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Socioeconomic patterning of children's accelerometer-assessed physical activity intensities and adiposity: a pooled analysis of individual-level data for 26,915 children and adolescents from 36 European cohorts

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Abstract:	Background Childhood obesity is increasing globally with widening socioeconomic inequalities. It is unclear if differences in the accumulation and intensity distribution of children's physical activity is contributing to these rising disparities. We investigated if the intensity patterning of physical activity differs between socioeconomic groups across Europe and if this relationship differs by national level income inequality and age to help explain obesity disparities. Methods We pooled and harmonised individual-participant accelerometer-assessed activity and socioeconomic position (SEP) data from 36 European child studies. Included participants were between 5 to 16 years of age with valid accelerometer data (≥480 minutes of daily wear time on 3 days), parental education and anthropometric measurements. Study-level multivariable linear regression models were run to assess differences in moderate-vigorous physical activity (MVPA), vigorous physical activity (VPA) and adiposity by socioeconomic position (by parental education). Effects were pooled in random effect meta-analyses. Findings 26,915 participants (mean age: 10·1y [SD:1.2]; 51·7% female) from 16 European countries met the inclusion criteria. Meta-analyses revealed proportionally more average daily minutes of VPA were performed by children from a higher socioeconomic position (High vs low SEP, b: 0·57, 95%CI: 0·28, 0·85 mins), despite lower overall levels of physical activity (MVPA; b: -1·51, 95%CI: -2·36, -0·67 mins). Higher intensity activity in children from a higher socioeconomic position was paralleled by lower levels of adiposity measured by BMI z-score (b: -0·20, 95%CI: -0·24, -0·16). Stepwise differences were apparent moving from low to medium to high socioeconomic position [e.g. BMI z-score: (Low vs Med SEP; b: -0·10, 95%CI: -0·14, -0·07) (Low vs High SEP; b: -0·20, 95%CI: -0·24, -0·16)]. Inequalities in VPA and BMI z-score widened with age and were not affected by national level income inequality. Interpretation

	Lower levels of adiposity in children from a higher socioeconomic position are paralleled by relatively higher amounts of VPA despite overall lower levels of MVPA. Physical activity promotion efforts should focus on providing opportunities for less affluent children to be vigorously active.

Title: Socioeconomic patterning of children's accelerometer-assessed physical activity intensities and adiposity: a pooled analysis of individual-level data for 26,915 children and adolescents from 36 European cohorts

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All authors declare that they have no conflicts of interest.

Key words:

Physical activity, Obesity, Children, Adolescents, Inequalities, ICAD, ALSPAC

ABSTRACT

Background: Childhood obesity is increasing globally with widening socioeconomic inequalities. It is unclear if differences in the accumulation and intensity distribution of children's physical activity is contributing to these rising disparities. We investigated if the intensity patterning of physical activity differs between socioeconomic groups across Europe and if this relationship differs by national level income inequality and age to help explain obesity disparities.

Methods: We pooled and harmonised individual-participant accelerometer-assessed activity and socioeconomic position (SEP) data from 36 European child studies. Included participants were between 5 to 16 years of age with valid accelerometer data (≥480 minutes of daily wear time on 3 days), parental education and anthropometric measurements. Study-level multivariable linear regression models were run to assess differences in moderate-vigorous physical activity (MVPA), vigorous physical activity (VPA) and adiposity by socioeconomic position (by parental education). Effects were pooled in random effect meta-analyses.

Findings: 26,915 participants (mean age: 10·1y [SD:1.2]; 51·7% female) from 16 European countries met the inclusion criteria. Meta-analyses revealed proportionally more average daily minutes of VPA were performed by children from a higher socioeconomic position (High vs low SEP, *b*: 0·57, 95%CI: 0·28, 0·85 mins), despite lower overall levels of physical activity (MVPA; *b*: -1·51, 95%CI: -2·36, -0·67 mins). Higher intensity activity in children from a higher socioeconomic position was paralleled by lower levels of adiposity measured by BMI z-score (*b*: -0·20, 95%CI: -0·24, -0·16). Stepwise differences were apparent moving from low to medium to high socioeconomic position [e.g. BMI z-score: (Low vs Med SEP; *b:* -0·10, 95%CI: -0·14, -0·07) (Low vs High SEP; *b:* -0·20, 95%CI: -0·24, -0·16)]. Inequalities in VPA and BMI z-score widened with age and were not affected by national level income inequality.

Interpretation: Lower levels of adiposity in children from a higher socioeconomic position are paralleled by relatively higher amounts of VPA despite overall lower levels of MVPA. Physical activity promotion efforts should focus on providing opportunities for less affluent children to be vigorously active.

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INTRODUCTION

Rates of obesity are increasing fastest within low-socioeconomic populations globally.[1,2] Given the association of obesity and some non-communicable diseases (NCDs), these differences are amplifying inequalities in morbidity and premature mortality across the life-course.[3] Concerningly, these differences manifest early, with evidence revealing worsening socioeconomic differences in childhood obesity, with increasingly higher rates of obesity in more deprived groups.[4,5] In practice, we have limited understanding of the factors driving widening socioeconomic inequalities in childhood adiposity.

The benefits of physical activity that have been observed during childhood and adolescence in promoting health and well-being, and reducing future disease risk have led to an international focus on its promotion across populations.[6] Current international physical activity guidelines recommend children accumulate 'at least 60 minutes of moderate-to-vigorous physical activity (MVPA) daily'.[7] The guidelines secondarily recommend that vigorous activities are incorporated three times a week, without further specification.

Unlike in adults, the literature on the relationship between socioeconomic position (SEP) and levels of MVPA in children is inconclusive. Some studies conclude children from lower SEP backgrounds engage in slightly less MVPA while many others found no pattern of effect.[8,9] The majority of studies using objectively measured physical activity illustrate no apparent socioeconomic patterning in children's adherence to international physical activity guidelines. This evidence base does not reflect known socioeconomic inequalities in adiposity and other health outcomes in children.

Dose response evidence demonstrates that the association between MVPA and adiposity is driven by duration and intensity of activity.[10,11] Vigorous physical activity (VPA) is strongly associated with lower levels of adiposity and associated risk factors independent of its effect on energy expenditure.[12] Additionally, higher intensities of physical activity in the vigorous range have been shown to be most strongly associated with metabolic health in children.[13] Analyses in both European and international studies have identified VPA to act as a key factor discriminating between children who have normal versus an unhealthy weight (overweight or obese).[14,15]

Despite this evidence, in line with current guidelines, most epidemiological research and intervention trials target and assess the aggregate measure of MVPA. Considering the distinct characteristics of moderate physical activity (MPA) (e.g. walking to school) versus VPA (e.g. organized sport participation), it is conceivable that differences exists between socioeconomic groups.[16] Evidence demonstrates that some activities that drive VPA, such as organized sport, are socially patterned due to unequal access, support and costs.[17] By repeatedly using the aggregate measure of MVPA we may be overlooking important differences between socio-economic subgroups.

Global analyses suggest that countries with political and economic systems that produce greater income inequality have poorer child and adolescent health outcomes and higher rates of NCDs in adulthood.[18] An investigation within a low-income country setting revealed that children accumulate high amounts of incidental MPA but low amounts of VPA, which is associated with low cardiorespiratory fitness and poorer health outcomes.[19] An ensuing analysis from a high-income country context revealed that children from lower individual SEP accumulate MVPA from lower intensity distributions than socioeconomically affluent children.[16] Overall, we have limited understanding of whether the influence of individual SEP on physical activity intensities changes between national contexts with varying levels of economic inequality, thus differentially driving inequalities in obesity and ultimately NCDs.

Accelerometer measurement is critical to accurately understand intensity differences in physical activity behavior and address this question.

Using a large international harmonised accelerometer dataset from 36 studies across 16 countries, the objective of this analysis was to determine if there are socio-economic differences in the intensity patterning of physical activity in European children and investigate if individual level inequalities are driven by national level income inequality and age.

METHODS

The DEDIPAC (DEterminants of DIet and Physical ACtivity) Knowledge Hub was established in 2013 by a multidisciplinary consortium of 68 research centers from member states across the European Union.[20] A central aim of the hub was the standardization and harmonization of existing European studies to describe population levels of behavior, including physical activity. The analyses presented here use data from the DEDIPAC database on children's accelerometer-assessed activity, which pooled and harmonized all available accelerometer data in European children and adolescents (5-16 years of age), and is based at the Norwegian School of Sports Science, Oslo, Norway.

Following a systematic literature search, principal investigator teams of studies eligible for inclusion were contacted. Those that agreed to take part signed data sharing agreements and accelerometer and descriptive data files were transferred to the analytic team. The full details of this search and harmonization process are described elsewhere,[21] and details of the original studies included in Supplementary File 1. All data were stored, managed and processed following the data policies of the Norwegian School of Sports Science.

Data from all studies included within the DEDIPAC database were considered for inclusion in this analysis.

Selection criteria and strategy

Following initial scoping investigations of the availability of socioeconomic data within DEDIPAC studies, parental education (preferably maternal) was selected as the indicator of SEP. This decision was made in consideration of evidence evaluating the reliability of measures of SEP in child and adolescent populations [22,23] and pragmatically based on data availability within the included studies.

Studies from the DEDIPAC children's accelerometer database were included if 1) study authors approved the use of their data for this analysis, 2) the study did not receive food industry sponsorship (in accordance with institutional policy) and 3) authors were able to provide education data on the study participants' parents (with a preference for maternal education).

Lead study authors were contacted in July 2018 with an analysis proposal requesting their participation (Included in Supplementary File 2). Those that agreed to participate were asked to send parental education data for all included participants, using the same ID numbers as initially used when they provided data as part of the DEDIPAC consortium. Where multiple waves of follow-up were available for a cohort, inclusion was restricted to the first.

Data processing

Accelerometer data

Physical activity was assessed across all studies using Actigraph accelerometers. The details of physical activity data collection by individual study, including years and months of data collection, design, accelerometer model and epoch length are outlined in Supplementary File 3. A 60-second epoch length was used for the purpose of data harmonisation within the DEDIPAC database. Accelerometer data were considered daily, across 06:00 – 23:00 hours, with a minimum wear time for a valid day of 480 minutes.[24] Inclusion was restricted to participants with three or more valid days of accelerometer wear-time irrespective of weekday or weekend days.[25] Evenson cut points were used to calculate the average daily minutes spent in MPA (2296-4011 cpm), VPA ($\geq$ 4012 cpm) and MVPA per day. Evenson cut points were used based on demonstrated validity and accuracy of classification among children of all ages.[26]

Values of average daily minutes of MPA at the individual participant level? were assessed, and the maximum observations deemed to be within reasonable limits (99^{th} percentile: 185 mins per day). For average daily minutes of VPA, five participants with observations above 360 minutes (6 hours) were set to 360. As there is no single accepted standard for identifying extreme values of MVPA, alternative approaches including the exclusion of values outside the upper 99^{th} percentile and 3·5 standard deviations from the mean, were tested; this did not impact the findings.

Socioeconomic position (SEP)

Parental education was used as the measure of SEP. A priori prioritization decision were made as follows: a) maternal education was prioritized over paternal education and combined parental measures; b) a hierarchy of operationalisation of education constructs was developed with educational institutions attended/completed preferred to qualifications attained which was preferred to years of education completed; c) data collection via parental self-report was prioritized over partner-proxy report and lastly child report.

Parental education was harmonised into a three-level SEP variable categorized as (Low) ‘up to and including completion of compulsory education’, (Middle) ‘some post-compulsory education or vocational training’, and (High) ‘completed undergraduate or postgraduate university education’. Classification decisions were made based on input of the authors and by consulting standards of education within the national context of what constitutes compulsory vs post-compulsory education.[27] This harmonisation procedure is equivalent to that conducted for the International Children’s Accelerometery Database with full details of the harmonisation process for each study outlined in Supplementary File 4. For the remainder of the paper, low, medium and high SEP are used to refer to these three categories.

Body Mass Index

Body Mass Index (BMI) z-score was used to characterise the adiposity of participants. Child anthropometric measurements (weight (kg) and height (cm)) were transformed to age and sex adjusted BMI z-scores using the World Health Organizations Child Growth Standards 2007.[28] All studies used objective measurement methods. Children and adolescents were subsequently categorized into weight categories representing 'normal weight', 'overweight' and 'obese' using international BMI cut-offs (WHO Child Growth Standards). BMI z-score and associated categories were calculated using extensions to the Stata *egen* functions *zanthro* and *zbmicat*.[29]

National variation in inequality

The Gini coefficient was used as indicator of national level income inequality. The Gini coefficient measures the income distribution within a country and the extent to which that distribution deviates from a perfectly even distribution representing absolute equality. A Gini coefficient of 0 represents perfect equality while an index of 100 denotes complete inequality. Data outlining the Gini coefficient of the 16 included countries was obtained from the World Bank.[30]

Statistical Analysis

All analyses were conducted using STATA 15·1 (Statacorp, College Station, Texas, USA). Drop out analyses were conducted to determine differences between the analytic and excluded sample. These were conducted through chi-square tests, on the overall dataset, across SEP, BMI, age and gender. Continuous summary statistics at the study level were calculated using a weighted mean by participant size.

Two-stage individual level meta-analyses were conducted using the Stata command *ipdmetan*.[31] This command first fits the data to the specific model for each individual study, then pools the study effects and variances into a meta-analysis model using inverse-variance weighting. In the first stage, multivariable linear regressions were fitted to analyse differences in 1) absolute mean daily minutes of VPA 2) absolute mean daily minutes of MVPA and 3) BMI z-score, across the three categories of SEP, by study. Unadjusted models were run, with adjustments for each identified confounding factor sequentially tested and added. The respective final models are adjusted for: 1) mean minutes of MPA, accelerometer wear time, age and sex, 2) accelerometer wear time, age and sex, and 3) age and sex. In the second stage, individual study estimates were pooled through a meta-analysis approach and results displayed as forest plots. For each model, estimates were plotted in two forest plots using low SEP as the reference category. The first outlines the effect of low (reference category) versus middle SEP; and the second low (reference category) versus high SEP. Heterogeneity was assessed across all models using the I^2 statistic. By convention, I^2 values of 25% were considered low, 50% moderate and 75% high.[32]

Subgroup meta-analyses by the Gini coefficient were pre-planned to explore differences in the socioeconomic patterning of VPA, MVPA and BMI across low, medium and high national level income inequality. Given the wide range of children included in the analyses, subgroup meta-analyses were also planned by age for children below and above 10 years of age.

Additionally, to visually examine differences in physical activity intensity distributions, a figure was developed presenting the proportion of VPA within overall physical activity (mins of MVPA) stratified by low, medium and high SEP.

Role of the funding source

The funders of the study had no role in the study design, data analysis, data interpretation and writing of this report. The corresponding author (RL) had full access to all the data and has final responsibility for analyses presented.

RESULTS

Of the 43 studies included in the DEDIPAC children's accelerometer database, 40 met the inclusion criteria for this study and were sent data requests. We received and successfully harmonised SEP data for 36 studies. Each country within a multinational study was treated as one study. Figure 1 outlines the flow of studies and participants at each stage, including the stepwise reasons for exclusion. From an initial pool of 39,516 participants following data harmonisation, 14% participants were excluded due to missing parental education data, an additional 17% did not meet the accelerometer processing criteria. Thus, 26,915 individual participants from 16 European countries were included in the final analytic sample. Less than 1% (N=200) of participants were not included in the BMI meta-analysis due to missing height and/or weight data.

Of the 26,915 included study participants 51·7% were female and average age was 10·1 years. When split by BMI categories, 8·6% of participants were underweight, 73·2% a healthy weight, 14·1% overweight and 4·1% obese. On average, participants accumulated 34·9 (standard deviation (SD): 16·7) minutes of MPA and 12·7 (SD: 12·5) minutes of VPA and 762·0 (SD: 121·4) minutes of wear time per day. Sociodemographic and physical activity summary characteristics of the analytic sample are outlined in Table 1 and included by individual study in Supplementary File 6.

Drop out analyses revealed that participants in the analytic sample were more likely to be from a higher SEP, have a lower BMI z-score, be older and more likely to be female than those in the excluded sample.

Unadjusted models for VPA alongside supplementary models of the comparative effect of MPA, adjusted for VPA, accelerometer wear time, age and sex, are included in Supplementary File 5.

VPA, MVPA and BMI by individual level socioeconomic position

Table 2 and Figures 2-4 show the results of the meta-analyses. Lower SEP children spend less time per day in VPA, despite higher levels of overall MVPA (Low vs. High SEP; VPA, 0·57 mins) (95% CI: 0·28, 0·85 mins); MVPA, -1·51 mins (95% CI: -2·36, -0·67 mins)). Figure 5 shows the proportion of VPA in overall MVPA, by level of activity, with participants grouped by SEP. This figure reveals that irrespective of MVPA level, children from higher SEP backgrounds accumulate a greater proportion of their daily MVPA from VPA. Parallel differences in adiposity were evident with higher SEP being associated with lower BMI z-scores (Low vs High SEP, -0·20 (95% CI: -0·24, -0·16)). These relationships demonstrated stepwise increases moving from low to medium to high SEP.

Exploration of heterogeneity by national level income inequality and age

Overall heterogeneity, assessed through the I^2 statistic, ranged from low to moderate (12-45%) across all models.[32]

Subsequent subgroup meta-analyses by low, medium and high national income inequality revealed no substantially consistent patterning in effect estimates across VPA, MVPA or BMI z-score (See Table 3 and forest plots in Supplementary File 8). The only pronounced difference across all estimates was that lower levels of MVPA with increasing individual SEP were not present in countries with low income inequality.

Subgroup meta-analyses by age revealed distinct patterning. Lower amounts of MVPA with increasing SEP only manifested in participants 10 years of age and older. Inequalities in VPA and BMI z-score became more pronounced with increasing age (See Table 4 and forest plots in Supplementary File 9).

DISCUSSION

Our analyses of 26,915 participants with accelerometer-assessed physical activity suggest that children with a higher SEP spend more time engaged in VPA despite lower overall levels of MVPA. These differences mirror higher BMI z-scores observed in lower socioeconomic subgroups and follow a stepwise trend from low to middle to high SEP. These relationships are consistent across European countries irrespective of national level income inequality and become more pronounced in children aged over 10 years.

Although the differences observed are relatively small (e.g. 0·60 and 1·5 minutes per day; and 0·20 z-score units for VPA, MVPA and BMI z-score, between low and high socioeconomic subgroups of children, respectively), we suggest that the trend of higher intensity activity accumulated by more affluent children despite lower levels of overall activity are relevant at a population level and may have implications for the parallel trend in widening inequalities in adiposity. This is in consideration of evidence that VPA is more strongly associated with lower adiposity and more strongly associated with cardiorespiratory fitness than MPA or MVPA, and suggest that these benefits are attained at only 10 minutes of VPA per day.[33] Thus, even small improvements at a population level could result in meaningful public health benefit. Longitudinal analyses have demonstrated that metabolic syndrome at 36 years was independently associated with a greater shift from VPA to lower intensity activity earlier in life.[34] We further suggest that the lower levels of VPA in low SEP children are meaningful in light of recent evidence demonstrating that age-related declines in VPA are greater in socioeconomically disadvantaged adolescents.[35] Considering these faster rates of age-related decline and assuming a prospective association between VPA and adiposity, the differences revealed in this analysis can be assumed to worsen as participants age and have implications for the parallel trend in widening inequalities in adiposity.

This work substantially adds to the current limited knowledge on the association between SEP and children's physical activity behaviour. To date, the relationship between SEP and physical activity in children has been inconclusive, with a recent umbrella review concluding this is due to weak research designs and a lack of accuracy in the activity and socioeconomic assessment methods used.[36] Accelerometer measurement enables the valid and reliable assessment of physical activity across socioeconomic subgroups of children,[37] unlike self-reported data which are likely to be differentially biased.[38] Additionally, self-reported data are challenging to accurately harmonise between national contexts due to inconsistent data collection and assessment methodologies.[39] The dataset developed for this analysis is the largest to date with both harmonised accelerometer-assessed activity and individual SEP data, both in terms of the number of children included and variety of contexts. The inclusion of 16 countries represents the widest diversity of accelerometer data combined to date across the European context. The harmonisation of parental education data across country settings to create comparable SEP categories adds further value. Through capturing knowledge-related assets, parental education is a strong predictor of children's health and enables cross-country comparisions.[40,41]

Our finding of a patterning of increased VPA despite lower levels of MVPA in children from high socioeconomic backgrounds is novel as few previous analyses have investigated this relationship. While prior studies have looked at activity intensity,[42] the majority have not accounted for MPA or are unable to investigate differences across socioeconomic subgroups due to sample homogeneity.

The findings presented indicate that the central focus of physical activity promotion and guidelines on MVPA may be masking meaningful inequalities between socioeconomic groups. We echo prior calls for a greater focus on VPA in physical activity guidelines including more specific dose recommendations.[43] Only five of the 16 countries included in this analysis have children's physical activity guidelines that include a recommendation regarding the frequency of engaging in VPA with only one (Denmark) specifying a dose that '*vigorous intensity activities of at least 30 minutes, at least 2-3 times a week'* should be incorporated. Further research is needed to determine the most appropriate dose of VPA including consideration of what quantity is feasible for children as a target.

There are multiple reasons why the differences in VPA and MVPA by SEP reported here may exist. Organised sports (which are more associated with the accumulation of VPA) are engaged in more by more versus less socio-economically advantaged children due to costs and other differences in access.[17,44,45] These and other barriers, including parental time commitments, [46] seem to systematically influence low SEP children's access to activities that facilitate VPA.

There is an evident need for the development of programs that effectively engage children in physical activity of a sufficient intensity to accrue health benefits. While there are examples of interventions successfully improving levels of VPA,[47] these are limited in size, quality and without a focus on the SEP of children. We highlight recent concerning evidence of a lack of effectiveness of school-based activity interventions across all SEP subgroups of children,[48] and raise the need for the assessment and maximisation of implementation fidelity within intervention development efforts.

Findings from this study should be interpreted with caution in consideration of its limitations. The recruitment and sampling procedures differed between the 36 included studies. In some, but not all, studies, stratified sampling was adopted to ensure that low socioeconomic groups were well represented. Similarly, the assessment methods used to measure SEP varied between studies in terms of the respondent (e.g. maternal versus paternal) and the constructs assessed (e.g. educational institutions attended vs. years of education). Furthermore, it is possible that the relationship between education and access to resources is different between countries, accordingly influencing the lived reality of the socioeconomic groups in unpredictable manners. We were unable to control for potiential confounders including sleep and diet. Lastly, this analysis used intermediate physical activity intensities which may raise issues of collinearity based on more recent methodological analyses from the field.[13,49]

Accelerometers underestimate activity involving vertical movement (e.g. cycling) and those for which accelerometers should not to be worn (e.g. aquatic activities or contact sports).[50] If these activities are socioeconomically or culturally patterned, they may affect the associations observed. However, considering that organised activities are more frequent in higher SEP children and linked to VPA, this mechanism, if anything, would have led to an underestimation of the associations observed.[17,44,45] Lastly, to maximise data use, accelerometer data were harmonised using 60 second epoch lengths, which may have affected the findings. It may be conceivable that using longer epoch lengths, short bursts of high intensity activity are combined with lower intensity activity, leading to an under-estimation of MVPA and VPA.[51]

CONCLUSION

In conclusion, our study illustrates that lower levels of adiposity in children from a higher socioeconomic position are paralleled by relatively higher amounts of VPA despite overall lower levels of MVPA. Physical activity promotion efforts should focus on providing opportunities for less affluent children to be vigorously active. The development and testing of interventions are needed to determine how this can be effectively achieved.

RESEARCH IN CONTEXT

Evidence before this study

We searched PubMed with the terms "Child" OR "Youth" AND "Socioeconomic" OR "Socioeconomic status" OR "Socioeconomic position" OR "Disparities" AND "Physical activity" OR "Objectively-assessed physical activity" OR "Accelerometer measurement". We found four high quality systematic reviews and a large number of primary research studies that addressed if socioeconomic position (SEP) is related to children's physical activity (PA). Findings are varied, inconsistent and inconclusive, with the most up to date systematic review concluding no established associations between PA and SEP in children. There is overall uncertainty regarding if socioeconomic differences exist in PA intensity. We found no multi-country studies that investigated differences in PA intensities between socioeconomic groups, and the potential contribution to obesity inequalities. It, furthermore, is unclear if associations between SEP and PA intensity differ across national contexts.

Added value of this study

We found that children with a higher SEP spend more time engaged in vigorous physical activity (VPA) despite lower overall levels of moderate-to-vigorous physical activity (MVPA). These differences mirror increases in BMI z-score observed in lower socioeconomic subgroups and follow a stepwise trend from low to middle to high SEP. These relationships are consistent across European countries existing irrespective of national level income inequality and become more pronounced with age.

Implications of all the available evidence

The study findings suggest children from a lower socioeconomic position with higher levels of adiposity participate in relatively higher amounts of MVPA, yet lower amounts of VPA. There is a need for greater focus on VPA, including in national PA guidelines comprising more specific dose recommendations and in research to determine the most appropriate daily dose of VPA. Policy-makers should focus on the provision of programs and opportunities that effectively engage children in PA of a sufficient intensity to accrue health benefits, with a specific focus on less affluent children.

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Figure legends

Figure 1: Flow chart of study and participant selection: DEDIPAC children's accelerometer and SEP database

Figure 2: Multivariate meta-analysis of individual participant data (N=26,915) by study: Multivariable linear regressions of MVPA (mins/day) by three levels of socioeconomic position (SEP) 1) Low [reference category] vs. medium SEP, 2) Low [reference category] vs high SEP, adjusted for daily accelerometer wear time, age and sex

Note for figure: The box area of each study is proportional to the inverse of the variance, and the horizontal lines show the 95% CI. Study is listed on the y-axis with effect estimates and weight given to each study indicated in the right-hand columns. The pooled estimate based on a fixed-effects model is shown by a dashed vertical line and diamond (95% CI)'.

Figure 3: Multivariate meta-analysis of individual participant data (N=26,915) by study: Multivariable linear regressions of VPA (mins/day) by three levels of socioeconomic position (SEP) 1) Low [reference category] vs. medium SEP, 2) Low [reference category] vs high SEP adjusted for MPA, daily accelerometer wear time, age and sex

Note for figure: The box area of each study is proportional to the inverse of the variance, and the horizontal lines show the 95% CI. Study is listed on the y-axis with effect estimates and weight given to each study indicated in the right-hand columns. The pooled estimate based on a fixed-effects model is shown by a dashed vertical line and diamond (95% CI)'.

Figure 4: Multivariate meta-analysis of individual participant data (N=26,915) by study: Multivariable linear regressions of BMI z-score by three levels of socioeconomic position (SEP) 1) Low [reference category] vs. medium SEP, 2) Low [reference category] vs high SEP, adjusted for age and sex

Note for figure: The box area of each study is proportional to the inverse of the variance, and the horizontal lines show the 95% CI. Study is listed on the y-axis with effect estimates and weight given to each study indicated in the right-hand columns. The pooled estimate based on a fixed-effects model is shown by a dashed vertical line and diamond (95% CI)'.

Figure 5: The proportion (%) of VPA within MVPA minutes per day by level of SEP: DEDIPAC children's accelerometer and SEP database (N=26,915)

Table 1. Characteristics of analytic sample: DEDIPAC children's accelerometer and SEP database (N=26,915 participants) [1]

Continuous variables		**Mean (SD)**
Age in years		10·1 (1·17)
Bmi z-score		0·3 (1·1)
VPA mean mins per day [2]		12·7 (12·5)
MPA mean mins per day [2]		34·9 (16·7)
Accelerometer wear time, mean mins per day [2]		762·0 (121·4)
Categorical variables		**% (N)**
Gender	Males	48·3% (13,000)
	Females	51·7% (13,915)
BMI categories	Underweight	8·6% (2,288)
	Normal weight	73·2% (19,568)
	Overweight	14·1% (3,776)
	Obese	4·1% (1,083)
Socioeconomic position (SEP)	Low (Up to and including competition of compulsory education)	24·0% (6,467)
	Middle (Some post compulsory education including vocational training)	38·7% (10,427)
	High (Completed undergraduate or postgraduate education)	37·2% (10,021)

[1] All characteristics by individual study are included in Supplementary File 6.
[2] Physical activity characteristics by level of SEP are outlined in Supplementary File 7.

Table 2. Summary of overall effect estimates of meta-analyses of individual participant data of multivariable linear regressions of identified variable by SEP: DEDIPAC children's accelerometer and SEP database (N=26,915)[1]

Level of SEP [2] Low SEP (reference category) vs.	**MVPA [3]** Differences in mins (95% CI)	I^2	**VPA [4]** Differences in mins (95% CI)	I^2	**BMI z-score [5]** Differences in z-score (95% CI)	I^2
Medium SEP	**-1·20 (-2·02, -0·38)**	11·7%	0·12 (-0·15, 0·38)	1·7%	**-0·10 (-0·14, -0·07)**	27·0%
High SEP	**-1·51 (-2·36, -0·67)**	24·1%	**0·57 (0·28, 0·85)**	28·5%	**-0·20 (-0·24, -0·16)**	45.1%

[1] N-participants included in BMI z-score analysis is 26,715

[2] Low SEP: compulsory education, Medium SEP: some post-compulsory education and High SEP: undergraduate or postgraduate education

[3] Model adjusted for daily accelerometer wear time, age & sex

[4] Model adjusted for daily accelerometer wear time, moderate physical activity, age & sex

[5] Model adjusted for age & sex

Table 3. Summary of overall effect estimates of multivariate subgroup meta-analyses of individual participant data by low, medium and high national level income inequality: DEDIPAC children's accelerometer and SEP database (N=26,915) [1]

Mean differences (95% CI) [2]		**MVPA**			**VPA**			**BMI z-score**		
Individual level of SEP	Low SEP (ref cat) vs	*Low national level income inequality*	*Medium national level income inequality*	*High national level income inequality*	*Low national level income inequality*	*Medium national level income inequality*	*High national level income inequality*	*Low national level income inequality*	*Medium national level income inequality*	*High national level income inequality*
	Medium SEP	-1·18 (-2·84, 0·47)	-1·43 (-3·37, 0·51)	**-1·13 (-2·21, -0·06)**	0·17 (-0·36, 0·71)	0·31 (-0·41, 1·03)	0·05 (-0·29, 0·39)	-0·04 (-0·11, 0·04)	**-0·15 (-0·23, -0·06)**	**-0·12 (-0·18, -0·07)**
	High SEP	-1·33 (-2·86, 0·20)	**-0·94 (2·97, 1·09)**	**-1·81 (-2·96, -0·64)**	**0·68 (0·12, 1·23)**	**1·17 (0·41, 1·93)**	**0·38 (0·02, 0·75)**	**-0·17 (-0·24, -0·11)**	**-0·22 (-0·31, -0·13)**	**-0·22 (-0·28, -0·16)**

[1] N-participants included in BMI z-score analysis is 26,715

[2] Forest plots for all of the estimates presented are included in Supplementary File 8.

Table 4. Summary of overall effect estimates of multivariate subgroup meta-analyses of individual participant data split by age (under 10 years of age versus over 10 years of age): DEDIPAC children's accelerometer and SEP database (N=26,915) [1]

Mean differences (95% CI) [2]		**MVPA**		**VPA**		**BMI z-score**	
Individual level of SEP	Low SEP (ref cat) vs	*Under 10*	*Above 10*	*Under 10*	*Above 10*	*Under 10*	*Above 10*
	Medium SEP	-0·59 (-2·06, 0·87)	**-1·50 (-2·78, -0·21)**	0·02 (-0·36, 0·41)	0·26 (-0·19, 0·71)	**-0·13 (-0·23, -0·03)**	**-0·10 (-0·17, -0·04)**
	High SEP	-0·93 (-2·84, 0·97)	**-1·83 (-2·90, -0·77)**	**0·46 (0·07, 0·86)**	**0·86 (0·24, 1·48)**	**-0·18 (-0·27, -0·09)**	**-0·22 (-0·29, -0·15)**

[1] N-participants included in BMI z-score analysis is 26,715

[2] Forest plots for all of the estimates presented are included in Supplementary File 9.

Data Sharing

The datasets generated for this analysis are available from the corresponding author on reasonable request

Ethics approval and consent to participate

Not applicable

Competing Interests Statement:

All authors have completed the Unified Competing Interest form (available on request from the corresponding author) and declare: no support from any organisation for the submitted work [beyond those research funders outlined]; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

Statement of Independence

All researchers are independent from funders.

Authors' contributions

RL, EvS and JA designed the study. JSJ and UE provided inputs to the analysis plan. JSJ and UE ;ed the physical activity harmpnisation. RL collected, harmonised and merged all of the SEP data. RL conducted all of the analyses at the Norwegian School of Sports Science, Oslo, Norway, where the DEDIPAC database is stored. RL critically interpreted all of the results and drafted the manuscript. All of the authors listed contributed to the interpretation of the results and critically reviewed drafts of the manuscript. All authors read and approved the final manuscript. RL is the guarantor and responsible for the overall content.

Transparency Declaration

The lead author RL affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned and registered have been explained.

Figure 1 Click here to download Figure Figure1_Love_LPH.png

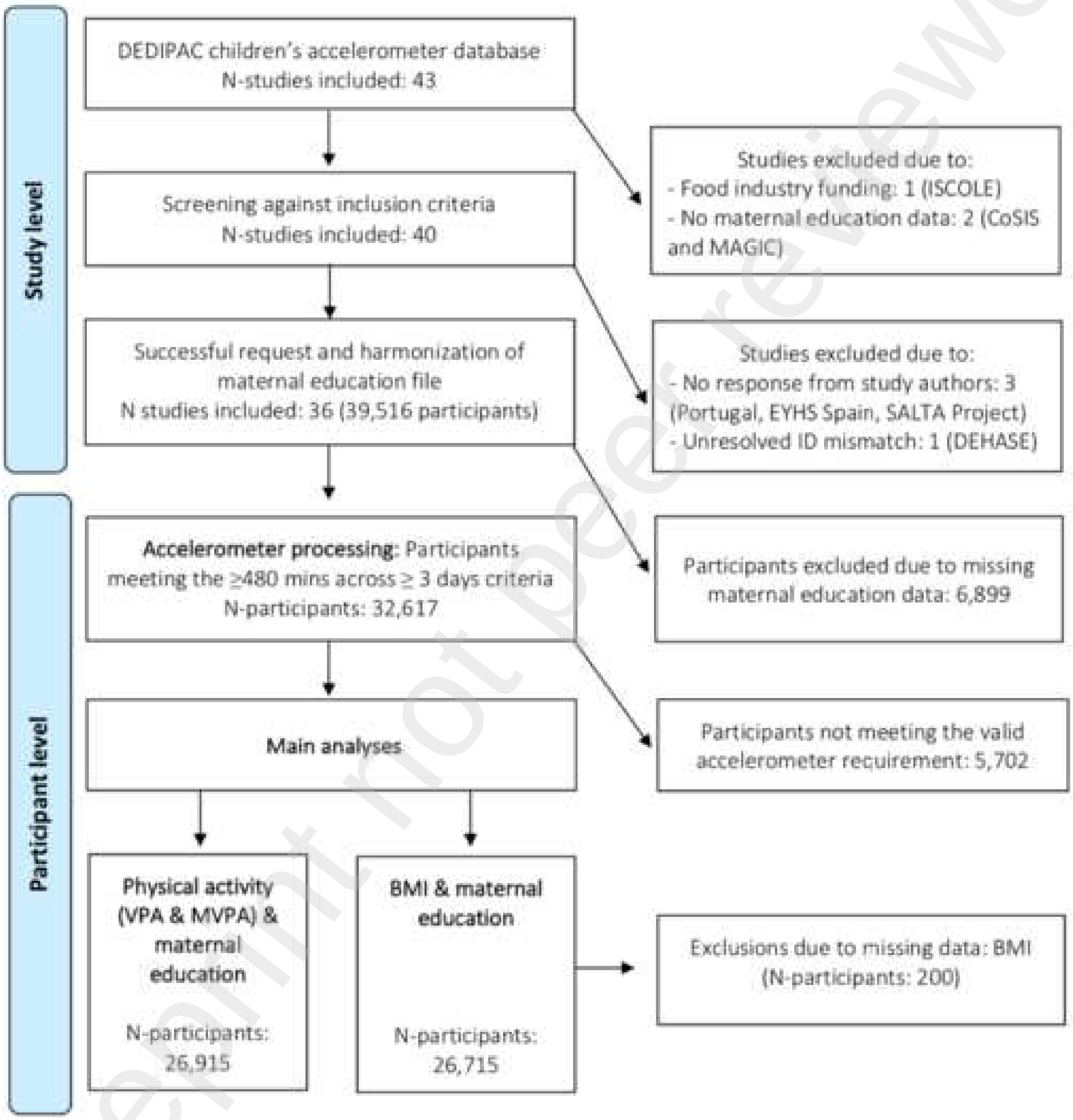

Figure 2

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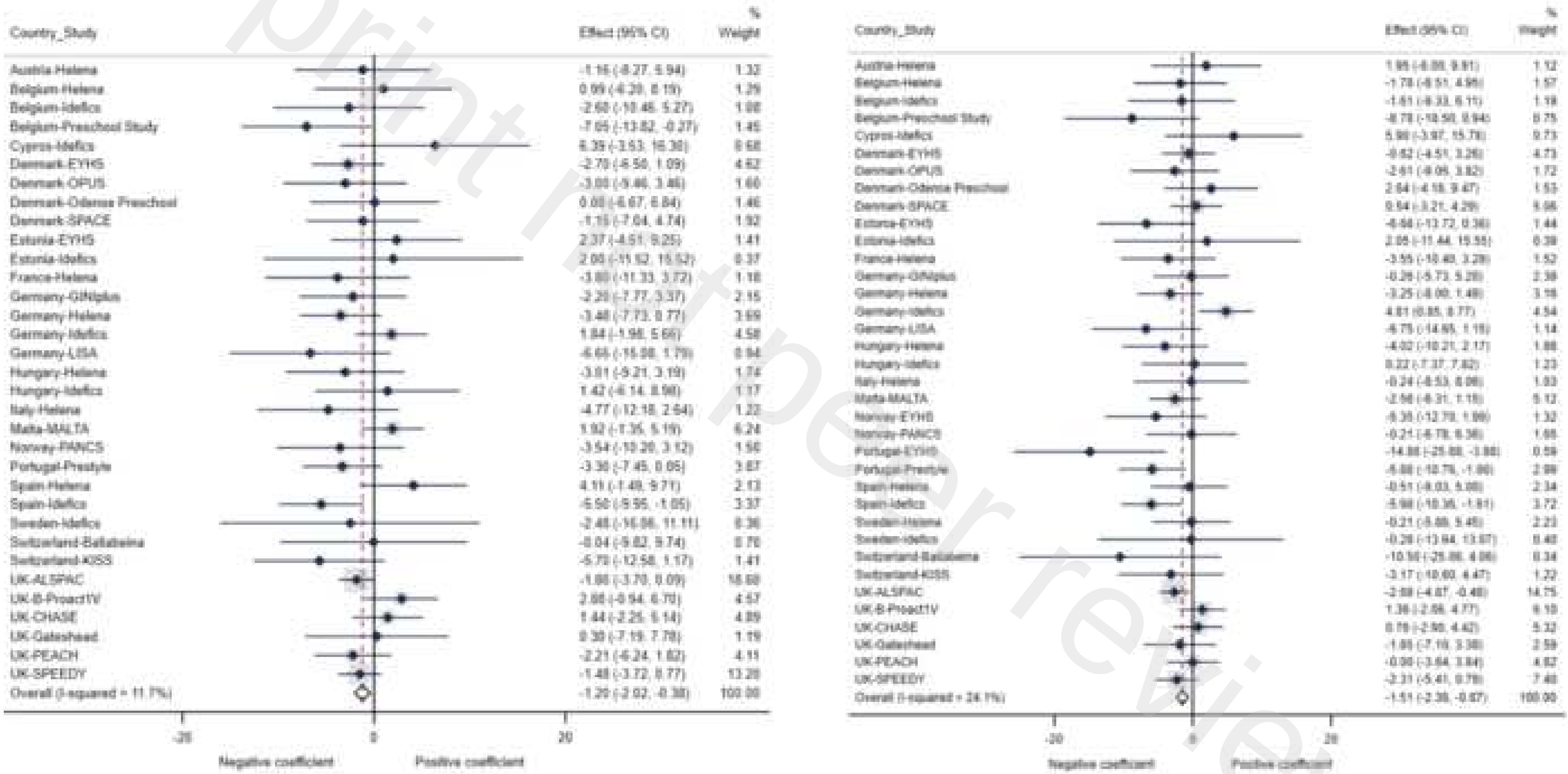

Figure 3

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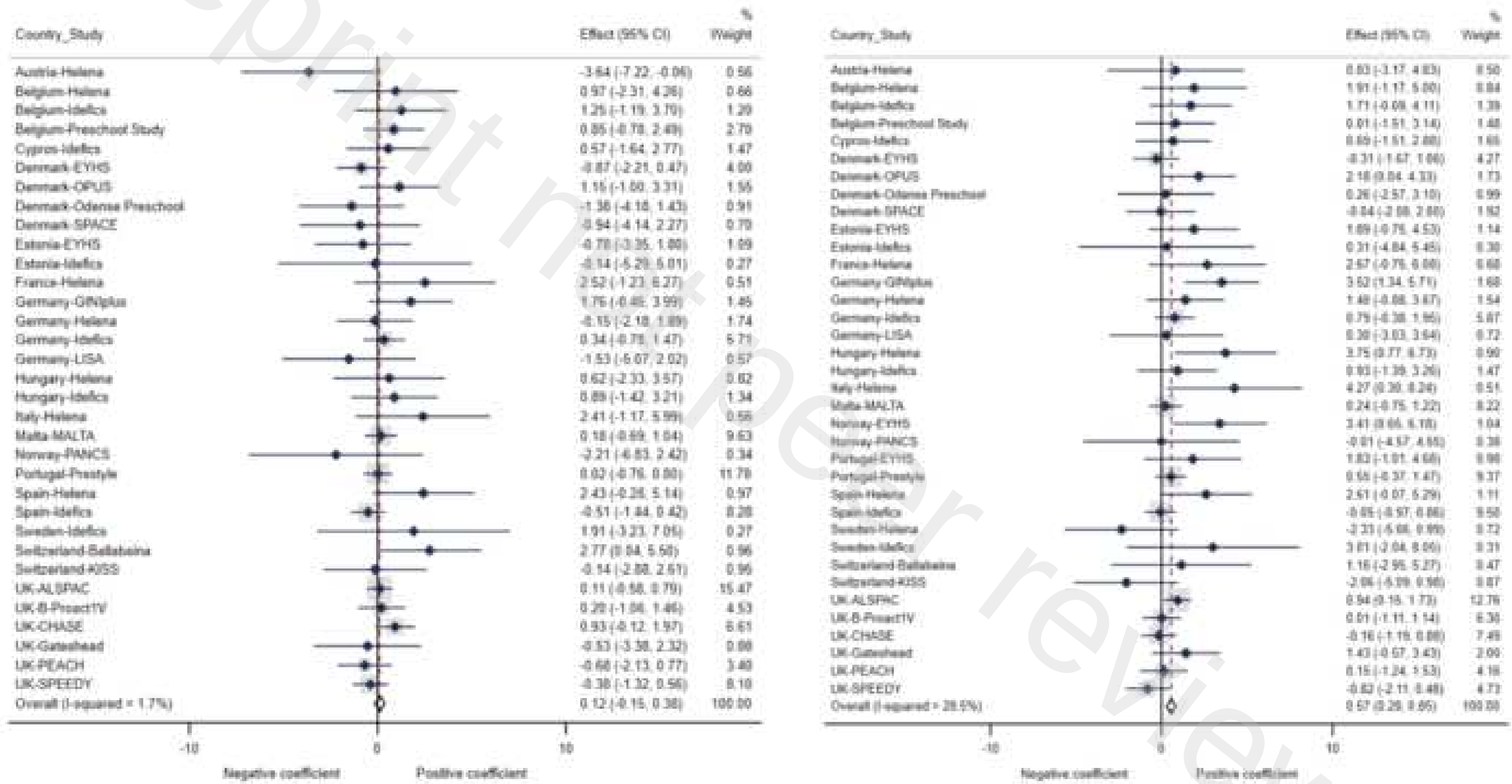
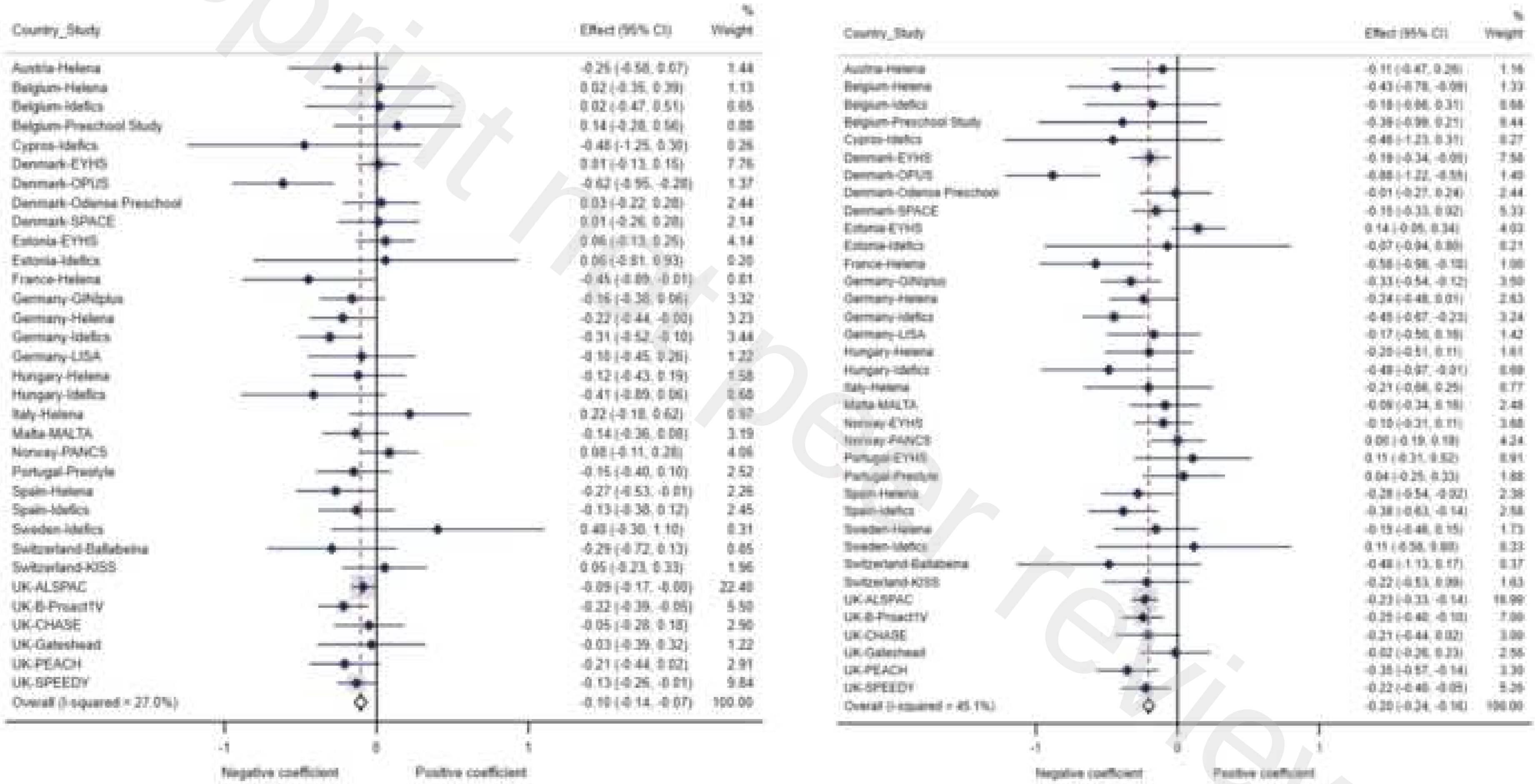


Figure 4



Country_Study
Effect (95% CI)
% Weight
Austria-Helena -0.25 (-0.58, 0.07) 1.44
Belgium-Helena 0.02 (-0.35, 0.39) 1.13
Belgium-Idefics 0.02 (-0.47, 0.51) 0.65
Belgium-Preschool Study 0.14 (-0.28, 0.56) 0.88
Cyprus-Idefics -0.48 (-1.25, 0.30) 0.26
Denmark-EYHS 0.01 (-0.13, 0.15) 7.76
Denmark-OPUS -0.62 (-0.95, -0.28) 1.37
Denmark-Odense Preschool 0.03 (-0.22, 0.28) 2.44
Denmark-SPACE 0.01 (-0.26, 0.28) 2.14
Estonia-EYHS 0.06 (-0.13, 0.25) 4.14
Estonia-Idefics 0.06 (-0.81, 0.93) 0.20
France-Helena -0.45 (-0.89, -0.01) 0.81
Germany-GINIplus -0.16 (-0.38, 0.06) 3.32
Germany-Helena -0.22 (-0.44, -0.00) 3.23
Germany-Idefics -0.31 (-0.52, -0.10) 3.44
Germany-LISA -0.10 (-0.45, 0.26) 1.22
Hungary-Helena -0.12 (-0.43, 0.19) 1.58
Hungary-Idefics -0.41 (-0.89, 0.06) 0.68
Italy-Helena 0.22 (-0.18, 0.62) 0.97
Malta-MALTA -0.14 (-0.36, 0.08) 3.19
Norway-PANCS 0.08 (-0.11, 0.28) 4.06
Portugal-Prestyle -0.15 (-0.40, 0.10) 2.52
Spain-Helena -0.27 (-0.53, -0.01) 2.26
Spain-Idefics -0.13 (-0.38, 0.12) 2.45
Sweden-Idefics 0.40 (-0.30, 1.10) 0.31
Switzerland-Ballabeina -0.29 (-0.72, 0.13) 0.85
Switzerland-KISS 0.05 (-0.23, 0.33) 1.96
UK-ALSPAC -0.09 (-0.17, -0.00) 22.40
UK-B-Proact1V -0.22 (-0.39, -0.05) 5.50
UK-CHASE -0.05 (-0.28, 0.18) 2.90
UK-Gateshead -0.03 (-0.39, 0.32) 1.22
UK-PEACH -0.21 (-0.44, 0.02) 2.91
UK-SPEEDY -0.13 (-0.26, -0.01) 9.84
Overall (I-squared = 27.0%) -0.10 (-0.14, -0.07) 100.00
-1
0
1
Negative coefficient
Positive coefficient
Country_Study
Effect (95% CI)
% Weight
Austria-Helena -0.11 (-0.47, 0.26) 1.16
Belgium-Helena -0.43 (-0.78, -0.08) 1.33
Belgium-Idefics -0.18 (-0.66, 0.31) 0.66
Belgium-Preschool Study -0.39 (-0.98, 0.21) 0.44
Cyprus-Idefics -0.46 (-1.23, 0.31) 0.27
Denmark-EYHS -0.19 (-0.34, -0.05) 7.56
Denmark-OPUS -0.88 (-1.22, -0.55) 1.49
Denmark-Odense Preschool -0.01 (-0.27, 0.24) 2.44
Denmark-SPACE -0.15 (-0.33, 0.02) 5.33
Estonia-EYHS 0.14 (-0.05, 0.34) 4.03
Estonia-Idefics -0.07 (-0.94, 0.80) 0.21
France-Helena -0.58 (-0.98, -0.18) 1.00
Germany-GINIplus -0.33 (-0.54, -0.12) 3.50
Germany-Helena -0.24 (-0.48, 0.01) 2.63
Germany-Idefics -0.45 (-0.67, -0.23) 3.24
Germany-LISA -0.17 (-0.50, 0.16) 1.42
Hungary-Helena -0.20 (-0.51, 0.11) 1.61
Hungary-Idefics -0.49 (-0.97, -0.01) 0.69
Italy-Helena -0.21 (-0.66, 0.25) 0.77
Malta-MALTA -0.09 (-0.34, 0.16) 2.48
Norway-EYHS -0.10 (-0.31, 0.11) 3.68
Norway-PANCS 0.00 (-0.19, 0.18) 4.24
Portugal-EYHS 0.11 (-0.31, 0.52) 0.91
Portugal-Prestyle 0.04 (-0.25, 0.33) 1.88
Spain-Helena -0.28 (-0.54, -0.02) 2.38
Spain-Idefics -0.38 (-0.63, -0.14) 2.58
Sweden-Helena -0.15 (-0.46, 0.15) 1.73
Sweden-Idefics 0.11 (-0.58, 0.80) 0.33
Switzerland-Ballabeina -0.48 (-1.13, 0.17) 0.37
Switzerland-KISS -0.22 (-0.53, 0.09) 1.63
UK-ALSPAC -0.23 (-0.33, -0.14) 18.99
UK-B-Proact1V -0.25 (-0.40, -0.10) 7.00
UK-CHASE -0.21 (-0.44, 0.02) 3.00
UK-Gateshead -0.02 (-0.26, 0.23) 2.56
UK-PEACH -0.35 (-0.57, -0.14) 3.30
UK-SPEEDY -0.22 (-0.40, -0.05) 5.26
Overall (I-squared = 45.1%) -0.20 (-0.24, -0.16) 100.00
-1
0
1
Negative coefficient
Positive coefficient

Figure 5

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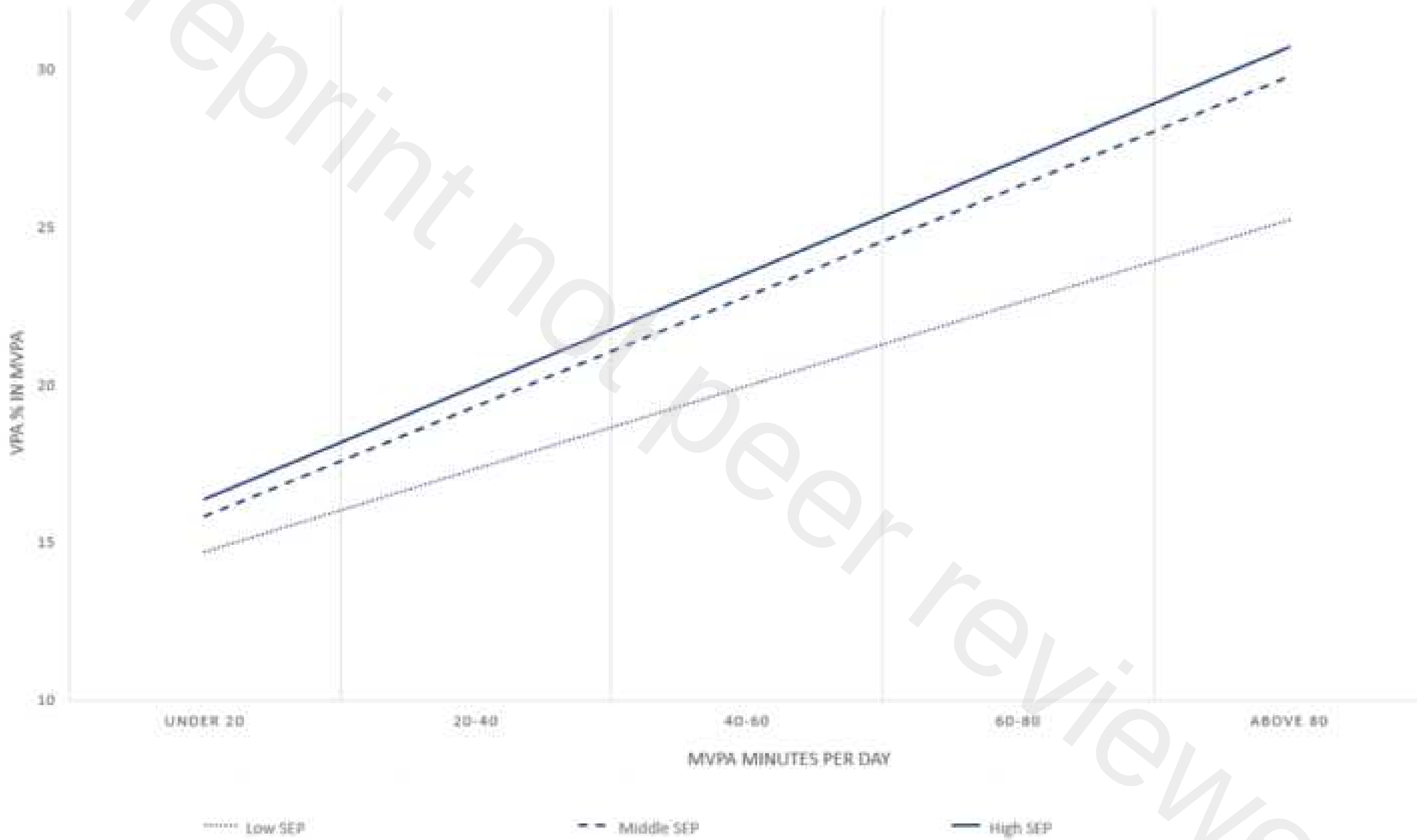

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