



Physical Activity and Sedentary Behavior in Children During the COVID-19 Pandemic: Implications for Mental Health

Betty Pfefferbaum¹ · Richard L. Van Horn²

Published online: 1 September 2022

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract

Purpose of Review This paper examines children's physical activity and sedentary behavior and associated psychological outcomes coincident with the COVID-19 pandemic.

Recent Findings Generally, the research has found decreased physical activity and increased sedentary behavior, both of which are associated with various psychological outcomes. The research on sedentary behavior has focused on screen time with minimal consideration of other sedentary behaviors or of specific physical activities or the context in which these behaviors occurred.

Summary Changes in children's daily routines and activities have received little attention in the mass trauma research despite the fact that disasters disrupt individual, family, and community life. Thus, the current report contributes to an understanding of the breadth of mass trauma effects, underscores the importance of physical activity and sedentary behavior and their associations with health and psychological outcomes, and is a reminder to consider children's daily lives both during times of crisis and under usual circumstances.

Keywords Children · COVID-19 · Disasters · Physical activity · Screen time · Sedentary behavior

Introduction

With its contagious nature and global reach, the COVID-19 pandemic has affected far more people than affected by most disasters and it has generated unparalleled social and economic repercussions. The public health measures prompted by the pandemic resulted in widespread and enduring school closure and home confinement that disrupted children's routines and activities. Much of children's physical activity typically occurs in connection with school including during transit from home to

school and back, physical education classes and team sports, and recess [1]. In general, relative to days when school is in session, children engage in less physical activity and are more sedentary (i.e., no increase in energy expenditure greatly above that at rest [2, 3••] such as sleeping, lying down, sitting, and using screens [2]) on non-school days [1]. For many children, the pandemic lockdown resulted in less structure and supervision and in the loss of social contacts thus potentially affecting their physical activity and screen time (the amount of time spent looking at devices that display electronic images such as televisions, computer screens, phones or tablets with screens, and monitors for game consoles), dietary habits, and sleep. Children's physical activity, sedentary behavior (including screen time), and sleep are collectively known as movement behaviors [4, 5••, 6•]. While these behaviors have not been commonly considered in the research on other disasters, changes in children's movement behaviors and their associations with psychological outcomes have been examined in general [3••, 4, 5••, 7–10] and recently in the context of COVID-19.

The Current Review

This review describes general guidelines and recommendations regarding movement behaviors in children, adherence to these guidelines, and exemplary COVID-19 studies on changes in

This article is part of the Topical Collection on *Child and Family Disaster Psychiatry*

✉ Betty Pfefferbaum
Betty-Pfefferbaum@ouhsc.edu

Richard L. Van Horn
rvanhorn@ou.edu

¹ Department of Psychiatry and Behavioral Sciences, College of Medicine, University of Oklahoma Health Sciences Center, 920 Stanton L. Young Boulevard, WP 3217, P.O. Box 26901, Oklahoma City, OK 73126-0901, USA

² University of Oklahoma, 920 Stanton L. Young Boulevard, WP 3217, P.O. Box 26901, Oklahoma City, OK 73126-0901, USA

physical activity and sedentary behavior (including screen time). The paper explores research on the associations of physical activity and sedentary behavior with health and mental health outcomes, describes potential mechanisms for these associations, and presents exemplary COVID-19 studies examining these associations. The discussion covers the strengths and limitations of the extant research and identifies directions for future investigation. Issues related to children's sleep and dietary habits, which overlap with their physical activity and sedentary behaviors, are not addressed in this paper but are reserved for a separate publication. Space constraints preclude the examination of studies of special populations such as children with health limitations, disabling conditions, obesity, mental health problems, and developmental disorders or those with potentially consequential socioeconomic constraints (e.g., crowded living spaces). Likewise, the review does not include studies of preventive or protective behavior, internet and other addictions, or services and interventions.

Guidelines Regarding Children's Movement Behaviors

Various health agencies and professional groups have developed guidelines for children's health-related movement behaviors—physical activity, sedentary behavior, and sleep. For example, based on an updated review of the evidence, the World Health Organization (WHO) recently published revised 2020 guidelines for physical activity and sedentary behavior including guidelines for children aged five years and older [11•]. In 2018, the United States (US) Department of Health and Human Services [12] issued guidelines on children's physical activity. An expert panel on risk for cardiovascular disease reported age-specific evidence-based cardiovascular health guidelines for use by pediatric primary care providers which, among other things, addressed physical activity and screen time as well as diet and nutrition [13]. Noting its association with health and mental health outcomes, the American Academy of Sleep Medicine [14] published a consensus statement and recommendations for sleep duration in children and adolescents, which was endorsed by the American Academy of Pediatrics. Given the finite number of hours in the day, time spent in any one movement behavior (physical activity, sedentary behavior, sleep) is limited by, and is likely to affect, time spent in any other [15]. Thus, time engaged in various behaviors should not be considered independently from one another when developing recommendations and guidelines [15]. Recognizing the important link between and among movement behaviors and various health indicators, the Canadian Society for Exercise Physiology [6•] developed the *Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration*

of Physical Activity, Sedentary Behaviour, and Sleep, which offered evidence-informed recommendations for daily physical activity, sedentary behavior, and sleep for children 5 to 17 years of age. Current guidelines, which are available online, recommend that children aged 5 to 17 years spend at least 60 min per day in moderate to vigorous physical activity, no more than 2 h per day in recreational screen time, and “limited sitting for extended periods” [16]. The guidelines recommend that children aged 5 to 13 years sleep 9 to 11 h per night and those aged 14 to 17 years sleep 8 to 10 h per night and that bed and wake times be consistent [16]. Recommendations also are provided for infants and children younger than 5 years of age [17].

Adherence to Guidelines

Pre-COVID-19 studies have examined adherence to movement guidelines. For example, using National Health and Nutrition Examination Survey data representing US children (aged 6 to 11 years) from 2009 to 2010, Fakhouri et al. [18] found that 70% of the participants met physical activity recommendations, 54% met screen-time viewing recommendations, and 38% met both recommendations concurrently. A study of children (aged 9 to 11 years), conducted in 12 countries from 2011 to 2013, revealed that only 7% concurrently met Canadian 24 h movement recommendations for moderate-to-vigorous physical activity, screen time, and sleep [19•]. A recent meta-analysis of pre-pandemic studies revealed that 24.7% of children below the age of two years met screen time guidelines and 35.6% of those two to five years of age met these guidelines [20].

COVID-19 Studies on Changes in Children's Physical Activity and Sedentary Behavior

Numerous COVID-19 studies have assessed changes in children's movement behaviors. A recent review, which included six studies on physical activity and five studies on sedentary behavior in healthy children and adolescents, found decreased physical activity and increased sedentary behavior during the pandemic [21]. A scoping review of adult and child investigations found a decrease in physical activity during the pandemic regardless of how activity was measured (e.g., frequency, duration) [22••]. Fewer studies have examined children's sedentary behaviors collectively while more studies have addressed children's screen time specifically. A recent review found an increase in screen time (especially online leisure activities, television viewing, news consumption, and overall use of internet but generally excluding social media use and video gaming) and social media use in most studies of adolescents during the pandemic and suggested that screen use and consumption of

news may have helped inform children and facilitated coping though it also may have increased fear of infection [23••].

Among exemplary COVID-19 studies, a prospective investigation of adolescents (aged 13 to 19 years) assessed before and after the implementation of physical distancing policies in New South Wales, Australia, found that physical activity decreased; sedentary behavior, social media and internet use, and screen time increased; and there was no change in television viewing [24]. In an investigation fielded one month after the WHO declared COVID-19 a global pandemic, a nationally representative sample of Canadian parents (demographically comparable to the census) reported that their children (aged 5 to 17 years) engaged in less physical activity and outdoor play and more sedentary behavior, spent less time outside, and slept more during the pandemic [25]. Comparing findings to the Canadian 24-h movement guidelines [6•, 25], very few children met recommendations for all three behaviors (physical activity, sedentary behavior, and sleep), and the proportion of children who met guidelines for all three behaviors was much lower than the proportion in prior national samples assessed before the pandemic [25]. A comparison of representative cohorts of school children (aged 8 to 16 years) in a region north of Spain, assessed before and during COVID-19 confinement, found a decrease in physical activity and an increase in screen time in those assessed during the pandemic [26]. There was a dramatic decrease in physical activity and an increase in screen time between January 2020 and March 2020 in participants in a longitudinal study of a random sample of over 2000 children and adolescents (aged 6 to 17 years) in Shanghai, China [27].

Relatively few studies have examined detailed aspects of children's behavior or the reasons for their behavior. One study of adolescents (including middle and high school students) in a nationally representative Korean sample reported a decrease in physical activity and time spent sitting to study and an increase in time spent sitting for other purposes and sleeping during the pandemic compared to pre-pandemic levels [28]. A sizeable proportion of adolescents (aged 15 to 19 years) in a study conducted in five countries—Sweden, Vietnam, Serbia, Morocco, and the USA—reported that since the pandemic the time they spent outside and meeting friends in person decreased while the time they spent doing things they did not have time to do before, staying connected with friends through social media and video games and with relatives through telephone or internet, working out, and spending quality time with family increased [29]. A survey of a random sample of Canadian parents of children (aged 5 to 17 years) in Calgary, conducted in the first few months after the onset of the pandemic, revealed that comparable proportions of children increased and decreased outdoor physical activity though children's physical activity at home increased or remained unchanged, over one-half of the

children decreased playing at the park and in public spaces, and over two-thirds decreased time with friends outdoors and indoors [30]. Over one-half of the children increased their time viewing television, playing video games, and using screen devices [30]. Ribner et al. [31] surveyed parents of over 2000 children (aged 3 to 7 years) from six countries. Media use for entertainment, education, and socializing with family and friends increased during the pandemic relative to retrospectively reported pre-pandemic use. The increase in media use was predominantly for entertainment and, to a lesser extent, education, with no change for socializing [31].

Developmental differences also have been examined in the COVID-19 movement behavior research. Using parent report, an international longitudinal study of movement behaviors in young children (aged 3 to 5 years) in 14 countries, assessed before and during strict public health COVID-19 restrictions, revealed that change in physical activity was small compared to that in studies of older children, perhaps due to the ability of parents to spend more time with their children while at home during public health restrictions and/or to methodological differences across studies [32•]. Children spent less time outdoors, sedentary screen time increased, and the proportion of children meeting 2019 WHO guidelines for sedentary screen time for children under the age of five years decreased [32•]. Children from low- and middle-income countries were more likely than those from high-income countries to meet the WHO physical activity and sedentary screen time guidelines for children under the age of five years, and children of parents with higher stress were less likely than those with lower stress to meet guidelines [32•]. A survey of parents of preschool children (aged 1 to 4.5 years) and of school-aged children (aged 9 to 10.7 years) in Singapore, conducted one to three months after strict movement restrictions ended, found that one-fourth of preschool children and more than one-third of school-aged children completely eliminated outdoor play during restrictions [33].

The Associations of Physical Activity and Sedentary Behavior with Health and Mental Health Outcomes

The associations of physical activity with various health and mental health indicators has been well studied. A literature review by Janssen and LeBlanc [8] found an association and a dose–response relationship between physical activity and a variety of health benefits. Physical activity also appears to be associated with positive mental health effects [7, 9] (including enhanced self-esteem, improved cognitive functioning and academic achievement, and decreased depression and anxiety [7]). The 2020 revised WHO guidelines for physical activity in children aged five years and older rated recommendations

as strong based on moderate certainty of evidence on the beneficial associations with health indicators [11•].

The association between sedentary behavior and emotional outcomes has been less well investigated empirically [3••]. The 2020 revised WHO guidelines for children aged five years and older made strong recommendations for sedentary behavior based on low certainty of evidence that greater time spent in sedentary behavior, especially television viewing or recreational screen time, was related to adverse health indicators [11•]. A recent review and meta-analysis of adult and child studies revealed a small effect of sedentary behavior on anxiety symptoms especially for adults as opposed to children and adolescents [34]. A review of pre-COVID-19 studies of sedentary behavior revealed a dose–response relationship with various adverse physical and psychological outcomes independent of physical activity in children (aged 5 to 17 years) [35]. In the studies reviewed, the most commonly assessed sedentary behavior was television viewing and the most common health outcome measured was body composition [35]. Another review that included studies of sedentary behavior (assessed as overall sedentary behavior and/or specific sedentary behaviors) found an association with at least one indicator of poorer mental health in studies that adjusted for physical activity, suggesting that sedentary behavior exerts an influence independent of physical activity [3••]. While not conclusive, the results of longitudinal and intervention studies suggest a causal connection with sedentary behavior leading to unfavorable outcomes though some studies suggest that those with poor mental health engaged in more sedentary behavior [3••].

A pre-pandemic analysis of review papers documented moderately strong evidence for associations of screen time with less healthy diet, poorer quality of life, and depression symptoms though evidence was limited for the association between social media contact and depression symptoms [10]. Weak evidence supported associations of screen time with behavior problems, anxiety, hyperactivity and inattention, lower self-esteem, poorer psychosocial health, negative effects on cognitive development, lower educational achievement, and adverse sleep outcomes [10]. There also was weak evidence that small amounts of daily screen use may not be harmful and may even confer some benefit [10]. Other pre-pandemic reviews also found associations of screen time with some physical and psychological outcomes. A review of the studies of children and youth (aged 5 to 17 years) across 71 countries revealed positive associations of various media-use behaviors and adverse health, fitness, emotional, and behavioral outcomes [4]. In their literature review, Suchert et al. [3••] found strong support for the association of screen time with more internalizing problems and hyperactivity/inattention problems and with lower psychological well-being and quality of life; results for self-esteem, depression, anxiety, and eating disorder

symptoms were inconclusive. A recent meta-analysis that excluded COVID-19 studies found a small but significant association of duration of screen time with internalizing and externalizing problems [36].

Comparing the relative benefit of movement behaviors, a review study by Saunders et al. [5••] found that health benefits were more consistently associated with physical activity than with either sedentary behavior or sleep in children and youth (aged 5 to 17 years) though the quality of the evidence was low. A combination of high levels of physical activity and sleep along with low levels of sedentary behavior was associated with better cardiometabolic health and lower adiposity than other combinations of physical activity, sedentary behavior, and sleep [5••].

Mechanisms Linking Physical Activity and Sedentary Behavior with Psychological Outcomes

Potential mechanisms for the association between physical activity and emotional outcomes reflect biological, psychological, behavioral, and psychosocial influences [37]. Biological influences involve various physiologic pathways (e.g., metabolic, cardiovascular, immunologic, endocrine, neurotransmitter) [37]. Psychological determinants include self-esteem and a sense of mastery and control [37, 38•]. Behaviorally, physically active children may have better dietary and sleep habits which also are associated with more positive mental health [37]. Psychosocial determinants include social relationships and interactions [38•]. Contextual factors such as the structure of daily routines also may result from and/or reinforce healthy behaviors [39]. Sedentary behavior has been less well studied but is likely to involve similar determinants. Importantly, time spent in sedentary behavior may supplant time spent in physical activity [3••].

Several possible mechanisms may explain the associations of screen time or technology use with children's physical and mental health. Excessive screen time or technology use can adversely affect children's physical health through a concomitant decrease in physical activity and changes in sleep [40, 41]. Screen or technology use may displace other behaviors, with daytime use supplanting time spent in more active, social, and/or productive pursuits and nighttime use interfering with sleep [42]. With respect to psychological outcomes, media messages themselves may influence children's emotions and behaviors [42]. Children often consume media alone, potentially intensifying social isolation and feelings of loneliness leading to adverse mental health consequences [42]. Screen activities also offer opportunities for comparison of physical attributes, skills, and other characteristics that may lead to negative social and emotional outcomes [3••].

The associations of psychological outcomes with physical activity, sedentary behavior, and/or screen time do not suppose causation. Moreover, the effects of these behaviors may not reflect clinically significant outcomes. For example, a meta-analysis found an association of increased physical activity with fewer depression symptoms but not with a decrease in major depressive disorder [43]; that is, there was no evidence that children's depression symptoms met criteria for a clinical disorder.

The Associations of Physical Activity and Sedentary Behavior with Psychological Outcomes in Child COVID-19 Studies

Research has found that decreased physical activity in the context of the COVID-19 pandemic and home confinement was associated with various psychological outcomes including perceived stress [39], psychological distress [44], depression [39, 45–48], anxiety [46], and hyperactivity-inattention and prosocial behaviors problems [49]. For example, a longitudinal study using accelerometry found a decrease in physical activity and sleep efficiency and an increase in sedentary time and in internalizing and externalizing problems in a sample of Spanish preschool children during lockdown [50]. Relative to non-active peers, children in this sample who met 2019 WHO recommendations for physical activity in children under the age of five years had fewer internalizing problems [50]. A study of adolescents in Southern China conducted shortly after schools were reopened following lockdown found that those with high levels of physical activity were less likely than those with low levels to develop depression symptoms and those with high levels of sedentary behavior were more likely than those with low levels to develop depression and anxiety symptoms [51]. A meta-analysis of child COVID-19 research by Marciano et al. [23••] revealed a marginally significant negative association between screen time and well-being, but the associations of screen time with ill-being and with lifestyle behaviors were not significant. While there was no significant association between time using social media and well-being, time using social media was associated with ill-being and with COVID-19 stress [23••]. No child review studies or meta-analyses for other sedentary behaviors or for physical activity in the context of the pandemic were identified.

Examining both physical activity and screen time, a study of parents of preschool (aged 2 to 5 years) and school-aged (aged 6 to 12 years) children from 18 districts in Hong Kong, conducted during the pandemic, found that daily exercise was negatively associated with perceived stress and problem behaviors and that time using electronic devices for gaming was associated with an increase in behavior problems while time spent using electronic devices for learning was

associated with psychosocial problems only in the preschool children [52]. A nationally-representative study of 6- to 10-year-old children using parent report and of 11- to 17-year-old children using parent and child report, matched with a US Census sampling frame, revealed an association of better mental health outcomes with greater physical activity in older children and with less screen time for both age groups [53]. A study of a convenience sample of over 20,000 adolescent students (not diagnosed with COVID-19) in Wuhan, China, during the period of quarantine and home confinement found that greater physical activity was associated with lower risk of depression and that increased screen time and increased browsing for information about COVID-19 were associated with greater risk of anxiety [47]. Among the variables examined in a sample of Brazilian adolescents (aged 12 to 17 years) from private and public schools during school closure, emotional well-being was positively associated with physical activity and negatively associated with screen time [54]. Ellis et al. [45] assessed daily activities in a convenience sample of adolescents in Ontario, Canada, three weeks after schools were closed as part of COVID-19 containment measures. Many adolescents reported participating in no physical activity, especially intense exercise, and many reported increased social media use relative to pre-COVID-19 levels [45]. Physical activity was negatively associated with loneliness and depression [45]. Consumption of COVID-19 news was associated with greater COVID-19 stress (e.g., fear about being infected, concerns about physical distancing) but not depression or loneliness while greater social media use—both before and during the pandemic—was positively associated with depression and COVID-19-related stress but not loneliness [45].

Few investigators have distinguished media forms in their analyses. A longitudinal study of adolescents in New South Wales, Australia, that queried traditional and social media separately found that traditional media consumption about COVID-19 was associated with anxiety but not depression or life satisfaction while social media consumption about COVID-19 was not associated with any of these outcomes [55]. In their study of Chinese children in a region that was not severely affected by the pandemic, Yue et al. [56] considered two measures of media consumption: (1) attention to COVID-19 information (using a scale from not at all to very much) which the investigators described as a measure of subjective media consumption and (2) time spent reading and watching COVID-19 news (using a scale from within 1 h to more than 5 h) which they considered to be a more objective measure. Time spent consuming COVID-19 news was associated with anxiety and posttraumatic stress disorder (PTSD) but not depression, while attention to COVID-19 information was associated with PTSD but not anxiety or depression [56].

Research exploring the child's purpose for consuming media coverage (e.g., news, education, socializing, entertainment) has been limited. For example, shortly after social distancing measures were implemented, over 80% of parents in a US sample reported that the restrictions had at least a small negative effect on their children's mental health, and over 80% reported their children had increased their use of technology to connect with others [57]. Children with greater anxiety were more likely to have increased their use of technology to connect with others [57]. A study of adolescents (aged 13 to 17 years) from 42 states across the USA found that daily social media and technology use (e.g., social media, phone calls, video games, television) for coping increased significantly after the onset of the pandemic and that anxiety and depression symptoms were associated with increased social media use [58].

Discussion

Changes in children's daily routines and movement behaviors have received little attention in the child mass trauma research. Much of the extant child COVID-19 research has been conducted while restrictive public health measures like school closure and home confinement were in effect, which surely exacerbated the disruption and distress in children's lives. Even absent such restrictive measures, mass trauma and disasters disrupt individual, family, and community life through, for example, displacement, damage to homes and community facilities and structures, and interrupted services. Thus, the body of work represented in the current report adds substantially to our understanding of the breadth of mass trauma effects, underscores the importance of these outcomes, and serves as a reminder to consider children's daily lives both during times of crisis and under usual circumstances. Generally, COVID-19 studies have found a decrease in physical activity and a concomitant increase in sedentary behavior such as screen time and associations between these activities and various psychological outcomes. These findings are consistent with the general child health literature in recognizing the importance of physical activity in health and mental health.

Strengths and Limitations in the COVID-19 Movement Behavior Research and Recommendations for Future Study

A strength of the emerging child COVID-19 research is its inclusion of studies of children across the developmental spectrum. In their recent review and meta-analysis of over 100 pre-COVID-19 studies on the influence of physical activity and sedentary behavior on mental health in children and adolescents, Rodriguez-Ayllon

et al. [42] found no studies on preschool children. Thus, it is noteworthy that several COVID-19 studies have investigated physical activity and sedentary behavior in preschool children in the context of the pandemic [e.g., 31, 32, 33, 50, 52].

Like the general literature, most of this child COVID-19 research has examined overall physical activity with minimal attention to specific pursuits or to the context in which they occurred. The emphasis of the extant research on sedentary behavior has been on screen time with a dearth of attention to other forms and aspects of children's inactivity. Though limited in some regards, the emerging research adds to the child mass trauma media literature by more intense focus on social media, but much of the child COVID-19 media research has concentrated on overall screen time lacking the detail needed to fully understand the outcomes and attendant issues. Like the broader child disaster media research, few studies have distinguished media forms (e.g., television, print, internet), the child's purpose for consuming media (e.g., news, education, socializing, entertainment), and the context of media contact (e.g., in the presence of parents).

The current report focused exclusively on physical activity and sedentary behavior (including screen time). Unfortunately, space constraints precluded a comprehensive analysis of potential covariates such as children's individual COVID-19 exposures and experiences, demographic (e.g., gender, age and development) and socio-economic influences, and contextual factors that may have affected the findings. Critically important are the interrelationships of physical activity and sedentary behavior with sleep and diet which have received relatively little attention in the extant research. Among a host of other important issues, additional research is needed to determine the long-term effects of changes in movement behaviors and the extent to which various activities and environmental influences promote adaptive coping and resilience in children during pandemics; to explore the challenges and effects of reentry into in-person environments after schools and other facilities reopen and post pandemic; and to consider strategies for family, school, and professional intervention.

The methodological quality and rigor varied across investigations and, while this review concentrated on exemplary studies, much of the COVID-19 research assessed non-representative samples using cross-sectional design to measure current movement behaviors and/or changes in these behaviors by retrospective report asking children and/or parents about current behaviors relative to pre-pandemic levels. For the most part, cause and effect could not be determined. In addition, most studies have not addressed the degree to which outcomes were clinically meaningful. Future research should assess representative samples using validated assessment tools in studies with robust methodology and longitudinal design and should consider the clinical significance of the results.

Implications and Conclusions

The current review revealed significant effects of the pandemic and attendant public health restrictions on children's movement behaviors and associations between these behaviors and psychological outcomes. While COVID-19 home confinement restrictions have eased and, for the most part, children have returned to school, intermittent and partial school closures and individual quarantine continue in some situations. Structure along with monitoring and supervision of children's activities are a crucial aspect of their care especially as they move from one environment to another. Attention to daily routine and structure should be part of child and family mental health assessment and intervention both during a pandemic and as the crisis abates. A lesson of the COVID-19 pandemic is the importance of these concerns in response to future epidemics, pandemics, and other biohazards, and, more generally, to natural and man-made disasters especially given the influence of movement behaviors on health and mental health.

Acknowledgements The editors would like to thank Dr. Vijaya Ekambaran for taking the time to review this manuscript.

Declarations

Conflict of Interest Betty Pfefferbaum and Richard L. Van Horn each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Guan H, Okely AD, Aguilar-Farias N, del Pozo CB, Draper CE, El Hamdouchi A, et al. Promoting healthy movement behaviours among children during the COVID-19 pandemic. *Lancet Child Adolesc Health*. 2020;4:416–8. [https://doi.org/10.1016/s2352-4642\(20\)30131-0](https://doi.org/10.1016/s2352-4642(20)30131-0).
2. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary." *Exerc Sport Sci Rev*. 2008;36(4):173–8. <https://doi.org/10.1097/jes.0b013e3181877d1a>.
- 3.●● Suchert V, Hanewinkel R, Isensee B. Sedentary behavior and indicators of mental health in school-aged children and adolescents: A systematic review. *Prev Med*. 2015;76:48–57. <https://doi.org/10.1016/j.ypmed.2015.03.026>. **This review of research on sedentary behavior (assessed as overall sedentary behavior and/or specific sedentary behaviors) in children found strong support for the association of screen time with more internalizing problems and hyperactivity/inattention problems and with lower psychological well-being**
4. Carson V, Hunter S, Kuzik N, Gray CE, Poitras VJ, Chaput JP, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. *Appl Physiol Nutr Metab*. 2016;41(Suppl. 3):S240–65. <https://doi.org/10.1139/apnm-2015-0630>.
- 5.●● Saunders TJ, Gray CE, Poitras VJ, Chaput JP, Janssen I, Katzmarzyk PT, et al. Combinations of physical activity, sedentary behavior and sleep: relationships with health indicators in school-aged children and youth. *Appl Physiol Nutr Metab*. 2016;41(6, Suppl. 3):S283–93. <https://doi.org/10.1139/apnm-2015-0626>. **This review examined the association of time spent in combinations of physical activity, sedentary behavior, and sleep with a number of health indicators including emotional and behavioral outcomes in children and youth (aged 5 to 17 years). Though the quality of the evidence was low, health benefits were more consistently associated with physical activity than with either sedentary behavior or sleep. A combination of high levels of physical activity and sleep along with low levels of sedentary behavior was associated with better cardiometabolic health and lower adiposity than other combinations of physical activity, sedentary behavior, and sleep.**
- 6.● Tremblay MS, Carson V, Chaput JP, Connor Gorber S, Dinh T, Duggan M, 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. <https://doi.org/10.1139/apnm-2016-0151>. **Recognizing the important link between and among movement behaviors and various health indicators, this paper described the *Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep*, developed by the Canadian Society for Exercise Physiology. Evidence-informed recommendations for daily moderate-to-vigorous physical activity, sedentary behavior and recreational screen time, and sleep for children 5 to 17 years of age were offered.**
7. Biddle SJH, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. *Br J Sports Med*. 2011;45(11):886–95. <https://doi.org/10.1136/bjsports-2011-090185>.
8. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act*. 2010;7:40. <https://doi.org/10.1186/1479-5868-7-40>.
9. Okuyama J, Seto S, Fukuda Y, Funakoshi S, Amae S, Onobe J, et al. Mental health and physical activity among children and adolescents during the COVID-19 pandemic. *Tohoku J Exp Med*. 2021;253:203–15. <https://doi.org/10.1620/tjem.253.203>.
10. Stiglic N, Viner RM. Effects of screentime on the health and well-being of children and adolescents: a systematic review of reviews. *BMJ Open*. 2019;9:e023191. <https://doi.org/10.1136/bmjopen-2018-023191>.
- 11.● Bull C, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*. 2020;54:1451–62. <https://doi.org/10.1136/bjsports-2020-102955>. **This report described revised 2020 World Health Organization guidelines on physical activity and sedentary behavior, including guidelines for children five years of age and older, and supporting evidence on associated health indicators.**

12. U.S. Department of Health and Human Services. Physical activity guidelines for Americans, 2nd Edition. Washington, DC: USDHHS, 2018. Available from https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf.
13. Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents. Expert panel on integrated guidelines for cardiovascular health and risk reduction in children and adolescents: Summary report. *Pediatrics*. 2011;128(Suppl. 5):S213–56. <https://doi.org/10.1542/peds.2009-2107c>.
14. Paruthi S, Brooks LJ, D'Ambrosio C, Hall WA, Kotagal S, Lloyd RM, et al. Recommended amount of sleep for pediatric populations: A consensus statement of the American Academy of Sleep Medicine. *J Clin Sleep Med*. 2016;12(6):785–6. <https://doi.org/10.5664/jcsm.5866>.
15. Bates LC, Zieff G, Stanford K, Moore JB, Kerr ZY, Hanson ED, et al. COVID-19 impact on behaviors across the 24-hour day in children and adolescents: Physical activity, sedentary behavior, and sleep. *Children*. 2020;7(138):1–9. <https://doi.org/10.3390/children7090138>.
16. Canadian 24-hour Movement Guidelines for the Children and Youth: An integration of physical activity, sedentary behaviour, and sleep. Available at: <https://csepguidelines.ca/guidelines/children-youth/>. Accessed 20 Jul 2022.
17. Canadian 24-hour Movement Guidelines for the Early Years (0–4 Years): An integration of physical activity, sedentary behaviour, and sleep. Available at: <https://csepguidelines.ca/guidelines/early-years/>. Accessed 20 Jul 2022.
18. Fakhouri THI, Hughes JP, Brody DJ, Kit BK, Ogden CL. Physical activity and screen-time viewing among elementary school-aged children in the United States from 2009 to 2010. *JAMA Pediatr*. 2013;167(3):223–9. <https://doi.org/10.1001/2013.jamapediatrics.122>.
19. ● Roman-Viñas B, Chaput JP, Katzmarzyk PT, Fogelholm M, Lambert EV, Maher C, et al. Proportion of children meeting recommendations for 24-hour movement guidelines and associations with adiposity in a 12-country study. *Int J Behav Nutr Phys Act*. 2016;13:123. <https://doi.org/10.1186/s12966-016-0449-8>. **This study evaluated adherence to Canadian 24-hour movement guidelines for physical activity, screen time, and sleep in children (aged 9 to 11 years) in 12 countries from 2011 to 2013. Only 7% met recommendations concurrently for all three activities.**
20. 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*. 2022;176(4):373–83. <https://doi.org/10.1001/jamapediatrics.2021.6386>.
21. Stockwell S, Trott M, Tully M, Shin J, Barnett Y, Butler L, et al. Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: A systematic review. *BMJ Open Sport Exercise Med*. 2021;7:e000960. <https://doi.org/10.1136/bmjsem-2020-000960>.
22. ●● Caputo EL, Reichert FF. Studies of physical activity and COVID-19 during the pandemic: A scoping review. *J Phys Act Health*. 2020;17:1275–84. <https://doi.org/10.1123/jpah.2020-0406>. **This scoping review of adult and child studies on changes in physical activity during the COVID-19 pandemic revealed a decrease in activity related to restrictive public health measures regardless of how physical activity was measured (e.g., frequency, duration).**
23. ●● Marciano L, Ostroumova M, Schulz Peter J, Camerini AL. Digital media use and adolescents' mental health during the COVID-19 pandemic: A systematic review and meta-analysis. *Front Public Health*. 2022;9:793868. <https://doi.org/10.3389/fpubh.2021.793868>. **This meta-analysis of child COVID-19 studies revealed a marginally significant negative association between screen time and well-being, but the associations of screen time with ill-being and with lifestyle behaviors were not significant. While there was no significant association between time using social media and well-being, time using social media was associated with ill-being and with COVID-19 stress.**
24. Munasinghe S, Sperandei S, Freebairn L, Conroy E, Jani H, Marjanovic S, Page A. The impact of physical distancing policies during the COVID-19 pandemic on health and well-being among Australian adolescents. *J Adolesc Health*. 2020;67(5):653–61. <https://doi.org/10.1016/j.jadohealth.2020.08.008>.
25. Moore SA, Faulkner G, Rhodes RE, Brussoni M, Chulak-Bozzer T, Ferguson LJ, et al. Impact of the COVID-19 virus outbreak on movement and play behaviours of Canadian children and youth: a national survey. *Int J Behav Nutr Phys Act*. 2020;17:85. <https://doi.org/10.1186/s12966-020-00987-8>.
26. Medrano M, Cadenas-Sanchez C, Osés M, Arenaza L, Amasene M, Labayen I. Changes in lifestyle behaviours during the COVID-19 confinement in Spanish children: A longitudinal analysis from the MUGI project. *Pediatr Obesity*. 2021;16:e12731. <https://doi.org/10.1111/jjpo.12731>.
27. Xiang M, Zhang Z, Kuwahara K. Impact of COVID-19 pandemic on children and adolescents' lifestyle behavior larger than expected. *Prog Cardiovasc Dis*. 2020;63:531–2. <https://doi.org/10.1016/j.pcad.2020.04.013>.
28. Yu S, Choe C. The COVID-19 pandemic and sustainable life of Korean adolescents: Exploring gender differences. *Sustainability*. 2021;13:8821. <https://doi.org/10.3390/su13168821>.
29. Kerekes N, Bador K, Sfindla A, Belaatar M, El Mzadi A, Jovic V, et al. Changes in adolescents' psychosocial functioning and well-being as a consequence of long-term COVID-19 restrictions. *Int J Environ Res Public Health*. 2021;18:8755. <https://doi.org/10.3390/ijerph18168755>.
30. McCormack GR, Doyle-Baker PK, Petersen JA, Ghoneim D. Parent anxiety and perceptions of their children's physical activity and sedentary behavior during the COVID-19 pandemic in Canada. *Prev Med Rep*. 2020;20:101275. <https://doi.org/10.1016/j.pmedr.2020.101275>.
31. Ribner AD, Coulanges L, Friedman S, Libertus ME, I-FAM-Covid Consortium. Screen time in the Coronavirus 2019 era: International trends of increasing use among 3- to 7-year-old children. *J Pediatr*. 2021;239:59–66. <https://doi.org/10.1016/j.jpeds.2021.08.068>.
32. ● Okely AD, Kariippanon KE, Guan H, Taylor EK, Suesse T, Cross PL, et al. Global effect of COVID-19 pandemic on physical activity, sedentary behaviour and sleep among 3- to 5-year-old children: a longitudinal study of 14 countries. *BMC Public Health*. 2021;21:940. <https://doi.org/10.1186/s12889-021-10852-3>. **This international longitudinal study used parent report to assess movement behaviors in young children (aged 3 to 5 years) in 14 countries before and during strict public health COVID-19 restrictions. Children spent less time outdoors, sedentary screen time increased, and the proportion of children meeting World Health Organization (WHO) guidelines for sedentary screen time for children under the age of five years decreased. Children from low- and middle-income countries were more likely than those from high-income countries to meet the WHO physical activity and sedentary screen time guidelines for children under the age of five years, and children of parents with higher stress were less likely than those with lower stress to meet guidelines.**
33. Sum KK, Cai S, Law E, Cheon B, Tan G, Loo E, et al. COVID-19-related life experiences, outdoor play, and long-term adiposity changes among preschool- and school-aged children in Singapore 1 year after lockdown. *JAMA Pediatr*. 2022;176(3):280–9. <https://doi.org/10.1001/jamapediatrics.2021.5585>.

34. Stanczykiewicz B, Banik A, Knoll N, Keller J, Hohl DH, Rosiński J, Luszczynska A. Sedentary behaviors and anxiety among children, adolescents and adults: a systematic review and meta analysis. *BMC Public Health*. 2019;19:459. <https://doi.org/10.1186/s12889-019-6715-3>.
35. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *Int J Behav Nutr Phys Act*. 2011;8(98):1–22. <http://www.ijbnpa.org/content/8/1/98>.
36. Eirich R, McArthur BA, Anhorn C, McGuinness C, Christakis DA, Madigan S. Association of screen time with internalizing and externalizing behavior problems in children 12 years or younger. A systematic review and meta-analysis. *JAMA Psychiatr*. 2022. <https://doi.org/10.1001/jamapsychiatry.2022.0155>.
37. Mikkelsen K, Stojanovska L, Polenakovic M, Bosevski M, Apostolopoulos V. Exercise and mental health. *Maturitas*. 2017;106:45–56. <https://doi.org/10.1016/j.maturitas.2017.09.003>.
38. Lubans D, Richards J, Hillman C, Faulkner G, Beauchamp M, Nilsson M, et al. Physical activity for cognitive and mental health in youth: A systematic review of mechanisms. *Pediatrics*. 2016;138(3):e20161642. <https://doi.org/10.1542/peds.2016-1642>. **This paper offered a conceptual model to describe neurobiological, psychosocial, and behavioral mechanisms for the association of physical activity with cognitive and emotional outcomes and presented the results of a systematic review of the evidence. Studies on psychosocial mechanisms predominated and no conclusions were drawn regarding the influence of neurobiological or behavioral mechanisms on cognitive or mental health outcomes.**
39. Wright LJ, Williams SE, Veldhuijzen van Zanten JJCS. Physical activity protects against the negative impact of coronavirus fear and adolescent mental health and well-being during the COVID-19 pandemic. *Front Psychol*. 2021;11:1–10. <https://doi.org/10.3389/fpsyg.2021.580511>.
40. Fomby P, Goode JA, Truong-Vu KP, Mollborn S. Adolescent technology, sleep, and physical activity in two U.S. cohorts. *Youth Soc*. 2021;53(4):585–609. <https://doi.org/10.1177/0044118x19868365>.
41. Singh S, Balhara YPS. “Screen-time” for children and adolescents in COVID-19 times: Need to have the contextually informed perspective. *Indian J Psychiatry*. 2021;63(2):192–5. https://doi.org/10.4103/psychiatry.indianjpsychiatry_646_20.
42. Rodriguez-Ayllon M, Cadenas-Sánchez C, Estévez-López F, Muñoz NE, Mora-Gonzalez J, Migueles JH, et al. Role of physical activity and sedentary behavior in the mental health of preschoolers, children and adolescents: A systematic review and meta-analysis. *Sports Med*. 2019;49:1383–410. <https://doi.org/10.1007/s40279-019-01099-5>.
43. Korczak DJ, Madigan S, Colasanto M. Children’s physical activity and depression: A meta-analysis. *Pediatrics*. 2017;139:1–14. <https://doi.org/10.1542/peds.2016-2266>.
44. Qin Z, Shi L, Xue Y, Lin H, Zhang J, Liang P, et al. Prevalence and risk factors associated with self-reported psychological distress among children and adolescents during the COVID-19 pandemic in China. *JAMA Netw Open*. 2021;4(1):e2035487. <https://doi.org/10.1001/jamanetworkopen.2020.35487>.
45. Ellis WE, Dumas TM, Forbes LM. Physically isolated but socially connected: Psychological adjustment and stress among adolescents during the initial COVID-19 crisis. *Can J Behav Sci*. 2020;52(3):177–87. <https://doi.org/10.1037/cbs0000215>.
46. Hou T, Mao X, Dong W, Cai W, Deng G. Prevalence of and factors associated with mental health problems and suicidality among senior high school students in rural China during the COVID-19 outbreak. *Asian J Psychiatr*. 2020;54:102305. <https://doi.org/10.1016/j.ajp.2020.102305>.
47. Li W, Zhang Y, Wang J, Ozaki A, Wang Q, Chen Y, Jiang Q. Association of home quarantine and mental health among teenagers in Wuhan, China, during the COVID-19 pandemic. *JAMA Pediatr*. 2021;175(3):313–6. <https://doi.org/10.1001/jamapediatrics.2020.5499>.
48. Zhang X, Zhu W, Kang S, Qiu L, Lu Z, Sun Y. Association between physical activity and mood states of children and adolescents in social isolation during the COVID-19 epidemic. *Int J Environ Res Public Health*. 2020;17:7666. <https://doi.org/10.3390/ijerph17207666>.
49. Liu Q, Zhou Y, Xie X, Xue Q, Zhu K, Wan Z, et al. The prevalence of behavioral problems among school-aged children in home quarantine during the COVID-19 pandemic in China. *J Affect Disord*. 2021;279:412–6. <https://doi.org/10.1016/j.jad.2020.10.008>.
50. Alonso-Martínez AM, Ramírez-Vélez R, García-Alonso Y, Izquierdo M, García-Hermoso A. Physical activity, sedentary behavior, sleep and self-regulation in Spanish preschoolers during the COVID-19 lockdown. *Int J Environ Res Public Health*. 2021;18:1–8. <https://doi.org/10.3390/ijerph18020693>.
51. Lu C, Chi X, Liang K, Chen ST, Huang L, Guo T, et al. Moving more and sitting less as healthy lifestyle behaviors are protective factors for insomnia, depression, and anxiety among adolescents during the COVID-19 pandemic. *Psychol Res Behav Manage*. 2020;13:1223–33. <https://doi.org/10.2147/prbm.s284103>.
52. Tso WWY, Wong RS, Tung KTS, Rao N, Fu KW, Yam JCS, et al. Vulnerability and resilience in children during the COVID-19 pandemic. *Eur Child Adolesc Psychiatry*. 2022;31(1):161–76. <https://doi.org/10.1007/s00787-020-01680-8>.
53. Tandon PS, Zhou C, Johnson AM, Schoenfelder Gonzalez E, Kroshus E. Association of children’s physical activity and screen time with mental health during the COVID-19 pandemic. *JAMA Netw Open*. 2021;4(10):e2127892. <https://doi.org/10.1001/jamanetworkopen.2021.27892>.
54. Szwarcwald CL, Malta DC, Barros, MBDA, de Souza Júnior PRB, Romero D, de Almeida WDS, et al. Associations of sociodemographic factors and health behaviors with the emotional well-being of adolescents during the COVID-19 pandemic in Brazil. *Int. J. Environ. Res. Public Health*. 2021;18:6160. <https://doi.org/10.3390/ijerph18116160>.
55. Magson NR, Freeman JYA, Rapee RM, Richardson CE, Oar EL, Fardouly J. Risk and protective factors for prospective changes in adolescent mental health during the COVID-19 pandemic. *J Youth Adolesc*. 2021;50:44–57. <https://doi.org/10.1007/s10964-020-01332-9>.
56. Yue J, Zang X, Le Y, An Y. Anxiety, depression and PTSD among children and their parent during 2019 novel coronavirus disease (COVID-19) outbreak in China. *Curr Psychol*. 2020;14:1–8. <https://doi.org/10.1007/s12144-020-01191-4>.
57. Drouin M, McDaniel BT, Pater J, Toscos T. How parents and their children used social media and technology at the beginning of the COVID-19 pandemic and associations with anxiety. *Cyberpsychol Behav Soc Netw*. 2020;23(11):727–36. <https://doi.org/10.1089/cyber.2020.0284>.
58. Burke TA, Kutok ER, Dunsiger S, Nugent NR, Patena JV, Riese A, Ranney ML. A national snapshot of U.S. adolescents’ mental health and changing technology use during COVID-19. *Gen Hosp Psychiatry*. 2021;71:147–8. <https://doi.org/10.1016/j.genhosppsy.2021.05.006>.

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.