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Title: Associations between meeting 24-hour movement guidelines and health in the early years: A systematic review and meta-analysis

Abstract

This systematic review examined the compliance with the 24-hour movement guidelines, and investigated its associations with health indicators for healthy children under 5 years of age. MEDLINE, PsycINFO, EMBASE, PubMed, Web of Science and SPORTDiscus were searched for peer-reviewed studies and the last search was conducted on 27 October 2020. The Newcastle-Ottawa Scales were used to assess the quality of included studies. Eighteen articles including 8,943 participants from 11 countries were included. On average around 13% of children met all three guidelines. Meta-analyses of the associations between meeting all three guidelines and adiposity yielded no significant results ($r = -0.03$; 95% CI = –0.12, 0.06; I^2 = 51%; P = 0.48). Meeting more guidelines was associated with better psychosocial health (3/4 studies). Associations between meeting individual or combined guidelines and motor development yielded mixed results (2/2 studies), while no associations between meeting guidelines and cognitive development were observed (1 study). Compliance with all three guidelines was low. Further evidence is required to understand the associations between meeting the 24-hour movement guidelines and health outcomes. Nevertheless, there was evidence of a dose-response relationship between meeting the guidelines and better psychosocial health in the early years.

Keywords: physical activity, screen time, sleep, health indicators, early years

Introduction

Early childhood (under 5 years of age) is an important period for children's health and development,[1] and lifestyle and habits at this stage have an important impact on future life.[2,3] Physical activity (PA),[4,5] sedentary behaviour (SB),[6,7] and sleep are associated with health-related indicators in the early years.[8,9]

For example, higher PA levels and sufficient sleep are related to lower risk of adiposity and better psychosocial health, motor development, cognitive development and cardiometabolic health,[8,10] and high levels of SB are associated with increased risk of adiposity.[11,12] Higher PA, longer sleep and lower SB have been shown to be the ideal combination for optimal health in children.[13] Because of the finite time in a day, an increase in the time spent on one activity means an equivalent decrease in the time spent on the other activities. Therefore, movement behaviours including PA, SB and sleep need to be considered simultaneously.

Recently developed 24-hour movement guidelines have demonstrated a shift from the traditional view of movement behaviours in isolation to new integrated guidelines. Canada and Australia issued guidelines for the early years in 2017,[14,15] followed thereafter by WHO, the United Kingdom and South Africa also recommendations and integrated guidelines for the early years.[16–18] In general, these guidelines are as follows: Infants aged less than 1 year should be physically active several times per day, have 14 to 17 hours (aged 0-3 months) or 12 to 16 hours (aged 4-11 months) of good-quality sleep (including naps), not be restrained for more than 1 hour at a time, and not have screen time (ST); Toddlers (1-2 years) should have at least 180 min of PA per day, 11 to 14 hours of good-quality sleep (including naps), and less than 1 hour of being restrained at a time. No sedentary ST is recommended for toddlers younger than 2 years, and no more than 1 hour of ST per day is recommended for those aged 2 years. Preschoolers (3-4.99 years) should spend at least 180 min of PA, including 60 min of energetic play (moderate-to-vigorous-intensity PA), and have 10 to 13 hours of good-quality sleep per day. Their time spent being restrained should be no more than 1 hour at a time, and sedentary ST should be less than 1 hour per day.[14–18]

Since the release of the first 24-hour movement guidelines in 2017, numerous studies have examined

compliance with guidelines and associations with health indicators in the early years.[19–23] However, the evidence regarding whether children in the early years who meet the guidelines are healthier than those who do not seems to be inconsistent.[22–25] Therefore, the purposes of this systematic review were to: (1) examine the association between meeting 24-hour movement guidelines (individual and in combination) and health in the early years; (2) determine whether there is a dose-response relationship between the number of guidelines met and health indicators; (3) examine compliance with the 24-hour movement guidelines in the early years.

Methods

Information sources and search strategy

Six databases were electronically searched: MEDLINE (Ovid), PsycINFO (ProQuest), EMBASE (Ovid), PubMed, Web of Science, and SPORTDiscus (EBSCO). Also, a manual search of reference lists of eligible papers was performed to identify additional records. The initial search was conducted on 26 March 2020 and an update search was conducted on 27 October 2020. There were no date limits or study design limits (see Supplementary Table 1 for the complete search strategy). This systematic review was guided by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) and guidance on systematic reviews and meta-analysis of observational studies.[26–28] It was registered on Open Science Framework (OSF; DOI: 10.17605/OSF.IO/QS4VD).

Eligibility criteria

Cross-sectional, cohort, longitudinal studies, and baseline from intervention studies were included. The specific inclusion criteria were: (1) peer-reviewed articles; (2) written in English; (3) targeting

apparently healthy children aged from 1.00 month to 4.99 years (infants: 1.00 month-0.99 year; toddlers: 1.00-2.99 years; preschoolers: 3.00-4.99 years); (4) assessing all of the movement behaviours including PA, ST and sleep. Studies were excluded if they were (1) qualitative studies; (2) case studies and case series; (3) grey literature; (4) comments/editorials; (5) reviews; and (6) studies focusing on children with clinical diagnoses (with the exception of obesity/overweight).

Exposures and health outcomes

PA, ST and sleep were the exposures in this systematic review, and they had to be assessed simultaneously. PA and sleep could be assessed by either objective (e.g. pedometers, accelerometers) or subjective (e.g. self-reported or proxy-reported questionnaire, interview, diary) measurements. ST could be assessed by subjective measurement (e.g. self-reported or proxy-reported questionnaire, interview, diary).

A total of nine health indicators were included and searched with reference to the previous systematic reviews.[4,13] All indicators were ranked as "critical" or "important" according to the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework:[29] (1) adiposity, e.g. body mass index (BMI), waist circumference (WC), body fat; (2) motor development (e.g. locomotion skills, ball skills); (3) psychosocial health (e.g. emotional regulation, anxiety, social-cognitive function, quality of life); (4) cognitive development (e.g. attention, executive function); (5) fitness (e.g. cardiovascular fitness, musculoskeletal fitness); (6) growth (e.g. head circumference); (7) bone and skeletal health (e.g. risk of fractures, bone density); (8) cardiometabolic health (e.g. blood pressure, glucose); and (9) risks/harm (e.g. injury, accidental fall, fracture).

Data extraction

Data selection and coding were conducted by two reviewers (JF and CZ) independently. Any disagreement was resolved by discussion or a third reviewer (WH). Titles and abstracts of potentially relevant articles were imported into Endnote and screened by two reviewers (JF and CZ). Full-text articles were then screened by two reviewers (JF and CZ) independently. Basic characteristics of the articles were extracted (e.g. author, publication year, country, design, population, exposure measurements, outcomes and main results). Missing data were requested from the authors.

Quality assessment

The Newcastle-Ottawa Scales for cross-sectional studies and cohort studies were used to assess the quality of the included studies,[30,31] by two reviewers (JF and CZ) independently. If there was any difference in their assessments, it was resolved by discussion or with a third reviewer (WH). The maximal score was 10 for cross-sectional studies and 9 for cohort studies. Studies were not excluded in meta-analysis based on the quality score. However, this information was reported and discussed.

Data synthesis

Meta-analysis was conducted using Review Manager version 5.3[32] where at least three studies reported the same exposure (PA, ST, sleep) and health outcomes and used the same design (e.g. cross-sectional). Based on these criteria, meta-analyses were performed only for studies reporting associations between meeting 24-hour movement guidelines and adiposity. The correlation coefficient (r) was used to calculate the effect size in the meta-analysis. For studies reporting a standard regression coefficient (β), standardised mean difference (Cohen's d) and F value, these estimates were converted to correlation coefficients (r) and then transformed to Fisher's z for further analysis.[33–36] For presentation, Fisher's z was converted back to correlations. Inconsistency was determined by I-square (I^2) values, which were

categorised as low, moderate, or high, with upper limits of 25%, 50%, and 75%, respectively.[37] Random effect models were used in the data synthesis to estimate pooled effect size and 95% confidence interval (CI). Subgroup analysis was not conducted because of the limited number of studies. Where meta-analysis was not appropriate, a narrative synthesis was conducted.

Results

Description of studies

A total of 1,285 records were identified through database searches, and 8 additional records were identified through a manual search of the reference lists. The PRISMA flow chart is shown in Figure 1. After title and abstract screening, 33 records remained for full-text screening. Of these, 15 articles were excluded due to the following reasons: children not being in the target age range (n = 1), not using 24-hour movement guidelines (n = 8), only using a part of 24-hour movement guidelines (n = 3), data reported on the same study sample (n = 1), and inability to retrieve data from authors (n = 2). Consequently, 18 studies met the inclusion criteria, and 4 out of the 6 authors who were contacted provided us with data requested. There was agreement on the selection of all 18 included studies (100%) between the two reviewers (JF and CZ).

The 18 studies included 8,943 individual participants (51% boys) from eleven countries. The mean ages in the individual studies ranged from 3.60 months to 5.11 years old. All 18 studies used an observational design, with 14 cross-sectional studies and 4 longitudinal studies. The health outcomes presented in this review were adiposity (n = 8), psychosocial health (n = 4), motor development (n = 2), and cognitive development (n = 1). The full list of the study characteristics of the included studies is shown in Tables

1 and 2. In the quality assessment, 13 of the articles scored at least 7,[19-25,38-43] 1 article scored as 6,[44] and the other 4 were scored as 4 or lower (Supplementary Tables 2 and 3).[45–48]

Measurement of movement behaviours

To assess PA, studies used accelerometers (n = 15)[19-23,25,38-44,46,48] or parent-report questionnaires (n = 3).[24,45,47] To assess ST, parent-reported questionnaires were used most often (n = 16),[19,21,23–25,38–48] while the other studies used either a parent interview (n = 1)[20] or a parent-reported diary (n = 1).[22] Sleep was assessed by parent-reported questionnaires (n = 9),[19,21,41,42,44–48] accelerometer data matched with activity logs (n = 3),[23,25,38] accelerometers alone (n = 3),[39,40,43] a combination of parent-reported sleep diary and questionnaire (n = 1)[24], parent-reported sleep diary alone (n = 1)[22], or parent interview (n = 1).[20] In one study, the sleep time component was excluded from the data analysis because of the unreliable and largely unusable data for daytime naps.[24]

Compliance proportion

Table 1 shows the proportions of compliance with the 24-hour movement guidelines reported in all 18 studies. The mean percentages and standard deviations (SD) of meeting the PA, ST and sleep guidelines were 67.0% ± 29.9% (n = 18), 28.3% ± 20.5% (n = 18) and 77.3% ± 19.7% (n = 17), respectively. On average, 12.8% (SD = 8.4%, n = 17) of the participants met all three guidelines, and the compliance proportions varied by age group: infants (3.5%; n = 1), toddlers (13.8% ± 4.4%; n = 3) and preschoolers (13.5% ± 9.6%; n = 13).

Associations between meeting 24-hour movement guidelines and adiposity

Associations between meeting 24-hour movement guidelines and adiposity were assessed in eight studies and the results are summarized in Table 2. BMI *z*-score was used most frequently (n =

153 5).[19,20,23,24,40] The quality of evidence of the eight studies was scored at least 7 (Supplementary Tables 2
154 and 3). For individual guideline compliance, 2/8 studies found an association between meeting PA
155 guideline and adiposity (higher SAT[24], lower WC[22]), 2/8 studies reported an association between
156 meeting ST guideline and adiposity (higher VAT,[24] lower risk for overweight and obesity[25]), and 1/8
157 studies reported an association between meeting sleep guideline and adiposity (lower WC, lower
158 BMI).[22] The association between meeting both PA and sleep guidelines and adiposity (lower WC, lower
159 BMI) was reported in 1/8 studies,[22] while other studies found the association between neither meeting
160 other combinations (PA and ST, ST and sleep) nor all three guidelines and adiposity.

161 Five studies of associations between meeting 24-hour movement guidelines and BMI *z*-score were
162 included in the meta-analysis.[19,20,23,24,40] The remaining three studies were excluded because they did not
163 report the same exposure (e.g. meeting all three guidelines) and same adiposity indicator (e.g. BMI,
164 weight status).[22,25,39] The meta-analysis of the association between meeting individual guidelines and
165 BMI *z*-score is available in Figure 2. There was no evidence of associations between meeting the PA
166 guideline and the BMI *z*-score (r = 0.11; 95% CI = –0.02, 0.23; I^2 = 73%; P = 0.10),[19,20,23,24] between
167 meeting the ST guideline and the BMI *z*-score (r = 0.07; 95% CI = –0.08, 0.22; I^2 = 81; P = 0.38),[19,20,23,24]
168 or between meeting the sleep guideline and the BMI *z*-score (r = 0.01; 95% CI = –0.05, 0.07; I^2 = 0%;
169 P = 0.72).[19,20,23] The meta-analyses that examined the association between meeting specific
170 combinations of guidelines (PA and ST, PA and sleep, ST and sleep) and the BMI *z*-score included three
171 studies (available in Supplementary Figure 1),[19,20,23] and no associations were found. Three studies were
172 also included in the meta-analysis of the association between meeting all three guidelines and the BMI
173 *z*-score.[19,20,40] The overall association was not significantly different from zero (r = –0.03; 95% CI =
174 –0.12, 0.06; I^2 = 51%; P = 0.48) (Figure 2d).

The associations between the number of guidelines met and adiposity was reported in five studies.[19,22–24,39] Three of these did not find any dose-response relationships (3/5 studies),[19,23,39] whereas the other two observed mixed associations (2/5 studies).[22,24] One study found that meeting two or three guidelines was associated with lower BMI and WC in preschoolers compared to meeting one or none, but found no difference between meeting three and two guidelines.[22] Another study found that meeting one guideline compared to none was associated with higher SAT among infants and toddlers, but no difference was found between meeting two and none.[24]

Associations between meeting 24-hour movement guidelines and psychosocial health

Studies (3 cross-sectional studies and 1 longitudinal study) of associations between meeting 24-hour movement guidelines and psychosocial health are summarized in Table 2.[21,38,42,47] The quality of three studies were scored at least 8,[21,38,42] and one study was scored as 4.[47] Based on narrative synthesis, three of the studies examining the association between meeting individual guidelines and psychosocial health did not find significant results for the PA guideline.[21,38,42] Meeting the ST guideline was associated with fewer behavioural and emotional problems in 1/3 studies,[38] but the other two did not (2/3 studies).[21,42] Two studies found no association with sleep (2/3 studies),[38,42] whereas the other study produced mixed findings:[21] meeting the sleep guideline was associated with the Test of Emotional Comprehension (TEC) but not with Theory of Mind (ToM) tasks. In this study, TEC was used to assess children's emotional understanding and ToM was used to assess the ability of children to attribute mental states to others.[21]

Associations between specific combinations of guidelines and psychosocial health were reported in three studies, and the findings were mixed.[21,38,42] For the combination of PA and ST, 2/3 studies did not find it to be associated with social-cognitive development[21] or psychological difficulties,[42] whereas the

other observed a significant trend of meeting more guidelines associated with lower behavioural and emotional problems.[38] For the combination of PA and sleep, 2/3 studies did not find associations with behavioural and emotional problems[38] or psychological difficulties,[42] whereas the other found it to be associated with TEC but not ToM.[21] In 2/3 studies, the combination of ST and sleep was not associated with social-cognitive development[21] or psychological difficulties.[42] However, the other study found that meeting more ST and sleep guidelines was associated with fewer behavioural and emotional problems (1/3 studies).[38] No study reported an association between meeting all three guidelines and psychosocial health. The four studies examining the dose-response relationship between the number of guidelines met and psychosocial health and 3/4 studies reported consistent results,[21,38,47] i.e., meeting a larger number of guidelines was favourably associated with behavioural and emotional problems,[38] quality of life[47] and social-cognitive development.[21] However, the dose-response relationship was not observed in the other study.[42]

Associations between meeting 24-hour movement guidelines and motor development

Associations between meeting 24-hour movement guidelines and motor development were reported in one longitudinal study and one observational study involving 319 preschoolers.[43,44] The quality appraisal scores of these two studies were 8[43] and 6.[44] In one study, meeting the PA guideline was positively associated with locomotion skills and ball skills in 3- and 4-year-olds, while the association became negative in 5-year-olds; meeting the ST guideline was positively associated with locomotion and ball skills in 3-year-olds, while the association became negative for 4- and 5-year-olds; meeting the sleep guideline was negatively associated with locomotion and ball skills (1/2 studies).[44] However, no association was found in the other study (1/2 studies).[43] Furthermore, the longitudinal study found that meeting the ST guideline at baseline (3.2 years old) was positively associated with fundamental motor

skill at one-year follow-up, while the association between meeting other individual guideline and motor skill was not found (1/2 studies).[43] The associations between meeting the combinations of guidelines and motor skills were not examined in both studies (2/2 studies).[43,44] The dose-response relationship between the number of guidelines met and motor skills was reported in the longitudinal study (1/2 studies): meeting all three guidelines at baseline was positively associated with total fundamental motor skill at one-year follow-up, compared to meeting one guideline.[43]

Associations between meeting 24-hour movement guidelines and cognitive development

Associations between meeting 24-hour movement guidelines and cognitive development were reported in only one longitudinal study, involving 247 preschoolers (Table 2).[42] This study explored the cross-sectional and longitudinal associations between meeting guidelines (alone and in combination) and executive function (e.g. visual spatial working memory, phonological working memory, shifting and inhibition), as well as their dose-response relationship.[42] It found that meeting PA and sleep guidelines was positively associated with phonological working memory and shifting performance. Compared to meeting none or one guideline, children who met two or three guidelines displayed better executive function. Meeting PA guideline at baseline was positively associated with shifting performance 12 months later, and no longitudinal associations were observed for other executive functions.[42] The quality of evidence of this study was scored 9 (Supplementary Table 3).

Discussion

To the best of our knowledge, this is the first systematic review and meta-analysis to summarize the evidence on compliance with the WHO 24-hour movement guidelines, and to explore whether meeting

the 24-hour movement guidelines is associated with health-related indicators in the early years. Eighteen studies published after the release of the first combined 24-hour movement behaviour guidelines from Canada and Australia in 2017 were reviewed. Prevalence of meeting all three guidelines was low. The results of the meta-analysis did not support an association between meeting 24-hour movement guidelines and adiposity; however, the findings were based on a limited number of mainly cross-sectional studies with high heterogeneity. Although the current evidence on the associations of meeting individual or combinations of the guidelines with psychosocial health, motor development, and cognitive development was inconclusive for the early years, a dose-response relationship between the number of guidelines met and psychosocial health was observed in 3 of 4 studies.

The inconclusive associations between meeting the guidelines and the BMI *z*-score in the current review echoes the mixed findings in a systematic review of the relationships between movement behaviour combinations and adiposity in the early years.[13] Also, these findings are consistent with a recent review, which found null association between meeting the 24-hour movement guidelines and adiposity in toddlers, based on a narrative synthesis.[49] However, the findings of no associations between movement behaviours and adiposity in the early years are in contrast to that in school-aged children and youth.[49,50] These findings may be due to several reasons. First, the long-term impact of high PA, low ST and long sleep on adiposity indicators in children takes time to manifest.[41] Second, the studies included in the meta-analysis had relatively high guideline compliance rate, especially for the PA and sleep guidelines.[19,20,23,24,40] Thus, the findings may not necessarily reflect the whole spectrum of children who are generally less physically active and have insufficient sleep. Third, study designs were largely cross-sectional and majority of them used retrospective analyses. Thus, they may have inadequate power to tease out temporal relationships. Although the majority of the studies included in meta-analyses used

accelerometers to assess PA, one study relied on parent-reported questionnaire that has not been validated,[24] though the quality score was relatively high (scored 7). Additional sensitivity analysis was performed by excluding this study,[24] and no different results were found (data not shown). Finally, the outcome studies used in 5 out of 8 of the eligible studies in the meta-analysis were crude proxies for adiposity: BMI *z*-score is a poor indicator of adiposity among children aged 2-19 years.[51] Exposure measures of the movement behaviours were also rather crude in many cases (e.g. parent-reported measures). It is worth noting that eating behaviour was not considered in data analysis in most of the included studies examining the associations between meeting guidelines and adiposity, although some of them identified it as one of the limitations.[20,22,23,25] Such potential confounders should be better controlled in future studies.

Inconsistent findings were also observed for other adiposity indicators (e.g. WC, VAT). Although BMI and percentage fat are widely used indicators of adiposity, they are affected by gender, age and ethnicity.[52] It is possible that movement behaviours affect fatness rather than weight.[53] As an indicator of overall adiposity, a higher BMI indicates "overweight" rather than "overfatness",[54] whereas WC, VAT and SAT indicate central adiposity, which is the accumulation of fat around the abdomen.[55] Furthermore, it is worth noting that adiposity increases during infancy and then decreases, with a rebound at 3-7 years.[56] Such variability makes exploring the association between meeting guidelines and adiposity in this age group more complicated. It is therefore necessary to combine various indicators to estimate adiposity more accurately and comprehensively. More longitudinal studies are encouraged to identify whether meeting 24-hour guidelines affects body fatness in children under 5 years of age.

Psychosocial health is another health indicator that has been commonly examined for the early years. Except for one study focusing on psychological difficulties,[42] three eligible studies showed that the more

guidelines were met, the better the psychosocial health observed.[21,38,47] These findings are consistent with previous reviews indicating that PA, ST and sleep are favourably associated with psychosocial health during early childhood.[7,8,10,57] Three studies also examined the association between psychosocial health and individual and combined guidelines;[21,38,42] however, for specific guidelines, the association with different types of psychosocial health (behavioural and emotional problems, quality of life, social-cognitive development, psychological difficulties) was inconsistent. Considering the small number of included studies and different psychosocial health indicators, it is difficult to compare the findings of these three studies.[21,38,42]

Other health indicators such as motor development and cognitive development have been less examined for the early years. Two studies included in the current review showed that the associations between meeting guidelines and fundamental motor skills were mixed.[43,44] Previous systematic reviews found consistent association between PA and favorable motor skills in the early years,[4] while association between ST, sleep and motor skills were predominantly null.[6,8] In addition, experimental studies generally found favorable associations between the combinations of longer PA and lower sedentary behavior and motor development among preschoolers.[13] However, the quality of evidence was graded as "low" or "very low" in these previous reviews, and their exposures were the time spent in movement behaviors,[4,6,8] which is different from compliance rate. The cross-sectional and longitudinal relationships between meeting 24-hour movement guidelines and cognitive development were examined in only one study.[42] A previous systematic review of relationships between combinations of movement behaviours and health indicators did not identify any studies examining cognitive functions in the early years.[13] In the other reviews of individual behaviours,[4,6,8,10] the evidence of association between executive function and PA,[4,10] ST,[6] and sleep[8] was inconclusive in observational studies in the early

years. The limited number of studies and mixed findings preclude definitive conclusions.

Across the studies, the proportion of children meeting all three guidelines varied but was generally low. More importantly, the compliance proportion was extremely low in infants compared with toddlers and preschoolers, although the compliance in infants was reported in only one study.[45] Given the low compliance in the early years, interventions for health-related lifestyles may need to be introduced earlier. Moreover, previous studies found that there was moderate to high tracking of movement behaviours from early childhood onward.[2] Similarly, the longitudinal study included in the current review found that children who met all three guidelines at an early age were more likely to meet all guidelines later.[40] Thus, early childhood should be considered as a key period for promoting healthy movement behaviours. Of note, the average age of participants in one study was 5.11 years (age range: 4.1-6.3 years old), which is higher than the upper age limits of the early years specified in the guidelines, but is preschool age in the country in which it was conducted.[25] The compliance rates for the sleep and ST guidelines may be underestimated because shorter sleep duration and higher upper limits of ST were recommended for children aged 5-13 years.[58] Factors that may influence compliance, such as gender, ethnicity and socioeconomic status, were reported in some studies, but conclusions could not be drawn due to the limited number of studies. Future studies should consider the direct influence and mediating role of children's characteristics and family factors, which affect movement behaviours.[59]

Continuous and accurate assessment of movement behaviours across the whole 24-hour day is challenging,[60] especially in the early years. It is not surprising that some of the studies included in the current review assessed PA (n = 3) and sleep (n = 12) using subjective methods. Device-based measurement of PA in the included studies also demonstrated variations, such as different requirements for numbers of valid days of accelerometer data, large proportions of excluded participants and a lack

of validated accelerometer cut-points in the early years.[19,23,25,38] Furthermore, the recommended sleep duration in the guidelines included both night-time sleep and daytime naps,[14] but a considerable proportion of studies did not include daytime naps (n = 8). Those studies conducted in infants and toddlers consistently included daytime naps in sleep measurement, and similarly the longitudinal study reported the nap time for children aged 1 and 2 years, but not for 5-year-old children.[40] Although the age when children stop napping may vary, it has been reported that preschool-aged children usually don't have daytime naps.[40,48] Regarding the specific guideline of SB, most studies focused on ST only (n = 16), and the specific activities of ST assessed in the parent-reported questionnaire differed across studies. Wearable cameras may provide an alternative measurement to overcome the limitations of proxy report in young children.[61]

The current systematic review applied a rigorous approach and used a comprehensive search strategy to include a wide range of health indicators. Nevertheless, the findings should be interpreted cautiously given the limitations. First, the measurements of PA, ST, and sleep vary across studies, making the findings less comparable. Second, there might be publication bias given that the search was limited to English-language and peer-reviewed studies. Third, the current review included only observational studies and found that almost all of the eligible observational studies were cross-sectional, so a causal relationship cannot be determined. Experimental designs are needed to investigate the benefits of meeting 24-hour movement guidelines on health in the early years.

Conclusions

Compliance with the 24-hour movement guidelines is low for children under 5 years of age, although

the proportions of children meeting the three individual recommendations vary by age group. There was insufficient evidence to conclude whether or not meeting the 24-hour movement guidelines was related to adiposity, motor development, and cognitive development in the early years. However, there appears to be consistent evidence of a dose-response relationship between meeting the guidelines and better psychosocial health in this age group. Future studies should examine the associations between meeting the guidelines and other health-related indicators.

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Disclosure statement

No competing financial interests exist.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

References

1. Gilmore JH, Knickmeyer RC, Gao W. Imaging structural and functional brain development in

early childhood. *Nat Rev Neurosci*. 2018;19(3):123-137.

2. Telama R, Yang X, Leskinen E, et al. Tracking of physical activity from early childhood through youth into adulthood. *Med Sci Sport Exerc*. 2014;46(5):955-962.

3. Chen B, Bernard JY, Padmapriya N, et al. Associations between early-life screen viewing and 24 hour movement behaviours: findings from a longitudinal birth cohort study. *Lancet Child Adolesc Health*. 2020;4(3):201-209.

4. Carson V, Lee E-Y, Hewitt L, et al. Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17(5):854.

5. Carson V, Hunter S, Kuzik N, et al. Systematic review of physical activity and cognitive development in early childhood. *J Sci Med Sport*. 2016;19(7):573-578.

6. Poitras VJ, Gray CE, Janssen X, et al. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0–4 years). *BMC Public Health*. 2017;17(5):868.

7. Carson V, Kuzik N, Hunter S, et al. Systematic review of sedentary behavior and cognitive development in early childhood. *Prev Med*. 2015;78:115-122.

8. Chaput J-P, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17(5):855.

9. Chen X, Beydoun MA, Wang Y. Is sleep duration associated with childhood obesity? A systematic review and meta-analysis. *Obesity*. 2008;16(2):265-274.

10. Timmons BW, Leblanc AG, Carson V, et al. Systematic review of physical activity and health

in the early years (aged 0-4 years). *Appl Physiol Nutr Metab*. 2012;37(4):773-792.

11. Mendoza JA, Zimmerman FJ, Christakis DA. Television viewing, computer use, obesity, and adiposity in US preschool children. *Int J Behav Nutr Phys Act*. 2007;4(1):44.

12. Fitzpatrick C, Pagani LS, Barnett TA. Early childhood television viewing predicts explosive leg strength and waist circumference by middle childhood. *Int J Behav Nutr Phys Act*. 2012;9(1):87.

13. Kuzik N, Poitras VJ, Tremblay MS, Lee E-Y, Hunter S, Carson V. Systematic review of the relationships between combinations of movement behaviours and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17(5):849.

14. Tremblay MS, Chaput JP, Adamo KB, et al. Canadian 24-hour movement guidelines for the early years (0-4 years): An integration of physical activity, sedentary behaviour, and sleep. *BMC Public Health*. 2017;17(June):S311–27.

15. Okely AD, Ghersi D, Hesketh KD, et al. A collaborative approach to adopting/adapting guidelines - The Australian 24-hour movement guidelines for the early years (birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. *BMC Public Health*. 2017;17(5):869.

16. Willumsen J, Bull F. Development of WHO guidelines on physical activity, sedentary behavior, and sleep for children less than 5 years of age. *J Phys Act Health*. 2020;17(1):96-100.

17. Reilly JJ, Hughes AR, Janssen X, et al. GRADE-ADOLOPMENT process to develop 24-hour movement behavior recommendations and physical activity guidelines for the under 5s in the United Kingdom, 2019. *J Phys Act Health*. 2020;17(1):101-108.

18. Draper CE, Tomaz SA, Biersteker L, et al. The South African 24-hour movement guidelines

for birth to 5 years: An integration of physical activity, sitting behavior, screen time, and sleep. *J Phys Act Health*. 2020;17(4):109-119.

19. Lee EY, Hesketh KD, Hunter S, et al. Meeting new Canadian 24-hour movement guidelines for the early years and associations with adiposity among toddlers living in Edmonton, Canada. *BMC Public Health*. 2017;17(Suppl 5):840.

20. Chaput JP, Colley RC, Aubert S, et al. Proportion of preschool-aged children meeting the Canadian 24-hour movement guidelines and associations with adiposity: Results from the Canadian health measures survey. *BMC Public Health*. 2017;17(Suppl 5):829.

21. Cliff DP, McNeill J, Vella SA, et al. Adherence to 24-hour movement guidelines for the early years and associations with social-cognitive development among Australian preschool children. *BMC Public Health*. 2017;17(Suppl 5):857.

22. Leppänen MH, Ray C, Wennman H, et al. Compliance with the 24-h movement guidelines and the relationship with anthropometry in Finnish preschoolers: The DAGIS study. *BMC Public Health*. 2019;19(1):1-8.

23. Santos R, Zhang Z, Pereira JR, Sousa-Sá E, Cliff DP, Okely AD. Compliance with the Australian 24-hour movement guidelines for the early years: Associations with weight status. *BMC Public Health*. 2017;17(Suppl 5):867.

24. Prioreschi A, Micklesfield LK. Compliance with physical activity and sedentary behavior guidelines and associations with abdominal adiposity in a sample of infants and toddlers from Soweto, South Africa. *J Phys Act Health*. 2019;16(10):872-879.

25. Guan H, Zhang Z, Wang B, et al. Proportion of kindergarten children meeting the WHO guidelines on physical activity, sedentary behaviour and sleep and associations with adiposity

in urban Beijing. *BMC Pediatr*. 2020;20(1):1-9.

26. Dekkers OM, Vandenbroucke JP, Cevallos M, Renehan AG, Altman DG, Egger M. COSMOS-E: Guidance on conducting systematic reviews and meta-analyses of observational studies of etiology. *PLoS Med*. 2019;16(2):e1002742.

27. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: A proposal for reporting. *JAMA*. 2000;283(15):2008-2012.

28. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339:b2535.

29. Guyatt GH, Oxman AD, Kunz R, et al. GRADE guidelines: 2. Framing the question and deciding on important outcomes. *J Clin Epidemiol*. 2011;64(4):395-400.

30. Herzog R, Álvarez-Pasquin MJ, Díaz C, Del Barrio JL, Estrada JM, Gil Á. Are healthcare workers' intentions to vaccinate related to their knowledge, beliefs and attitudes? A systematic review. *BMC Public Health*. 2013;13(1):154.

31. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25(9):603-605.

32. Review Manager (RevMan) [Computer program]. Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014.

33. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. *Introduction to Meta-Analysis*. Hoboken, NJ: John Wiley & Sons Inc; 2009.

34. Lenhard W, Lenhard A. Calculation of Effect Sizes. https://www.psychometrica.de/effect_size.html. Published 2016. Accessed Accessed May 30, 2020.

35. Becker LA. Effect Size Calculators. https://lbecker.uccs.edu/. Published 1998. Updated March 20, 2000. Accessed May 30, 2020.

36. Peterson RA, Brown SP. On the use of beta coefficients in meta-analysis. *J Appl Psychol*. 2005;90(1):175-181.

37. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557-560.

38. Carson V, Ezeugwu VE, Tamana SK, et al. Associations between meeting the Canadian 24-hour movement guidelines for the early years and behavioral and emotional problems among 3-year-olds. *J Sci Med Sport*. 2019;22(7):797-802.

39. Kracht CL, Webster EK, Staiano AE. Sociodemographic differences in young children meeting 24-hour movement guidelines. *J Phys Act Health*. 2019;16(10):908-915.

40. Meredith-Jones K, Galland B, Haszard J, et al. Do young children consistently meet 24-h sleep and activity guidelines? A longitudinal analysis using actigraphy. *Int J Obes*. 2019;43(12):2555-2564.

41. Hinkley T, Timperio A, Watson A, et al. Prospective associations with physiological, psychosocial and educational outcomes of meeting Australian 24-hour movement guidelines for the early years. *Int J Behav Nutr Phys Act*. 2020;17(1):36.

42. McNeill J, Howard SJ, Vella SA, Cliff DP. Compliance with the 24-hour movement guidelines for the early years: Cross-sectional and longitudinal associations with executive function and psychosocial health in preschool children. *J Sci Med Sport*. 2020;23(9):846-853.

43. Kracht CL, Webster EK, Staiano AE. Relationship between the 24-hour movement guidelines and fundamental motor skills in preschoolers. *J Sci Med Sport*. 2020;23(12):1185-1190.

44. Lucena Martins CM, Clark CC, Ribeiro Bandeira PF, Mota J, Duncan MJ. Association between compliance with the 24-hour movement guidelines and fundamental movement skills in preschoolers: A network perspective. *Int J Environ Res Public Health*. 2020;17(15):5443.

45. Hesketh KD, Downing KL, Campbell K, Crawford D, Salmon J, Hnatiuk JA. Proportion of infants meeting the Australian 24-hour movement guidelines for the early years: Data from the Melbourne InFANT Program. *BMC Public Health*. 2017;17(Suppl 5):856.

46. De Craemer M, McGregor D, Androutsos O, Manios Y, Cardon G. Compliance with 24-h movement behaviour guidelines among Belgian pre-school children: The ToyBox-study. *Int J Environ Res Public Health*. 2018;15(10):1-10.

47. Chia MYH, Tay LY, Chua TBK. Quality of life and meeting 24-h WHO guidelines among preschool children in Singapore. *Early Child Educ J*. 2019;48(3):313-323.

48. Vale S, Mota J. Adherence to 24-hour movement guidelines among Portuguese preschool children: the prestyle study. *J Sports Sci*. 2020;38(18):2149-2154.

49. Rollo S, Antsygina O, Tremblay MS. The whole day matters: Understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. *J Sport Health Sci*. 2020;9(6):493-510.

50. Saunders TJ, Gray CE, Poitras VJ, et al. Combinations of physical activity, sedentary behaviour and sleep: Relationships with health indicators in school-aged children and youth. *Appl Physiol Nutr Metab*. 2016;41(6 (Suppl. 3)):S283-S293.

51. Freedman DS, Butte NF, Taveras EM, et al. BMI z-scores are a poor indicator of adiposity among 2- to 19-year-olds with very high BMIs, NHANES 1999-2000 to 2013-2014. *Obesity*. 2017;25(4):739-746.

52. Jackson AS, Stanforth PR, Gagnon J, et al. The effect of sex, age and race on estimating percentage body fat from body mass index: The Heritage Family Study. *Int J Obes*. 2002;26(6):789-796.

53. Must A, Bandini LG, Tybor DJ, Phillips SM, Naumova EN, Dietz WH. Activity, inactivity, and screen time in relation to weight and fatness over adolescence in girls. *Obesity*. 2007;15(7):1774-1781.

54. Rolland-Cachera MF. Childhood obesity: Current definitions and recommendations for their use. *Int J Pediatr Obes*. 2011;6(5-6):325-331.

55. Smith SR, Lovejoy JC, Greenway F, et al. Contributions of total body fat, abdominal subcutaneous adipose tissue compartments, and visceral adipose tissue to the metabolic complications of obesity. *Metabolism*. 2001;50(4):425-435.

56. Rolland-Cachera MF, Deheeger M, Maillot M, Bellisle F. Early adiposity rebound: Causes and consequences for obesity in children and adults. *Int J Obes*. 2006;30(4):S11-S17.

57. Hinkley T, Teychenne M, Downing KL, Ball K, Salmon J, Hesketh KD. Early childhood physical activity, sedentary behaviors and psychosocial well-being: A systematic review. *Prev Med*. 2014;62:182-192.

58. Tremblay MS, Carson V, Chaput J-P, et al. Canadian 24-hour movement guidelines for children and youth: An integration of physical activity, sedentary behaviour, and sleep. *Appl Physiol Nutr Metab*. 2016;41(6 (Suppl. 3)):S311-27.

59. Tonge KL, Jones RA, Okely AD. Correlates of children's objectively measured physical activity and sedentary behavior in early childhood education and care services: A systematic review. *Prev Med*. 2016;89:129-139.

60. Rosenberger ME, Buman MP, Haskell WL, McConnell M V, Carstensen LL. Twenty-four hours of sleep, sedentary behavior, and physical activity with nine wearable devices. *Med Sci Sports Exerc*. 2016;48(3):457-465.

61. Downing KL, Janssen X, Reilly JJ. Feasibility of wearable cameras to assess screen time and time spent restrained in children aged 3 to 5 years: A study protocol. *BMJ Open*. 2019;9(5):e028265.