (Jones et al., 2011), (Puder et al., 2011), (Elder et al., 2014), (M V O'Dwyer et al., 2013), (Marieke De Craemer et al., 2014), (Sofiya Alhassan et al., 2012), (L. Bellows & Anderson, 2013)	(De Bock et al., 2013), (Annesi et al., 2013a, 2013d), (S G Trost et al., 2008), (Mareesa V O'Dwyer et al., 2012), (Annesi et al., 2013b), (Sofiya Alhassan et al.,	8/16	??

			2013), (Yin et al., 2012)		
Provider knowledge*		(Engelen et al., 2013), (Marieke De Craemer et al., 2014)		0/2	0
Provider social support*		(Puder et al., 2011)		0/1	0
Additional providers*		(M V O'Dwyer et al., 2013)	(De Bock et al., 2013), (Eliakim et al., 2007)	2/3	+
Increased active time*		(Puder et al., 2011), (M. M. L. Fitzgibbon et al., 2013), (M. L. Fitzgibbon et al., 2011), (S Alhassan et al., 2007), (M V O'Dwyer et al., 2013), (M. Fitzgibbon et al., 2005), (M. L. Fitzgibbon et al., 2006)	(S G Trost et al., 2008), (Sofiya Alhassan et al., 2013), (Eliakim et al., 2007), (Yin et al., 2012)	4/11	??
Structured physical activity*			(Sofiya Alhassan et al., 2013)	1/1	+
Playground density (low)*			(Van Cauwenberghe et al., 2012)	1/1	+
Playground markings*		(Cardon et al., 2009)	(Stratton & Mullan, 2005)	1/2	0
Portable equipment*		(Cardon et al., 2009), (Engelen et al., 2013), (Bonvin et al., 2013), (Puder et al., 2011)	(Hannon & Brown, 2008)	1/5	00
Curriculum Materials*		(M. M. L. Fitzgibbon et al., 2013), (M. L. Fitzgibbon et al., 2011), (Puder et al., 2011), (Bonvin et al., 2013), (Marieke De Craemer et al., 2014), (L. Bellows & Anderson, 2013), (De Coen et al., 2012), (M. Fitzgibbon et al., 2005), (M. L. Fitzgibbon et al., 2006)	(De Bock et al., 2013), (Sofiya Alhassan et al., 2013)	2/11	00
Preschool policy change*		(De Coen et al., 2012)		0/1	0
Centre monitoring/ feedback*		(Elder et al., 2014)		0/1	0
Community					
Community awareness*		(Elder et al., 2014), (K. Davison et al., 2013), (De Coen et al., 2012)		0/3	0

*Intervention components. For 1-3 studies: 0: 0-33% of papers support positive/negative association; ?: 34-59% support positive/negative association; +/ -: 60-100% support positive or negative association. For ≥4 studies: 00: 0-33% of papers support positive/negative association; ??: 34-59% support positive/negative association; ++/--: 60-100% support positive or negative association. Total activity/ counts per epoch; MVPA; steps/ pedometer; questionnaire

Determinants of Change in Physical Activity in Children 0-6 years of age: A Systematic Review of Quantitative Literature

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Key Points

- Forty-four determinants of change in young children's physical activity were assessed across 44 papers, predominately in the intrapersonal, interpersonal and organisational domain.
- Although 14 determinants were assessed in 4 or more studies, only parental monitoring was consistently positively associated with change in physical activity

and provider training associated with change in moderate-to-vigorous physical activity.

- Evidence in community and policy domains, and from low/middle-income countries, is required.

Abstract

Background: Understanding the determinants of children's health behaviours is important to develop successful behaviour-change interventions.

Objective: We aimed to synthesise the evidence around determinants ('preceding predictors') of change in physical activity (PA) in young children (0-6 years of age).

Methods: As part of a suite of reviews, prospective quantitative studies investigating change in physical activity in children aged 0-6 years were identified from eight databases (to October 2015): MEDLINE; Embase; CINHAL; PsycINFO; Web of Knowledge; British Nursing Index; Applied Social Sciences Index and Abstracts; and Sociological Abstracts. Determinants and direction of association were extracted, described and synthesised according to the Socio-ecological model (individual; interpersonal; organisational; community; policy).

Results: Forty-four determinants, predominantly in the interpersonal and organisational domains, were reported across 44 papers (6 prospective cohort, 38 intervention); 14 determinants were assessed in four or more papers. Parental monitoring showed a consistent positive association with change in PA; provider training was positively association with change in children's moderate-to-vigorous PA only. Five (sex; parental goal setting; social support; motor skill training; and increased time for PA) showed no clear association. A further seven (child knowledge; parental knowledge; parental motivation; parenting skills; parental self-efficacy; curriculum materials; portable equipment) were consistently not associated with change in children's PA. Maternal role-modelling was positively associated with change in PA in all 3 studies in which it was examined.

Conclusions: A range of studied determinants of change in young children's PA were identified, but only parental monitoring was found to be consistently positively associated. More evidence in community and policy domains, from low/middle-income countries, and lesser-explored modifiable family- and childcare-related determinants is required.

International Prospective Register for Systematic Reviews (PROSPERO) Registration number: CRD42012002881

1 Background

By the age of five, over 1 in 5 children are overweight or obese the UK and US.[1,2] Obesity in childhood is associated with a range of unfavourable outcomes including type 2 diabetes, hyperlipidaemia, and psychosocial problems,[3] with obesity known to track and be associated with unfavourable outcomes in adulthood.[4,5] Early childhood is a period of rapid growth and development, and the preschool years (defined here as up to the age of 6 years) are therefore ideal to both prevent and reverse unhealthy weight gain, by establishing healthy habits and behaviours.

As a result, interventions aiming to effect positive dietary, physical activity and sedentary behaviour change have been developed to prevent or halt obesity in the preschool years.[6–9] However, with a few notable exceptions,[10–12] many of these intervention studies showed small effects which are not sustained over time, or have no effect at all.[6–9] One difficulty in establishing the reasons for a lack of intervention success is that multiple behaviours are often targeted simultaneously.[8,9] However, as each health behaviour has an independent significant impact on children's health,[13,14] it is important to establish the most important determinants of each individual behaviour, and therefore how they may differ across behaviours. The socio-ecological model (SEM)[15] is a commonly used framework for categorising levels of influence on behaviours,[16,17] classifying them into five broad categories: individual; interpersonal; organizational; community; and public policy. By grouping potential influences on behaviour in this way, commonalities and differences can be identified and subsequently used to develop more targeted interventions to effectively change children's health behaviours.[18]

In addition to consuming a balanced nutritious diet, children up to the age of 5 years are recommended to engage in 180 minutes of physical activity daily.[19,20] In addition to higher levels of physical activity being associated with decreased adiposity in preschool-aged children, it is positively associated with motor skill development, psychosocial health, and with decreased cardio-metabolic risk prospectively.[13] Cross-sectional studies in older preschool-aged children (2 years and over) also indicate that increased physical activity is linked to better gross motor control[21] and improved social

skills.[22] Yet despite the importance of physical activity for young children's health and development,[13] studies suggest that young children do not engage in sufficient levels of physical activity.[23]

In order to specifically increase physical activity in targeted interventions, it is important to establish which factors influence activity behaviour.[24] A number of systematic reviews have been conducted to examine the associations between cross-sectional factors ('correlates') and young children's physical activity.[16,25,26] A broad range of correlates have been investigated, including demographic, biological, environmental, social, and psychological influences. Although conclusions about the influences on physical activity differ between reviews,[25,27] there is a suggestion that familial influences,[16,25,26] time spent outside[25] and elements in the physical environment[25,27] may be associated with increased activity in preschoolers. An additional review,[28] including cross-sectional studies and a small number prospective cohorts, also suggests that home influences may be key for young children's physical activity. However, it is difficult to draw firm conclusions about causality from cross-sectional studies. It is therefore necessary to use evidence from both prospective and intervention studies as these provide the best evidence to establish the longitudinal predictors (or 'determinants') of change in young children's physical activity, and to aid understanding of how to effect positive behaviour change.

This systematic review is part of a suite of reviews to explore the determinants of obesogenic behaviours in children 0-6 years (focussed on fruit and vegetable intake; sugar sweetened beverages and unhealthy diet intake; physical activity and sedentary behaviour).[29,30] It aims to synthesise the quantitative literature from prospective and intervention studies to ascertain the determinants (a 'preceding predictor') of change in physical activity in young children. It also aims to establish which (modifiable) determinants are associated with change; at which levels of influence these factors operate (i.e. individual, family, childcare setting, community or policy level); and where gaps in the literature exist for future research.

2 Methods

The protocol for this review project has been described previously.[29] The International Prospective Register for Systematic Reviews (PROSPERO) Registration number is CRD42012002881. Following established criteria for the rigorous conduct and reporting of systematic reviews,[31,32] this review was carried out in three stages.[33,34] One search (led by HM) was conducted to identify studies across all reviews; at the data extraction stage, smaller teams led each of the reviews focusing on specific behaviours of interest (i.e. physical activity (Review lead: KH), fruit and vegetable consumption (COM), sugar sweetened beverages (VP)). KH also conducted the search update specific to physical activity in October 2015.

2.1 Generic Review Methods

2.1.1 Identification of studies for review

A systematic search, common to all reviews, was undertaken in August 2012. Four sets of search terms were used related to: the population; study design (capturing observational, intervention, and review articles); outcome; and exclusion of clinical populations. An extensive scoping phase was conducted prior to implementing the full search to maximize sensitivity and specificity of included papers. This involved contacting experts in the field and identifying key publications to be included for each behaviour, with searches run to ensure that these publications were captured. An electronic search was conducted in eight databases (MEDLINE, Embase (via OVID), CINHAL, PsycINFO (via EBSCO), Web of Knowledge (via Thomson Reuters), British Nursing Index (BNI), Applied Social Sciences Index and Abstracts (ASSIA) and Sociological Abstracts (via ProQuest)). Citations were downloaded into Endnote citation management software (Thomson Reuters, Philadelphia, PA, USA). Included papers were searched for additional relevant publications, as were relevant reviews. No language restrictions were placed on the search, but articles were limited to published full texts. An updated search was conducted in October 2015, to capture studies with outcomes relating to physical activity only, published in the interim period (Electronic Supplementary Material Table S1).

2.1.2 Study selection

In 2012, two batches of 500 titles and abstracts were screened for inclusion by the review leads (KH, VP, COM) and checked for fidelity by a fourth reviewer (CS). With less than a 5% discrepancy, each reviewer subsequently screened approximately 12,000 papers individually. For quality control, two random 5% samples (total n=3600) were double screened by two additional reviewers (RL and EvS). All full texts were obtained and distributed for the behaviour-specific reviews to progress in parallel. Additional texts retrieved in 2015 were screened by KH and a subsample (15%) reviewed by EvS.

2.2 Methods for Physical Activity Review

2.2.1 Inclusion/ exclusion criteria

Articles were included if a) they reported results from either a longitudinal observational study, randomized controlled trial (RCT) or controlled trial (CT), b) quantified a within-child change in physical activity behaviour (as primary/second outcome in interventions) and c) assessed at least one potential determinant of change. Children had to be aged between 0-6 years at baseline, and studies assessing physical activity using objective or subjective measures were included. Exclusion criteria included: i) clinical populations (e.g. children who were malnourished; had asthma, cerebral palsy, cystic fibrosis, autism etc.) ii) non-human studies; iii) quantitative cross-sectional studies; iv) qualitative studies v) and laboratory-based studies (e.g. validation studies).

2.2.2 Quality Assessment

For descriptive purposes, a quality appraisal of each of the included studies was conducted focusing on internal and external validity using assessment criteria adapted from those used previously[34,35] (Electronic Supplementary Material Table S2). Criteria included: sample representativeness, size and retention, use of objective exposure and outcomes measures, appropriateness of analysis strategy, and randomisation method for RCTs. Scores out of 6 (or 7, for RCTs) were allocated and categorised accordingly (high quality: $\geq$5; medium: 3 - 4; low: 1 - 2).

2.2.3 Data extraction

All full texts identified for inclusion were read by KH, and double screened for inclusion by EvS. For relevant papers, data were extracted using a standardized form. Data extracted included first author; publication year; country; study design, setting and population; and baseline descriptive characteristics. Data were also extracted about physical activity measurement and outcome; potential determinants; method of analysis; duration of follow-up; loss to follow-up; and results. All outcome measures used in prospective and intervention studies (e.g. percentage time or minutes spent at differing activity intensities (i.e. light (LPA), moderate (MPA), vigorous (VPA), moderate to vigorous (MVPA) or total activity (LMVPA)) were extracted. However, in some studies, activity was only assessed during specific periods (i.e. at weekends, during recess). In an attempt to standardise findings across studies, where more than one physical activity outcome was reported, we report total physical activity/ counts per epoch (given current guidelines for young children's activity[19,20]), followed by MVPA, LPA and MPA/VPA. For intervention studies, each of the described elements targeted in the intervention (e.g. parental knowledge, parental modelling) were extracted as potential determinants of change in physical activity. For each determinant, the smallest included sub-sample was considered for extraction (e.g. if stratified by sex). Where results were stratified by specific times of the day, results for the largest time periods were reviewed and extracted. For longitudinal studies, the latest data available before the children were 6 years old was included; where two or more papers reported on the same study sample, both were included if they reported determinants associated with different outcome measures. For intervention studies, we assessed the difference in physical activity between control and intervention groups over time to classify determinants, as this provided evidence of factors targeted in interventions (i.e. determinants) which were associated with change. Where possible, results of multivariable rather than univariable models were included.

2.3 Data synthesis

Narrative data synthesis was undertaken for all studies. Due to the heterogeneous nature of included quantitative studies and the physical activity outcomes used, meta-analysis

was not appropriate. Each extracted determinant was scored based on direction and strength of evidence: '−' significant decrease in physical activity; '0' no significant association/effect or '+' significant increase in physical activity. Evidence from cohort and intervention studies were weighted equally, as both provide prospective determinants of change in physical activity behaviour. As per previous reviews,[16,17,36] consistency across studies for any given determinant was then summarized according to the following metric: '0' (no association) if supported by 0–33% of individual studies; '?' (indeterminate/possible) if supported by 34–59%; and '+' or '−' if supported by 60–100%. Where four or more studies reported on a potential determinant, double indicators were used (e.g. '00', '??', '++' and '− −') to indicate greater levels of evidence and therefore confidence in findings. Determinants, study score and consistency across studies were then presented according to the SEM (individual; interpersonal; organisational; community; and policy).[17,36]

3 Results

A total of 37,686 (full review) and 3,652 (physical activity-specific update) references were retrieved in 2012 and 2015 respectively, of which 220 were read in full and 44 papers included for review (representing 42 study samples: 4 prospective cohort and 38 intervention studies, see Figure 1). A descriptive summary of the included study samples is presented in Table 1; study-specific information is provided in Table 2.

3.1 Summary of Study Characteristics

Study samples originated in the USA (n=24), Australasia (n=6) and Europe (n=12); no papers were identified from developing nations, and all bar one was published after 2003. Of included studies, 15 (34%; 13 intervention, 2 prospective) had a final sample size greater than 250 children, and most included similar numbers of boys and girls. Objective measures of physical activity were used in 34 (77%) papers (accelerometer: 27; pedometer: 4; heart-rate/ Actiheart: 3) although those paper using proxy-report measures were also included (n=10; 1 prospective, 9 intervention). Interventions often targeted a number of behaviours, including diet and sedentary behaviour, but 18 (38%) specifically aimed to increase physical activity.[37–54] The measurement period (from baseline to

last contact) was a median 2.5 years (range: 1-5 years) for prospective papers and 34.5 weeks (range: 1 day to 5 years post-intervention) for intervention papers. One prospective paper and 26 intervention papers (61%) were deemed to be of high quality (score ≥ 5), 9 were of medium quality (score 3-4) and 6 were low quality (score of 2). Of the intervention studies, 28 (64%) randomised participants. Most study samples drew participants from White populations; some targeted lower socioeconomic or racial minority groups.[11,55–58] A retention rate of ≥70% was reported in 20 papers (46%), and 27 intervention studies reported final analysis samples by study group, indicating similar levels of attrition.

3.2 Overview of prospective and intervention studies

A total of 44 potential determinants of change were reported (Table 3) across papers. The same cohort study (Children Living in Active Neighborhoods (CLAN) [59]) was described in three[60–62] of the six prospective papers. One paper describing this study contributed all 16 determinants identified across prospective studies in intrapersonal, interpersonal and temporal domains. This paper predominantly reported on determinants relating to parental influence on change in physical activity.

The 38 intervention studies targeted 28 potential (modifiable) determinants at intrapersonal (n=6), interpersonal (n=10), organisational (n=10) and community levels (n=1). No determinants at the policy level were identified across included studies. Of the 38 intervention studies, 27 (68%) were classified as multi-level;[11,42,44,46–48,50–52,54–56,58,63–76] these most commonly targeted individual/ interpersonal (i.e. children, parents, teachers) and organisational (i.e. preschool/ home environment) factors. Of these, 11 multi-level interventions (42%) effected a positive change in children's physical activity,[42,44,46,47,54,58,63,65,66,69,72] though no clear effective combinations of components emerged. Across all prospective studies, positive effect sizes were generally small, with increases of less than 10% in total activity or MVPA from relatively low baseline levels.

3.3 Determinants identified in four or more studies

Fourteen determinants were assessed in four or more studies. One, sex, was reported in five prospective papers [60,61,77–79] (from 4 study samples: the association between sex and two different outcome measures were assessed within the same CLAN study sample). The remaining 13 determinants, reported four or more times, were all intervention components, including at the intrapersonal level: motor/skills training[46,47,50–52,54,65,66,75,80] and child knowledge[11,42,50,55,56,64,71,73,75,76,81], and at the interpersonal level: parental monitoring[42,44,66,69,70,72]; parental motivation [49,57,72,82]; goal setting[69,72,76,83]; parental knowledge [11,42,44,48–50,55,56,58,64,66,69–73,75,76,80–83]; general parental skills[49,51,76,81–84]; parent self-efficacy[57,66,70,82]; parental social support[69,72,75,83,84]; and provider training[38,44–47,49–54,64,66,72,75,80]. Those determinants at the organisational level included: more physical activity opportunities[11,38,40,45,53,55,56,65,66,73,75]; use of portable equipment [37,41,48,50,75]; and supplying curriculum materials[11,49,50,53,55,56,64,71,73,75,80].

Of these 14 more frequently studied determinants, parental monitoring was consistently shown to be positively associated with change in young children's physical activity across intensities, with four of six study samples reporting a positive association. Provider training was also positively associated with change in children's MVPA in six of nine studies[38,44,46,47,53,54] but showed no clear association with physical activity overall (positive association in 8/16 studies), suggesting that determinants may be intensity specific.

Five determinants, across the intra- and interpersonal domains, namely sex (positive association in 2/5 studies); motor skill training (5/10); parental goal setting (2/4); parental social support (2/5); and increased time for physical activity (usually within the care setting; 4/11) showed no consistent association with change in physical activity. In the case of sex, evidence from the CLAN study served to highlight how determinants may differ within the same sample depending on the outcome used and time of follow up (i.e. no association with counts per epoch at first follow up[60] but a positive association

between (male) sex and MVPA at second follow up[61]). For motor skills training[46,47,54,65,66] and increased time for physical activity [38,53,65,66] the majority of intervention studies that found a positive association with change in physical activity used objective measures.

The remaining seven determinants assessed in four or more studies, i.e. child knowledge (positive association in 2/12 studies); parental knowledge (7/22); parenting skills (2/7); parental motivation (1/4); parental self-efficacy (1/4); curriculum materials (2/11); and portable equipment (1/5), consistently showed no association with change in young children's physical activity (i.e. >67% of studies reported no association).

3.4 Determinants identified in fewer than four studies

Determinants assessed in three study samples in the intra/interpersonal domains included child monitoring,[42,70,82] parental role-modelling [70,76,82] and maternal role modelling,[44,58,61], with only the latter shown to be positively associated with change in physical activity in all three studies (one using proxy-reported physical activity[58]). In the organisational domain, increasing the number of care providers within the childcare setting was found to be positively associated with change in two (out of three) intervention studies.[49,65] Community awareness showed no association with change in children's physical activity.[71,72,81] Positive associations with change in physical activity were also found for providing additional opportunities for play within the home (two studies)[44,58] and sibling co-participation (one study)[61], and with structured physical activity[53] and lowering playground density[43] in one study each within the organisational domain.

4 Discussion

This review is the first to synthesise evidence from longitudinal studies relating to the determinants of change in physical activity in preschool-aged children. Forty-four determinants were identified; determinants at the interpersonal and organisational levels were most commonly evaluated. Fourteen determinants were identified in four or more quantitative studies: parental monitoring showed a consistent positive association with

change in physical activity. Provider training was positively associated with change in MVPA, but showed no clear association with physical activity overall. Of the remaining 12 determinants, a further five showed no clear association, and seven were consistently not associated with change in children's physical activity. Moreover, maternal role modelling was positively associated with physical activity in three studies.[44,58,61] A range of modifiable family- and childcare-related elements also showed positive associations with change in young children's activity in fewer studies. Where positive effects on change in physical activity were seen, they were often small in magnitude, particularly in studies reporting accelerometer-measured outcomes. Despite identifying a range of determinants that have been assessed, there appears to be little evidence of what results in positive change in preschoolers' physical activity. Where determinants have shown no positive effect (e.g. child/ parental knowledge) researchers should divert emphasis instead to other potentially influential determinants. Both parental monitoring and maternal role modelling may provide feasible and effective determinants of change; given the lack of longitudinal evidence from the community and policy domains, and with no evidence to date from developing countries, further exploration of possible determinants of change in these areas is also required.

As also shown in cross-sectional studies,[16,25] the association between the child's sex and change in physical activity[60,61,77–79] was not consistent here. In general, boys' absolute levels of physical activity were reported to be higher than those of girls[61,79] suggesting that, regardless of change, boys may remain more active than girls over time. The aim of this review was not to assess whether a determinant was associated with increased physical activity over time, but rather if different levels of a determinant predict differences in change in PA over time. Sex is a good example of this: boys' physical activity may increase over time whilst girls' activity remains stable, or boys' activity may remain stable whilst girls' activity decreases. Although the data available do not allow us to explore the actual direction of change, this is an important consideration for future research. Based on current evidence and quality of measurement, boys appear to be more active than girls, but firm conclusions about the influence of sex on changes in young children's activity over time cannot be drawn.

Determinants in the interpersonal domain were most frequently assessed. Only one determinant, parental monitoring, was consistently positively associated with change in physical activity in both prospective and intervention studies this age group. This was operationalized in a range of ways by increasing parental awareness of the child's physical activity,[66,69] including using log books[44] and pedometers.[42] Although evidence of parental monitoring effecting a positive change in physical activity prospectively in older children is sparse,[85,86] cross-sectional evidence from a small sample of US children (n=99) suggests that where parenting is permissive, parental monitoring may lead to increases in MVPA in children.[87] Evidence tends to suggest that parents tend to over-estimate their children's physical activity in general.[88] Yet conscious parental monitoring of the target behaviour may increase its salience, resulting in a greater number of prompts to be active and therefore higher subsequent physical activity.

Three further studies reported a positive effect of maternal role modelling on children's activity;[44,58,61] this ranged from assessing mothers' own physical activity[61] to increasing maternal awareness and encouraging increased physical activity within families, with or without her child so as to model activity behaviour.[44,58] These findings are supported by qualitative literature, with parents consistently suggesting that active parents and parents as role models were important facilitators of children's activity.[89–94] Positive associations between parents' and children's activity have also been reported previously in cross-sectional studies.[95–97] Intervention studies targeting other interpersonal factors such as increasing parental knowledge[11,42,44,48–50,55,56,58,64,66,69–73,75,76,80–83] or social support,[69,72,75,83,84] and improving parenting skills[49,51,76,81] showed indeterminate associations; both high and lower quality studies reported both positive[42,44,49,58,66,69,83] and no associations[11,48,50,51,55,56,64,70–73,75,76,80–82,84] for these intervention components. It may therefore be that it is parental awareness and their own activity behaviours that are important for their child's activity. Further research is needed to

explore how objectively measured physical activity in preschool-aged children and their parents are associated longitudinally.

Several reviews conducted previously suggest that elements in the preschool environment may be positively associated with children's activity.[27,98] Many intervention studies here specifically targeted the childcare environment, providing curriculum materials or modified elements within childcare settings, but no clear determinants were identified. [11,37,39,41,43,48–50,53,55,56,64,71,73,75,80] Four of the intervention studies used variations of the same 'Hip-Hop-to-Health' intervention,[11,55,56,73] targeting a range of elements in the childcare setting: only one[56] showed a positive sustained effect on accelerometer-measured activity in a predominantly African American population. This highlights that even with a consistent core intervention, factors including cultural variability, differing reported outcomes and intervention fidelity likely influence intervention success.

Yet although environmental childcare determinants showed inconclusive results, of 16 intervention studies incorporating provider training, eight noted positive increases in children's activity[38,44,46,47,49,53,54,66], and MVPA in particular. Interestingly, those interventions showing positive effects often incorporated few additional environmental elements, including providing additional curriculum materials;[49,53] they did however tend to include motor skill training, [46,47,54,66] parental elements[44,66] and/or allocate additional time for physical activity.[38,53,66] Introducing additional providers also led to increased physical activity in two out of three high quality intervention studies, where external gym trainers[49] and professional coaches[65] led physical activity sessions.

Given the increasing amount of time children now spend in childcare, care providers feasibly to play an important role in shaping children's health behaviours. It is not possible here to disentangle which elements of training resulted in positive physical activity change, but encouraging care providers to build on their skill-base and/or confidence in multi-component interventions may be important. Moreover, qualitative

literature suggests that care providers perceive themselves to be both a positive[99–101] and negative[99,102,103] influence on children's physical activity, yet no quantitative studies to date have specifically focused on care-providers own behaviour as a potential determinant. Doing so may be timely given providers believe they can influence children's activity and that young children should be active, but many are not aware of how much physical activity young children require.[104]

Despite an obvious lack of observational research informing intervention development, the majority of intervention studies (68%) were classified as multi-level,[11,42,44,46–48,50–52,54–56,58,63–76] targeting determinants across a range of domains. Though these studies used notionally similar exposures, e.g. targeting children, their parents and changing the preschool environment, inconsistent results were seen. As with all multi-faceted interventions, it is therefore difficult to tease out which components were effective and may explain in part why so few determinants were consistently associated with change in physical activity. Determinants across interpersonal and organisational levels may act synergistically or may counteract each other leading to null results. Although we attempted to determine how each intervention component influenced activity, no formal mediation analyses were identified and further exploration of how elements within an intervention result in positive change would be beneficial. For example, mixed-methods process evaluations may help to delineate determinants of children's physical activity and aid future intervention development.

This review also highlights where research evidence and gaps exist. A large number of (intervention) studies have targeted determinants such as child motor/skills training; child and parental knowledge; provision of extra time for physical activity or curriculum materials; and provider training, with the studies overall showing no or indeterminate effects. Comparatively few studies have assessed a wide range of other determinants such as child/parent goal setting, and provider monitoring or social support. There is also a lack of studies assessing paternal determinants, and where this information is provided, studies tend to use maternal report. Only one determinant has been assessed in the community domain and none in the policy domain; no studies have been conducted to

assess determinants in developing countries. Focusing research were such gaps exist will yield novel evidence, potentially prevent wastage of resources and promote physical activity change.

Moreover, little work has been conducted to explore how children's activity levels change from infancy to the preschool period, with only 6 studies including children aged 2 years or younger.[57,58,69,70,83,84] Questions remain about the optimal method for assessing physical activity in infants and toddlers.[105] Moreover, assessing physical activity across developmental periods may necessitate different measurement and processing protocols, complicating the assessment of change in physical activity. Nevertheless, given the early years represent a period of rapid development and a crucial window for positive habit formation, it is important to determine for whom, how, and why physical activity may change *throughout early childhood*, and whether behaviour and potential inequalities in health manifest and remain in later years.

Finally, determinants may be time or situation specific. Very few prospective observational studies have assessed determinants of physical activity change in young children. Including both prospective and intervention studies (and treating intervention components as determinants in the latter) allowed us to identify a wider range of factors that have been posited to effect change in physical activity. This review also indicates that determinants may differ within the same cohort depending on measurement method and follow-up period (i.e. in the CLAN study, there was no association between sex and counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]). Prospective studies allow assessment of change in behaviour over relatively long periods of time; interventions, with generally much shorter follow-up periods than prospective studies, may be able to capture more short-term fluctuations in behaviour. Both types of study also tend to assess differing types of determinants. Prospective studies have focused on child's sex, parental psychosocial and temporal factors, whereas intervention studies target child skill and knowledge, parental knowledge and behaviour, and elements in the preschool environment including care-provider training and provision of curriculum materials. Both types of study are therefore

beneficial to establish whether a determinant is associated with behaviour change, and whether change is sustained over time. In combination, a more comprehensive picture of the determinants landscape in children 0-6 years of age can emerge; this will ensure future research focuses on where gaps in the current evidence exist, whilst focusing work on areas where potential positive gains in changing young childrens' physcial activity are most likely to be made.

4.1 Strengths and limitations

This is the first systematic review, to our knowledge, to specifically explore determinants of change of physical activity in children aged six years and under across prospective cohort and intervention studies. Given that cohort and intervention studies offered the most appropriate design to extract determinants of change, our research strategy was restricted to prospective studies. We applied rigorous review methods and did not exclude papers based on language, but it is possible that all relevant publications may not have been included, as illustrated by the identification of an additional study at the data extraction phase. As this review was restricted to published studies, publication bias cannot be discounted. One determinant (sex) was assessed in the same study twice and contributed more than one paper;[60,61] however in general, our methods reduced potential bias by lending more weight to determinants assessed in four or more studies. The inclusion of a range of study types and measures of activity is both a strength and limitation of this review; studies using pedometers and questionnaires tended to report positive intervention effects. Studies also used differing accelerometer cut points and adjusted for differing covariates in regression models. This heterogeneity highlights how differing study methods may influence findings and intervention success. All studies were conducted in high-income countries and approximately half of the studies had small final sample sizes ($n<50$; studies=15), which may have limited their statistical power to detect significant associations. Although we attempted to standardise outcomes across studies, five and 23 different outcome measures were used in prospective and intervention studies respectively, preventing the use of meta-analysis here.

Conclusions

This review identified a range of predominantly interpersonal and organisational determinants of change in young children's physical activity; however, only parental monitoring of their child's physical activity emerged as a consistent positive determinant of change, with provider training positively associated with change in children's MVPA. Maternal role modelling was also positively associated with change in all 3 studies in which it was examined. Many determinants were explored in fewer than four studies, and multiple determinants were targeted within each intervention study. This heterogeneity in the determinants considered, and also in outcome measures used, limited the ability to identify consistent evidence for specific determinants. Future work should investigate potentially important lesser-explored or overlooked modifiable family- and childcare-related determinants; explore how determinants influence physical activity throughout the day and week; and deconstruct how the multiple elements within an intervention result in positive behaviour change. Assessment of determinants in the community and policy domains, in addition to studies conducted in developing countries, is also required. Such information will provide more robust evidence about the determinants of change in activity in preschool-aged young children, which is needed to inform the development of successful targeted interventions to increase activity levels in this population.

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Compliance with Ethical Standards

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Conflicts of Interest

Kathryn Hesketh, Claire O'Malley, Veena Mazarello Paes, Helen Moore, Carolyn Summerbell, Ken Ong, Rajalakshmi Lakshman and Esther van Sluijs declare that they have no conflicts of interest relevant to the content of this review.

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Table 1 Characteristics of included papers[a]

Sample characteristic	Reference	Total number of papers (%)
Study design		
Prospective	[60–62,77–79]	6 (14)
Intervention	[11,37–58,64–67,69–76,81,83,84]	38 (84)
Total sample size		
<100	[37–40,42,44,51,53,58,69,73,76,79,81]	15 (34)
101-199	[41,43,56,60–62,65,67,70,73,77]	11 (25)
200-299	[45,48,54,66,74,78]	6 (14)
300-399	[11,47,50,55,84]	5 (11)
400-499	[64,72,75]	3 (7)
500+	[46,49,57,71]	4 (9)
Method of physical activity measurement		
Objective	[37–50,53–56,61,62,64–67,73–76,78,79,81,83]	33 (77)
Subjective	[11,51,55,57,58,60,69–71,77,84]	11 (23)
Continent		
Australasia	[48,51,60–62,78,83]	8 (18)
Europe	[39,41,43–45,49,50,64,65,75,77,79]	12 (27)
North America	[11,37,38,40,42,46,47,52–58,66,67,69,71–74,76,81]	24 (55)
High quality ($\geq$5[b])		
Prospective	[78]	1 (4)
Intervention	[11,40,41,43–48,50,52–56,64,65,67,72–76,78,83,84]	26 (59)

a: A total of 44 papers were included, describing 42 prospective and intervention studies; b: Prospective studies scored out of 6, intervention studies scored out of 7.

Table 2: Summary of studies included to assess determinants of physical activity levels in young children

Reference	Study design/ name	Population	Age at start (mean±SD and/or range)	Setting	Intervention and provider	Targeted determinants [theoretical model]	Intervention duration (or follow-up)	Outcome	Measure	Effect	Quality score[a]
Prospective Studies											
Ball et al (2009); Cleland et al (2008); Cleland et al (2011) [60–62] Australia	Prospective cohort - CLAN	19 public elementary schools n=168 (stratified by low/med/high SES)	5-6 y	Schools	N/A	Child: sex Parents: behaviour, psychosocial Temporal: time of day, week, season	Up to 5 y	Ball: Change in cpm Cleland: change in MVPA	Accelerometer	cpm: 0 MVPA: + (for limited determinants)	4
Reilly et al (2004) [79] UK	Prospective cohort - SPARKLE	Community level stratification n=72 (51% M)	3.7±0.5 y	Community	N/A	Children: sex	1 y	Change in total PA	Accelero-meter	TEE: +	3
Saakslahti et al (2006) [77] Finland	Prospective cohort -	Cohort of children n=155 (53% M)	4-7y	Study subsample	N/A	Children: sex	2 y	Change in time spent in high intensity PA	Questionnaire	Change in high intensity PA: 0	2
Taylor et al (2008) [78] New Zealand	Prospective cohort – FLAME	Population-based n=244 (56% M; 86% W, 11% Moari, 3% PI; higher SES)	2.96-3.15	Birth cohort	N/A	Children: sex	3 y	Change in MVPA	Accelerometer	MVPA: 0	5
Intervention Studies											
Alhassan et al (2007) [40] USA	Pre-post; quasi-randomised	1 Low-income preschool n=32 (63% M, predominantly Latino)	C: 3.59±0.5 I: 3.89±0.5	Headstart	60 mins of additional recess time per day, divided into two 30-min blocks (one in the morning and one in the afternoon) [vs. usual recess time]	Preschool: additional PA time [No theory identified]	2 d	Change in cpm	Accelero-meter	cpm: 0	2
Alhassan et al (2012) [52] USA	Pre-post; quasi-randomised	2 preschools n=78 (49% M; 39% AA, 61% H; 65% single-family homes)	C: 4.1 ± 0.6 I: 4.5 ± 0.6	Preschools	Delivered for 30 min/day, five days/w for six months during morning gross motor playtime. Motor skill curriculum: 30 individual lesson, with one skill per lesson, e.g. 5 min low-intensity musical activity, 20 min of motor skills, 5 min of reinforcement.	Multi-level, including Children: motor skills Preschool: provider training (8hr) [No theory identified]	6 mo	Change in % time MVPA	Accelero-meter	% MVPA: 0	5
Alhassan et al (2013) [53] USA	RCT - SPARK	2 preschools n (baseline)=75; n (follow-up)=67 (57% M)	2.9-5y	Preschools	Both I&C given 30 mins of additional outdoor playtime for three d/w for 4 w. I: Providers delivered 12 sessions structured activity programme to increase MVPA.	Preschool: provider training (8hr), additional PA time [No theory identified]	4 w	Change in minutes % time in MVPA	Accelero-meter	% MVPA: 0	6
Annesi et al (2013) [54] USA	cRCT – Start for Life	32 classrooms n=275 (44% M; predominantly AA)	3.5-5.6y (4.6± 0.5y)	YMCA Preschools	Provider-delivered structured activity including gross motor skills and behavioural skills training	Multi-level, including Children: motor, behavioural skills	8 w	Change in MVPA	Accelero-meter	MVPA: +	6

					(30min/d).	Preschool: provider training (4hr) [Social cognitive and self-efficacy theory]					
Annesi et al (2013) [47] USA	cRCT – Start for Life	19 classrooms n=338 (46% M; lower/ lower–middle class; 92% AA)	C: 4.7±0.3 I: 4.6±0.6	YMCA Preschools	Provider-delivered structured activity including gross motor skills and behavioural skills training for 30min/d.	Multi-level, including Children: motor, behavioural skills Preschool: provider training (4hr) [Social cognitive and self-efficacy theory]	8 w	Change in MVPA	Accelero-meter	MVPA: +	6
Annesi et al (2011) [46] USA	cRCT – Start for Life	26 classrooms n=885 (46% M; lower/ lower–middle class; 92% AA)	3.5-5.6 y (4.4±0.5y)	YMCA Preschools	Provider-delivered structured activity including gross motor skills and behavioural skills training for 30min/d.	Multi-level, including Children: motor, behavioural skills Preschool: provider training (4hr) [Social cognitive and self-efficacy theory]	8 w (9 mo)	Change in MVPA	Accelero-meter	MVPA: +	6
Bellows et al (2013) [67] USA	RCT - The Food Friends: Get Movin' with Mighty Moves	8 lower income Headstart centres n=201 (55% M; 59%H, 32%W,9%O)	I: 53.0±6.8mo C: 51.5±6.6mo	Headstart centres	Provider led skills-based 72 lesson programme (4 d/w for 15–20 min, for 18 ws). Focus on stability, locomotor or manipulation, then skill patterns. Use of Food Friends characters and other materials to support lessons. Materials sent home.	Multi-level, including Children: motor, behavioural skills Parents: knowledge Preschool: provider training (8hr) [No theory identified]	18 w	Change in mean daily steps (w/e and w/ds) (2o)	Pedometer	Steps: 0	6
Bonvin et al (2015) [50] Switzerland	RCT - Youp'là Bouge	58 childcare centres n=388 (50% M; 18% low educated parents; 58% migrant parents)	I: 3.4±0.6y C: 3.3±0.6y	Childcare centres in 3 French-speaking Cantons	Multi-component physical activity programme, delivered to children and parents via providers in preschools. Preschools left to implement PA programme according to their own needs.	Multi-level, including Children: skills, knowledge Parents: encouraged engagement, knowledge Preschool: provider training/ support; changes in built environment ($1500) [No theory identified]	9 mo	Change in cpm, MVPA (2o)	Accelero-meter	cpm: 0	6
Cardon et al (2009) [41] Belgium	RCT	40 preschools n=583 (52% M)	5.3±0.4y	Public Preschools	Factorial Design: 1: Play equipment provided (150 children); 2: Markings painted on the playground (161); 3: Play equipment & markings provided (161)	Preschool: changes in environment [No theory identified]	6 mo	Change in cpe	Accelero-meter	Cpe: 0	6
Cottrell et al (2013) [42] USA	RCT - CARDIAC-Kinder	29 preschools n (baseline)= 203 (49% M; 93% W) n (follow-up)=50	5±0.47 y	Preschools	Children received 2 pedometers – one for themselves and for a parent (vs. one for child in C group) and step log. Also received information	Multi-level, including Children: monitoring, knowledge Parents: monitoring,	4 w	Change in weekly average steps	Pedometer	Weekly steps: + (week 4)	2

					building on activity and diet recommendations.	knowledge. [No theory identified]					
Davis et al (2013) [69] USA	Pilot intervention	Teen mothers, n= 60 (61% M; 73% AA; 16% W; 7% NA; 4% O),	0-53 mo (15.7±13.4)	Child development programme	In-home intervention focusing on nutrition and activity: 3 sessions for mother, 3 focused on child. Providing information, and including behavioural topics such as goal setting, tracking, social support.	Multi-level, incl Parents: knowledge, monitoring, goal setting, social support Organisational: facilitator training (4hrs) [No theory identified]	3 mo	PA in past week; PA in typical week	Questionnaire	Change in typical week: +	2
Davison et al (2013) [81] USA	Pilot intervention	5 Headstart centres n (baseline)= 117 (45% M; 68% W; 22% AA; 6% non-H; 4% O) n (follow-up)=57	3.59±1.01y	Headstart centres	Multi-component intervention delivered through Head Start centres, including health communication campaign, body mass index letters, family nutrition counselling, parent skill sessions, and similar programme for children.	Multi-level, including Children: encouragement, knowledge Parents: skills training, knowledge. Community: awareness [Family Ecological Model]	6 mo	Change in mins/hr LPA, MPA (2o)	Accelero-meter	LPA: + MPA: 0	4
De Bock et al (2013) [49] Germany	cRCT	37 preschools n (baseline)=809 (52% M; low income:25%, middle income: 55%) n (follow-up)=467	5.05y	Preschools	Augmentation of 6 mo State program (+ 3 mo) to motivate parents to promote children's PA. Introductory video and project ideas, with external gym trainers provided for I school to coordinate parent activities. Initial workshop followed by teambuilding and implementation of projects as regular activities.	Multi-level, including Parents: motivation, skills training, knowledge. Preschool: additional providers, provider training [Participatory intervention approach]	9 mo	Change in cp15s	Accelero-meter	Cp15: +	4
De Meij et al (2010) [71] Belgium	Cluster-RCT "Prevention of Overweight among Pre-school and school children (POP)"	31 schools across high, medium and low SES. n=1589 at baseline (I: 1032; C:557) n=694 at 2 year (I: 396 C: 298)	4.95 ± 1.31y	Pre-primary and primary schools	Health promotion programme with child at centre, including range of potential carers/ those influencing activity (family, friends, schools, community, stakeholders, local policy and media).	Multi-level, including Child: knowledge Parents: knowledge School: knowledge, Policies change Community: knowledge [Socio-ecological theory]	2 school y (09/08-04/10)	Change in hrs of sports club and after-school activity participation (2o)	Question-naire	Sport: 0 After-school: 0	4
De Craemer et al (2014) [64] Belgium	cRCT - Toybox	27 Kindergartens in Flanders n=472 (55% M)	4.43±0.55y	Kindergartens	Health promotion programme with children within centres, PA component implemented in ws 5-8, with 2-w repetition period in ws 19-20. Materials provided to be used for minimum of 1hr/w. Newsletters (with key messages on PA) and tip-cards sent home.	Multi-level, including Child: knowledge Parents: knowledge School: curriculum materials, provider knowledge, provider training [PRECEDE-PROCEED,	24 w	Change in total PA on w days,	Accelero-meter	Total PA: 0	5

						intervention mapping]					
Elder et al (2014) [72] USA	RCT "MOVE/ Me Muevo"	30 sites n= 541 (45% M; 41% H)	6.6±0.7y	Recreation centres	Tailored to the family's needs to target physical and social aspects of the home environment. Initial call; 1.5hr group workshop and 1hr home visit. Tip sheets to promote healthy eating and physical activity to their children. PA:(i) increase the amount of MVPA to 60 min/d; (ii) increase PA opportunities; (iii) increase the variety of fun, developmentally/ culturally appropriate PA.	Multi-level, including Parents: knowledge, social support Centre: facilitator training Community: awareness [No theory identified]	2 y	Change in total active time	Accelero-meter	Total PA: +	6
Eliakim et al (2007) [65] Israel	RCT	4 preschools n=101 (55% M; upper middle class)	5.5y	Preschools	Health promotion programme (4mo) PA: 45min/d of exercise (6 day/w), twice co-ordinated by a professional youth coach; sessions spilt into 3x15min sessions. Training: duration, intensity, co-ordination and flexibility plus reduce sedentary time & increase after school PA.	Multi-level, including Children: Skills training Preschool: Additional PA time; additional providers [No theory identified]	14 w	Change in total daily steps	Pedo-meters	Steps: +	5
Engelen et al (2013) [48] Australia	cRCT	12 schools n=221 (54% M; ICSEA: 980-1170)	6.0±0.6y	Catholic Primary Schools	Playground-based intervention introducing portable equipment (13ws) and a 2-hour teacher-parent intervention exploring risk administered (2-3 ws post playground intervention initiation).	Multi-level, including Parents: knowledge School environment: change in environment, provider knowledge [No theory identified]	13 w	Change in cpm, MVPA daily	Accelero-meter	cpm: 0	5
Fitzgibbon et al (2005) [11] USA	cRCT - Hip-Hop to Health Jr	12 Headstart centres n=409 (50% M; I: 99% AA, 1% O; C: 80.7% AA, 12.7% H, 6.6% O)	I: 48.6±7.6 mo; C: 50.8±6.4mo	Headstart centres	Health promotion programme. 40min sessions 3/w, covering a different theme: 20 minutes of introducing health promoting topic and 20 minutes of PA, including the use of colourful puppets. Parents received a weekly newsletter, covering healthy eating, PA and a homework task (5mins daily or 15mins one off)	Multi-level, including Children: knowledge, Parents: knowledge Preschool: Additional PA time, curriculum materials [Social cognitive theory]	14 w	Change in PA (2o)	Parental self-report: frequency/ intensity (% >7 x /w, Borg scale)	Frequency: 0 Intensity: 0	5
Fitzgibbon et al (2006) [55] USA	cRCT - Hip-Hop to Health Jr	12 Headstart centres n=293 (50% M; I: 15.8% AA, 73.3% H, 10.9% O; 6.5%; C: AA, 89.4% H, 4.0% O)	I: 50.8±7.3 mo; C: 51.0±7.0mo	Headstart centres	Health promotion programme. 40min sessions 3/w, covering a different theme: 20 mins on nutrition (food pyramid) and 20 mins aerobic PA. Parents received 12 homework assignments during the 14-week intervention (with incentive).	Multi-level, including Children: knowledge Parents: knowledge Preschool: additional PA time, curriculum materials [Social cognitive theory]	14 w [1 and 2 y post intervention]	Change in PA (2o)	Parental self-report frequency/ intensity (% >7 x /w, Borg scale)	Frequency: 0 Intensity: 0	5
Fitzgibbon et al (2014) [56] USA	cRCT - Hip-Hop to	18 Headstart centres n (baseline)=223 (44% M;	I: 50.7±6.8mo	Headstart programmes	Health promotion programme. 40mins 2/w (optional 3rd). 20 mins	Multi-level, including Children: knowledge	14 w	Change in MVPA	Accelero-meter	Cpm: 0 MVPA: +	5

	Health	I: 97% AA, 1% H, 2% O; C: 91% AA, 5% H, 4% O) n(follow-up)=190	C: 51.9±6.3mo		on nutrition (food pyramid) and 20 mins aerobic PA, incorporating musical CD for teachers. Parental homework: 6 areas related to cultural practices and beliefs: food, family, music, community, social roles, and relationships.	Parents: knowledge Preschool: additional PA time, curriculum materials [Social cognitive and self-determination theory]		(min/d) and counts/min (2o)			
Fitzgibbon et al (2013) [73] USA	cRCT - Hip-Hop to Health	4 centres n(baseline)=146 (50% M; 94% H; 2% AA; 4% O) n (follow-up)=123	54.2±5.0mo	Early Childhood education programmes	Health promotion programme. 40min sessions 3/w, covering a different theme: 20 mins on nutrition (food pyramid) and 20 mins aerobic PA. Parents also participated in a 30min exercise session. Parent component: 6x90min/w (60 mins of interactive instruction on diet and PA, 30mins MVPA classes) + Newsletters for a lower-income, Hispanic population.	Multi-level, including Children: knowledge Parents: knowledge, PA classes Preschool: additional PA time, curriculum materials [Social cognitive theory]	14 w	Change in cpm / MVPA (2o)	Accelero-meter	Cpm: 0 MVPA: 0	5
Hannon and Brown (2008) [37] USA	Pre-post intervention	1 centre n=64 (47% M; predominantly W)	3.9±0.8 y	Preschool	Introduction of age-appropriate portable toys in playground on intervention days, including hurdles, hoops, tunnels, balance beams, balls	Preschool: change in environment [No theory identified]	5 d pre/ post	Change in % MPA/VPA outdoor play/d	Accelero-meter & OSRAC-P	MPA: + VPA: +	5
Jones et al (2011) [83] Australia	Non-randomised pilot "Time 2bHealthy"	Overweight preschool children and parents; n(baseline)=46 (~80% parents had degree/ tech trade cert) n(follow-up)=40	2-5 y	Home based	Interactive online parental education and discussion forums (5 modules, each module lasting 2 weeks) to promote healthy lifestyles in overweight preschool-aged children.	Parents: knowledge, parenting skills, social support. [Aligned to Healthy Eating and Physical Activity (Australian Government)]	10 w	Change in PA behaviours	Parental self-report	Child doing regular PA: +	2
Jones et al (2011) [51] Australia	Pilot RCT "Jump Start"	2 low-income centres n=97	4.1y	Preschools	Structured lessons 3x week for 20 weeks: 20-min lesson focused on one fundamental movement skill. Each skill comprised a number of components, e.g. running had four. Practice through fun activities and games. Unstructured activities facilitated in the afternoons for practice with equipment.	Multi-level, including Children: motor skills Preschool: provider training (2hr) [No theory identified]	20 w	Change in cpm	Accelero-meter	cpm: 0	3
Klohe-Lehman et al (2007) [58] USA	Non-randomised trial	Low-income, overweight or obese mothers n=235 (62.6% H)	1-3y (mean 2.1y)	Public health clinics / groups	Weight loss intervention for mothers (8x weekly 2-hr classes: 15-min weigh-in, 1.25-hr discussion and activities, 30-min exercise). Delivered by registered dieticians.	Multilevel, including Parents (mothers) knowledge, modelling, parenting skills Home environment opportunities for PA	8 w	Change in PA (mothers & child)	Toddler Behavior Assessment Questionnaire (TBAQ)	Change PA: +	3

						[Social Cognitive Theory]					
O'Dwyer et al (2012) [44] UK	cRCT	8 preschools n=79 (52% M)	<5y	Home based	5 sessions (70 minutes: 10 mins registration, 60 mins delivery) 1 every 2ws. Parents and children separate for first 20mins, 40 mins spent together as a group. Active play for children delivered by play workers, educational workshop for parents. Parents monitored PA at home with logbook, linked to a reward system. Text message reinforcement.	Multilevel, including Children: additional PA time Parents (mothers) knowledge, modelling, monitoring [Socio-ecological theory]	10 w	Change in total weekday PA	Accelero-meter	Weekday PA: +	6
O'Dwyer et al (2013) [45] UK	cRCT	12 centres n=240 (56% M; I: 84.3% W; C:75.3 W)	3.7±0.6y	Sure Start centres	Active play intervention (60mins 1/w) with staff training to deliver active curriculum. 2-2-2 format: 2ws practitioner, 2 ws co-delivery, 2 ws teacher, with practitioner facilitating. Resource pack provided to preschools along with user manual and exemplar lesson plans and promotion poster.	Preschool: staff training, additional staff [Socio-ecological theory]	6 w [& 6 mo]	Change in MVPA	Accelero-meter	MVPA: 0	6
Ostbye et al (2013) [74] USA	RCT – KAN-DO	Patient records n=400 (56% M)	3.1±1.0y	Healthcare	8 monthly mailed interactive kits; 20–30 min motivational interviewing coaching session via phone. Kits included activities and incentives Targeted healthy weight via instruction in parenting styles and skills, techniques for stress management and education. One semi-structured group session also included: a healthy meal and free childcare were provided.	Multi-level, including Children: monitoring Parents: knowledge, social support, monitoring [Socio-cognitive theory]	8 mo	Minutes of MVPA per day	Accelerome ter	MVPA: 0	6
Puder et al (2011) [75] Switzerland	cRCT - Ballerbina	40 centres n=652 (50% M; 40% speak foreign language at home; 62% with 2 educated parents)	5.1±0.7y	Preschools	Multidimensional culturally tailored lifestyle intervention, with workshops, lessons, home activities, offers of extracurricular activities and adaption of the built environment. Teacher training (2 workshops); PA programme (4x45mins/w with CD); Activity cards to take home; 1 meeting of parents and teachers.	Multi-level, including Children: skills and fitness Parents: knowledge, participation, social support Preschool: provider training, change in built environment, social support, additional PA time, curriculum materials [Socio-ecological theory]	11 mo	Change in PA (2o)	Accelero-meter	Accelerometer: 0	6
Stark et al (2011)	Pilot RCT	Children with BMI ≥	2-5y	Home &	Enhanced Pediatric Counselling.	Multi-level, including	36 w [6 and	Change in	Accelero-	MPA: 0	5

[76] USA	"LAUNCH"	95th% and 1+ overweight parent n=15	(mean 4.7 ± 1.1y)	clinics	Intervention and maintenance: 12 wly and 2 wly sessions (Group-based clinic parent-child sessions or individual home visits. Children and parents given pedometers and goals of 5,000 and 10,000 steps/d, as feedback. Delivered by paediatricians and psychologists at parent-groups, child-groups and home visits.	Children: knowledge, goals Parents: knowledge, parenting skills, parental modelling, goal setting [Social Cognitive Theory]	12 mo]	MPA, VPA (2o)	meter	VPA: 0	
Stratton and Mullan (2005) [39] UK	Pilot RCT	4 schools n=54 (46% M; low SES areas)	4-7y	Primary Schools	Playgrounds markings; painted in bright fluorescent colours according to school preference: e.g. castles, dragons, clock faces, mazes, fun trails, dens, hopscotch, letter squares, snakes and ladders	Preschool: change in environment [No theory identified]	6 mo	Heart rate; Play time in MPA, VPA	Telemeter	MPA: 0 VPA: +	4
Trost et al (2008) [38] USA	RCT – Move and Learn	1 centre n=42 (55% M; 23.7% with high school diploma)	4.1±0.7y	Childcare centre	PA opportunities integrated into all aspects of the preschool curriculum. Teachers were required to include 2 Move and Learn curriculum activities lasting 10mins or longer in each 2.5-hr session (4/d). Activities were typically repeated several times throughout the week.	Preschool: Additional PA time, Provider training [No theory identified]	10 w	Change in MVPA	Accelero-meter & OSRAP	MVPA (w5-8): +	2
van Cauwenerghe et al (2012) [43] Belgium	Pilot intervention	4 preschools n=128 (55% M)	4-6y	Preschools	Lowering playground density	Preschool: change in environment [No theory identified]	1 w	Change in daily LMVPA	Accelero-meter	Daily LMVPA: 0	5
Verstestel et al (2015) [70] Belgium	Pilot RCT	60 centres n=203 (54% M)	15.5± mo	Daycare centres	Family-based healthy lifestyle intervention: improve diet, PA levels and decrease screen-time. Two components: (i) guidelines and tips on poster with stickers (every 2 months, along with additional tip sheet) (ii) a tailored feedback form for parents about their children's activity- and dietary- related behaviours.	Multi-level, including Children: goal setting Parents: knowledge, goal setting, monitoring [Information processing; Elaboration likelihood model; Precaution-adoption-process model]	1 y	Time spent in PA	Question	PA time: 0	4
Wen et al (2012); Wen et al (2015) [84,106] Australia	Non-randomised intervention "Healthy Beginnings"	Low-income mothers n=465 (11% spoke language other than English at home)	From birth	WIC sites	8 home visits from nurses delivering staged home-based intervention: one antenatal visit, then at 1, 3, 5, 9, 12, 18, and 24 months after birth, with ongoing telephone support. One hour visits: monitoring the parent-child feeding interaction and practice, and behaviours promoting physical activity/inactivity in the	Parents: parenting skills, social support [No theory identified]	2 y, 5 y post intervention	Outdoor play ≥120 min/d	Questionna ire	Outdoor play: 0	5

					child. Needs identified with checklist and fed back. Problem-solving, individualized information kit and phone feedback provided.						
Whaley et al (2010) [57] USA	Non-randomised trial "Child health and intervention research project" (CHIRP)	Low-income mothers n(baseline)=821, (94% H; 50% mothers of M); n(follow-up)=589	1-5y (mean 23 ± 9.2 mo)	WIC sites	Enhanced questionnaire and 1-2-1 MI with mothers to discuss one of 6 health behaviour topics [PA: getting up and moving more] at their 6 monthly WIC recertification appointments. Delivered by WIC staff using motivational interviewing techniques.	Parents motivation, social support [Trans Theoretical Model]	1 y: 6 mo & 12 mo	Engaging in > 60 min of PA (d/w)	Question-naire	Engaging in PA: 0	3
Yin et al (2012) [66] USA	Pre-post intervention	4 centres n=390 (59% M; 62% normal weight; predominantly H)	4.1±0.56y	Headstart centres	Home, centre and curriculum based intervention for diet and physical activity. Factorial design (centre, home, centre and home). Centre based including staff training, curriculum resources and 60mins structured and free play/d. Home based peer-led parent obesity education, homework, family support and monitoring for PA.	Multi-level, including Children: motor skills Parents: knowledge, social support, monitoring Preschool: provider training, additional PA time [Early child development and systems approach]	18 w	Steps/ min in outdoor play	Pedo-meters	Steps/min in outdoor play: +	4

PA: physical activity; RCT: randomised controlled trial; cRCT: cluster randomised controlled trial; KAN-DO: Kids and Adults Now – Defeat Obesity!; SPARK: Sports, Play, and Active Recreation for Kids; SPARKLE: Study of Preschool Activity, Lifestyle and Energetics; LAUNCH: Learning about Activity and Understanding Nutrition for Child Health; FLAME: Family Lifestyle, Activity, Movement, and Eating; ICSEA: The Index of Community Socio-Educational Advantage; PRECEDE-PROCEED: Predisposing, Reinforcing and Enabling Constructs in Educational Diagnosis and Evaluation - Policy, Regulatory, and Organizational Constructs in Educational and Environmental Development; OSRAP: observation system for recording activity in preschools; OSRAC-P: Observational System for Recording Physical Activity in Children-Preschool Version; MI: motivational interviewing; I: Intervention group; C: Control group; cpm: counts per minute; cpe: counts per epoch; cp15: counts per 15 seconds; LPA: Light physical activity; MPA: moderate physical activity; MVPA: moderate to vigorous physical activity; VPA: vigorous physical activity; LMVPA: Total physical activity (i.e. light, moderate and vigorous physical activity; TEE: total energy expenditure; SES: Socio-economic status; M: male; W: White; AA: African American; H: Hispanic; NA: Native American; O: Other racial group; PI: Pacific Islander; 2o: measured as secondary outcome; BMI: Body Mass Index; w/e: weekend; w/d:weekday; d: day; hr: hour; w: week; y: years; mo: months; N/A: Not applicable; WIC: Women, Infants and Children; +: statistically significant positive effect of intervention; 0: no effect of intervention; a: Score out of 6 for prospective and 7 for intervention studies.

Table 3 Determinants assessed in prospective and intervention studies

	Association with change in physical activity				
Determinant	-	0	+	Studies showing positive association	Outcome
INTRAPERSONAL (child)					
Sex (boys)				2/5	??
Questionnaire	[77]				
Total Activity (counts per epoch)		*[60]*	[79]		
MVPA		[78]	*[61]*		
Motor/ skill training [a]				5/10	??
Total Activity (counts per epoch)		[50,51,75]			
Pedometer		[80]	[65,66]		
MVPA		[52],	[46,47,54]		
Knowledge[a]				1/11	00
Questionnaire		[71,11,55]			
Total Activity (counts per epoch)		[50,73,56,75]			
Pedometer			[42]		
MVPA		[64,76,81]			
Goal setting[a]		[76]		0/1	0
Monitoring[a]				1/3	0
Questionnaire		[70]			
Pedometer			[42]		
MVPA		[82]			
Fitness[a]		[75]		0/1	0
INTERPERSONAL					
Family demographics					
Maternal SES		*[60]*		0/1	0
Sibling PA level		*[61]*		0/1	0
Parental psychosocial					
Maternal reinforcement		*[61]*		0/1	0
Paternal reinforcement		*[61]*		0/1	0

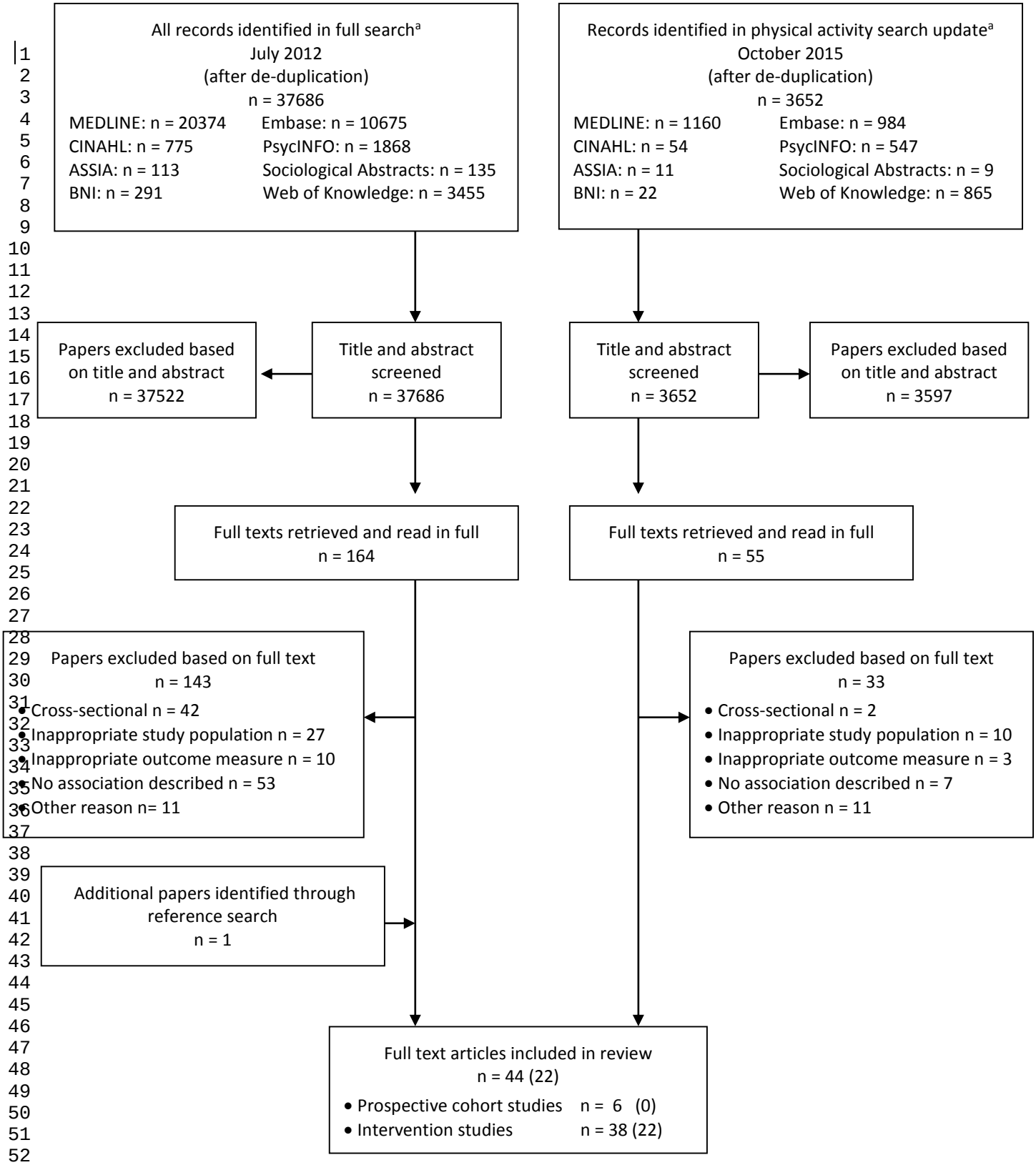
Maternal Role-modelling[a]			3/3	+
Questionnaire		[58]		
MVPA		*[61]*[44]		
Paternal role-modelling	*[61]*		0/1	0
Parental role-modelling[a]			0/3	0
Questionnaire	[70]			
MVPA	[76,82]			
Parental monitoring[a]			4/6	++
Questionnaire	[70]	[69]		
Total Activity (counts per epoch)	[72]			
Pedometer		[42,66]		
MVPA		[44]		
Parental motivation[a]			1/4	00
Questionnaire	[57]			
Total Activity (counts per epoch)	[72]	[49]		
MVPA	[82]			
Parental goal setting[a]			2/4	??
Questionnaire		[83,69]		
Total Activity (counts per epoch)	[72]			
MVPA	[76]			
Parental knowledge[a]		,	7/22	00
Questionnaire	[71,11,55,70]	[83,58,69]		
Total Activity (counts per epoch)	[48,50,75,56,73,72]	[49]		
Pedometer	[80]	[42,66]		
MVPA	[64,81,76,82]	[44]		
Parent skills[a]			2/7	00
Questionnaire	[84]	[83]		
Total Activity (counts per epoch)	[51]	[49]		
MVPA	[81,76,82]			
Parental self efficacy[a]			1/4	00
Questionnaire	[70,57]			
Pedometer		[66]		
MVPA	[82]			
Parental social support[a]	,		2/5	??
Questionnaire	[84]	[83,69]		
Total Activity (counts per epoch)	[75,72]			
Parental Behaviour				

Maternal co-participation	*[61]*		0/1	0
Paternal co-participation	*[61]*		0/1	0
Parental co-participation[a]	[75]		0/1	0
Siblings co-participation		*[61]*	1/1	+
Family participation	*[61]*		0/1	0
Maternal direct support	*[61]*		0/1	0
Paternal direct support	*[61]*		0/1	0
Opportunities for play[a]			2/2	+
Questionnaire		[58]		
MVPA		[44]		
ORGANISATIONAL				
Preschool environment				
Provider training*			8/16	??
Total Activity (counts per epoch)	[50,51,75,72]	[49]		
Pedometer	[80]	[66]		
MVPA	[45,52,64]	[38,44,46,47,53,54}		
Provider knowledge[a]			0/2	0
Total Activity (counts per epoch)	[48]			
MVPA	[64]			
Provider social support[a]	[75]		0/1	0
Additional providers[a]			2/3	+
Total Activity (counts per epoch)		[49]		
Pedometer		[65]		
MVPA	[45]			
Increased active time[a]	[11,55]		4/11	??
Questionnaire				
Total Activity (counts per epoch)	[56,73,75]			
Pedometer		[65,66]		
MVPA	[40,45]	[38,53]		
Structured physical activity[a]		[53]	1/1	+
Playground density (low) [a]		[43]	1/1	+
Playground markings[a]	[41]	[39]	1/2	0
Portable equipment[a]			1/5	00
Total Activity (counts per epoch)	[41,48,50,75]			
MVPA		[37]		
Curriculum materials[a]			2/11	00

Questionnaire	[11,51,71]			
Total Activity (counts per epoch)	[50,56,70,73]	[49]		
Pedometer	[80]			
MVPA	[64]	[53]		
Preschool policy change[a]	[71]		0/1	0
Centre monitoring/ feedback[a]	[72]		0/1	0
COMMUNITY				
Community awareness[a]			0/3	0
Total Activity (counts per epoch)	[72]			
Pedometer	[71]			
MVPA	[81]			
TEMPORAL				
Time of the day	*[62]*		0/1	0
Time of the week	*[62]* [78]		0/2	0
Season	*[62]*		0/1	0

Italicised reference numbers indicate prospective studies, all others are intervention studies; a: Intervention components; SES: socio-economic status; PA: physical activity; MVPA: moderate-to-vigorous physical activity. For 1-3 studies: 0: 0-33% of papers support positive/negative association; ?: 34-59% support positive/negative association; +/ -: 60-100% support positive or negative association. For ≥4 studies: 00: 0-33% of papers support positive/negative association; ??: 34-59% support positive/negative association; ++/--: 60-100% support positive or negative association.

Figure 1 Flowchart outlining identification of papers for inclusion



a: Full search conducted including terms for all health behaviours (i.e. diet, physical activity), physical activity search update included terms for physical activity behaviours only; ASSIA: Applied Social Science Index and Abstracts; BNI: British Nursing Index.

Determinants of Change in Physical Activity in Children 0-6 years of age: A Systematic Review of Quantitative Literature

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Key Points

- Forty-four determinants of change in young children's physical activity were assessed across 44 papers, predominately in the intrapersonal, interpersonal and organisational domain.
- Although 14 determinants were assessed in 4 or more studies, only parental monitoring was consistently positively associated with change in physical activity

and provider training associated with change in moderate-to-vigorous physical activity.

- Evidence in community and policy domains, and from low/middle-income countries, is required.

Abstract

Background: Understanding the determinants of children's health behaviours is important to develop successful behaviour-change interventions.

Objective: We aimed to synthesise the evidence around determinants ('preceding predictors') of change in physical activity (PA) in young children (0-6 years of age).

Methods: As part of a suite of reviews, prospective quantitative studies investigating change in physical activity in children aged 0-6 years were identified from eight databases (to October 2015): MEDLINE; Embase; CINHAL; PsycINFO; Web of Knowledge; British Nursing Index; Applied Social Sciences Index and Abstracts; and Sociological Abstracts. Determinants and direction of association were extracted, described and synthesised according to the Socio-ecological model (individual; interpersonal; organisational; community; policy).

Results: Forty-four determinants, predominantly in the interpersonal and organisational domains, were reported across 44 papers (6 prospective cohort, 38 intervention); 14 determinants were assessed in four or more papers. Parental monitoring showed a consistent positive association with change in PA; provider training was positively association with change in children's moderate-to-vigorous PA only. Five (sex; parental goal setting; social support; motor skill training; and increased time for PA) showed no clear association. A further seven (child knowledge; parental knowledge; parental motivation; parenting skills; parental self-efficacy; curriculum materials; portable equipment) were consistently not associated with change in children's PA. Maternal role-modelling was positively associated with change in PA in all 3 studies in which it was examined.

Conclusions: A range of studied determinants of change in young children's PA were identified, but only parental monitoring was found to be consistently positively associated. More evidence in community and policy domains, from low/middle-income countries, and lesser-explored modifiable family- and childcare-related determinants is required.

International Prospective Register for Systematic Reviews (PROSPERO) Registration number: CRD42012002881

1 Background

By the age of five, over 1 in 5 children are overweight or obese the UK and US.[1,2] Obesity in childhood is associated with a range of unfavourable outcomes including type 2 diabetes, hyperlipidaemia, and psychosocial problems,[3] with obesity known to track and be associated with unfavourable outcomes in adulthood.[4,5] Early childhood is a period of rapid growth and development, and the preschool years (defined here as up to the age of 6 years) are therefore ideal to both prevent and reverse unhealthy weight gain, by establishing healthy habits and behaviours.

As a result, interventions aiming to effect positive dietary, physical activity and sedentary behaviour change have been developed to prevent or halt obesity in the preschool years.[6–9] However, with a few notable exceptions,[10–12] many of these intervention studies showed small effects which are not sustained over time, or have no effect at all.[6–9] One difficulty in establishing the reasons for a lack of intervention success is that multiple behaviours are often targeted simultaneously.[8,9] However, as each health behaviour has an independent significant impact on children's health,[13,14] it is important to establish the most important determinants of each individual behaviour, and therefore how they may differ across behaviours. The socio-ecological model (SEM)[15] is a commonly used framework for categorising levels of influence on behaviours,[16,17] classifying them into five broad categories: individual; interpersonal; organizational; community; and public policy. By grouping potential influences on behaviour in this way, commonalities and differences can be identified and subsequently used to develop more targeted interventions to effectively change children's health behaviours.[18]

In addition to consuming a balanced nutritious diet, children up to the age of 5 years are recommended to engage in 180 minutes of physical activity daily.[19,20] In addition to higher levels of physical activity being associated with decreased adiposity in preschool-aged children, it is positively associated with motor skill development, psychosocial health, and with decreased cardio-metabolic risk prospectively.[13] Cross-sectional studies in older preschool-aged children (2 years and over) also indicate that increased physical activity is linked to better gross motor control[21] and improved social

skills.[22] Yet despite the importance of physical activity for young children's health and development,[13] studies suggest that young children do not engage in sufficient levels of physical activity.[23]

In order to specifically increase physical activity in targeted interventions, it is important to establish which factors influence activity behaviour.[24] A number of systematic reviews have been conducted to examine the associations between cross-sectional factors ('correlates') and young children's physical activity.[16,25,26] A broad range of correlates have been investigated, including demographic, biological, environmental, social, and psychological influences. Although conclusions about the influences on physical activity differ between reviews,[25,27] there is a suggestion that familial influences,[16,25,26] time spent outside[25] and elements in the physical environment[25,27] may be associated with increased activity in preschoolers. An additional review,[28] including cross-sectional studies and a small number prospective cohorts, also suggests that home influences may be key for young children's physical activity. However, it is difficult to draw firm conclusions about causality from cross-sectional studies. It is therefore necessary to use evidence from both prospective and intervention studies as these provide the best evidence to establish the longitudinal predictors (or 'determinants') of change in young children's physical activity, and to aid understanding of how to effect positive behaviour change.

This systematic review is part of a suite of reviews to explore the determinants of obesogenic behaviours in children 0-6 years (focussed on fruit and vegetable intake; sugar sweetened beverages and unhealthy diet intake; physical activity and sedentary behaviour).[29,30] It aims to synthesise the quantitative literature from prospective and intervention studies to ascertain the determinants (a 'preceding predictor') of change in physical activity in young children. It also aims to establish which (modifiable) determinants are associated with change; at which levels of influence these factors operate (i.e. individual, family, childcare setting, community or policy level); and where gaps in the literature exist for future research.

2 Methods

The protocol for this review project has been described previously.[29] The International Prospective Register for Systematic Reviews (PROSPERO) Registration number is CRD42012002881. Following established criteria for the rigorous conduct and reporting of systematic reviews,[31,32] this review was carried out in three stages.[33,34] One search (led by HM) was conducted to identify studies across all reviews; at the data extraction stage, smaller teams led each of the reviews focusing on specific behaviours of interest (i.e. physical activity (Review lead: KH), fruit and vegetable consumption (COM), sugar sweetened beverages (VP)). KH also conducted the search update specific to physical activity in October 2015.

2.1 Generic Review Methods

2.1.1 Identification of studies for review

A systematic search, common to all reviews, was undertaken in August 2012. Four sets of search terms were used related to: the population; study design (capturing observational, intervention, and review articles); outcome; and exclusion of clinical populations. An extensive scoping phase was conducted prior to implementing the full search to maximize sensitivity and specificity of included papers. This involved contacting experts in the field and identifying key publications to be included for each behaviour, with searches run to ensure that these publications were captured. An electronic search was conducted in eight databases (MEDLINE, Embase (via OVID), CINHAL, PsycINFO (via EBSCO), Web of Knowledge (via Thomson Reuters), British Nursing Index (BNI), Applied Social Sciences Index and Abstracts (ASSIA) and Sociological Abstracts (via ProQuest)). Citations were downloaded into Endnote citation management software (Thomson Reuters, Philadelphia, PA, USA). Included papers were searched for additional relevant publications, as were relevant reviews. No language restrictions were placed on the search, but articles were limited to published full texts. An updated search was conducted in October 2015, to capture studies with outcomes relating to physical activity only, published in the interim period (Electronic Supplementary Material Table S1).

2.1.2 Study selection

In 2012, two batches of 500 titles and abstracts were screened for inclusion by the review leads (KH, VP, COM) and checked for fidelity by a fourth reviewer (CS). With less than a 5% discrepancy, each reviewer subsequently screened approximately 12,000 papers individually. For quality control, two random 5% samples (total n=3600) were double screened by two additional reviewers (RL and EvS). All full texts were obtained and distributed for the behaviour-specific reviews to progress in parallel. Additional texts retrieved in 2015 were screened by KH and a subsample (15%) reviewed by EvS.

2.2 Methods for Physical Activity Review

2.2.1 Inclusion/ exclusion criteria

Articles were included if a) they reported results from either a longitudinal observational study, randomized controlled trial (RCT) or controlled trial (CT), b) quantified a within-child change in physical activity behaviour (as primary/second outcome in interventions) and c) assessed at least one potential determinant of change. Children had to be aged between 0-6 years at baseline, and studies assessing physical activity using objective or subjective measures were included. Exclusion criteria included: i) clinical populations (e.g. children who were malnourished; had asthma, cerebral palsy, cystic fibrosis, autism etc.) ii) non-human studies; iii) quantitative cross-sectional studies; iv) qualitative studies v) and laboratory-based studies (e.g. validation studies).

2.2.2 Quality Assessment

For descriptive purposes, a quality appraisal of each of the included studies was conducted focusing on internal and external validity using assessment criteria adapted from those used previously[34,35] (Electronic Supplementary Material Table S2). Criteria included: sample representativeness, size and retention, use of objective exposure and outcomes measures, appropriateness of analysis strategy, and randomisation method for RCTs. Scores out of 6 (or 7, for RCTs) were allocated and categorised accordingly (high quality: ≥5; medium: 3 - 4; low: 1 - 2).

2.2.3 Data extraction

All full texts identified for inclusion were read by KH, and double screened for inclusion by EvS. For relevant papers, data were extracted using a standardized form. Data extracted included first author; publication year; country; study design, setting and population; and baseline descriptive characteristics. Data were also extracted about physical activity measurement and outcome; potential determinants; method of analysis; duration of follow-up; loss to follow-up; and results. All outcome measures used in prospective and intervention studies (e.g. percentage time or minutes spent at differing activity intensities (i.e. light (LPA), moderate (MPA), vigorous (VPA), moderate to vigorous (MVPA) or total activity (LMVPA)) were extracted. However, in some studies, activity was only assessed during specific periods (i.e. at weekends, during recess). In an attempt to standardise findings across studies, where more than one physical activity outcome was reported, we report total physical activity/ counts per epoch (given current guidelines for young children's activity[19,20]), followed by MVPA, LPA and MPA/VPA. For intervention studies, each of the described elements targeted in the intervention (e.g. parental knowledge, parental modelling) were extracted as potential determinants of change in physical activity. For each determinant, the smallest included sub-sample was considered for extraction (e.g. if stratified by sex). Where results were stratified by specific times of the day, results for the largest time periods were reviewed and extracted. For longitudinal studies, the latest data available before the children were 6 years old was included; where two or more papers reported on the same study sample, both were included if they reported determinants associated with different outcome measures. For intervention studies, we assessed the difference in physical activity between control and intervention groups over time to classify determinants, as this provided evidence of factors targeted in interventions (i.e. determinants) which were associated with change. Where possible, results of multivariable rather than univariable models were included.

2.3 Data synthesis

Narrative data synthesis was undertaken for all studies. Due to the heterogeneous nature of included quantitative studies and the physical activity outcomes used, meta-analysis

was not appropriate. Each extracted determinant was scored based on direction and strength of evidence: '−' significant decrease in physical activity; '0' no significant association/effect or '+' significant increase in physical activity. Evidence from cohort and intervention studies were weighted equally, as both provide prospective determinants of change in physical activity behaviour. As per previous reviews,[16,17,36] consistency across studies for any given determinant was then summarized according to the following metric: '0' (no association) if supported by 0–33% of individual studies; '?' (indeterminate/possible) if supported by 34–59%; and '+' or '−' if supported by 60–100%. Where four or more studies reported on a potential determinant, double indicators were used (e.g. '00', '??', '++' and '− −') to indicate greater levels of evidence and therefore confidence in findings. Determinants, study score and consistency across studies were then presented according to the SEM (individual; interpersonal; organisational; community; and policy).[17,36]

3 Results

A total of 37,686 (full review) and 3,652 (physical activity-specific update) references were retrieved in 2012 and 2015 respectively, of which 220 were read in full and 44 papers included for review (representing 42 study samples: 4 prospective cohort and 38 intervention studies, see Figure 1). A descriptive summary of the included study samples is presented in Table 1; study-specific information is provided in Table 2.

3.1 Summary of Study Characteristics

Study samples originated in the USA (n=24), Australasia (n=6) and Europe (n=12); no papers were identified from developing nations, and all bar one was published after 2003. Of included studies, 15 (34%; 13 intervention, 2 prospective) had a final sample size greater than 250 children, and most included similar numbers of boys and girls. Objective measures of physical activity were used in 34 (77%) papers (accelerometer: 27; pedometer: 4; heart-rate/ Actiheart: 3) although those paper using proxy-report measures were also included (n=10; 1 prospective, 9 intervention). Interventions often targeted a number of behaviours, including diet and sedentary behaviour, but 18 (38%) specifically aimed to increase physical activity.[37–54] The measurement period (from baseline to

last contact) was a median 2.5 years (range: 1-5 years) for prospective papers and 34.5 weeks (range: 1 day to 5 years post-intervention) for intervention papers. One prospective paper and 26 intervention papers (61%) were deemed to be of high quality (score ≥ 5), 9 were of medium quality (score 3-4) and 6 were low quality (score of 2). Of the intervention studies, 28 (64%) randomised participants. Most study samples drew participants from White populations; some targeted lower socioeconomic or racial minority groups.[11,55–58] A retention rate of ≥70% was reported in 20 papers (46%), and 27 intervention studies reported final analysis samples by study group, indicating similar levels of attrition.

3.2 Overview of prospective and intervention studies

A total of 44 potential determinants of change were reported (Table 3) across papers. The same cohort study (Children Living in Active Neighborhoods (CLAN) [59]) was described in three[60–62] of the six prospective papers. One paper describing this study contributed all 16 determinants identified across prospective studies in intrapersonal, interpersonal and temporal domains. This paper predominantly reported on determinants relating to parental influence on change in physical activity.

The 38 intervention studies targeted 28 potential (modifiable) determinants at intrapersonal (n=6), interpersonal (n=10), organisational (n=10) and community levels (n=1). No determinants at the policy level were identified across included studies. Of the 38 intervention studies, 27 (68%) were classified as multi-level;[11,42,44,46–48,50–52,54–56,58,63–76] these most commonly targeted individual/ interpersonal (i.e. children, parents, teachers) and organisational (i.e. preschool/ home environment) factors. Of these, 11 multi-level interventions (42%) effected a positive change in children's physical activity,[42,44,46,47,54,58,63,65,66,69,72] though no clear effective combinations of components emerged. Across all prospective studies, positive effect sizes were generally small, with increases of less than 10% in total activity or MVPA from relatively low baseline levels.

3.3 Determinants identified in four or more studies

Fourteen determinants were assessed in four or more studies. One, sex, was reported in five prospective papers [60,61,77–79] (from 4 study samples: the association between sex and two different outcome measures were assessed within the same CLAN study sample). The remaining 13 determinants, reported four or more times, were all intervention components, including at the intrapersonal level: motor/skills training[46,47,50–52,54,65,66,75,80] and child knowledge[11,42,50,55,56,64,71,73,75,76,81], and at the interpersonal level: parental monitoring[42,44,66,69,70,72]; parental motivation [49,57,72,82]; goal setting[69,72,76,83]; parental knowledge [11,42,44,48–50,55,56,58,64,66,69–73,75,76,80–83]; general parental skills[49,51,76,81–84]; parent self-efficacy[57,66,70,82]; parental social support[69,72,75,83,84]; and provider training[38,44–47,49–54,64,66,72,75,80]. Those determinants at the organisational level included: more physical activity opportunities[11,38,40,45,53,55,56,65,66,73,75]; use of portable equipment [37,41,48,50,75]; and supplying curriculum materials[11,49,50,53,55,56,64,71,73,75,80].

Of these 14 more frequently studied determinants, parental monitoring was consistently shown to be positively associated with change in young children's physical activity across intensities, with four of six study samples reporting a positive association. Provider training was also positively associated with change in children's MVPA in six of nine studies[38,44,46,47,53,54] but showed no clear association with physical activity overall (positive association in 8/16 studies), suggesting that determinants may be intensity specific.

Five determinants, across the intra- and interpersonal domains, namely sex (positive association in 2/5 studies); motor skill training (5/10); parental goal setting (2/4); parental social support (2/5); and increased time for physical activity (usually within the care setting; 4/11) showed no consistent association with change in physical activity. In the case of sex, evidence from the CLAN study served to highlight how determinants may differ within the same sample depending on the outcome used and time of follow up (i.e. no association with counts per epoch at first follow up[60] but a positive association

between (male) sex and MVPA at second follow up[61]). For motor skills training[46,47,54,65,66] and increased time for physical activity [38,53,65,66] the majority of intervention studies that found a positive association with change in physical activity used objective measures.

The remaining seven determinants assessed in four or more studies, i.e. child knowledge (positive association in 2/12 studies); parental knowledge (7/22); parenting skills (2/7); parental motivation (1/4); parental self-efficacy (1/4); curriculum materials (2/11); and portable equipment (1/5), consistently showed no association with change in young children's physical activity (i.e. >67% of studies reported no association).

3.4 Determinants identified in fewer than four studies

Determinants assessed in three study samples in the intra/interpersonal domains included child monitoring,[42,70,82] parental role-modelling [70,76,82] and maternal role modelling,[44,58,61], with only the latter shown to be positively associated with change in physical activity in all three studies (one using proxy-reported physical activity[58]). In the organisational domain, increasing the number of care providers within the childcare setting was found to be positively associated with change in two (out of three) intervention studies.[49,65] Community awareness showed no association with change in children's physical activity.[71,72,81] Positive associations with change in physical activity were also found for providing additional opportunities for play within the home (two studies)[44,58] and sibling co-participation (one study)[61], and with structured physical activity[53] and lowering playground density[43] in one study each within the organisational domain.

4 Discussion

This review is the first to synthesise evidence from longitudinal studies relating to the determinants of change in physical activity in preschool-aged children. Forty-four determinants were identified; determinants at the interpersonal and organisational levels were most commonly evaluated. Fourteen determinants were identified in four or more quantitative studies: parental monitoring showed a consistent positive association with

change in physical activity. Provider training was positively associated with change in MVPA, but showed no clear association with physical activity overall. Of the remaining 12 determinants, a further five showed no clear association, and seven were consistently not associated with change in children's physical activity. Moreover, maternal role modelling was positively associated with physical activity in three studies.[44,58,61] A range of modifiable family- and childcare-related elements also showed positive associations with change in young children's activity in fewer studies. Where positive effects on change in physical activity were seen, they were often small in magnitude, particularly in studies reporting accelerometer-measured outcomes. Despite identifying a range of determinants that have been assessed, there appears to be little evidence of what results in positive change in preschoolers' physical activity. Where determinants have shown no positive effect (e.g. child/ parental knowledge) researchers should divert emphasis instead to other potentially influential determinants. Both parental monitoring and maternal role modelling may provide feasible and effective determinants of change; given the lack of longitudinal evidence from the community and policy domains, and with no evidence to date from developing countries, further exploration of possible determinants of change in these areas is also required.

As also shown in cross-sectional studies,[16,25] the association between the child's sex and change in physical activity[60,61,77–79] was not consistent here. In general, boys' absolute levels of physical activity were reported to be higher than those of girls[61,79] suggesting that, regardless of change, boys may remain more active than girls over time. The aim of this review was not to assess whether a determinant was associated with increased physical activity over time, but rather if different levels of a determinant predict differences in change in PA over time. Sex is a good example of this: boys' physical activity may increase over time whilst girls' activity remains stable, or boys' activity may remain stable whilst girls' activity decreases. Although the data available do not allow us to explore the actual direction of change, this is an important consideration for future research. Based on current evidence and quality of measurement, boys appear to be more active than girls, but firm conclusions about the influence of sex on changes in young children's activity over time cannot be drawn.

Determinants in the interpersonal domain were most frequently assessed. Only one determinant, parental monitoring, was consistently positively associated with change in physical activity in both prospective and intervention studies this age group. This was operationalized in a range of ways by increasing parental awareness of the child's physical activity,[66,69] including using log books[44] and pedometers.[42] Although evidence of parental monitoring effecting a positive change in physical activity prospectively in older children is sparse,[85,86] cross-sectional evidence from a small sample of US children (n=99) suggests that where parenting is permissive, parental monitoring may lead to increases in MVPA in children.[87] Evidence tends to suggest that parents tend to over-estimate their children's physical activity in general.[88] Yet conscious parental monitoring of the target behaviour may increase its salience, resulting in a greater number of prompts to be active and therefore higher subsequent physical activity.

Three further studies reported a positive effect of maternal role modelling on children's activity;[44,58,61] this ranged from assessing mothers' own physical activity[61] to increasing maternal awareness and encouraging increased physical activity within families, with or without her child so as to model activity behaviour.[44,58] These findings are supported by qualitative literature, with parents consistently suggesting that active parents and parents as role models were important facilitators of children's activity.[89–94] Positive associations between parents' and children's activity have also been reported previously in cross-sectional studies.[95–97] Intervention studies targeting other interpersonal factors such as increasing parental knowledge[11,42,44,48–50,55,56,58,64,66,69–73,75,76,80–83] or social support,[69,72,75,83,84] and improving parenting skills[49,51,76,81] showed indeterminate associations; both high and lower quality studies reported both positive[42,44,49,58,66,69,83] and no associations[11,48,50,51,55,56,64,70–73,75,76,80–82,84] for these intervention components. It may therefore be that it is parental awareness and their own activity behaviours that are important for their child's activity. Further research is needed to

explore how objectively measured physical activity in preschool-aged children and their parents are associated longitudinally.

Several reviews conducted previously suggest that elements in the preschool environment may be positively associated with children's activity.[27,98] Many intervention studies here specifically targeted the childcare environment, providing curriculum materials or modified elements within childcare settings, but no clear determinants were identified. [11,37,39,41,43,48–50,53,55,56,64,71,73,75,80] Four of the intervention studies used variations of the same 'Hip-Hop-to-Health' intervention,[11,55,56,73] targeting a range of elements in the childcare setting: only one[56] showed a positive sustained effect on accelerometer-measured activity in a predominantly African American population. This highlights that even with a consistent core intervention, factors including cultural variability, differing reported outcomes and intervention fidelity likely influence intervention success.

Yet although environmental childcare determinants showed inconclusive results, of 16 intervention studies incorporating provider training, eight noted positive increases in children's activity[38,44,46,47,49,53,54,66], and MVPA in particular. Interestingly, those interventions showing positive effects often incorporated few additional environmental elements, including providing additional curriculum materials;[49,53] they did however tend to include motor skill training, [46,47,54,66] parental elements[44,66] and/or allocate additional time for physical activity.[38,53,66] Introducing additional providers also led to increased physical activity in two out of three high quality intervention studies, where external gym trainers[49] and professional coaches[65] led physical activity sessions.

Given the increasing amount of time children now spend in childcare, care providers feasibly to play an important role in shaping children's health behaviours. It is not possible here to disentangle which elements of training resulted in positive physical activity change, but encouraging care providers to build on their skill-base and/or confidence in multi-component interventions may be important. Moreover, qualitative

literature suggests that care providers perceive themselves to be both a positive[99–101] and negative[99,102,103] influence on children's physical activity, yet no quantitative studies to date have specifically focused on care-providers own behaviour as a potential determinant. Doing so may be timely given providers believe they can influence children's activity and that young children should be active, but many are not aware of how much physical activity young children require.[104]

Despite an obvious lack of observational research informing intervention development, the majority of intervention studies (68%) were classified as multi-level,[11,42,44,46–48,50–52,54–56,58,63–76] targeting determinants across a range of domains. Though these studies used notionally similar exposures, e.g. targeting children, their parents and changing the preschool environment, inconsistent results were seen. As with all multi-faceted interventions, it is therefore difficult to tease out which components were effective and may explain in part why so few determinants were consistently associated with change in physical activity. Determinants across interpersonal and organisational levels may act synergistically or may counteract each other leading to null results. Although we attempted to determine how each intervention component influenced activity, no formal mediation analyses were identified and further exploration of how elements within an intervention result in positive change would be beneficial. For example, mixed-methods process evaluations may help to delineate determinants of children's physical activity and aid future intervention development.

This review also highlights where research evidence and gaps exist. A large number of (intervention) studies have targeted determinants such as child motor/skills training; child and parental knowledge; provision of extra time for physical activity or curriculum materials; and provider training, with the studies overall showing no or indeterminate effects. Comparatively few studies have assessed a wide range of other determinants such as child/parent goal setting, and provider monitoring or social support. There is also a lack of studies assessing paternal determinants, and where this information is provided, studies tend to use maternal report. Only one determinant has been assessed in the community domain and none in the policy domain; no studies have been conducted to

assess determinants in developing countries. Focusing research were such gaps exist will yield novel evidence, potentially prevent wastage of resources and promote physical activity change.

Moreover, little work has been conducted to explore how children's activity levels change from infancy to the preschool period, with only 6 studies including children aged 2 years or younger.[57,58,69,70,83,84] Questions remain about the optimal method for assessing physical activity in infants and toddlers.[105] Moreover, assessing physical activity across developmental periods may necessitate different measurement and processing protocols, complicating the assessment of change in physical activity. Nevertheless, given the early years represent a period of rapid development and a crucial window for positive habit formation, it is important to determine for whom, how, and why physical activity may change *throughout early childhood*, and whether behaviour and potential inequalities in health manifest and remain in later years.

Finally, determinants may be time or situation specific. Very few prospective observational studies have assessed determinants of physical activity change in young children. Including both prospective and intervention studies (and treating intervention components as determinants in the latter) allowed us to identify a wider range of factors that have been posited to effect change in physical activity. This review also indicates that determinants may differ within the same cohort depending on measurement method and follow-up period (i.e. in the CLAN study, there was no association between sex and counts per epoch at first follow up[60] but a positive association between (male) sex and MVPA at second follow up[61]). Prospective studies allow assessment of change in behaviour over relatively long periods of time; interventions, with generally much shorter follow-up periods than prospective studies, may be able to capture more short-term fluctuations in behaviour. Both types of study also tend to assess differing types of determinants. Prospective studies have focused on child's sex, parental psychosocial and temporal factors, whereas intervention studies target child skill and knowledge, parental knowledge and behaviour, and elements in the preschool environment including care-provider training and provision of curriculum materials. Both types of study are therefore

beneficial to establish whether a determinant is associated with behaviour change, and whether change is sustained over time. In combination, a more comprehensive picture of the determinants landscape in children 0-6 years of age can emerge; this will ensure future research focuses on where gaps in the current evidence exist, whilst focusing work on areas where potential positive gains in changing young childrens' physcial activity are most likely to be made.

4.1 Strengths and limitations

This is the first systematic review, to our knowledge, to specifically explore determinants of change of physical activity in children aged six years and under across prospective cohort and intervention studies. Given that cohort and intervention studies offered the most appropriate design to extract determinants of change, our research strategy was restricted to prospective studies. We applied rigorous review methods and did not exclude papers based on language, but it is possible that all relevant publications may not have been included, as illustrated by the identification of an additional study at the data extraction phase. As this review was restricted to published studies, publication bias cannot be discounted. One determinant (sex) was assessed in the same study twice and contributed more than one paper;[60,61] however in general, our methods reduced potential bias by lending more weight to determinants assessed in four or more studies. The inclusion of a range of study types and measures of activity is both a strength and limitation of this review; studies using pedometers and questionnaires tended to report positive intervention effects. Studies also used differing accelerometer cut points and adjusted for differing covariates in regression models. This heterogeneity highlights how differing study methods may influence findings and intervention success. All studies were conducted in high-income countries and approximately half of the studies had small final sample sizes ($n<50$; studies=15), which may have limited their statistical power to detect significant associations. Although we attempted to standardise outcomes across studies, five and 23 different outcome measures were used in prospective and intervention studies respectively, preventing the use of meta-analysis here.

Conclusions

This review identified a range of predominantly interpersonal and organisational determinants of change in young children's physical activity; however, only parental monitoring of their child's physical activity emerged as a consistent positive determinant of change, with provider training positively associated with change in children's MVPA. Maternal role modelling was also positively associated with change in all 3 studies in which it was examined. Many determinants were explored in fewer than four studies, and multiple determinants were targeted within each intervention study. This heterogeneity in the determinants considered, and also in outcome measures used, limited the ability to identify consistent evidence for specific determinants. Future work should investigate potentially important lesser-explored or overlooked modifiable family- and childcare-related determinants; explore how determinants influence physical activity throughout the day and week; and deconstruct how the multiple elements within an intervention result in positive behaviour change. Assessment of determinants in the community and policy domains, in addition to studies conducted in developing countries, is also required. Such information will provide more robust evidence about the determinants of change in activity in preschool-aged young children, which is needed to inform the development of successful targeted interventions to increase activity levels in this population.

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Compliance with Ethical Standards

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Conflicts of Interest

Kathryn Hesketh, Claire O'Malley, Veena Mazarello Paes, Helen Moore, Carolyn Summerbell, Ken Ong, Rajalakshmi Lakshman and Esther van Sluijs declare that they have no conflicts of interest relevant to the content of this review.

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Table 1 Characteristics of included papers[a]

Sample characteristic	Reference	Total number of papers (%)
Study design		
Prospective	[60–62,77–79]	6 (14)
Intervention	[11,37–58,64–67,69–76,81,83,84]	38 (84)
Total sample size		
<100	[37–40,42,44,51,53,58,69,73,76,79,81]	15 (34)
101-199	[41,43,56,60–62,65,67,70,73,77]	11 (25)
200-299	[45,48,54,66,74,78]	6 (14)
300-399	[11,47,50,55,84]	5 (11)
400-499	[64,72,75]	3 (7)
500+	[46,49,57,71]	4 (9)
Method of physical activity measurement		
Objective	[37–50,53–56,61,62,64–67,73–76,78,79,81,83]	33 (77)
Subjective	[11,51,55,57,58,60,69–71,77,84]	11 (23)
Continent		
Australasia	[48,51,60–62,78,83]	8 (18)
Europe	[39,41,43–45,49,50,64,65,75,77,79]	12 (27)
North America	[11,37,38,40,42,46,47,52–58,66,67,69,71–74,76,81]	24 (55)
High quality (≥5[b])		
Prospective	[78]	1 (4)
Intervention	[11,40,41,43–48,50,52–56,64,65,67,72–76,78,83,84]	26 (59)

a: A total of 44 papers were included, describing 42 prospective and intervention studies; b: Prospective studies scored out of 6, intervention studies scored out of 7.

Table 2: Summary of studies included to assess determinants of physical activity levels in young children

Reference	Study design/ name	Population	Age at start (mean±SD and/or range)	Setting	Intervention and provider	Targeted determinants [theoretical model]	Intervention duration (or follow-up)	Outcome	Measure	Effect	Quality score[a]
Prospective Studies											
Ball et al (2009); Cleland et al (2008); Cleland et al (2011) [60–62] Australia	Prospective cohort - CLAN	19 public elementary schools n=168 (stratified by low/med/high SES)	5-6 y	Schools	N/A	Child: sex Parents: behaviour, psychosocial Temporal: time of day, week, season	Up to 5 y	Ball: Change in cpm Cleland: change in MVPA	Accelerometer	cpm: 0 MVPA: + (for limited determinants)	4
Reilly et al (2004) [79] UK	Prospective cohort - SPARKLE	Community level stratification n=72 (51% M)	3.7±0.5 y	Community	N/A	Children: sex	1 y	Change in total PA	Accelero-meter	TEE: +	3
Saakslahti et al (2006) [77] Finland	Prospective cohort -	Cohort of children n=155 (53% M)	4-7y	Study subsample	N/A	Children: sex	2 y	Change in time spent in high intensity PA	Questionnaire	Change in high intensity PA: 0	2
Taylor et al (2008) [78] New Zealand	Prospective cohort – FLAME	Population-based n=244 (56% M; 86% W, 11% Moari, 3% PI; higher SES)	2.96-3.15	Birth cohort	N/A	Children: sex	3 y	Change in MVPA	Accelerometer	MVPA: 0	5
Intervention Studies											
Alhassan et al (2007) [40] USA	Pre-post; quasi-randomised	1 Low-income preschool n=32 (63% M, predominantly Latino)	C: 3.59±0.5 I: 3.89±0.5	Headstart	60 mins of additional recess time per day, divided into two 30-min blocks (one in the morning and one in the afternoon) [vs. usual recess time]	Preschool: additional PA time [No theory identified]	2 d	Change in cpm	Accelero-meter	cpm: 0	2
Alhassan et al (2012) [52] USA	Pre-post; quasi-randomised	2 preschools n=78 (49% M; 39% AA, 61% H; 65% single-family homes)	C: 4.1 ± 0.6 I: 4.5 ± 0.6	Preschools	Delivered for 30 min/day, five days/w for six months during morning gross motor playtime. Motor skill curriculum: 30 individual lesson, with one skill per lesson, e.g. 5 min low-intensity musical activity, 20 min of motor skills, 5 min of reinforcement.	Multi-level, including Children: motor skills Preschool: provider training (8hr) [No theory identified]	6 mo	Change in % time MVPA	Accelero-meter	% MVPA: 0	5
Alhassan et al (2013) [53] USA	RCT - SPARK	2 preschools n (baseline)=75; n (follow-up)=67 (57% M)	2.9-5y	Preschools	Both I&C given 30 mins of additional outdoor playtime for three d/w for 4 w. I: Providers delivered 12 sessions structured activity programme to increase MVPA.	Preschool: provider training (8hr), additional PA time [No theory identified]	4 w	Change in minutes % time in MVPA	Accelero-meter	% MVPA: 0	6
Annesi et al (2013) [54] USA	cRCT – Start for Life	32 classrooms n=275 (44% M; predominantly AA)	3.5-5.6y (4.6± 0.5y)	YMCA Preschools	Provider-delivered structured activity including gross motor skills and behavioural skills training	Multi-level, including Children: motor, behavioural skills	8 w	Change in MVPA	Accelero-meter	MVPA: +	6

					(30min/d).	Preschool: provider training (4hr) [Social cognitive and self-efficacy theory]					
Annesi et al (2013) [47] USA	cRCT – Start for Life	19 classrooms n=338 (46% M; lower/ lower–middle class; 92% AA)	C: 4.7±0.3 I: 4.6±0.6	YMCA Preschools	Provider-delivered structured activity including gross motor skills and behavioural skills training for 30min/d.	Multi-level, including Children: motor, behavioural skills Preschool: provider training (4hr) [Social cognitive and self-efficacy theory]	8 w	Change in MVPA	Accelero-meter	MVPA: +	6
Annesi et al (2011) [46] USA	cRCT – Start for Life	26 classrooms n=885 (46% M; lower/ lower–middle class; 92% AA)	3.5-5.6 y (4.4±0.5y)	YMCA Preschools	Provider-delivered structured activity including gross motor skills and behavioural skills training for 30min/d.	Multi-level, including Children: motor, behavioural skills Preschool: provider training (4hr) [Social cognitive and self-efficacy theory]	8 w (9 mo)	Change in MVPA	Accelero-meter	MVPA: +	6
Bellows et al (2013) [67] USA	RCT - The Food Friends: Get Movin' with Mighty Moves	8 lower income Headstart centres n=201 (55% M; 59%H, 32%W,9%O)	I: 53.0±6.8mo C: 51.5±6.6mo	Headstart centres	Provider led skills-based 72 lesson programme (4 d/w for 15–20 min, for 18 ws). Focus on stability, locomotor or manipulation, then skill patterns. Use of Food Friends characters and other materials to support lessons. Materials sent home.	Multi-level, including Children: motor, behavioural skills Parents: knowledge Preschool: provider training (8hr) [No theory identified]	18 w	Change in mean daily steps (w/e and w/ds) (2o)	Pedometer	Steps: 0	6
Bonvin et al (2015) [50] Switzerland	RCT - Youp'là Bouge	58 childcare centres n=388 (50% M; 18% low educated parents; 58% migrant parents)	I: 3.4±0.6y C: 3.3±0.6y	Childcare centres in 3 French-speaking Cantons	Multi-component physical activity programme, delivered to children and parents via providers in preschools. Preschools left to implement PA programme according to their own needs.	Multi-level, including Children: skills, knowledge Parents: encouraged engagement, knowledge Preschool: provider training/ support; changes in built environment ($1500) [No theory identified]	9 mo	Change in cpm, MVPA (2o)	Accelero-meter	cpm: 0	6
Cardon et al (2009) [41] Belgium	RCT	40 preschools n=583 (52% M)	5.3±0.4y	Public Preschools	Factorial Design: 1: Play equipment provided (150 children); 2: Markings painted on the playground (161); 3: Play equipment & markings provided (161)	Preschool: changes in environment [No theory identified]	6 mo	Change in cpe	Accelero-meter	Cpe: 0	6
Cottrell et al (2015) [42] USA	RCT - CARDIAC-Kinder	29 preschools n (baseline)= 203 (49% M; 93% W) n (follow-up)=50	5±0.47 y	Preschools	Children received 2 pedometers – one for themselves and for a parent (vs. one for child in C group) and step log. Also received information	Multi-level, including Children: monitoring, knowledge Parents: monitoring,	4 w	Change in weekly average steps	Pedometer	Weekly steps: + (week 4)	2

					building on activity and diet recommendations.	knowledge. [No theory identified]					
Davis et al (2013) [69] USA	Pilot intervention	Teen mothers, n= 60 (61% M; 73% AA; 16% W; 7% NA; 4% O),	0-53 mo (15.7±13.4)	Child development programme	In-home intervention focusing on nutrition and activity: 3 sessions for mother, 3 focused on child. Providing information, and including behavioural topics such as goal setting, tracking, social support.	Multi-level, incl Parents: knowledge, monitoring, goal setting, social support Organisational: facilitator training (4hrs) [No theory identified]	3 mo	PA in past week; PA in typical week	Questionnaire	Change in typical week: +	2
Davison et al (2013) [81] USA	Pilot intervention	5 Headstart centres n (baseline)= 117 (45% M; 68% W; 22% AA; 6% non-H; 4% O) n (follow-up)=57	3.59±1.01y	Headstart centres	Multi-component intervention delivered through Head Start centres, including health communication campaign, body mass index letters, family nutrition counselling, parent skill sessions, and similar programme for children.	Multi-level, including Children: encouragement, knowledge Parents: skills training, knowledge. Community: awareness [Family Ecological Model]	6 mo	Change in mins/hr LPA, MPA (2o)	Accelero-meter	LPA: + MPA: 0	4
De Bock et al (2013) [49] Germany	cRCT	37 preschools n (baseline)=809 (52% M; low income:25%, middle income: 55%) n (follow-up)=467	5.05y	Preschools	Augmentation of 6 mo State program (+ 3 mo) to motivate parents to promote children's PA. Introductory video and project ideas, with external gym trainers provided for I school to coordinate parent activities. Initial workshop followed by teambuilding and implementation of projects as regular activities.	Multi-level, including Parents: motivation, skills training, knowledge. Preschool: additional providers, provider training [Participatory intervention approach]	9 mo	Change in cp15s	Accelero-meter	Cp15: +	4
De Meij et al (2010) [71] Belgium	Cluster-RCT "Prevention of Overweight among Pre-school and school children (POP)"	31 schools across high, medium and low SES. n=1589 at baseline (I: 1032; C:557) n=694 at 2 year (I: 396 C: 298)	4.95 ± 1.31y	Pre-primary and primary schools	Health promotion programme with child at centre, including range of potential carers/ those influencing activity (family, friends, schools, community, stakeholders, local policy and media).	Multi-level, including Child: knowledge Parents: knowledge School: knowledge, Policies change Community: knowledge [Socio-ecological theory]	2 school y (09/08-04/10)	Change in hrs of sports club and after-school activity participation (2o)	Question-naire	Sport: 0 After-school: 0	4
De Craemer et al (2014) [64] Belgium	cRCT - Toybox	27 Kindergartens in Flanders n=472 (55% M)	4.43±0.55y	Kindergartens	Health promotion programme with children within centres, PA component implemented in ws 5-8, with 2-w repetition period in ws 19-20. Materials provided to be used for minimum of 1hr/w. Newsletters (with key messages on PA) and tip-cards sent home.	Multi-level, including Child: knowledge Parents: knowledge School: curriculum materials, provider knowledge, provider training [PRECEDE-PROCEED,	24 w	Change in total PA on w days,	Accelero-meter	Total PA: 0	5

						intervention mapping]					
Elder et al (2014) [72] USA	RCT "MOVE/ Me Muevo"	30 sites n= 541 (45% M; 41% H)	6.6±0.7y	Recreation centres	Tailored to the family's needs to target physical and social aspects of the home environment. Initial call; 1.5hr group workshop and 1hr home visit. Tip sheets to promote healthy eating and physical activity to their children. PA:(i) increase the amount of MVPA to 60 min/d; (ii) increase PA opportunities; (iii) increase the variety of fun, developmentally/ culturally appropriate PA.	Multi-level, including Parents: knowledge, social support Centre: facilitator training Community: awareness [No theory identified]	2 y	Change in total active time	Accelero-meter	Total PA: +	6
Eliakim et al (2007) [65] Israel	RCT	4 preschools n=101 (55% M; upper middle class)	5.5y	Preschools	Health promotion programme (4mo) PA: 45min/d of exercise (6 day/w), twice co-ordinated by a professional youth coach; sessions spilt into 3x15min sessions. Training: duration, intensity, co-ordination and flexibility plus reduce sedentary time & increase after school PA.	Multi-level, including Children: Skills training Preschool: Additional PA time; additional providers [No theory identified]	14 w	Change in total daily steps	Pedo-meters	Steps: +	5
Engelen et al (2018) [48] Australia	cRCT	12 schools n=221 (54% M; ICSEA: 980-1170)	6.0±0.6y	Catholic Primary Schools	Playground-based intervention introducing portable equipment (13ws) and a 2-hour teacher-parent intervention exploring risk administered (2-3 ws post playground intervention initiation).	Multi-level, including Parents: knowledge School environment: change in environment, provider knowledge [No theory identified]	13 w	Change in cpm, MVPA daily	Accelero-meter	cpm: 0	5
Fitzgibbon et al (2005) [11] USA	cRCT - Hip-Hop to Health Jr	12 Headstart centres n=409 (50% M; I: 99% AA, 1% O; C: 80.7% AA, 12.7% H, 6.6% O)	I: 48.6±7.6 mo; C: 50.8±6.4mo	Headstart centres	Health promotion programme. 40min sessions 3/w, covering a different theme: 20 minutes of introducing health promoting topic and 20 minutes of PA, including the use of colourful puppets. Parents received a weekly newsletter, covering healthy eating, PA and a homework task (5mins daily or 15mins one off)	Multi-level, including Children: knowledge, Parents: knowledge Preschool: Additional PA time, curriculum materials [Social cognitive theory]	14 w	Change in PA (2o)	Parental self-report: frequency/ intensity (% >7 x /w, Borg scale)	Frequency: 0 Intensity: 0	5
Fitzgibbon et al (2006) [55] USA	cRCT - Hip-Hop to Health Jr	12 Headstart centres n=293 (50% M; I: 15.8% AA, 73.3% H, 10.9% O; 6.5%; C: AA, 89.4% H, 4.0% O)	I: 50.8±7.3 mo; C: 51.0±7.0mo	Headstart centres	Health promotion programme. 40min sessions 3/w, covering a different theme: 20 mins on nutrition (food pyramid) and 20 mins aerobic PA. Parents received 12 homework assignments during the 14-week intervention (with incentive).	Multi-level, including Children: knowledge Parents: knowledge Preschool: additional PA time, curriculum materials [Social cognitive theory]	14 w [1 and 2 y post intervention]	Change in PA (2o)	Parental self-report frequency/ intensity (% >7 x /w, Borg scale)	Frequency: 0 Intensity: 0	5
Fitzgibbon et al (2014) [56] USA	cRCT - Hip-Hop to	18 Headstart centres n (baseline)=223 (44% M;	I: 50.7±6.8mo	Headstart programmes	Health promotion programme. 40mins 2/w (optional 3rd). 20 mins	Multi-level, including Children: knowledge	14 w	Change in MVPA	Accelero-meter	Cpm: 0 MVPA: +	5

	Health	I: 97% AA, 1% H, 2% O; C: 91% AA, 5% H, 4% O) n(follow-up)=190	C: 51.9±6.3mo		on nutrition (food pyramid) and 20 mins aerobic PA, incorporating musical CD for teachers. Parental homework: 6 areas related to cultural practices and beliefs: food, family, music, community, social roles, and relationships.	Parents: knowledge Preschool: additional PA time, curriculum materials [Social cognitive and self-determination theory]		(min/d) and counts/min (2o)			
Fitzgibbon et al (2013) [73] USA	cRCT - Hip-Hop to Health	4 centres n(baseline)=146 (50% M; 94% H; 2% AA; 4% O) n (follow-up)=123	54.2±5.0mo	Early Childhood education programmes	Health promotion programme. 40min sessions 3/w, covering a different theme: 20 mins on nutrition (food pyramid) and 20 mins aerobic PA. Parents also participated in a 30min exercise session. Parent component: 6x90min/w (60 mins of interactive instruction on diet and PA, 30mins MVPA classes) + Newsletters for a lower-income, Hispanic population.	Multi-level, including Children: knowledge Parents: knowledge, PA classes Preschool: additional PA time, curriculum materials [Social cognitive theory]	14 w	Change in cpm / MVPA (2o)	Accelero-meter	Cpm: 0 MVPA: 0	5
Hannon and Brown (2008) [37] USA	Pre-post intervention	1 centre n=64 (47% M; predominantly W)	3.9±0.8 y	Preschool	Introduction of age-appropriate portable toys in playground on intervention days, including hurdles, hoops, tunnels, balance beams, balls	Preschool: change in environment [No theory identified]	5 d pre/ post	Change in % MPA/VPA outdoor play/d	Accelero-meter & OSRAC-P	MPA: + VPA: +	5
Jones et al (2011) [83] Australia	Non-randomised pilot "Time 2bHealthy"	Overweight preschool children and parents; n(baseline)=46 (~80% parents had degree/ tech trade cert) n(follow-up)=40	2-5 y	Home based	Interactive online parental education and discussion forums (5 modules, each module lasting 2 weeks) to promote healthy lifestyles in overweight preschool-aged children.	Parents: knowledge, parenting skills, social support. [Aligned to Healthy Eating and Physical Activity (Australian Government)]	10 w	Change in PA behaviours	Parental self-report	Child doing regular PA: +	2
Jones et al (2011) [51] Australia	Pilot RCT "Jump Start"	2 low-income centres n=97	4.1y	Preschools	Structured lessons 3x week for 20 weeks: 20-min lesson focused on one fundamental movement skill. Each skill comprised a number of components, e.g. running had four. Practice through fun activities and games. Unstructured activities facilitated in the afternoons for practice with equipment.	Multi-level, including Children: motor skills Preschool: provider training (2hr) [No theory identified]	20 w	Change in cpm	Accelero-meter	cpm: 0	3
Klohe-Lehman et al (2007) [58] USA	Non-randomised trial	Low-income, overweight or obese mothers n=235 (62.6% H)	1-3y (mean 2.1y)	Public health clinics / groups	Weight loss intervention for mothers (8x weekly 2-hr classes: 15-min weigh-in, 1.25-hr discussion and activities, 30-min exercise). Delivered by registered dieticians.	Multilevel, including Parents (mothers) knowledge, modelling, parenting skills Home environment opportunities for PA	8 w	Change in PA (mothers & child)	Toddler Behavior Assessment Questionnaire (TBAQ)	Change PA: +	3

						[Social Cognitive Theory]					
O'Dwyer et al (2012) [44] UK	cRCT	8 preschools n=79 (52% M)	<5y	Home based	5 sessions (70 minutes: 10 mins registration, 60 mins delivery) 1 every 2ws. Parents and children separate for first 20mins, 40 mins spent together as a group. Active play for children delivered by play workers, educational workshop for parents. Parents monitored PA at home with logbook, linked to a reward system. Text message reinforcement.	Multilevel, including Children: additional PA time Parents (mothers) knowledge, modelling, monitoring [Socio-ecological theory]	10 w	Change in total weekday PA	Accelero-meter	Weekday PA: +	6
O'Dwyer et al (2013) [45] UK	cRCT	12 centres n=240 (56% M; I: 84.3% W; C:75.3 W)	3.7±0.6y	Sure Start centres	Active play intervention (60mins 1/w) with staff training to deliver active curriculum. 2-2-2 format: 2ws practitioner, 2 ws co-delivery, 2 ws teacher, with practitioner facilitating. Resource pack provided to preschools along with user manual and exemplar lesson plans and promotion poster.	Preschool: staff training, additional staff [Socio-ecological theory]	6 w [& 6 mo]	Change in MVPA	Accelero-meter	MVPA: 0	6
Ostbye et al (2013) [74] USA	RCT – KAN-DO	Patient records n=400 (56% M)	3.1±1.0y	Healthcare	8 monthly mailed interactive kits; 20–30 min motivational interviewing coaching session via phone. Kits included activities and incentives Targeted healthy weight via instruction in parenting styles and skills, techniques for stress management and education. One semi-structured group session also included: a healthy meal and free childcare were provided.	Multi-level, including Children: monitoring Parents: knowledge, social support, monitoring [Socio-cognitive theory]	8 mo	Minutes of MVPA per day	Accelerome ter	MVPA: 0	6
Puder et al (2011) [75] Switzerland	cRCT - Ballerbina	40 centres n=652 (50% M; 40% speak foreign language at home; 62% with 2 educated parents)	5.1±0.7y	Preschools	Multidimensional culturally tailored lifestyle intervention, with workshops, lessons, home activities, offers of extracurricular activities and adaption of the built environment. Teacher training (2 workshops); PA programme (4x45mins/w with CD); Activity cards to take home; 1 meeting of parents and teachers.	Multi-level, including Children: skills and fitness Parents: knowledge, participation, social support Preschool: provider training, change in built environment, social support, additional PA time, curriculum materials [Socio-ecological theory]	11 mo	Change in PA (2o)	Accelero-meter	Accelerometer: 0	6
Stark et al (2011)	Pilot RCT	Children with BMI ≥	2-5y	Home &	Enhanced Pediatric Counselling.	Multi-level, including	36 w [6 and	Change in	Accelero-	MPA: 0	5

[76] USA	"LAUNCH"	95th% and 1+ overweight parent n=15	(mean 4.7 ± 1.1y)	clinics	Intervention and maintenance: 12 wly and 2 wly sessions (Group-based clinic parent-child sessions or individual home visits. Children and parents given pedometers and goals of 5,000 and 10,000 steps/d, as feedback. Delivered by paediatricians and psychologists at parent-groups, child-groups and home visits.	Children: knowledge, goals Parents: knowledge, parenting skills, parental modelling, goal setting [Social Cognitive Theory]	12 mo]	MPA, VPA (2o)	meter	VPA: 0	
Stratton and Mullan (2005) [39] UK	Pilot RCT	4 schools n=54 (46% M; low SES areas)	4-7y	Primary Schools	Playgrounds markings; painted in bright fluorescent colours according to school preference: e.g. castles, dragons, clock faces, mazes, fun trails, dens, hopscotch, letter squares, snakes and ladders	Preschool: change in environment [No theory identified]	6 mo	Heart rate; Play time in MPA, VPA	Telemeter	MPA: 0 VPA: +	4
Trost et al (2008) [38] USA	RCT – Move and Learn	1 centre n=42 (55% M; 23.7% with high school diploma)	4.1±0.7y	Childcare centre	PA opportunities integrated into all aspects of the preschool curriculum. Teachers were required to include 2 Move and Learn curriculum activities lasting 10mins or longer in each 2.5-hr session (4/d). Activities were typically repeated several times throughout the week.	Preschool: Additional PA time, Provider training [No theory identified]	10 w	Change in MVPA	Accelero-meter & OSRAP	MVPA (w5-8): +	2
van Cauwenerghe et al (2012) [43] Belgium	Pilot intervention	4 preschools n=128 (55% M)	4-6y	Preschools	Lowering playground density	Preschool: change in environment [No theory identified]	1 w	Change in daily LMVPA	Accelero-meter	Daily LMVPA: 0	5
Verstestel et al (2015) [70] Belgium	Pilot RCT	60 centres n=203 (54% M)	15.5± mo	Daycare centres	Family-based healthy lifestyle intervention: improve diet, PA levels and decrease screen-time. Two components: (i) guidelines and tips on poster with stickers (every 2 months, along with additional tip sheet) (ii) a tailored feedback form for parents about their children's activity- and dietary- related behaviours.	Multi-level, including Children: goal setting Parents: knowledge, goal setting, monitoring [Information processing; Elaboration likelihood model; Precaution-adoption-process model]	1 y	Time spent in PA	Question	PA time: 0	4
Wen et al (2012); Wen et al (2015) [84,106] Australia	Non-randomised intervention "Healthy Beginnings"	Low-income mothers n=465 (11% spoke language other than English at home)	From birth	WIC sites	8 home visits from nurses delivering staged home-based intervention: one antenatal visit, then at 1, 3, 5, 9, 12, 18, and 24 months after birth, with ongoing telephone support. One hour visits: monitoring the parent-child feeding interaction and practice, and behaviours promoting physical activity/inactivity in the	Parents: parenting skills, social support [No theory identified]	2 y, 5 y post intervention	Outdoor play ≥120 min/d	Questionna ire	Outdoor play: 0	5

					child. Needs identified with checklist and fed back. Problem-solving, individualized information kit and phone feedback provided.						
Whaley et al (2010) [57] USA	Non-randomised trial "Child health and intervention research project" (CHIRP)	Low-income mothers n(baseline)=821, (94% H; 50% mothers of M); n(follow-up)=589	1-5y (mean 23 ± 9.2 mo)	WIC sites	Enhanced questionnaire and 1-2-1 MI with mothers to discuss one of 6 health behaviour topics [PA: getting up and moving more] at their 6 monthly WIC recertification appointments. Delivered by WIC staff using motivational interviewing techniques.	Parents motivation, social support [Trans Theoretical Model]	1 y: 6 mo & 12 mo	Engaging in > 60 min of PA (d/w)	Question-naire	Engaging in PA: 0	3
Yin et al (2012) [66] USA	Pre-post intervention	4 centres n=390 (59% M; 62% normal weight; predominantly H)	4.1±0.56y	Headstart centres	Home, centre and curriculum based intervention for diet and physical activity. Factorial design (centre, home, centre and home). Centre based including staff training, curriculum resources and 60mins structured and free play/d. Home based peer-led parent obesity education, homework, family support and monitoring for PA.	Multi-level, including Children: motor skills Parents: knowledge, social support, monitoring Preschool: provider training, additional PA time [Early child development and systems approach]	18 w	Steps/ min in outdoor play	Pedo-meters	Steps/min in outdoor play: +	4

PA: physical activity; RCT: randomised controlled trial; cRCT: cluster randomised controlled trial; KAN-DO: Kids and Adults Now – Defeat Obesity!; SPARK: Sports, Play, and Active Recreation for Kids; SPARKLE: Study of Preschool Activity, Lifestyle and Energetics; LAUNCH: Learning about Activity and Understanding Nutrition for Child Health; FLAME: Family Lifestyle, Activity, Movement, and Eating; ICSEA: The Index of Community Socio-Educational Advantage; PRECEDE-PROCEED: Predisposing, Reinforcing and Enabling Constructs in Educational Diagnosis and Evaluation - Policy, Regulatory, and Organizational Constructs in Educational and Environmental Development; OSRAP: observation system for recording activity in preschools; OSRAC-P: Observational System for Recording Physical Activity in Children-Preschool Version; MI: motivational interviewing; I: Intervention group; C: Control group; cpm: counts per minute; cpe: counts per epoch; cp15: counts per 15 seconds; LPA: Light physical activity; MPA: moderate physical activity; MVPA: moderate to vigorous physical activity; VPA: vigorous physical activity; LMVPA: Total physical activity (i.e. light, moderate and vigorous physical activity; TEE: total energy expenditure; SES: Socio-economic status; M: male; W: White; AA: African American; H: Hispanic; NA: Native American; O: Other racial group; PI: Pacific Islander; 2o: measured as secondary outcome; BMI: Body Mass Index; w/e: weekend; w/d:weekday; d: day; hr: hour; w: week; y: years; mo: months; N/A: Not applicable; WIC: Women, Infants and Children; +: statistically significant positive effect of intervention; 0: no effect of intervention; a: Score out of 6 for prospective and 7 for intervention studies.

Table 3 Determinants assessed in prospective and intervention studies

	Association with change in physical activity				
Determinant	-	0	+	Studies showing positive association	Outcome
INTRAPERSONAL (child)					
Sex (boys)				2/5	??
Questionnaire	[77]				
Total Activity (counts per epoch)		*[60]*	[79]		
MVPA		[78]	*[61]*		
Motor/ skill training [a]				5/10	??
Total Activity (counts per epoch)		[50,51,75]			
Pedometer		[80]	[65,66]		
MVPA		[52],	[46,47,54]		
Knowledge[a]				1/11	00
Questionnaire		[71,11,55]			
Total Activity (counts per epoch)		[50,73,56,75]			
Pedometer			[42]		
MVPA		[64,76,81]			
Goal setting[a]		[76]		0/1	0
Monitoring[a]				1/3	0
Questionnaire		[70]			
Pedometer			[42]		
MVPA		[82]			
Fitness[a]		[75]		0/1	0
INTERPERSONAL					
Family demographics					
Maternal SES		*[60]*		0/1	0
Sibling PA level		*[61]*		0/1	0
Parental psychosocial					
Maternal reinforcement		*[61]*		0/1	0
Paternal reinforcement		*[61]*		0/1	0

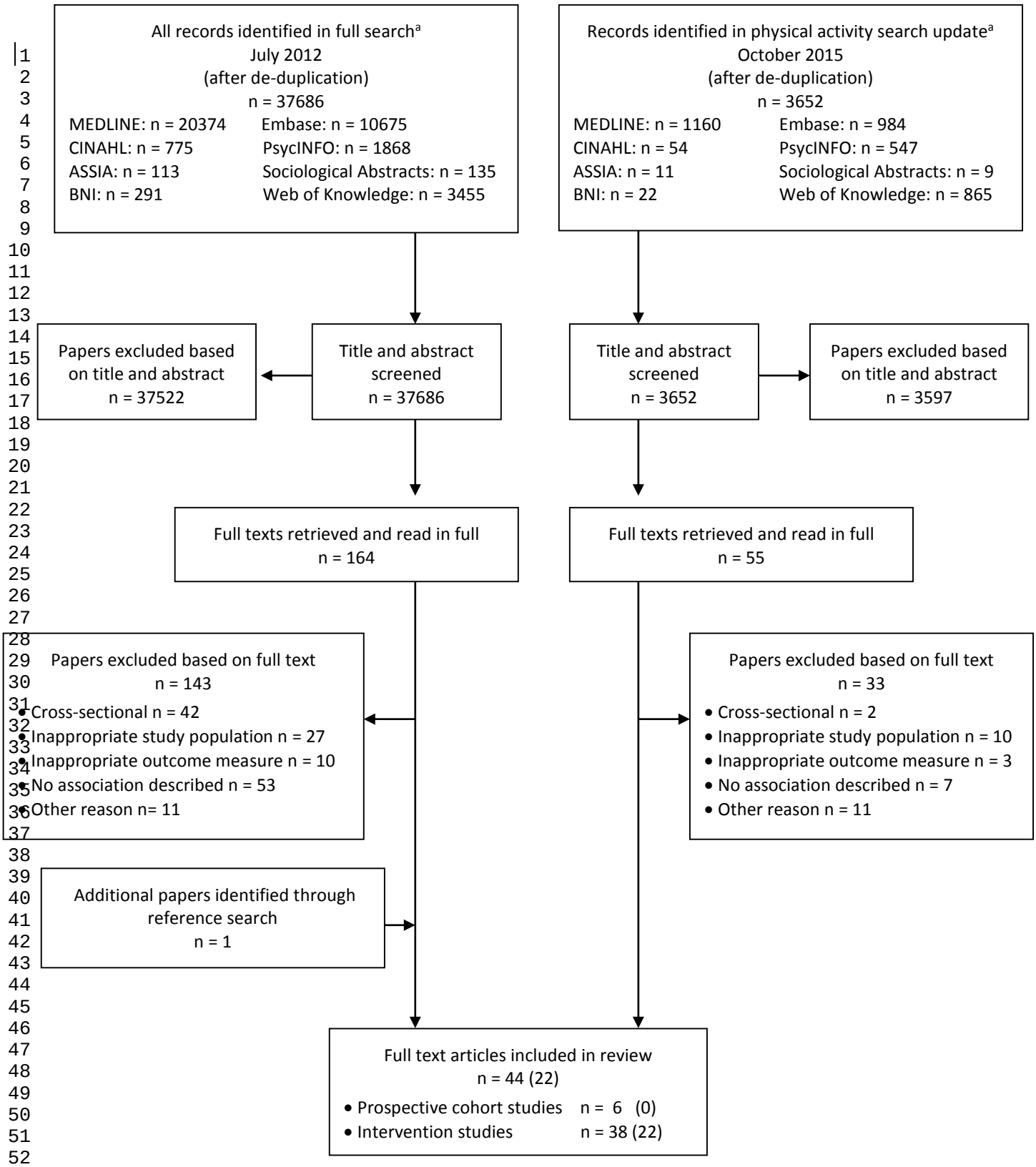
Maternal Role-modelling[a]			3/3	+
Questionnaire		[58]		
MVPA		*[61]*[44]		
Paternal role-modelling	*[61]*		0/1	0
Parental role-modelling[a]			0/3	0
Questionnaire	[70]			
MVPA	[76,82]			
Parental monitoring[a]			4/6	++
Questionnaire	[70]	[69]		
Total Activity (counts per epoch)	[72]			
Pedometer		[42,66]		
MVPA		[44]		
Parental motivation[a]			1/4	00
Questionnaire	[57]			
Total Activity (counts per epoch)	[72]	[49]		
MVPA	[82]			
Parental goal setting[a]			2/4	??
Questionnaire		[83,69]		
Total Activity (counts per epoch)	[72]			
MVPA	[76]			
Parental knowledge[a]		,	7/22	00
Questionnaire	[71,11,55,70]	[83,58,69]		
Total Activity (counts per epoch)	[48,50,75,56,73,72]	[49]		
Pedometer	[80]	[42,66]		
MVPA	[64,81,76,82]	[44]		
Parent skills[a]			2/7	00
Questionnaire	[84]	[83]		
Total Activity (counts per epoch)	[51]	[49]		
MVPA	[81,76,82]			
Parental self efficacy[a]			1/4	00
Questionnaire	[70,57]			
Pedometer		[66]		
MVPA	[82]			
Parental social support[a]	,		2/5	??
Questionnaire	[84]	[83,69]		
Total Activity (counts per epoch)	[75,72]			
Parental Behaviour				

Maternal co-participation	*[61]*		0/1	0
Paternal co-participation	*[61]*		0/1	0
Parental co-participation[a]	[75]		0/1	0
Siblings co-participation		*[61]*	1/1	+
Family participation	*[61]*		0/1	0
Maternal direct support	*[61]*		0/1	0
Paternal direct support	*[61]*		0/1	0
Opportunities for play[a]			2/2	+
Questionnaire		[58]		
MVPA		[44]		
ORGANISATIONAL				
Preschool environment				
Provider training*			8/16	??
Total Activity (counts per epoch)	[50,51,75,72]	[49]		
Pedometer	[80]	[66]		
MVPA	[45,52,64]	[38,44,46,47,53,54}		
Provider knowledge[a]			0/2	0
Total Activity (counts per epoch)	[48]			
MVPA	[64]			
Provider social support[a]	[75]		0/1	0
Additional providers[a]			2/3	+
Total Activity (counts per epoch)		[49]		
Pedometer		[65]		
MVPA	[45]			
Increased active time[a]	[11,55]		4/11	??
Questionnaire				
Total Activity (counts per epoch)	[56,73,75]			
Pedometer		[65,66]		
MVPA	[40,45]	[38,53]		
Structured physical activity[a]		[53]	1/1	+
Playground density (low) [a]		[43]	1/1	+
Playground markings[a]	[41]	[39]	1/2	0
Portable equipment[a]			1/5	00
Total Activity (counts per epoch)	[41,48,50,75]			
MVPA		[37]		
Curriculum materials[a]			2/11	00

Questionnaire	[11,51,71]			
Total Activity (counts per epoch)	[50,56,70,73]	[49]		
Pedometer	[80]			
MVPA	[64]	[53]		
Preschool policy change[a]	[71]		0/1	0
Centre monitoring/ feedback[a]	[72]		0/1	0
COMMUNITY				
Community awareness[a]			0/3	0
Total Activity (counts per epoch)	[72]			
Pedometer	[71]			
MVPA	[81]			
TEMPORAL				
Time of the day	*[62]*		0/1	0
Time of the week	*[62]* [78]		0/2	0
Season	*[62]*		0/1	0

Italicised reference numbers indicate prospective studies, all others are intervention studies; a: Intervention components; SES: socio-economic status; PA: physical activity; MVPA: moderate-to-vigorous physical activity. For 1-3 studies: 0: 0-33% of papers support positive/negative association; ?: 34-59% support positive/negative association; +/ -: 60-100% support positive or negative association. For ≥4 studies: 00: 0-33% of papers support positive/negative association; ??: 34-59% support positive/negative association; ++/--: 60-100% support positive or negative association.

Figure 1 Flowchart outlining identification of papers for inclusion



a: Full search conducted including terms for all health behaviours (i.e. diet, physical activity), physical activity search update included terms for physical activity behaviours only; ASSIA: Applied Social Science Index and Abstracts; BNI: British Nursing Index.

Determinants of Change in Physical Activity in Children 0-6 years: A Systematic Review of Quantitative Literature (*Sports Medicine)*

Kathryn R. Hesketh (UCL Institute of Child Health, Kathryn.hesketh@ucl.ac.uk), Claire O'Malley, Veena Mazarello Paes, Helen Moore, Carolyn Summerbell, Ken K. Ong, Simon Griffin, Rajalakshmi Lakshman, Esther MF van Sluijs

Electronic Supplementary Material Table S1: Search strategy for full review and physical activity-specific update[a]

1	(Determin*4 or correlates or factors or predict*3 or associate*3 or interaction or influence*1 or temperament or beliefs or attitudes or knowledge or perceptions or views or intentions or facilitators or barriers or experiences or prevent*3 or reduc*5 or increas*3 or promot*3 or education or curriculum or program*3 or polic*3 or media or campaign or review or intervention*1 or initiative*1 or strategy*3 or evaluation or trial).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
2	(Infant* or Toddler* or Preschool* or Nurser*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
3[a]	((Fruit*1 or Vegetable*1 or juice or sugar sweetened beverage*1 or fizzy drinks or soft drinks or junk food or fast food or processed food or unhealthy food or takeaway food or non-core food or energy dense food or high fat food or fatty food or nutrient poor food or unhealthy diet or healthy eating or portion size or empty calories or confectionery or sweet*1 or dessert*1 or chocolate*1 or cake*1 or biscuit*1 or burger*1 or chip*1 or crisp*1 or snack*1 or breakfast or lunch or dinner or obes*6 or overweight).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
4	(physical activ*5 or inactiv*3 or exercise*1 or outdoor or TV or Television or Tele or sedentary or (screen adj time)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
5	1 AND 2 AND 3 AND 4
6	5 not (cerebral palsy or asthma or cystic fibrosis or autism).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

[a] Search terms omitted in physical activity-specific update conducted in 2015

Kathryn R. Hesketh (UCL Institute of Child Health, Kathryn.hesketh@ucl.ac.uk), Claire O'Malley, Veena Mazarello Paes, Helen Moore, Carolyn Summerbell, Ken K. Ong, Simon Griffin, Rajalakshmi Lakshman, Esther MF van Sluijs

Electronic Supplementary Material Table S2: Quality assessment criteria by study design

Type of Study	Assessment Criteria	Operationalisation	
Prospective	• Sample recruitment	Representative of general population: 1	
	• Measure of exposure	Objective measure used: 1 (subjective: 0)	
	• Measure of outcome	Objective measure used: 1 (subjective: 0)	
	• Number of participants	>100 participants: 1 (<50: low quality)	
	• Participant retention	>70%: 1	
	• Analysis strategy	Multivariable: 1	
	Total possible score		6
Intervention	• Sample recruitment	Representative of general population: 1	
	• Randomised design	Randomisation of I/C groups: 1	
	• Measure of exposure	Objective measure used: 1 (subjective: 0)	
	• Measure of outcome	Objective measure used: 1 (subjective: 0)	
	• Number of participants	>100 participants: 1 (<50: low quality)	
	• Participant retention (>70%)	>70%: 1	
	• Analysis strategy	Multivariable: 1	
	Total possible score		7

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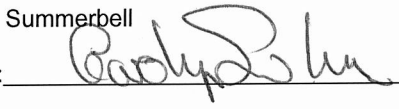
Signature (please **HAND-WRITE**): 

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