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REVIEW

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24-hour movement behavior adherence and associations with health outcomes: an umbrella review

Chelsea L. Kracht[1*], Sarah Burkart[2], Claire I. Groves[3], Guilherme Moraes Balbim[4], Christopher D. Pfledderer[5], Carah D. Porter[7], Christine W. St. Laurent[6], Emily K. Johnson[3] and Denver M. Y. Brown[7]

Abstract

Background Physical activity, sedentary behavior, and sleep, collectively known as the 24-hour movement behaviors, demonstrate individual and joint benefits on physical and mental health. Examination of these behaviors has expanded beyond guideline adherence to reviews of isotemporal substitution models (ISM) and compositional data analysis (CoDA). This umbrella review sought to review existing systematic reviews to (1) characterize the breadth and scope, (2) examine prevalence estimates for 24-hour movement guideline adherence, and (3) examine the relationship between these behaviors with health outcomes based on various approaches.

Methods Eight databases and multiple supplementary strategies were used to identify systematic reviews, meta-analyses and pooled analyses that included two or more of the three 24-hour movement behaviors and a multi-behavior assessment approach. Overall review characteristics, movement behavior definitions, approaches, and health outcomes assessed were extracted, and methodological quality was assessed using the AMSTAR2 tool. Review characteristics (Aim 1), guideline prevalence estimates (Aim 2), and associations with health outcomes (Aim 3) were examined.

Findings Thirty-two reviews (20 systematic reviews, 10 meta-analyses, and 2 pooled analyses) were included. Reviews captured the entire lifespan, global regions, and several physical and mental health outcomes. Individual and total guideline adherence waned from preschool to adolescence, but reviews reported similar prevalence estimates and ranges (i.e., within 10%). Common approaches included ISM and CoDA, evaluating 24-hour movement behavior's interactive associations with health outcomes, guideline adherence, and profile-based analysis. Despite heterogeneous approaches, reviews found consistent evidence for beneficial associations between meeting all three guidelines and high amount of physical activity on physical and mental health outcomes, but varied assessment of sedentary behavior or sleep. Most reviews were rated as low or critically low quality.

Conclusions The breadth and scope of current reviews on 24-hour movement behaviors was wide and varied in this umbrella review, including all ages and across the globe. Prevalence estimates among populations beyond children need to be synthesized. Amongst the variety of definitions and approaches, reviews found benefit from achieving

*Correspondence:
Chelsea L. Kracht
Ckracht@kumc.edu

Full list of author information is available at the end of the article

healthy amounts of all three behaviors. Longitudinal multi-behavior original research studies with rigorous assessment of sleep and sedentary behavior may help improve future systematic reviews of these various approaches.

Keywords Screen-time, Sitting time, Sedentary behavior, Sleep, Physical activity, Adherence

Introduction

Physical activity, sedentary behavior, and sleep, which are collectively referred to as 24-hour movement behaviors, are critical for physical and mental health across the lifespan [1–6]. These behaviors are unique, due to their mutually exclusive properties and reciprocal relationships across the 24-hour day. Their mutually exclusive properties refer to engaging in one behavior at a time, whereas their reciprocal relationship is shown in engaging in one behavior may influence amounts of other behaviors. An example of this reciprocal association is engaging in more physical activity during the day may result in additional overnight sleep [7]. Recognizing these interrelated and distinct properties, multi-behavior guidance for children's physical activity, recreational (children and adolescents) or sedentary (young children) screen-time, and sleep, and subsequent guidelines were created from a Canadian group in 2016 [8–10]. These integrative guidelines mirror individual behavior guidance but propose a focus on achieving healthy amounts of all three behaviors across the course of a whole day. The early years (ages 0–5 years), child, and adolescent guidelines have since been adopted by multiple high-income countries [11, 12], low- and middle-income countries [13], and most recently, adult and older adult public health guidance has been established [14]. Since the creation of these guidelines, frameworks to advance 24-hour movement research have emerged, which has been accompanied by the application of several analytic approaches to examine associations with health beyond threshold-based guideline adherence [15]. The Viable Integrative Research in Time-Use Epidemiology (VIRTUE) Framework proposes a path forward to advance research in field of time-use epidemiology through adequately accounting for the compositional nature of 24-hour movement behaviors when investigating methods, association with outcomes, optimal time balance and prevalence, correlates of time-use, and eventual design of effective interventions [15]. As noted by others, a consensus on 24-hour-related terminology does not exist; the 24-hour movement behaviors may also be referred to as the 24-hour activity cycle, time-use behaviors, time-use activity behaviors, and physical behaviors [16]. This heterogeneity in terms and application may make gathering and comparing scientific investigations difficult, hence impeding ability to quantify the collective contribution of 24-hour movement behaviors to health outcomes and advance to eventual time-use interventions [15].

Since the release of the initial 24-Hour Movement Guidelines for Children and Youth, 24- hour movement research has grown globally; two major events occurring in 2020 may have contributed to the proliferation of research in this area. First, the World Health Organization released integrative guidelines for both physical activity and sedentary behavior, which represent key time-use components within a 24-hour day [17, 18]. However, this momentous step towards a multi-behavior focus was overshadowed by a global pandemic occurring in the same year. In early 2020, individuals began social distancing amongst the SARS COVID-19 pandemic; many were less active, spent additional time sitting, and varying changes in sleep durations and timing due to these macrosystem level changes [19]. These changes in 24-hour movement behaviors were linked to gaining additional weight and impaired mental health, especially in children, amongst multiple systematic reviews [19, 20]. These reviews also indirectly captured the increase in 24-hour movement behavior research. As shown by two separate systematic reviews, publications on 24-hour movement behaviors prior to 2020 ($n=51$) [21] tripled within the year 2020–2021 alone ($n=150$) [19].

This multi-behavior approach has also prompted the adoption of innovative analytic approaches to handle their collinear properties, namely isotemporal substitution modelling (ISM) and compositional data analysis (CoDA). ISM is an analytic approach that allows for hypothetical substitutions or reallocations of time across different movement behaviors within a fixed period (e.g., 24-hour day) [22]. Initial systematic reviews of studies using the ISM approach to 24-hour movement behaviors display predicted benefit from reallocating time, namely sedentary time, to moderate-to-vigorous physical activity (MVPA) and sleep on multiple physical and mental health outcomes [23, 24]. Another approach is CoDA, which was adopted from other fields [25] and first applied to 24-hour movement behaviors to examine associations with indicators of health in 2015 [26]. Application of CoDA techniques is central to the VIRTUE Framework [15]. CoDA involves transformation of behavioral data via log ratios to consider that each movement behavior represents a unique and relative (i.e., versus absolute) component of a fixed period [27]. The transformed data can then be explored as total, combined, and individual parts of the day in relation to health outcomes. Relationships with health outcomes based on these approaches may be slightly different than traditional approaches (i.e., linear regression with absolute behavioral values), as this

approach considers the multicollinear nature of 24-hour time-use data, taking into account the influence of each behavior relative to time spent engaging in other behaviors [27, 28]. CoDA approach utilization has grown over the past decade, leading to subsequent reviews further exploring associations between 24-hour movement compositions and health outcomes [29], and creating a digital interface to estimate the exact reduction in health risk based on previous CoDA studies [30].

As the interest in 24-hour movement behaviors rose, so did reviews to synthesize the collective impact of these behaviors on health outcomes. Early systematic reviews assessed 24-hour movement behaviors by adherence to the child and youth 24-hour movement guidelines (i.e., physical activity duration, recreational screen-time, and sleep duration) and found the most benefit from meeting all three guidelines [31]. Though amongst the proliferation of 24-hour movement guideline adherence and CoDA, multiple reiterations of movement behaviors and approaches have emerged. For example, others have examined profile-based analysis (e.g., high physical activity, low sleep) on health outcomes [32], or conducted pooled analyses of all three behaviors using device-based measures [33].

A systematic search of existing systematic reviews is a lucrative method to characterize current evidence on 24-hour movement behavior guideline adherence, and relationships between these behaviors with health outcomes. Synthesizing the breadth and scope of these systematic reviews may help identify population and knowledge gaps for future systematic reviews and original research studies. Additionally, examining the various approaches to understand 24-hour movement behaviors in relation to health outcomes may provide detailed guidance for future reporting recommendations. Therefore, the purpose of this systematic review was two-fold: **Aim 1**) to characterize the breadth, and scope of systematic reviews and meta-analyses examining at least two of the physical activity, sedentary behavior, and sleep concurrently; **Aim 2**) examine prevalence estimates for 24-hour movement guideline adherence; **Aim 3**) to examine associations with health outcomes by various approaches. Together these efforts may help describe the current landscape of 24-hour movement behavior research to help harmonize investigations in the literature, identify actionable targets for future research, and focus efforts to promote appropriate amounts of all behaviors.

Methods

Search strategy

This umbrella review followed a scoping review methodology, thus follows the recommended reporting guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR, Supplemental Table 1) [34]. The protocol (i.e., research question, search strategy, inclusion/exclusion, risk of bias, data extraction items) was registered prior to the conduct of the review (registration osf.io/hwv2r). In collaboration with a librarian, the search strategy was created based on past reviews focusing on 24-hour movement behaviors with the addition of terms to obtain systematic reviews and meta-analyses [6]. There were no specific outcomes for this review (e.g., obesity), so the primary search strategy focused on the behaviors. A key component of this search was including possible grey literature and global reach, given the focus on 24-hour movement behaviors beyond high-income countries. Accordingly, we searched eight databases in total (See Supplemental Table 2). The first 6 databases were searched from inception to October 12th, 2023, including: CINAHL, Medline (EBSCO), PsychINFO, SportDiscus, Scopus, and Web of Science. The seventh (Cochrane Library) and eighth (Embase) were then searched from inception to October 24th, 2023 and October 31st, 2023, respectively. Supplemental search strategies included backward citations (searching references of included papers), forward citations (reviewing citations of the included references), reviewing published articles from a recently created 24-hour movement behavior specific journal (*Journal of Activity, Sleep, and Sedentary Behavior*) and international database of time-use epidemiology (*International Network of Time-Use Epidemiologists*), contacting experts in the field, and inclusion of gray literature.

Eligibility criteria

Detailed inclusion and exclusion criteria can be found in Table 1. In brief, systematic reviews, meta-analyses, or harmonized (pooled) data analyses were eligible if they were published in the English language, in peer-reviewed literature, or gray literature (e.g., dissertation). The population included was humans without age constraints, and the exposure was at least 2 of the 3 possible 24-hour movement constructs (physical activity, sedentary behavior, or sleep) in their research question. These constructs were created based on recognized criteria for each behavior (Table 1) [15, 35–38]. As of current, there is no consensus on terminology or reporting for 24-hour movement behaviors though many consider all three constructs a requirement for this research [15, 39]. Two constructs were allowed to accommodate related 24-hour movement terminologies (i.e., physical behaviors, which includes only physical activity and sedentary behavior) [16, 40] and current World Health Organization guidance (only physical activity and sedentary behavior) [18] as both align with 24-hour movement research, and may have guided systematic review research questions. The major topics explored in each aim were breadth

Table 1 Detailed inclusion and exclusion criteria for review

Component	Inclusion	Exclusion
Language	English	Non-English
Information source	Peer-reviewed literature, grey literature: dissertations or theses, and conference proceedings and abstracts	Sources of gray literature not identified in the inclusion criteria (e.g., book chapters)
Population	Humans, no age constraints	Animals
Exposure	Includes 2 of the 3 24-hour movement behaviors (sleep, sedentary behavior, and physical activity) within research question. Below are definitions of each behavior. • *Sleep*: a spontaneous and reversible state of rest characterized by inhibition of nearly all voluntary muscles and reduced interactions with surrounding environment. o *Metrics included*: All possible time-based sleep metrics (time in bed, actual sleep time). • *Sedentary behavior/time*: Time spent sitting or reclining posture (Metabolic equivalent of tasks [METs] < 1.5). Time and context were considered. o *Metrics included*: Sedentary or recreational screen-time (TV, Computer, portable devices, etc.), sedentary time as measured by accelerometry or actigraphy, and sitting time / stationary behavior. • *Physical Activity*: Physical activity is activity > 1.5 METs. Time and context were considered. o *Metrics included*: Light physical activity (PA), Moderate PA, Vigorous PA, Total PA, Moderate-to-vigorous PA (MVPA) o Time spent outdoors or activities that usually elicit physical activity benefit (e.g., sports, yoga) was also considered	• Only includes 1 of the 3 24-hour movement behaviors • Assesses requirements not related to 24-hour movement behaviors (e.g., Non-wear time)
Outcomes	• *Aim 2*: No health outcomes, but report prevalence estimates of 24-hour movement guideline adherence • *Aim 3*: Physical (e.g., obesity) or mental health (e.g., stress) outcomes	• Methodologies to assess 24-hour movement behaviors • Health Behavior (e.g., smoking, diet)
Study Design	• Systematic Review • Meta-Analyses	• Commentary (i.e., no new data is presented) • Narrative Review • Original Investigation • Reviews of Qualitative studies • Case studies

and scope, prevalence estimates, and associations with health outcomes, respectively. Health outcomes were not required for Aim 1 or 2. The outcomes for Aim 3 included physical (e.g., obesity) or mental health (e.g., quality of life) outcomes.

Articles were excluded if they were in a language other than English, a form other than systematic review (e.g., narrative review, commentary, book chapter, etc.), or included animal studies within the review. The original references for country-specific 24-hour movement guidelines were excluded if their systematic review process was not documented in detail in the current article. However, if they referenced another article with additional detail on their systematic review process, the referenced article was then retrieved for consideration. Beyond article type and population, there were five other main exclusion reasons starting from study design, behaviors included, and outcomes. These main exclusion reasons were operationalized as reviews focused on (1) solely interventions to change 24-hour movement behaviors (e.g., school-based interventions to improve physical activity and limit sitting) [41], (2) methods to assess 24-hour movement behaviors (e.g., quality assessment of methods) [42], (3) only one behavior assessed [43], (4) different investigation of movement behaviors as either part of a cluster of modifiable factors [44], correlates of movement behaviors [45], or as the outcome (e.g., ambient air quality impacting physical activity or sedentary behavior) [46], and (5) investigating the association between movement behaviors with another health behavior (e.g., alcohol consumption), amongst themselves [47], or other health marker (e.g., energy compensation) [48] as an outcome.

Study selection

Abstract and full-text screening stages were performed by eight independent reviewers (CLK, SB, CWSL, CDPf, GMB, CG, CDPo, DMYB) in duplicate, and conflicts were resolved by a third reviewer. A pre-piloted protocol for both stages was created prior to study selection. Reviewers reached > 80% agreement prior to completing both stages. Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia) was used to facilitate study flow for abstract and full text screening, and subsequent data extraction.

Data extraction and critical appraisal

Data extracted was related to article information (author, year of publication), review question, population included, 24-hour movement behavior definitions, approaches, health outcome definitions, prevalence

estimates of meeting public health guidelines for each movement behavior, relationships between movement behaviors (in total and individually) with health outcomes, overall results, proposed future directions, and information related to review quality and risk of bias. This information was curated based on past reviews and expert opinions, as experts ($n=10$) were asked to provide input on extraction items when surveyed for additional reviews. Data was extracted in duplicate by independent reviewers and disagreements were resolved by a third reviewer.

The Measurement Tool to Assess Systematic Reviews (AMSTAR) 2 was used as a critical appraisal tool for the included systematic reviews and meta-analyses [49]. Pooled analyses were graded but no total score was assigned. This tool assesses seven critical domains of the review including (1) protocol registration, (2) appropriateness of literature search, (3) exclusion reasons, (4) risk of bias for the included studies, (5) meta-analysis methods (when applicable), (6) interpretation of risk of bias, and (7) publication bias assessment. AMSTAR-2 scores were categorized based on number of critical and non-critical weaknesses, with categories ranging from "high " (no critical or non-critical weaknesses), "moderate" (no critical weaknesses, with one or more non-critical weakness), "low" (one critical weakness and multiple non-critical weaknesses), or "critically low" (multiple critical and non-critical weaknesses).

Synthesis of results

For Aim 1, a numerical analysis (central tendencies) related to population included, and review conduct. Countries included in systematic reviews were classified into regions based on updated World Health Organization region guidance [50]. Reviews were further described by their AMSTAR 2 quality rating (critically low, low, moderate, and high). For Aim 2, prevalence estimates for meeting individual and total guidelines were extracted and compared. A meta meta-analysis was not conducted with prevalence estimates due to significant study overlap; rather, each review's calculated estimates are described as reported by authors. For Aim 3 reviews that assessed the relationship between 24-hour movement behaviors and health outcomes were included. Within these reviews, a qualitative description of 24-hour movement behavior terminology and approaches used, associations between movement behaviors with health outcomes, health outcome definitions, and review findings was conducted.

Results

The initial search yielded 1,841 references, of which 1,037 were removed as duplications (Figs. 1). After the title and abstract screening of 804 references, the remaining 104 full texts were considered for inclusion. Supplementary methods identified an additional 1,535 references, namely via citation searching, which resulted in 30 additional full texts for consideration (133 full texts total). Reviews could be excluded for multiple reasons, but based on the first reason many references were removed at the full-text stage for being the wrong article type ($n=42$) or wrong investigation of behaviors (e.g., behaviors as outcomes, $n=25$, Supplemental Table 3). The final sample included 32 reviews comprising 20 systematic reviews, 10 meta-analyses, and two pooled analyses. Review funding sources and conflicts of interests are presented in Supplemental Table 4.

Aim 1: breadth and scope of reviews

An overview of the population and behaviors included is provided in Table 2. The 32 reviews included a median of 26 studies (range: 5-141 studies) and compared 4,785,140 participants in total. All ages were represented in this umbrella review, with some reviews including all ages (5/32), or only children and adolescents (ages 3-17 [51–53] or 5–17 years) [19, 54–59]. Other age groups explored across the lifespan were young children (0–5 years) [29, 31, 60], college/university students (ages ~ 18–25 years) [61], and older adults (mean age ≥ 60 years) [62, 63]. Populations were also defined by nationality, location, and occupation, including: immigrant children [54], children and adolescents from Arabic countries [64], and airline pilots [65]. Population definitions were rarely confined to health or disease status, such as only including healthy populations [32, 60, 62, 66], or individuals with type 1 diabetes [55]. Beyond population characteristics, the time frame was another consideration as four reviews were specific to the COVID-19 pandemic [19, 20, 67, 68], while one review specifically excluded COVID-19 studies [51]. Finally, all reviews assessed physical activity, and most reviews assessed all three behaviors (physical activity, sedentary behavior or screen-time, and sleep, 26/32). Thirty reviews assessed sedentary behavior, of which three specifically did not assess screen-time [33, 65, 66], nine reviews explicitly allowed screen-time as either a sedentary behavior indicator or separate behavior [19, 21, 51, 52, 55, 56, 59, 60, 69], and the remaining 18 reviews did not clearly state if screen-time would be considered in their review (See Supplemental Table 5).

As for review conduct, most reviews were registered and noted all study designs were eligible (≥ 20/32, Table 2). The median number of scientific databases searched was 4 (range: 3–14), which were searched from inception and six reviews searched since the guidelines were created in 2015 or 2016. All reviews searched MEDLINE or Pubmed, followed closely by six databases: Embase (21/32), PsychINFO (20/32), SportDiscuss

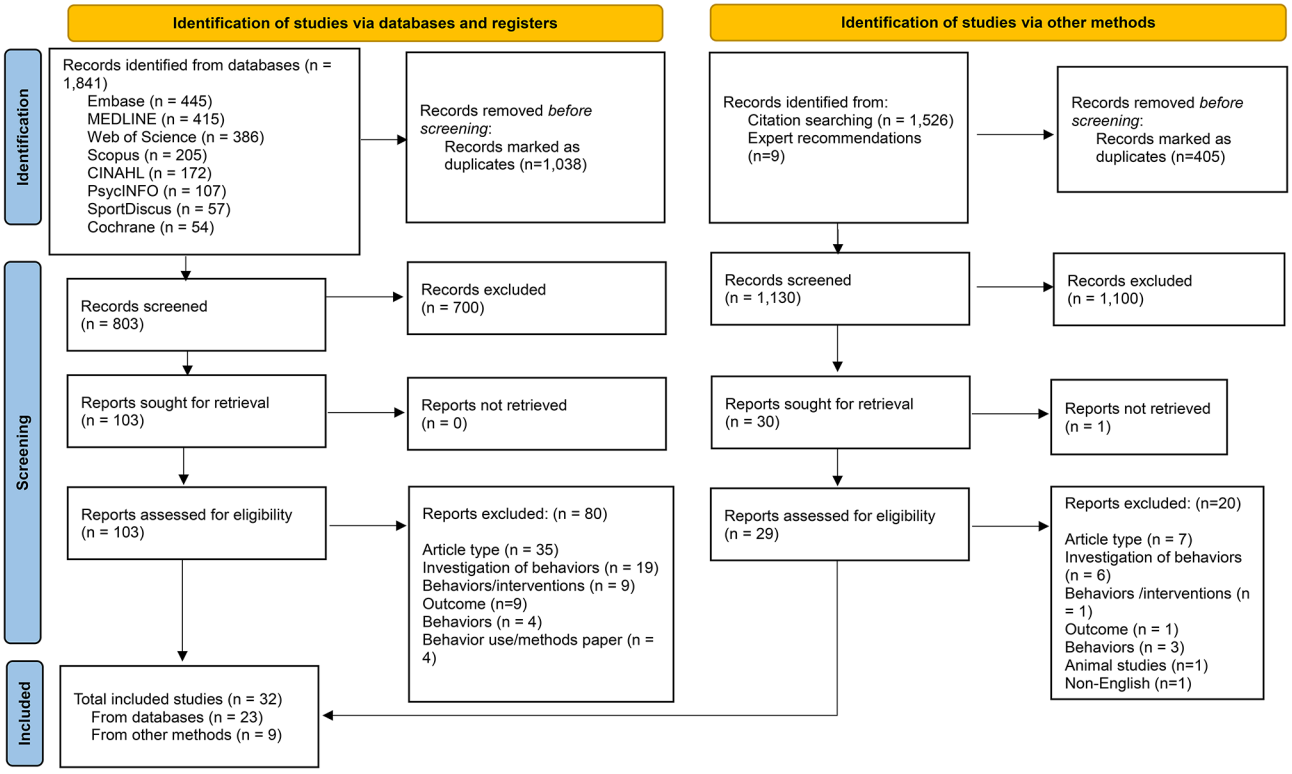


Fig. 1 PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources *From*: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: https://doi.org/10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

(18/32), Scopus (16/32), CINAHL (12/32) or Web of Science (11/32). Less than ten reviews searched Cochrane Libraries (4/32), specific gray literature sources (e.g., ProQuest, 1/32), or other search engines. Reviews obtained a median of 26 studies (range: 5-141), including studies conducted in predominately high-income western countries (e.g., Australia, Canada, United States), east or southeast Asia (e.g., China, Malaysia, Thailand), or Latin America and the Caribbean (e.g., Bahamas, Brazil, Chile,), though four reviews did not report the country where their retrieved studies occurred (Table 2) [24, 52, 62, 66]. Most reviews were published in 2023 (12/32), or between 2020 and 2022 (14/32). Details of included reviews in can be found in Supplemental Table 5.

Methodological quality

Thirty reviews were given overall ratings based on critical and non-critical domains, as the two pooled analyses were not given an overall rating. One systematic review [23] and one meta-analysis [51] were rated as "moderate" quality, indicating no critical weaknesses and few non-critical weaknesses. In contrast, due to the high number of critical weaknesses, seven reviews were rated as "low" [4, 31, 57, 59, 63, 68, 70], and the remaining 21 reviews were rated as "critically low" quality. Beginning with critical domains, most reviews achieved the partial or full standard for review methods (22/30 reviews), search strategy (30/32 reviews), risk of bias tool (26/32 reviews), or statistical methods (10/12 meta-analyses), but few provided a list of excluded studies with reasons (5/32 reviews) or assessed publication bias (4/12 meta-analyses). As for non-critical domains, about half of reviews met standards for delineating participant, intervention/exposure, comparator, and outcome, describing included studies, study selection, and reporting authors conflict of interest (≥19/32 reviews for each). Few reviews met the non-critical domains of clarifying study designs included (6/32 reviews), reporting funding for included studies (0/32 reviews), and risk of bias assessment in analysis (2/12 meta-analyses). Critical and non-critical domain scores for individual reviews are displayed in Supplemental Table 6.

Aim 2: prevalence of meeting 24-hour movement guidelines

Prevalence estimates were focused primarily on children and youth or during the pandemic, and only two reviews reported estimates for adults. As shown in Supplemental Table 7, estimates from the seven reviews that reported prevalence estimates for children and youth were derived from a median of 17 studies (range: 1–63 studies). Most child prevalence estimates were calculated based on the

Table 2 Characteristics of included reviews related to 24-hour movement behaviors ($n=32$)

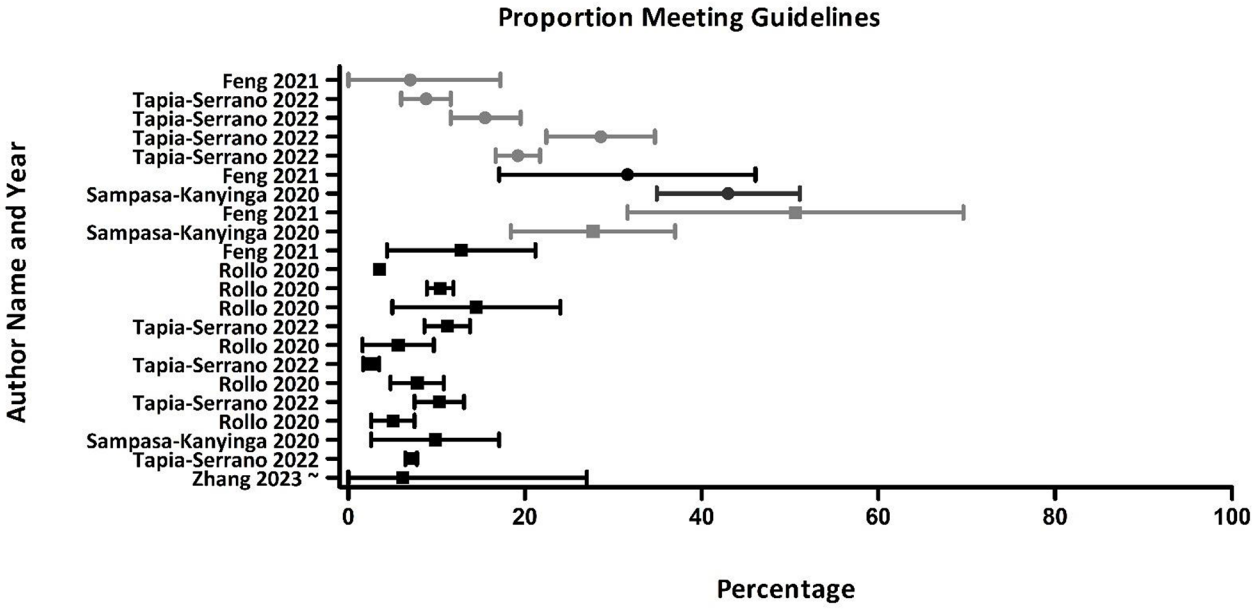
Characteristic	*n*	%
Life Stage Included[#]		
0-2y	12	38%
3-4y	15	47%
5–12 y	19	59%
13-17y	20	63%
18-25y	12	38%
26-55y	11	34%
55 + y	13	41%
All ages	5	16%
24-hour Movement Behaviors[#]		
Physical Activity	32	100%
Sedentary Behavior	30	94%
Sleep	28	88%
All three behaviors	26	81%
Screen-time^	9	28%
Review Registration		
PROSPERO	21	66%
Open Science Framework	4	13%
Not Registered	7	22%
Study Design Eligible[#]		
All study designs	20	63%
Observational studies	8	25%
Prospective Design	1	3%
Not described	3	9%
Search Dates		
Inception	23	72%
Guidelines Creation (2015 or 2016)	6	19%
COVID-19 date (2020 or 2021)	2	6%
Other	1	3%
Regions Represented in included studies[#]		
Central Asia, Middle East, North Africa	9	28%
Central and Eastern Europe	11	34%
East and Southeast Asia	17	53%
High-income Asia Pacific	15	46%
High-income western	26	81%
Latin America and Caribbean	16	50%
Oceania	1	3%
South Asia	10	31%
Sub-Saharan Africa	11	34%
Multination studies	4	13%
Country/region not described	5	16%
Review did not present region information	4	13%

^Specified screen-time as part of inclusion criteria; [#]Reviews may include multiple categories, hence the total amount will not add up to 100%

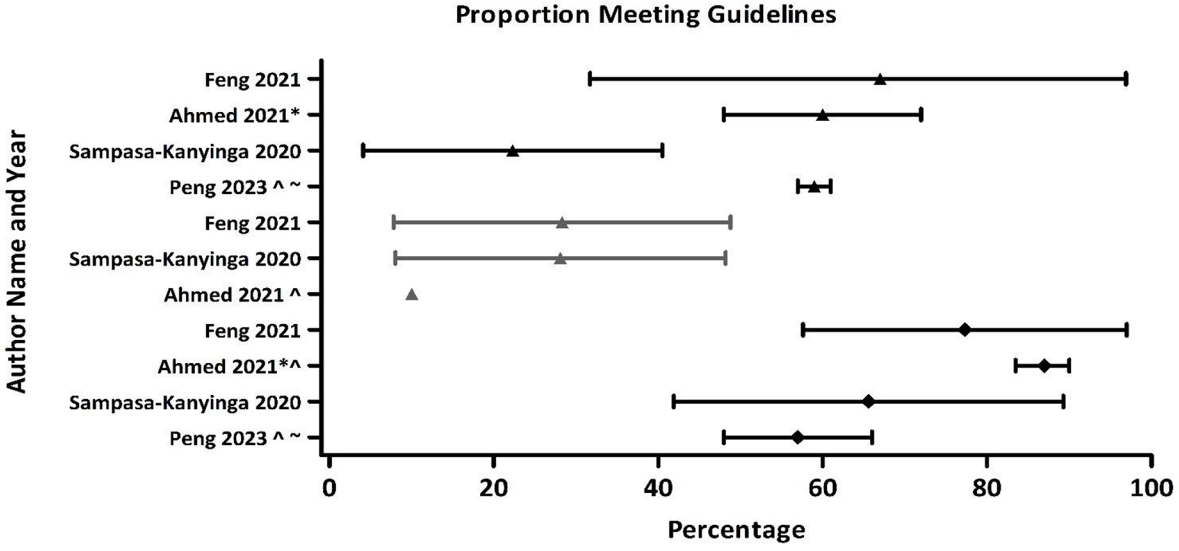
Canadian 24-hour movement guidelines (5/6), [21, 51, 56, 60, 68] with only one review using another guideline definition (i.e., >20 min of vigorous intensity physical activity or >30 min of moderate physical activity, >3 days/week)[54] In general, reviews found around half of children met the physical activity guideline (estimate range: 22.3–67%), less than a third met the screen-time guideline (estimate range: 10-28.3%), and half or more met the sleep guideline (estimate range: 57-83.5%, Supplemental Table 7 and Fig. 2). Some children (estimate range: 7-28.6%) met 0 guidelines, a third each met 1 or 2 guidelines (estimate range: 27.7–50.6%), and few met al.l the guidelines (estimate range: 3.5–12.8, Supplemental Table 7 and Fig. 2). Individual and total guideline adherence waned from preschool to adolescence. Two reviews that assessed behaviors during the COVID-19 pandemic documented slightly lower prevalence estimates for physical activity [68], sleep [68], and meeting all three guidelines [20]. These similarities are not without caution; the three meta-analyses pooled estimates revealed high heterogeneity amongst their individual studies ($i^2>95$)[51, 60, 68]. In addition to children, one systematic review and one pooled analysis assessed prevalence of 24-hour movement behaviors in adults, including in airline pilots and UK adults before and during the COVID-19 pandemic [65, 67]. These reviews used different metrics for insufficient activity (i.e., *not* meeting physical activity guidelines), which resulted in ranges of 51.3–51.7% for airline pilots (<150 min/week of MVPA, 5 studies, 2233 participants), [65] and 21.2–49.9% for adults pre-COVID-19 and 20-42.3% for adults during the COVID-19 pandemic (≤3days of at least 30 min/day of exercise, 6 studies, 19,331 participants) [67]. Similar sleep guidelines were used for insufficient sleep, which found 22% prevalence in airline pilots (<6 h/night, 3 studies, sample size not reported) [65] and various ranges for adults pre-COVID-19 (<6 h or 9+hours/night, range: 6.8–14.5%, 6 studies, 19,331 participants) and during the COVID-19 pandemic (12.2–29.9%) [67].

Aim 3: associations between 24-hour movement behaviors with health outcomes

Twenty-six studies were included in this Aim. An overview of review characteristics is presented in Table 3, and review details are documented in Supplemental Tables 8 and 9. These reviews predominantly approached 24-hour movement behaviors using ISM or CoDA techniques, evaluating 24-hour movement behavior's interactive associations with health outcomes, guideline adherence, and created profile-based groups based on level of engagement in 24-hour movement behaviors (e.g., high PA and low SB groups). Only three of the ISM reviews specifically focused on studies using the compositional ISM approach [4, 29, 30], and the five other ISM reviews included both compositional and traditional ISM approaches [23, 24, 58, 66, 70]. Reviews primarily assessed physical health outcomes (22/26). Overwhelmingly (≥11/26), many reviews assessed weight, cardiometabolic health markers, and fitness, and six reviews also included mortality [4, 23, 30, 32, 33, 70]. Reviews included a median of 26 studies (range: 5-141 studies), including a median of 21 cross-sectional (range: 0-119),



A.



B.

Fig. 2 Review-calculated proportion meeting respective guidelines. Panel A: Number of Guidelines; Panel B: Specific Guidelines Panel A: ^ denotes estimates that were recalculated to proportion met as they were reported as proportion who did not meet the guidelines; gray circle = 0 guidelines; black circle = 1 guideline; black square = 2 guidelines; gray square = 3 guidelines; Panel B: *Ahmed, 2021 physical activity guidelines used was " >20min of Vigorous intensity physical activity or > 30min of moderate physical activity, > 3 days/week", sleep guideline was not clearly defined; ~ denotes studies during SARS COVID-19 pandemic status; black triangle = physical activity guideline; gray triangle = screen-time guideline; black diamond = sleep guideline

and 5 longitudinal studies (range:0–25). Three reviews found no longitudinal studies [32, 56, 61, 62], and eight reviews included other study designs [19, 30, 31, 53, 55, 61, 64, 69], like results of an MVPA intervention on feelings of energy [61]. Reviews assessed study quality and risk of bias of included articles through differing tools with or without modifications (e.g., Down's and Black, Cochrane Library Risk of Bias tool, modified checklist based on reporting standards), resulting in diverse distributions of high- and low-quality articles. Notably, all

Table 3 Characteristics of included reviews related to 24-hour movement behaviors and health outcomes ($n = 26$)

Characteristic	*n*	%
Assessment of 24-hour movement behaviors		
Isotemporal Substitution Modelling	8	30%
Individual Behaviors	7	27%
Guideline Adherence	6	23%
Profile-Base Analysis	4	15%
Pooled Analysis	1	3%
Physical Health Outcomes Assessed[#]	22	84%
Weight-related	16	61%
Cardiometabolic Health Markers	11	42%
Fitness	11	42%
Mortality	6	23%
Motor Skills	4	15%
Other	7	27%
Mental Health Outcome Assessed[#]	14	53%
Depression or Anxiety	6	23%
Mental Wellness	4	15%
Quality of Life	4	15%
Cognition/cognitive development	3	12%
Behavioral Problems	2	7%
Other	6	23%

[#]Reviews may include multiple categories, hence the total amount will not add up to 100%; Other physical health outcomes included bone health, and chronic diseases; Other mental health outcomes included coping, energy or fatigue, mental health, psychosocial health, and perceived/general health status,

six reviews that used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) tool to assess level of evidence found "low" or "very low" quality of evidence for their health outcome, mainly due to serious risk of bias and inconsistency [4, 31, 56, 57, 63].

Physical activity, sedentary behavior, and sleep were clearly defined in less than a third of the reviews (see Supplemental Table 8). For physical activity, five reviews utilized the Caspersen definition of physical activity movement ("any bodily movement produced by skeletal muscles that results in caloric expenditure") [35] or metabolic equivalent of task (MET) intensity (>3.0 METs) [4, 29, 57, 63, 64], and two reviews defined it as sedentary screen-time [56]. Similarly, sedentary behavior was defined by wake-time MET intensity (<1.5 MET) and sitting, standing, or reclining state as well [4, 29, 56, 64], and two reviews defined it as sedentary screen-time [56] or non-screen and screen-based sedentary behaviors [55]. Sleep was defined broadly, including altered consciousness, inhibition of muscles and reduced interactions; [64] and MET intensity (~1) [63]. One review defined physical activity or sedentary behavior by any activity, time, or type; [32] another review defined each behavior based on the *Canadian Society for Exercise Physiology 24-hour movement guidelines* [71]. Other reviews indirectly defined these behaviors by solely including device-based measures for physical activity and sedentary behavior [66, 70], or only physical activity [23, 53]. One third of reviews did not define measurements (e.g., device-based only, device and questionnaire) as part of their inclusion criteria for physical activity (6/27), sedentary behavior (9/27), or sleep (9/27). Two reviews [66, 70] and the pooled analyses [33] were confined to only device-based measures, as all others considered device, questionnaire, or other measures for 24-hour movement behavior assessment (Supplementary Table 8). These heterogenous terminologies and methods precluded detailed investigation into how these various components may have influenced reviews findings, but overall results were qualitatively compared.

Interactive behavior examinations were common. Higher amounts of MVPA were favorable for child weight-related outcomes [64], child fitness [53], young child motor skills [60], and mortality [33]. This evidence was replicated in ISM reviews, where reallocating sedentary time to MVPA was related to favorable changes in weight [23, 24, 58], cardiometabolic health [58, 66, 70], fitness [4, 23], and mortality [4, 23, 33, 70]. These results were not always replicated when replacing sedentary time for light physical activity for weight-related outcomes [4, 24, 58] or fitness [58], but one review found evidence for waist circumference and fasting insulin [70]. Favorable results for increased amounts of MVPA on child depression [64], adult quality of life [55, 63], and other child mental health indicators were also found [71]. Accordingly, one ISM review found reallocating sedentary time to MVPA was related to favorable adult mental health [23]. The remaining behaviors of sedentary time and sleep had fewer comparisons, and results were mixed based on outcomes. Unfavorable results from high amounts of sedentary time were found for child fitness; [53, 64] while others found null or mixed results for adult cardiometabolic health markers [55, 66]. Chastin et al.'s pooled analysis found associations between the ratio of light physical activity and sedentary time to mortality in hip-measured accelerometer studies, but not wrist-measured studies [33]. One ISM review reported unfavorable results for hypothetically substituting MVPA to sedentary time on weight and mortality [4]. Better sleep, either sleep quality or duration, was associated with favorable results for depression and anxiety in individuals with type 1 diabetes [55] and adult fatigue/energy [61]. Mixed (i.e., some favorable, some null) or overall null associations were found between better sleep and young child [60] and child weight [64], and HbA1c in individuals with type 1 diabetes [55]. Substituting time in sleep to other behaviors had a null effect on weight [4, 30], cardiometabolic health markers [30], fitness [53], and mortality [4, 33].

Behaviors were also classified by adherence to the 24-hour movement guidelines or amongst profile-based

groups. Meeting all three guidelines was associated with favorable child weight-related outcomes [21, 52, 69], but these results did not translate consistently to toddlers [60] and preschoolers [60, 69]. Meeting all three guidelines was associated with favorable associations for young children's motor skills [60], children's cardiometabolic health markers, fitness, cognition, and mental health [21], and adolescent depression [56]. Few reviews evaluated meeting one or two guidelines, or dose response associations of meeting an increasing number of guidelines on health outcomes. Kuzik et al. found favorable results with meeting two guidelines of various iterations on young child weight, fitness and motor skills [31], but Feng et al. found an overall null effect for young child weight for those who met two guidelines [60]. Feng et al. also reported a mixed association between meeting more guidelines and young child weight, and null associations of meeting the screen-time guideline and young child weight [60]. Reviews that focused on classifications of physical activity, sedentary behavior, and sleep or 24-hour movement composition found similar results [29]. Children with high amounts of physical activity, low amounts of sedentary behavior, and longer sleep had favorable weight-related [57] and mental health outcomes [59]. Mellow et al. found only two studies that explored all three behaviors with older adult cognition, though their results generally support adequate amounts of all three behaviors [62]. Duncan et al. further explored the effect of physical activity and sleep on mortality to find that high levels of physical activity may reduce mortality risk in the presence of short sleep [32].

Discussion

This review's purpose was to characterize the breadth and scope of current 24-hour movement behavior reviews, examine prevalence estimates for 24-hour movement guideline adherence, and examine the association between these behaviors and health outcomes by differing approaches. The current landscape of systematic reviews has spanned all ages, global regions, and study designs, but in contrasting amounts and low or critically low systematic review quality. Differing approaches to 24-hour movement behavior research provide an opportunity to answer unique questions regarding the collective influence of these behaviors on health, further deepening our understanding of the implications of behavioral time-use across the course of a 24-hour day. High amounts of MVPA, reallocating sedentary behavior to MVPA, and meeting all three 24-hour movement guidelines demonstrated clear health benefit, with less certainty for sedentary behavior and sleep. This review demonstrates that systematic reviews, and hence our understanding, of the influence of 24-hour movement behaviors on health is in its nascency, with opportunities to increase future review's representation, rigor, and reporting.

The breadth and scope of current 24-hour movement behavior research is wide across ages, regions, and time frames (i.e., pre-COVID-19 and COVID-19), proving to be both a positive and negative quality. On the one hand, multiple ages, regions, and time periods were represented; on the other hand, this vast scope was not consistent across reviews (i.e., some only captured predominately high-income countries in a narrow age range) [29] and was conducted with varying rigor. Global representation is a key issue within behavioral research [72], as findings from predominately high-income western country may not translate to other geographical regions. A review focusing specifically on children from Arab-Speaking countries exemplified this consideration by solely investigating a specific region (i.e., Central Asia, Middle East, and North Africa) [64]. Few other reviews studied subpopulations as most reviews aligned with the early guidelines for children and adolescents [8, 9], and no reviews focused on the recent adult or older adult guidelines [14]. One review attempted to examine older adult literature but found few articles with all three behaviors [62]. This disparity is likely due to few papers using these standards, or current studies still using past individual guideline stipulations [73, 74], as demonstrated in the retrieved adult prevalence reviews [65, 67]. Guideline adherence and overall investigation during the COVID-19 pandemic was minor [19, 20, 67, 68], but this time period may continue to be a consideration as further systematic reviews are conducted from database inception.

Despite the many approaches used, these 24-hour movement behavior reviews consistently found high amounts of MVPA and meeting all three guidelines were beneficial for various indicators of health. The current yield of systematic reviews also found more reviews investigated physical health outcomes relative to mental health outcomes. The most explored outcome was weight, which may be due to the relative ease of obtaining this measure, and continuing increase in childhood obesity prevalence over the past decades [75]. Poor mental health, especially in youth, is another public health concern which was brought to the forefront amongst changes in all three behaviors during the COVID-19 pandemic [19, 76]. Even so, reviews focused on mental health were less represented in this population, but are deserving of more attention. Since this current umbrella review's search, another systematic review examined 24-hour movement behavior's association with indicators of mental health and wellbeing has been published; [6] this new publication and others is promising for mental health receiving additional attention. Future reviews into less represented outcomes, such as bone health,

functional measurements, stress, and coping may help expand our understanding of the entire 24-hour day for tailored interventions.

Consistent prevalence estimates and ranges (i.e., within 10%) were represented in adherence to individual and total guidelines across childhood. Notably, these multi-behavior results align with the original guidelines created based on single behavior investigations [1–3, 5]. Consistent support for high MVPA with improved health outcomes also aligns with existing evidence-based guidelines [18, 73], and general agreement for all reviews assessing the aerobic component of the guidelines (MVPA) rather than muscle-strengthening. These consistent standards and results did not translate to sedentary behavior or sleep. Excess wake time spent sedentary (MET value ≤ 1.5) is associated with poor health outcomes [77, 78], with pronounced impacts amongst those achieving lower amounts of MVPA [79], when considered as TV [80] or sedentary screen-viewing time [81], or using hip-mounted device-based measures compared to wrist-worn devices [33]. These intricacies were rarely addressed or defined in the current reviews, as exemplified by few reviews providing exact definitions for sedentary behavior, including wakeful state, MET value, and posture, or their inclusion of screen-time. These findings are disappointing as there have been agreed upon terminology for sedentary behavior and related states for almost a decade; moreover, these terms are a key consideration of existing frameworks and guidelines [15, 36]. These behavior nuances also translate to sleep, which may be considered based on duration, quality, timing, and many other metrics [77]. The metrics may not be considered amongst most approaches which solely focus on duration-based time-use estimates, whereas approaches using other groupings may consider the negative synergistic effects and other context considerations of low physical activity and poor sleep on health [31, 32, 82].

The critically low quality of reviews must be acknowledged in our consideration of movement behaviors in relation to physical and mental health outcomes. Though many areas could be improved, it is important to consider these two main areas: (1) not clearly describing eligible study designs and (2) assessing various sources of bias. Reviews predominately included all study designs, which may prevent utilizing this practice. This wide inclusion criteria may be able to capture a larger yield of articles in a growing landscape; this wide inclusion criteria may also be problematic in terms of introducing heterogeneity. Reviews conducted prior to 2020 likely had fewer studies available [21], but recent reviews did not improve this practice. The second area of consideration was evaluating and assessing publication and risk of bias amongst these retrieved studies. Without assessing these areas, it is unclear if meta-analytic results can be attributed to balanced, high-quality studies.

Strengths of the current review include the inclusion of a novel field of inquiry, rigorous review strategy by following review best practices [49], and timely evaluation as we approach a decade with the 24-hour movement guidelines. This review is not without limitations, namely confined to review conduct and topic matter considerations. The review conduct considerations include search date, English language stipulations, and included all three behaviors, which may impact inclusion of recent (published in 2024) [6, 83], non-English language reviews, and dual behavior studies. These limitations were addressed through a comprehensive search strategy of international experts and a leading international database (*International Network of Time-Use Epidemiologists*) to ensure all reviews that met these standards were included. The topic matter considerations are diverse approaches of included reviews, and restricted clinical utility of a hypothetical substitution approach. These considerations hinder major statements on the association between 24-hour movement behaviors and health outcomes but improve our understanding of 24-hour movement behaviors in differing ways (e.g., optimal amount, trends, and prevalence) [15]. Moreover, individual behavior focused reviews were not included in this review [84, 85], which may curb our prevalence estimates and understanding of individual behaviors. This review contributes to evidence of the current breadth and scope of reviews that included multiple 24-hour movement behaviors, and the relationship with these multiple behaviors and health outcomes.

Results of this review posit four major improvements in future research conduct and study design. First, multi-behavior longitudinal studies are warranted to enhance the quality of existing evidence. These secondary data analyses and future studies will only be helpful if agreed upon terms and reporting of 24-hour movement behaviors is achieved, which can in turn advance existing frameworks in this area [15]. Therefore, the second area is potential creation of reporting practices for 24-hour movement behaviors approaches, such as CoDA, guidelines adherence, and interactive associations, through an iterative process with experts and end-users. Beyond the number of guidelines achieved or correctly classifying approaches (i.e., individual behaviors evaluated collectively, guidelines), an activity [86] or movement index [87] allows characterizing of multiple behaviors and investigation in eventual 24-hour interventions [88]. Alignment of terminology also should be accompanied by assessment method, as there are challenge and opportunities to self-report and device-based methods for quantifying 24-hour movement behavior. Dissemination and wide-spread adoption of such approaches and possible reporting checklists is paramount, as evidenced by

few reviews using existing guidance for sedentary behavior terminology [36]. The third area of improvement is conducting systematic reviews evaluating the prevalence and benefit of 24-hour behaviors amongst special populations not currently represented in the literature, including individuals with physical and developmental disabilities [89, 90], and pregnant or postpartum individuals [91, 92], as they report even lower adherence to all three guidelines. These efforts should also support review approaches to improve inclusion globally and research initiatives to expand to lesser represented regions [93]. Finally, future reviews should consider consulting existing standards for high quality systematic reviews and meta-analyses [49] to vastly improve the current scenery of poor-quality reviews.

This umbrella review revealed that the breadth and scope of existing literature on 24-hour movement behaviors is wide; this literature spans all ages and regions in different capacities. Included reviews permitted many definitions and approaches to analyzing associations between 24-hour movement behaviors and health outcomes and were overall low quality; both qualities hindered harmonized synthesis. Amongst these weaknesses, a consistent finding was improved health benefit from additional MVPA and meeting all three guidelines, with inconsistent findings for sedentary behavior and sleep. Given the collective and individual benefit of these behaviors, the next decade should focus on harmonized rigorous research using a multi-behavior approach to improve existing evidence.

Supplementary Information

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Supplementary Material 1

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Author contributions

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare no competing interests.

Author details

[1]University of Kansas Medical Center, 3901 Rainbow Blvd, Kansas City, KS 66160, USA
[2]Arnold School of Public Health, University of South Carolina, 921 Assembly St, Columbia, SC 29208, USA
[3]The University of Texas at San Antonio, 1 UTSA Circle, San Antonio, TX 78249, USA
[4]The University of British Columbia, 2215 Wesbrook Mall, Vancouver, BC V6T 1Z3, Canada
[5]School of Public Health in Austin, The University of Texas Health Science Center Houston, Austin, TX 78701, USA
[6]The University of Massachusetts Amherst, Amherst, MA 01003, USA
[7]Department of Kinesiology, Kansas State University, 1105 Sunset Ave, Manhattan, Kansas 66502, USA

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References

1. Poitras VJ, Gray CE, Borghese MM, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. Appl Physiol Nutr Metabolism Jun. 2016;41(6):S197–239. https://doi.org/10.1139/apnm-2015-0663.
2. Chaput JP, 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 Nov 20 2017;17doi:ARTN 855. https://doi.org/10.1186/s12889-017-4850-2
3. Carson V, Hunter S, Kuzik N, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. Appl Physiol Nutr Metab Jun. 2016;41(6 Suppl 3):S240–65. https://doi.org/10.1139/apnm-2015-0630.
4. Janssen I, Clarke AE, Carson V, et al. A systematic review of compositional data analysis studies examining associations between sleep, sedentary behaviour, and physical activity with health outcomes in adults. Appl Physiol Nutr Metab Oct. 2020;45(10):S248–57. https://doi.org/10.1139/apnm-2020-0160.
5. Chaput JP, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. Appl Physiol Nutr Metabolism Jun. 2016;41(6):S266–82. https://doi.org/10.1139/apnm-2015-0627.
6. Groves CI, Huong C, Porter CD et al. Associations between 24-h movement behaviors and indicators of mental health and well-being across the lifespan: a systematic review. J Activity Sedentary Sleep Behav. 2024/03/14 2024;3(1):9. https://doi.org/10.1186/s44167-024-00048-6
7. Wendt A, da Silva ICM, Goncalves H, Menezes A, Barros F, Wehrmeister FC. Short-term effect of physical activity on sleep health: a population-based study using accelerometry. J Sport Health Sci Sep. 2022;11(5):630–8. https://doi.org/10.1016/j.jshs.2020.04.007.

8. Chaput JP, Carson V, Gray CE, Tremblay MS. Importance of all movement behaviors in a 24 hour period for overall health. Int J Environ Res Public Health Dec. 2014;4(12):12575–81. https://doi.org/10.3390/ijerph111212575.
9. Tremblay MS, Carson V, Chaput JP, et al. Canadian 24-Hour Movement Guidelines for Children and Youth: an integration of physical activity, sedentary Behaviour, and Sleep. Appl Physiol Nutr Metab Jun. 2016;41(6 Suppl 3):S311–27. https://doi.org/10.1139/apnm-2016-0151.
10. 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 Jan. 2020;1(1):96–100. https://doi.org/10.1123/jpah.2019-0457.
11. 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 Nov. 2017;20(Suppl 5):869. https://doi.org/10.1186/s12889-017-4867-6.
12. Loo BKG, Okely AD, Pulungan A, Jalaludin MY, Asia-Pacific 24-Hour Activity Guidelines for C, Adolescents C. May. Asia-Pacific Consensus Statement on integrated 24-hour activity guidelines for children and adolescents. *Br J Sports Med*. 2022;56(10):539–545. https://doi.org/10.1136/bjsports-2021-104527
13. 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 Jan. 2020;1(1):109–19. https://doi.org/10.1123/jpah.2019-0187.
14. Ross R, Chaput JP, Giangregorio LM, et al. Canadian 24-Hour Movement guidelines for adults aged 18–64 years and adults aged 65 years or older: an integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab. Oct 2020;45(10):S57–102. https://doi.org/10.1139/apnm-2020-0467.
15. Pedišić Ž, Dumuid D, Olds T, Integrating, Sleep, Sedentary Behaviour, And Physical Activity Research In The Emerging Field Of Time-Use Epidemiology. Definitions, Concepts, Statistical Methods, Theoretical Framework, And Future Directions. Kinesiology. 2017;49:252–69.
16. Falck RS, Davis JC, Li L, Stamatakis E, Liu-Ambrose T. Preventing the '24-hour Babel': the need for a consensus on a consistent terminology scheme for physical activity, sedentary behaviour and sleep. Br J Sports Med. Apr 2022;56(7):367–8. https://doi.org/10.1136/bjsports-2021-104487.
17. Chaput JP, Willumsen J, Bull F, et al. 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence. Int J Behav Nutr Phys Act Nov. 2020;26(1):141. https://doi.org/10.1186/s12966-020-01037-z.
18. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med Dec. 2020;54(24):1451–62. https://doi.org/10.1136/bjsports-2020-102955.
19. Paterson DC, Ramage K, Moore SA, Riazi N, Tremblay MS, Faulkner G. Exploring the impact of COVID-19 on the movement behaviors of children and youth: a scoping review of evidence after the first year. J Sport Health Sci Dec. 2021;10(6):675–89. https://doi.org/10.1016/j.jshs.2021.07.001.
20. Zhang D, Chen S, Lopez-Gil JF, Hong J, Wang F, Liu Y. 24-Hour movement behaviours research during the COVID-19 pandemic: a systematic scoping review. BMC Public Health Nov. 2023;7(1):2188. https://doi.org/10.1186/s12889-023-17136-y.
21. 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 Dec. 2020;9(6):493–510. https://doi.org/10.1016/j.jshs.2020.07.004.
22. Mekary RA, Willett WC, Hu FB, Ding EL. Isotemporal substitution paradigm for physical activity epidemiology and weight change. Am J Epidemiol Aug. 2009;15(4):519–27. https://doi.org/10.1093/aje/kwp163.
23. Grgic J, Dumuid D, Bengoechea EG, Shrestha N, Bauman A, Olds T, Pedisic Z. Health outcomes associated with reallocations of time between sleep, sedentary behaviour, and physical activity: a systematic scoping review of isotemporal substitution studies. Int J Behav Nutr Phys Act Jul. 2018;13(1):69. https://doi.org/10.1186/s12966-018-0691-3.
24. Garcia-Hermoso A, Saavedra JM, Ramirez-Velez R, Ekelund U, Del Pozo-Cruz B. Reallocating sedentary time to moderate-to-vigorous physical activity but not to light-intensity physical activity is effective to reduce adiposity among youths: a systematic review and meta-analysis. Obes Rev Sep. 2017;18(9):1088–95. https://doi.org/10.1111/obr.12552.
25. Aitchison J. The Statistical Analysis of Compositional Data. J Royal Stat Soc Ser B (Methodological). 1982;44(2):139–77.
26. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of Time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a Novel Compositional Data Analysis Approach. PLoS ONE. 2015;10(10):e0139984. https://doi.org/10.1371/journal.pone.0139984.
27. Dumuid D, Stanford TE, Martin-Fernandez JA, et al. Compositional data analysis for physical activity, sedentary time and sleep research. Stat Methods Med Res Dec. 2018;27(12):3726–38. https://doi.org/10.1177/0962280217710835.
28. Bird M, Datta GD, Chinerman D, Kakinami L, Mathieu M-E, Henderson M, Barnett TA. Associations of neighborhood walkability with moderate to vigorous physical activity: an application of compositional data analysis comparing compositional and non-compositional approaches. *International Journal of Behavioral Nutrition and Physical Activity*. 2022/05/18 2022;19(1):55. doi:https://doi.org/10.1186/s12966-022-01256-6.
29. Zahran S, Visser C, Ross-White A, Janssen I. A systematic review of compositional analysis studies examining the associations between sleep, sedentary behaviour, and physical activity with health indicators in early childhood. *Journal of Activity, Sedentary and Sleep Behaviors*. 2023/02/01 2023;2(1):1. https://doi.org/10.1186/s44167-022-00012-2
30. Miatke A, Olds T, Maher C, et al. The association between reallocations of time and health using compositional data analysis: a systematic scoping review with an interactive data exploration interface. Int J Behav Nutr Phys Act Oct. 2023;19(1):127. https://doi.org/10.1186/s12966-023-01526-x.
31. Kuzik N, Poitras VJ, Tremblay MS, Lee EY, 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 Nov. 2017;20(Suppl 5):849. https://doi.org/10.1186/s12889-017-4851-1.
32. Duncan MJ, Murphy L, Oftedal S, Fenwick MJ, Vincent GE, Fenton S. The associations between physical activity, sedentary behaviour, and sleep with mortality and incident cardiovascular disease, cancer, diabetes and mental health in adults: a systematic review and meta-analysis of prospective cohort studies. *Journal of Activity, Sedentary and Sleep Behaviors*. 2023/09/04 2023;2(1):19. https://doi.org/10.1186/s44167-023-00026-4
33. Chastin S, McGregor D, Palarea-Albaladejo J, et al. Joint association between accelerometry-measured daily combination of time spent in physical activity, sedentary behaviour and sleep and all-cause mortality: a pooled analysis of six prospective cohorts using compositional analysis. Br J Sports Med. Nov 2021;55(22):1277–85. https://doi.org/10.1136/bjsports-2020-102345.
34. Tricco AC, Lillie E, Zarin W, et al. PRISMA Extension for scoping reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med Oct. 2018;2(7):467–73. https://doi.org/10.7326/m18-0850.
35. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep Mar-Apr. 1985;100(2):126–31.
36. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN) - terminology Consensus Project process and outcome. Int J Behav Nutr Phys Act Jun. 2017;10(1):75. https://doi.org/10.1186/s12966-017-0525-8.
37. Herrmann SD, Willis EA, Ainsworth BE, et al. 2024 adult compendium of physical activities: a third update of the energy costs of human activities. J Sport Health Sci Jan. 2024;13(1):6–12. https://doi.org/10.1016/j.jshs.2023.10.010.
38. Chaput JP, Saunders TJ, Carson V. Interactions between sleep, movement and other non-movement behaviours in the pathogenesis of childhood obesity. Obes Rev Feb. 2017;18(Suppl 1):7–14. https://doi.org/10.1111/obr.12508.
39. Tremblay MS, Carson V, Chaput JP. Introduction to the 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):iii–iv. https://doi.org/10.1139/apnm-2016-0203.
40. Bussmann JB, van den Berg-Emons RJ. To total amount of activity..... and beyond: perspectives on measuring physical behavior. *Front Psychol*. 2013;4:463. https://doi.org/10.3389/fpsyg.2013.00463.
41. Amor-Barbosa M, Ortega-Martinez A, Carrasco-Uribarren A, Bagur-Calafat MC. Active school-based interventions to interrupt prolonged sitting Improve Daily Physical activity: a systematic review and Meta-analysis. Int J Environ Res Public Health Nov. 2022;21(22). https://doi.org/10.3390/ijerph192215409.
42. Giurgiu M, Timm I, Becker M, et al. Quality evaluation of Free-living Validation studies for the Assessment of 24-Hour physical behavior in adults via wearables: systematic review. JMIR Mhealth Uhealth Jun. 2022;9(6):e36377. https://doi.org/10.2196/36377.
43. Cliff DP, Hesketh KD, Vella SA, et al. Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. Obes Rev. 2016;17(4):330–44. https://doi.org/10.1111/obr.12371.

44. Crowther ME, Ferguson SA, Reynolds AC. Longitudinal studies of sleep, physical activity and nutritional intake in shift workers: a scoping review. Sleep Med Rev Jun. 2022;63:101612. https://doi.org/10.1016/j.smrv.2022.101612.
45. Curran F, Davis ME, Murphy K, Tersigni N, King A, Ngo N, O'Donoghue G. Correlates of physical activity and sedentary behavior in adults living with overweight and obesity: a systematic review. Obes Rev Nov. 2023;24(11):e13615. https://doi.org/10.1111/obr.13615.
46. An R, Shen J, Ying B, Tainio M, Andersen ZJ, de Nazelle A. Impact of ambient air pollution on physical activity and sedentary behavior in China: a systematic review. Environ Res Sep. 2019;176:108545. https://doi.org/10.1016/j.envres.2019.108545.
47. Janssen X, Martin A, Hughes AR, Hill CM, Kotronoulas G, Hesketh KR. Associations of screen time, sedentary time and physical activity with sleep in under 5s: a systematic review and meta-analysis. Sleep Med Rev Feb. 2020;49:101226. https://doi.org/10.1016/j.smrv.2019.101226.
48. Lamboglia CG, McCurdy AP, Kim YB, et al. Investigation of movement-related behaviors and energy compensation in people living with liver disease: a scoping review. J Sports Sci Jun. 2022;40(12):1299–307. https://doi.org/10.1080/02640414.2022.2065087.
49. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ Sep. 2017;21:358:j4008. https://doi.org/10.1136/bmj.j4008.
50. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. Lancet Glob Health Oct. 2018;6(10):e1077–86. https://doi.org/10.1016/S2214-109X(18)30357-7.
51. Tapia-Serrano MA, Sevil-Serrano J, Sanchez-Miguel PA, Lopez-Gil JF, Tremblay MS, Garcia-Hermoso A. Prevalence of meeting 24-Hour Movement guidelines from pre-school to adolescence: a systematic review and meta-analysis including 387,437 participants and 23 countries. J Sport Health Sci Jul. 2022;11(4):427–37. https://doi.org/10.1016/j.jshs.2022.01.005.
52. Lopez-Gil JF, Tapia-Serrano MA, Sevil-Serrano J, Sanchez-Miguel PA, Garcia-Hermoso A. Are 24-hour movement recommendations associated with obesity-related indicators in the young population? A meta-analysis. Obes (Silver Spring) Nov. 2023;31(11):2727–39. https://doi.org/10.1002/oby.23848.
53. Smith JJ, Eather N, Weaver RG, Riley N, Beets MW, Lubans DR. Behavioral correlates of muscular fitness in children and adolescents: a systematic review. Sports Med. 2019;49(6):887–904. https://doi.org/10.1007/s40279-019-01089-7.
54. Ahmed S, Uddin R, Ziviani J, Khan A. Global prevalence of physical activity, sedentary Behaviour, and sleep of immigrant children: a systematic review. J Racial Ethn Health Disparities Dec. 2021;8(6):1364–76. https://doi.org/10.1007/s40615-020-00898-1.
55. Patience M, Janssen X, Kirk A, McCrory S, Russell E, Hodgson W, Crawford M. 24-Hour Movement Behaviours (physical activity, sedentary Behaviour and Sleep) Association with Glycaemic Control and Psychosocial Outcomes in adolescents with type 1 diabetes: a systematic review of quantitative and qualitative studies. Int J Environ Res Public Health Feb. 2023;28(5). https://doi.org/10.3390/ijerph20054363.
56. Sampasa-Kanyinga H, Colman I, Goldfield GS, et al. Combinations of physical activity, sedentary time, and sleep duration and their associations with depressive symptoms and other mental health problems in children and adolescents: a systematic review. Int J Behav Nutr Phys Act Jun. 2020;5(1):72. https://doi.org/10.1186/s12966-020-00976-x.
57. 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 Jun. 2016;41(6 Suppl 3):S283–93. https://doi.org/10.1139/apnm-2015-0626.
58. Volpato LA, Costa JC, Lopes WA, Sasaki JE, Romanzini CLP, Ronque ERV, Romanzini M. Time reallocations from Sedentary Behavior to Physical Activity and Cardiovascular Risk factors in children and adolescents: a systematic review. J Phys Act Health Dec. 2023;1(12):1084–91. https://doi.org/10.1123/jpah.2022-0471.
59. Wilhite K, Booker B, Huang BH, et al. Combinations of physical activity, sedentary behavior, and Sleep Duration and their associations with Physical, Psychological, and Educational outcomes in Children and adolescents: a systematic review. Am J Epidemiol Apr. 2023;6(4):665–79. https://doi.org/10.1093/aje/kwac212.
60. Feng J, Zheng C, Sit CH, Reilly JJ, Huang WY. Associations between meeting 24-hour movement guidelines and health in the early years: a systematic review and meta-analysis. J Sports Sci Nov. 2021;39(22):2545–57. https://doi.org/10.1080/02640414.2021.1945183.
61. Frederick GM, O'Connor PJ, Schmidt MD, Evans EM. Relationships between components of the 24-hour activity cycle and feelings of energy and fatigue in college students: a systematic review. Ment Health Phys Act. 2021/10/01/ 2021;21:100409. https://doi.org/10.1016/j.mhpa.2021.100409
62. Mellow ML, Crozier AJ, Dumuid D, Wade AT, Goldsworthy MR, Dorrian J, Smith AE. How are combinations of physical activity, sedentary behaviour and sleep related to cognitive function in older adults? A systematic review. Exp Gerontol Mar. 2022;159:111698. https://doi.org/10.1016/j.exger.2022.111698.
63. Hakimi S, Kaur S, Ross-White A, Martin LJ, Rosenberg MW. A systematic review examining associations between physical activity, sedentary behaviour, and sleep duration with quality of life in older adults aged 65 years and above. Appl Physiol Nutr Metab Feb. 2023;1(2):97–162. https://doi.org/10.1139/apnm-2022-0298.
64. Alanazi YA, Sousa-Sa E, Chong KH, Parrish AM, Okely AD. Systematic review of the relationships between 24-Hour Movement Behaviours and Health indicators in School-aged children from arab-speaking countries. Int J Environ Res Public Health Aug. 2021;16(16). https://doi.org/10.3390/ijerph18168640.
65. Wilson D, Driller M, Johnston B, Gill N. The prevalence of Cardiometabolic Health Risk Factors among Airline pilots: a systematic review. Int J Environ Res Public Health Apr. 2022;16(8). https://doi.org/10.3390/ijerph19084848.
66. Cavallo FR, Golden C, Pearson-Stuttard J, Falconer C, Toumazou C. The association between sedentary behaviour, physical activity and type 2 diabetes markers: a systematic review of mixed analytic approaches. PLoS ONE. 2022;17(5):e0268289. https://doi.org/10.1371/journal.pone.0268289.
67. Wielgoszewska B, Maddock J, Green MJ, et al. The UK Coronavirus Job Retention Scheme and diet, physical activity, and sleep during the COVID-19 pandemic: evidence from eight longitudinal population surveys. BMC Med Apr. 2022;6(1):147. https://doi.org/10.1186/s12916-022-02343-y.
68. Peng B, Reeves KKL, Lee SWY, Chung THY, Hui HWL, Leung AHL, Pang JCY. Physical, psychological, and behavioral problems among children and adolescents in countries with different economic statuses during the COVID-19 pandemic: a systematic review and meta-analysis. Front Pediatr. 2023;11:1181186. https://doi.org/10.3389/fped.2023.1181186.
69. Marques A, Ramirez-Campillo R, Gouveia ER, et al. 24-h Movement guidelines and overweight and obesity indicators in toddlers, children and adolescents: a systematic review and Meta-analysis. Sports Med Open May. 2023;15(1):30. https://doi.org/10.1186/s40798-023-00569-5.
70. Del Pozo-Cruz J, Garcia-Hermoso A, Alfonso-Rosa RM, Alvarez-Barbosa F, Owen N, Chastin S, Del Pozo-Cruz B. Replacing Sedentary Time: Meta-analysis of Objective-Assessment studies. Am J Prev Med. Sep 2018;55(3):395–402. https://doi.org/10.1016/j.amepre.2018.04.042.
71. de Lannoy L, Barbeau K, Vanderloo LM, Goldfield G, Lang JJ, MacLeod O, Tremblay MS. Evidence supporting a combined movement behavior approach for children and youth's mental health – A scoping review and environmental scan. *Mental Health and Physical Activity*. 2023/03/01/2023;24:100511. doi:https://doi.org/10.1016/j.mhpa.2023.100511.
72. Ding D, Carson V, Hunter RF, et al. Science has no Borders, so should Scientific Publishing: A position Statement from the Journal of Physical Activity and Health. J Phys Act Health Dec. 2022;1(12):809–10. https://doi.org/10.1123/jpah.2022-0570.
73. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for americans. JAMA Nov. 2018;20(19):2020–8. https://doi.org/10.1001/jama.2018.14854.
74. Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health Mar. 2015;1(1):40–3. https://doi.org/10.1016/j.sleh.2014.12.010.
75. Collaboration NCDRF. Worldwide trends in underweight and obesity from 1990 to 2022: a pooled analysis of 3663 population-representative studies with 222 million children, adolescents, and adults. Lancet Mar. 2024;16(10431):1027–50. https://doi.org/10.1016/S0140-6736(23)02750-2.
76. Benton TD, Beers L, Carlson G, Kee Ng WY. The declaration of the National Emergency in child and adolescent Mental Health: it takes a village. Child Adolesc Psychiatr Clin N Am Jul. 2024;33(3):277–91. https://doi.org/10.1016/j.chc.2024.03.001.
77. Rosenberger ME, Fulton JE, Buman MP, Troiano RP, Grandner MA, Buchner DM, Haskell WL. The 24-Hour activity cycle: a new paradigm for physical activity. Med Sci Sports Exerc. Mar 2019;51(3):454–64. https://doi.org/10.1249/MSS.0000000000001811.
78. Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B. Physical Activity Guidelines Advisory C. Sedentary Behavior and Health:

Update from the 2018 Physical Activity Guidelines Advisory Committee. Med Sci Sports Exerc. Jun 2019;51(6):1227–41. https://doi.org/10.1249/MSS.0000000000001935.
79. Ekelund U, Tarp J, Steene-Johannessen J, et al. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. BMJ Aug. 2019;21:366:l4570. https://doi.org/10.1136/bmj.l4570.
80. Sun JW, Zhao LG, Yang Y, Ma X, Wang YY, Xiang YB. Association between Television Viewing Time and all-cause mortality: a Meta-analysis of Cohort studies. Am J Epidemiol. Dec 2015;1(11):908–16. https://doi.org/10.1093/aje/kwv164.
81. Sanders T, Noetel M, Parker P, et al. An umbrella review of the benefits and risks associated with youths' interactions with electronic screens. Nat Hum Behav Jan. 2024;8(1):82–99. https://doi.org/10.1038/s41562-023-01712-8.
82. Huang BH, Duncan MJ, Cistulli PA, Nassar N, Hamer M, Stamatakis E. Sleep and physical activity in relation to all-cause, cardiovascular disease and cancer mortality risk. Br J Sports Med. Jul 2022;56(13):718–24. https://doi.org/10.1136/bjsports-2021-104046.
83. Ahmadi MN, Blodgett JM, Atkin AJ, et al. Relationship of device measured physical activity type and posture with cardiometabolic health markers: pooled dose-response associations from the prospective physical activity, sitting and Sleep Consortium. Diabetologia Jun. 2024;67(6):1051–65. https://doi.org/10.1007/s00125-024-06090-y.
84. McArthur BA, Volkova V, Tomopoulos S, Madigan S. Global prevalence of meeting screen Time guidelines among children 5 years and younger: a systematic review and Meta-analysis. JAMA Pediatr Apr. 2022;1(4):373–83. https://doi.org/10.1001/jamapediatrics.2021.6386.
85. Bourke M, Haddara A, Loh A, Carson V, Breau B, Tucker P. Adherence to the World Health Organization's physical activity recommendation in preschool-aged children: a systematic review and meta-analysis of accelerometer studies. Int J Behav Nutr Phys Act Apr. 2023;26(1):52. https://doi.org/10.1186/s12966-023-01450-0.
86. Duncan MJ, Rayward AT, Holliday EG, Brown WJ, Vandelanotte C, Murawski B, Plotnikoff RC. Effect of a physical activity and sleep m-health intervention on a composite activity-sleep behaviour score and mental health: a mediation analysis of two randomised controlled trials. Int J Behav Nutr Phys Act Mar. 2021;25(1):45. https://doi.org/10.1186/s12966-021-01112-z.
87. Tremblay MS, Duncan MJ, Kuzik N, Silva DAS, Carson V. Towards precision 24-hour movement behavior recommendations-the next new paradigm? J Sport Health Sci May. 2024;9. https://doi.org/10.1016/j.jshs.2024.05.003.
88. Feng J, Huang WY, Sit CH. Effectiveness of a parent-focused intervention targeting 24-H Movement behaviors in Preschool-aged children: study protocol for a Randomized Controlled Trial. Front Public Health. 2022;10:870281. https://doi.org/10.3389/fpubh.2022.870281.
89. Arbour-Nicitopoulos KP, Bassett-Gunter RL, Leo J, Sharma R, Olds T, Latimer-Cheung AE, Martin Ginis KA. A cross-sectional examination of the 24-hour movement behaviours in Canadian youth with physical and sensory disabilities. Disabil Health J Jan. 2021;14(1):100980. https://doi.org/10.1016/j.dhjo.2020.100980.
90. Ross SM, Haegele JA, Schram BM, Healy S. 24-Hour Movement behaviors among US adults with functional disabilities. J Phys Act Health May. 2022;1(5):392–7. https://doi.org/10.1123/jpah.2021-0648.
91. Kracht CL, Drews KL, Flanagan EW, et al. Maternal 24-h movement patterns across pregnancy and postpartum: the LIFE-Moms consortium. Prev Med Rep Jun. 2024;42:102740. https://doi.org/10.1016/j.pmedr.2024.102740.
92. Badon SE, Ferrara A, Gabriel KP, Avalos LA, Hedderson MM. Changes in 24-Hour Movement behaviors from early to late pregnancy in individuals with prepregnancy overweight or obesity. J Phys Act Health Dec. 2022;1(12):842–6. https://doi.org/10.1123/jpah.2022-0333.
93. Okely T, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. BMJ Open Oct. 2021;25(10):e049267. https://doi.org/10.1136/bmjopen-2021-049267.

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