Taylor & Francis
Taylor & Francis Group

Disability and Rehabilitation

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/idre20

The temporal and bi-directional relationship between physical activity and sleep in ambulatory children with cerebral palsy

Anke Gerritsen, Raquel Y. Hulst, Ilse M. van Rijssen, Joyce Obeid, Sigrid Pillen, Jan Willem Gorter & Olaf Verschuren

To cite this article: Anke Gerritsen, Raquel Y. Hulst, Ilse M. van Rijssen, Joyce Obeid, Sigrid Pillen, Jan Willem Gorter & Olaf Verschuren (2024) The temporal and bi-directional relationship between physical activity and sleep in ambulatory children with cerebral palsy, Disability and Rehabilitation, 46:13, 2821-2827, DOI: 10.1080/09638288.2023.2232720

To link to this article: https://doi.org/10.1080/09638288.2023.2232720

Published online: 09 Jul 2023.

DISABILITY AND REHABILITATION
2024, VOL. 46, NO. 13, 2821–2827
https://doi.org/10.1080/09638288.2023.2232720

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

The temporal and bi-directional relationship between physical activity and sleep in ambulatory children with cerebral palsy

Anke Gerritsen[a,b], Raquel Y. Hulst[a], Ilse M. van Rijssen[a], Joyce Obeid[c], Sigrid Pillen[d,e], Jan Willem Gorter[a,c,f] and Olaf Verschuren[a]

[a]Center of Excellence for Rehabilitation Medicine, UMC Utrecht Brain Center, University Medical Center Utrecht, Utrecht University and De Hoogstraat Rehabilitation, Utrecht, The Netherlands; [b]Faculty of Health and Physical Activity, Saxion University of Applied Sciences, Enschede, the Netherlands; [c]CanChild, Department of Pediatrics, McMaster University, Hamilton, Canada; [d]Kinderslaapexpert BV (Pediatric Sleep Expert LTd), Mook, The Netherlands; [e]Department of Electrical Engineering, Technical University Eindhoven, Eindhoven, The Netherlands; [f]Department of Rehabilitation, Physical Therapy Science and Sports, UMC Utrecht Brain Center, University Medical Center Utrecht, Utrecht, The Netherlands

ABSTRACT

Purpose: Exploring the temporal and bi-directional relationship between device-based measures of physical activity and sleep in ambulatory children with cerebral palsy (CP).

Materials and Methods: 24-hour activity data were collected from children with CP (n=51, 43% girls, mean age (range); 6.8 (3–12) years; Gross Motor Function Classification System levels I to III). Nocturnal sleep parameters and daily physical activity were measured for seven consecutive days and nights using ActiGraph GT3X accelerometers. Linear mixed models were constructed to explore the relationships between sleep and activity.

Results: Light and moderate-to-vigorous activity were negatively associated with sleep efficiency (SE) (resp. p=0.04, p=0.010) and total sleep time (TST) (resp. p=0.007, p=0.016) the following night. Sedentary time was positively associated with SE and TST the following night (resp. p=0.014, p=0.004). SE and TST were positively associated with sedentary time (resp. p=0.011, p=0.001) and negatively with moderate-to-vigorous physical activity (resp. p<0.001, p=0.002) the following day. Total bedtime and TST were negatively associated with light physical activity (resp. p=0.046, p=0.004) the following day.

Conclusions: The findings from this study suggest that ambulatory children with CP may not sleep better after physical activity, and vice versa, indicating that the relationship is complex and needs further investigation.

IMPLICATIONS FOR REHABILITATION

- The use of device-based accelerometry is a feasible method to measure 24-hour activity patterns with sleep and physical activity in ambulatory children with cerebral palsy.
- The relationships between sleep and physical activity in children with cerebral palsy are not as expected based on patterns shown in peers with typical development.
- Interventions for sleep in children with cerebral palsy require a holistic approach, focusing on daily physical activity patterns and relevant child- and contextual factors.

ARTICLE HISTORY
Received 24 March 2022
Revised 29 June 2023
Accepted 30 June 2023

KEYWORDS
Cerebral palsy; children; sleep; physical activity; accelerometry

Introduction

Cerebral palsy (CP) is the most common cause of movement and posture disorders in children, with a worldwide prevalence of about 2 in every 1000 live births [1]. CP is defined as a group of non-progressive, neuro-motor disorders caused by disturbances that occur during the development of the fetal or infant brain [2]. Children with CP are more sedentary and engage in less moderate-to-vigorous physical activity (MVPA) than peers who are typically developing [3,4]. Lower levels of physical activity increase the risk for future health problems, including obesity and type II diabetes [5,6]. Similarly, health problems can be related to frequent sleep problems [7,8] Sleep problems are common in children with CP with prevalence rates ranging from 24% to 44%, including difficulty in initiating and maintaining sleep, disorders of sleep-wake transition, sleep breathing disorders, sleep bruxism, excessive day time sleeping, nightmares and sleep talking [9,10]. These sleep problems may be caused by a combination of child-related factors such as muscle spasms, apnea, musculoskeletal pain, epilepsy, and sensory or behavioural problems [11–13] and contextual factors, including social conditions and proper sleep hygiene by parents/caregivers [5]. It is therefore important that 24-h activities are considered in children with CP, meaning that these children are not only encouraged to engage in more physical activity and less sedentary time, but also to get them sufficient and good quality sleep.

Sleep, physical activity, and sedentary time are interconnected behaviours that make up a child's whole day (24-h movement behaviours) [14]. Therefore, if a child spends more time being sedentary there is less time to be spent sleeping or engaging in physical activity within a given day. Since a traditional approach of averaged

CONTACT Olaf Verschuren o.verschuren@dehoogstraat.nl Center of Excellence for Rehabilitation Medicine, UMC Utrecht & De Hoogstraat Rehabilitation. Rembrandtkade 10, 3583 TM Utrecht, The Netherlands.

movement behaviour outcome across several days may lack the temporal sensitivity to detect the intraindividual interplay between sleep and daytime movement behaviours, a temporal sensitive method is more appropriate when analysing associations between physical activity and sleep [15]. A systematic review by Huang et al. [16], which included 11 studies looking at children who are typically developing (5–15 years), found a weak association between physical activity and sleep. Their results suggest a positive relation between physical activity during the day and sleep the following night and a relation between better sleep quality and less sedentary time the following day [16]. These positive relations were mostly found in studies including and examining MVPA which affected sleep duration positively and vice versa [17–18]. This suggests that MVPA has a role in improving sleep quantity in children and that good quantity sleep supports higher MVPA-levels during the day.

Since the relationships mentioned above were only consistently found in studies using device-based measures, the authors highlighted the importance of the use of device-based measures, which are more precise and more accurate than subjective measures such as self- or proxy-reported questionnaires and diaries [19]. Nonetheless, evidence using device-based sleep and activity measures is still limited in research investigating the associations between sleep and physical activity in children with CP [20]. Just one study observed the bi-directional relationships between sleep, physical activity, and sedentary behaviour in children with CP and found only a small moderate negative correlation between sedentary behaviour and sleep, suggesting that more sedentary time resulted in less sleep quantity [21]. However, this study used average measures over a week and subjective measures for sleep. To our knowledge, the between-day, bi-directional associations between device-based measured sleep, physical activity and sedentary behaviour have not been investigated in children with CP. Understanding temporal relationships may help to identify important avenues in the 24-h movement behaviours in children with CP. Therefore, the aim of this study is to explore the temporal and bi-directional association between sleep, sedentary time, and physical activity in ambulatory children with CP using actigraphy. We hypothesized that higher physical activity levels during the day result in better sleep quality and quantity the following night and that a better sleep quality and quality during the night results in higher physical activity levels and lower sedentary time the following day.

Methods

Study design and setting

An observational, cross-sectional design was used to gather device-based measures of 24-h activity (sleep, sedentary behaviour, and physical activity) in children with CP. The study was approved by the Medical Ethics Research Committee of the University Medical Centre Utrecht (file number 19-630). Data were collected between January and December 2020. Due to the COVID-19 pandemic, data collection was paused during the lockdown period from 16th March until 11th April . A convenience sample was obtained by recruiting participants *via* paediatric rehabilitation medicine physicians in schools for special education and rehabilitation centres in The Netherlands. Children were not recruited based on existing sleep problems.

Population

Participants were children diagnosed with CP classified at Gross Motor Function Classification System (GMFCS) levels I to III, and between the age of 3 and 12 years. Before participation, parents and/or caregivers provided informed consent. Data were collected during a representative week as confirmed by participants, and participants were rescheduled or excluded when events or activities could influence the measurement during monitoring days (e.g., surgery, vacation, holidays, or quarantine).

General questionnaire & sleep checklist

Parents were asked to complete a general questionnaire regarding the age, sex, and GMFCS level of their children. Data were compared with the information on the child's medical record, when in doubt the treating physicians were contacted. For descriptive purposes, parents also completed a sleep checklist developed by Verschuren et al. [22] about their child to identify 1) any potential sleep problem; 2) use of sleep medication (e.g., melatonin); and 3) parent satisfaction with their child's sleep.

Measurements

Participants were instructed to wear the triaxial ActiGraph GT3X accelerometer for 7 consecutive days to collect 24-h activity behaviours. The ActiGraph is a reliable and valid instrument for measuring physical activity intensities and sleep in children who are typically developing [23–26]. Additionally, the ActiGraph shows promising results for research in children with CP as it was found reliable and valid to identify activity intensities and sleep [27–31]. Participants received two ActiGraphs each and were instructed to wear one at the waist during waking hours, and one at the non-dominant wrist during nocturnal sleep periods. During monitoring days, parents were asked to complete a wear time logbook, and instructed to note any times the accelerometer was put on or taken off during the day, reasons for removal (e.g., shower, swimming), and any important notes for the day (e.g., not feeling well). Parents were also instructed to complete a sleep logbook, in which they identified the "lights out" times, "out of bed" times, and any other general notes (e.g., sickness, stomach aches, use of pain medication). Both ActiGraphs were initialized at a 30-Hz sampling rate. Waist-worn units were downloaded in 15-s epoch length, while wrist-worn units were downloaded in 60-s epochs for sleep analysis using the ActiLife software (Version 6, ActiGraph, LLC., Pensacola FL).

Physical activity and sedentary time

Data from waist-worn units were cleaned using a semi-automated protocol, whereby any 5 min of zero counts were flagged and verified. Only non-wear periods identified in the participant logbook were excluded. The average vector magnitude counts per minute (VMCPM) and average vertical axis counts per minutes (VCPM) were extracted. Activity by intensity was also calculated, and included measures of sedentary time (SED), light physical activity (LPA) and moderate-to-vigorous activity (MVPA), as defined by the Evenson cut-points (using vertical axis counts) [23]. All activity-by-intensity outcomes were normalized to a 12-h day. Only participants that met the minimum wear time of ≥ 6 h per day on ≥ 4 days with at least one weekend day (Saturday or Sunday) were included in the analysis.

Sleep analysis

Lights out time and the out of bedtime according to the sleep logbook were used to define the start and the end of the sleep period, which was analysed with the Sadeh algorithm [25,31].

Nights were excluded if self-reported and measured sleeping time differed more than 10% of the total sleeping duration according to the sleep diary. To assess sleep quality the following parameters were extracted: sleep onset latency (SOL), which is defined as the time it takes to transition from full wakefulness to sleep and was computed by taking the time from "lights out" till the first epoch scored as sleep; and sleep efficiency (SE), this percentage was calculated by dividing TST by the TBT. To assess sleep quantity the following parameters were extracted: total time in bed (TBT), which is the time from "lights out" till the out of bedtime; and total sleep time (TST) is the sum of all sleep periods scored as sleep during TBT. Only participants with sleep measures for ≥ 4 nights with at least one weekend night (Friday on Saturday, or Saturday on Sunday) were included in the analysis.

Dataset and covariates

Only participants who met minimum wear time criteria for both waist- and wrist-worn units were included in the final analyses. To analyse the temporal relationship between physical activity/ sedentary time of the preceding day (exposure) and sleep of the following night (outcome), exposure and outcome variables per participant were paired. A second dataset was used to analyse the temporal relationship between sleep quality of the preceding night (exposure) and physical activity/sedentary time for the subsequent day (outcome), and variables were paired accordingly. Every participant had up to eight paired repeated measurements in both datasets. The participant's age, sex, and GMFCS-level were repeated for the corresponding rows in both datasets and included as covariates in the statistical model. Furthermore, separate analyses were performed for weekend and weekdays.

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 27.0 (Armonk, NY: IBM Corp). Descriptive statistics for all the measured variables were reported and paired sample *t*-test were used to analyse differences between the means of the weekday and weekend measures. Linear mixed models were constructed with the exposure as an independent variable and the outcome as dependent variable according to the dataset. Age, sex and GMFCS-level were included as co-variates in all analyses. Diagonal covariance structure was used to adjust for repeated measurements and a random intercept was selected. Unstandardized beta regression coefficients (β), *p*-value, and confidence intervals were reported. Level of significance was set at $\alpha = 0.05$, the confidence level for the intervals was 95%.

Results

Participant characteristics

Sixty-three children were recruited, three withdrew from inclusion before the start of the measurement, of whom one parent found it too stressful for their child, one due to sickness and one gave no reason. Hence, 60 children enrolled in this study, of whom one ended the measurement early due to discomfort during sleep, five did not wear both ActiGraphs due to discomfort and three were excluded based on missing sleep-data. In total, 51 participants were included for further analyses. Sample characteristics are presented in Table 1. Average (±SD) wear-time of the waist-worn ActiGraph over the whole sample was 12.3 (±0.9) hours per day for an average of 6.8 (±1.0) days. Average number of monitoring days for the wrist-worn ActiGraph for the sample was 6.6 (±0.5) days. Overall means for physical activity, sedentary, and sleep outcomes are shown in Table 2. No significant differences were found between weekdays and weekends for all measures.

Associations between physical activity/sedentary time and subsequent sleep

Table 3 shows the associations between physical activity the preceding day and sleep the following night. Overall, sedentary time was significantly positively associated with SE and TST. More specifically, for each unit increase in SED, SE increased by 0.015 SD units and TST by 0.134 units. Hence, a 60-min increase in SED is associated with a 0.9% increase in SE, and an 8-min increase in TST. Physical activity variables were negatively associated with SE and TST, such that for every unit increase in LPA and MVPA, SE decreased by 0.016 and 0.049 units, respectively, and TST decreased by 0.157 and 0.341 units, respectively. Therefore, for every 60-min increase in LPA and 30 min increase in MVPA, SE decreased by 1.0% and 1.5%, and TST decreased by 9 min and 10 min, respectively. Activity outcomes were not associated with TBT and SOL. Similar trends were observed for accelerometer count outcomes (VMCPM and VCPM). When analyses were split by weekday and weekends, SED, MVPA, VMCPM, and VCPM all demonstrated similar associations with SE and TST, while only SED and LPA were associated with TST on weekends.

Associations between sleep and physical activity/sedentary time

Table 4 shows the associations between sleep the preceding night and physical activity/sedentary time the following day. Overall, SE was significantly positively associated with SED and negatively with MVPA, VMCPM, and VCPM. That is, for every 5% increase in SE, SED increased by 7 min, and MVPA, VMCPM, and VCPM decreased by 3 min, 46 counts, and 26 counts, respectively. TST was significantly associated with all activity variables, wherein every 30-min increase in TST was associated with a 7-min increase in SED, and a decrease in LPA (-5 min), MVPA (-2 min), VMCPM (-39 counts), and VCPM (-20 counts). Furthermore, an increase in TBT

Table 1. Participants characteristics.

N = 51			
		Mean	SD
		6.8	2.6
Age (years)		N	%
Boys		29	56.9
Girls		22	43.1
GMFCS 1		30	58.8
GMFCS 2		12	23.5
GMFCS 3		9	17.6
General sleep questionnaire			
Reported sleep problems	Yes	11	21.6
	No	38	74.5
	N/A	2	3.9
Reported use of sleep medication or -aids	Yes	3	5.9
	No	46	90.2
	N/A	2	3.9
Generally satisfied with child's sleep	Never	2	3.9
	Sometimes	7	13.7
	Often	40	78.4
	N/A	2	3.9

GMFCS: gross motor function classification system; N/A: not answered.

Table 2. Means of physical activity, sedentary time, and sleep measures.

	All		Week		Weekend		
N = 51	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	p-value
SED (min/12h day)	439.6 (70.0)	216.9–673.4	440.8 (70.4)	258.5–668.7	432.7 (83.8)	216.9–673.4	0.686
LPA (min/12h day)	241.9 (56.8)	46.4–441.4	241.9 (58.0)	49.3–409.8	241.9 (68.6)	46.4–441.4	1.000
MVPA (min/12h day)	38.4 (18.9)	0.25–100.6	37.3 (18.9)	0.25–97.4	40.5 (23.8)	0.26–100.62	0.173
VM (counts/min)	987.7 (324.3)	104.1–1995.2	979.4 (328.4)	104.1–1762.3	1001.2 (376.8)	110.0–1995.2	0.499
V (counts/min)	455.6 (165.4)	41.7–1204.0	444.8 (167.4)	44.7–1204	476.9 (201.2)	41.7–1126.7	0.096
SE (%)	82.4 (5.9)	48.4–97.7	82.5 (6.0)	48.4–97.7	82.2 (7.1)	61.6–96.6	0.554
SOL (min)	19.3 (12.9)	0–114	20.4 (14.3)	0–114	17.1 (14.3)	0–98	0.066
TBT (min)	659.2 (46.0)	465–849	657.9 (44.5)	530–791	660.9 (63.9)	456-849	0.638
TST (min)	542.6 (50.4)	295–742	542.4 (50.3)	295–727	541.9 (62.6)	385-742	0.926

SED: sedentary time; LPA: light physical activity; MVPA: moderate-to-vigorous physical activity; VM: vector magnitude; V: vertical axis, SE: sleep efficiency, SOL: sleep onset latency; TBT: total in bed time, TST: total sleep time. *p*-value represents the significance level for the difference between week and weekend.

Table 3. Associations between physical activity the preceding day and sleep the following night.

PA/SED → Sleep			ALL (*N* = 51)		Week (*N* = 51)		Weekend (*N* = 51)	
			β (95% CI)	*p*-value	β (95% CI)	*p*-value	β (95% CI)	*p*-value
SED	>	SE	0.015 (0.003, 0.027)	**0.014**	0.016 (0.002, 0.030)	**0.025**	0.011 (−0.012, 0.033)	0.349
		SOL	0.006 (−0.023, 0.034)	0.694	0.002 (−0.034, 0.037)	0.915	−0.020 (−0.060, 0.021)	0.333
		TBT	0.014 (−0.056, 0.085)	0.689	0.013 (−0.060, 0.087)	0.718	0.035 (−0.121, 0.192)	0.654
		TST	0.134 (0.044, 0.223)	**0.004**	0.119 (0.015, 0.223)	**0.025**	0.183 (0.009, 0.357)	**0.040**
LPA	>	SE	−0.016 (−0.030, −0.001)	**0.041**	−0.017 (−0.034, 0.001)	0.063	−0.012 (−0.042, 0.017)	0.409
		SOL	−0.005 (−0.042, 0.031)	0.772	−0.005 (−0.049, 0.039)	0.822	0.027 (−0.027, 0.080)	0.327
		TBT	−0.035 (−0.124, 0.055)	0.449	−0.032 (−0.124, 0.060)	0.498	−0.068 (−0.277, 0.141)	0.517
		TST	−0.157 (−0.271, −0.043)	**0.007**	−0.128 (−0.259, 0.004)	0.056	−0.274 (−0.500, −0.048)	**0.018**
MVPA	>	SE	−0.049 (−0.085, −0.012)	**0.010**	−0.055 (−0.099, −0.010)	**0.017**	−0.026 (−0.094, 0.042)	0.441
		SOL	−0.022 (−0.107, 0.064)	0.615	0.015 (−0.098, 0.127)	0.796	0.040 (−0.071, 0.151)	0.468
		TBT	0.069 (−0.147, 0.285)	0.531	0.065 (−0.167, 0.296)	0.583	0.016 (−0.441, 0.472)	0.946
		TST	−0.341 (−0.619, −0.063)	**0.016**	−0.384 (−0.713, −0.056)	**0.022**	−0.179 (−0.632, 0.274)	0.434
VMCPM	>	SE	−0.004 (−0.006, −0.001)	**0.002**	−0.005 (−0.008, −0.002)	**0.002**	−0.002 (−0.006, 0.003)	0.487
		SOL	0.000 (−0.006, 0.006)	0.900	0.002 (−0.005, 0.010)	0.547	0.003 (−0.005, 0.011)	0.443
		TBT	−0.005 (−0.019, 0.010)	0.526	−0.001 (−0.017, 0.014)	0.849	−0.014 (−0.047, 0.019)	0.411
		TST	−0.032 (−0.050, −0.013)	**0.001**	−0.034 (−0.055, −0.012)	**0.002**	−0.025 (−0.060, 0.010)	0.156
VCPM	>	SE	−0.006 (−0.010, −0.002)	**0.007**	−0.007 (−0.012, −0.002)	**0.007**	−0.002 (−0.010, 0.007)	0.645
		SOL	0.000 (−0.010, 0.010)	0.986	0.006 (−0.007, 0.018)	0.372	0.005 (−0.007, 0.018)	0.384
		TBT	0.003 (−0.022, 0.028)	0.795	0.006 (-–.020, 0.032)	0.667	−0.013 (−0.074, 0.048)	0.647
		TST	−0.042 (−0.074, −0.010)	**0.011**	−0.045 (−0.083, −0.008)	**0.018**	−0.025 (−0.080, 0.030)	0.368

SE: sleep efficiency; SOL: sleep onset latency, TBT: Total in Bed Time; TST: Total Sleep Time, SED = sedentary time; LPA = light physical activity, MVPA: moderate-to-vigorous activity, VMCPM: vector magnitude average counts per minute, VCPM: vertical axis average counts per minute. SED, LPA & MVPA are standardized to 12 h per day. Significant *p*-values are highlighted in bold.
All models were adjusted for age, sex, GMFCS-level.

was associated with a decrease in LPA. That is, for every 30 min of increase in TBT, LPA decreased by 4 min. SE was still associated with MVPA, VMCPM, and VCPM, but not SED when controlling for the type of day (weekday/weekend). TST had similar associations with all activity variables during weekends compared to the overall associations, but only with MVPA, VMCPM an VCPM on weekdays. No associations between TBT and activity variables during weekdays were found; however, during weekends TBT was positively associated with SED and negatively with LPA. No relationship was found between SOL and physical activity or SED.

Discussion

The current study was the first to examine the temporal and bi-directional associations between daily physical activity, sedentary behaviour, and nightly sleep in ambulatory children with CP using device-based methods. Results show that higher physical activity levels and more sedentary time are significantly negatively associated with TST and SE, and that higher SE and TST are significantly negatively associated with physical activity and significantly positively associated with sedentary time.

These outcomes are not consistent with our hypotheses and the positive relationship between physical activity, sedentary behavior, and sleep that have previously been found in children who are typically developing [16]. A review by Simard-Tremblay et al. [32] showed that health factors, such as active epilepsy and visual impairment, that are prevalent in children with CP can have a negative effect on sleep. The review also highlighted behavioural and environmental actions (e.g., bedtime routine, parent education) that can influence sleep. These factors were not investigated in the current study. The outcomes of the current study may not support earlier research that recommends higher physical activity levels as an intervention to improve sleep. This does, however not mean that we should stop promoting physical activity and reducing sedentary time in this population to prevent health issues, to maintain mobility, and have a balanced interplay between the activity behaviours throughout the whole day [22].

Furthermore, a commonly reported behavioural problem that can negatively affect sleep in children with CP is hyperactivity and emotional dysregulation [13,33–35]. While the relationship between sleep and sensory processing disorders has not been studied in children with CP, it has been shown to affect sleep negatively in children with autism spectrum disorder [36]. On its

Table 4. Associations between sleep the preceding night and physical activity the following day.

			Sleep → PA/SED					
			All (N = 51)		*Week (N = 51)*		*Weekend (N = 51)*	
			β (95% CI)	*p*-value	β (95% CI)	*p*-value	β (95% CI)	*p*-value
SE	>	SED	1.410 (0.330, 2.489)	**0.011**	1.038 (−0.216, 2.292)	0.104	1.763 (−0.156, 3.682)	0.071
		LPA	−0.861 (−1.729, 0.006)	0.052	−0.641 (−1.661, 0.379)	0.217	−1.102 (−2.590, 0.387)	0.144
		MVPA	−0.569 (−0.894, −0.244)	**<0.001**	−0.474 (−0.850, −0.097)	**0.014**	−0.786 (−1.416, −0.156)	**0.015**
		VMCPM	−9.102 (−14.126, −4.078)	**<0.001**	−7.323 (−13.277, −1.370)	**0.016**	−11.067 (−20.606, −1.528)	**0.024**
		VCPM	−5.176 (−7.945, −2.407)	**<0.001**	−4.491 (−7.726, −1.256)	**0.007**	−6.240 (−11.469, −1.010)	**0.020**
SOL	>	SED	−0.099 (−0.551, 0.352)	0.665	−0.026 (−0.518, 0.466)	0.918	−0.128 (−1.086, 0.829)	0.789
		LPA	0.061 (−0.299, 0.421)	0.739	−0.037 (−0.436, 0.363)	0.856	0.234 (−0.512, 0.980)	0.532
		MVPA	0.052 (−0.087, 0.191)	0.460	0.049 (−0.098, 0.195)	0.514	0.083 (−0.218, 0.383)	0.583
		VMCPM	1.035 (−1.091, 3.161)	0.339	0.752 (−1.573, 3.076)	0.524	2.374 (−2.216, 6.963)	0.304
		VCPM	0.920 (−0.258, 2.098)	0.125	0.745 (−0.522, 2.011)	0.247	1.717 (−0.861, 4.295)	0.187
TBT	>	SED	0.139 (−0.035, 0.313)	0.116	0.003 (−0.231, 0.237)	0.980	0.301 (0.059, 0.544)	**0.015**
		LPA	−0.140 (−0.278, −0.003)	**0.046**	−0.008 (−0.196, 0.180)	0.935	−0.269 (−0.453, −0.085)	**0.005**
		MVPA	0.003 (−0.052, 0.057)	0.924	0.018 (−0.055, 0.091)	0.632	−0.016 (−0.095, 0.063)	0.687
		VMCPM	−0.445 (−1.261, 0.371)	0.283	0.162 (−0.690, 1.013)	0.708	−0.915 (−2.097, 0.268)	0.128
		VCPM	−0.116 (−0.581, 0.349)	0.623	0.235 (−0.397, 0.866)	0.464	−0.527 (−1.210, 0.157)	0.129
TST	>	SED	0.234 (0.093, 0.375)	**0.001**	0.114 (−0.053, 0.282)	0.179	0.423 (0.202, 0.644)	**<0.001**
		LPA	−0.169 (−0.281, −0.056)	**0.004**	−0.066 (−0.201, 0.069)	0.338	−0.338 (−0.509, −0.167)	**<0.001**
		MVPA	−0.068 (−0.111, −0.024)	**0.002**	−0.053 (−0.105, −0.002)	**0.042**	−0.091 (−0.166, −0.017)	**0.018**
		VMCPM	−1.285 (−1.943, −0.627)	**<0.001**	−0.860 (−1.650, −0.069)	**0.033**	−1.987 (−3.096, −0.878)	**<0.001**
		VCPM	−0.675 (−1.042, −0.308)	**<0.001**	−0.465 (−0.909, −0.022)	**0.040**	−1.051 (−1.670, −0.432)	**0.001**

SE: sleep efficiency; SOL: sleep onset latency; TBT: total in bed time; TST: total sleep time; SED: sedentary time; LPA: light physical activity; MVPA: moderate-to-vigorous activity; VMCPM = vector magnitude average counts per minute; VCPM: vertical axis average counts per minute. SED, LPA & MVPA are standardized to 12 h per day. Significant *p*-values are highlighted in bold.
All models were adjusted for age, sex, GMFCS-level.

turn, it is plausible that accelerometer-based measures of physical activity capture both planned/structured activities as well as movement that reflects hyperactivity/restlessness and therefore overestimates physical activity during measurements. This may represent an interesting avenue for future investigation when using actigraphy in children with CP.

Strengths of this study were the use of device-based measures to quantify sleep, physical activity, and sedentary behaviour. In addition, the analyses were adjusted for accelerometer wear-time and individual co-variates including sex, age and GMFCS level. Nevertheless, our findings should be interpreted with some limitations in mind. A small convenience sample was used, more children with CP should be included to be able to control for more covariates (e.g., type of CP, co-morbidity, BMI, contextual factors, including parental behaviour and social conditions) that might affect physical activity and/or sleep but still be able to analyse intra-individual and temporal associations. Also, while accelerometers provide robust measures of movement behaviours, the use of a sleep diary to identify SOL and TBT is subjective. Even though there is some evidence in support of the validity of using actigraphy for sleep assessment in children with CP, it is possible that the used Sadeh algorithm underestimates wake time and overestimates sleep time [29–31]. However, it is important to note that the Sadeh algorithm is commonly used in youth who are typically developing, including those with sleep disturbances [37]. Moreover, the devices were removed during water activities therefore sports like swimming were not captured (noted in 14 participants). Additionally, reported confidence intervals were wide and should be interpreted with caution due to small sample sizes relative to the number of included covariates used in the linear mixed models.

Even though significant relationships were found, results should be interpreted with care as this was the first study to examine the temporal relationships of sleep and physical activity across the 24-h continuum in children with CP. Key limitations were the cross-sectional nature of the study and the small sample size. Moreover, we did not collect data on other factors such as co-morbidity and contextual factors. Guided by our findings on the relationship between sleep and physical activity in ambulatory children with CP using device-based measures, further studies on the temporal relation between sleep and physical activities should have a longitudinal design with a larger sample size to be able to investigate the contribution of pre-determined and relevant social and behavioural factors. Moreover, a method to distinguish between physical activity and movements due to restlessness and hyperactivity in this population needs to be explored.

Conclusion

Our findings provide insights into the temporal and bi-directional relationships between device-based sleep, physical activity, and sedentary behaviour outcomes in ambulatory children with CP. They show that the assumption that more physical activity would lead to better sleep and vice versa should be further investigated in a larger study with a longitudinal design, as we found that the relationships are complex in nature in children with CP.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was kindly supported by a grant from JKF Kinderfonds and Kinderrevalidatiefonds Adriaanstichting, foundations aimed at improving the quality of life of children and adolescents with physical disabilities in The Netherlands.

ORCID

Anke Gerritsen http://orcid.org/0000-0003-3802-0034
Raquel Y. Hulst http://orcid.org/0000-0002-2674-7511

Ilse M. van Rijssen http://orcid.org/0000-0003-2596-3455
Joyce Obeid http://orcid.org/0000-0002-6209-1505
Sigrid Pillen http://orcid.org/0000-0001-8679-9535
Jan Willem Gorter http://orcid.org/0000-0002-3012-2119
Olaf Verschuren http://orcid.org/0000-0002-4443-5327

References

[1] Oskoui M, Coutinho F, Dykeman J, et al. An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. Dev Med Child Neurol. 2013;55(6):509–519. doi: 10.1111/dmcn.12080.
[2] Rosenbaum P, Paneth N, Leviton A, et al. A report: the definition and classification of cerebral palsy April 2006. Dev Med Child Neurol. 2007;109(suppl 109):8–14.
[3] Maher CA, Williams MT, Olds T, et al. Physical and sedentary activity in adolescents with cerebral palsy. Dev Med Child Neurol. 2007;49(6):450–457. doi: 10.1111/j.1469-8749.2007.00450.x.
[4] Verschuren O, Peterson MD, Balemans AC, et al. Exercise and physical activity recommendations for people with cerebral palsy. Dev Med Child Neurol. 2016;58(8):798–808. doi: 10.1111/dmcn.13053.
[5] Bathory E, Tomopoulos S. Sleep regulation, physiology and development, sleep duration and patterns, and sleep hygiene in infants, toddlers, and preschool-age children. Curr Probl Pediatr Adolesc Health Care. 2017;47(2):29–42. doi: 10.1016/j.cppeds.2016.12.001.
[6] Tremblay MS, LeBlanc AG, Kho ME, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act. 2011;8(1):98. doi: 10.1186/1479-5868-8-98.
[7] Chaput J-P, 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 Metab. 2016;41(6 Suppl 3):S266–S282. doi: 10.1139/apnm-2015-0627.
[8] Saunders TJ, Gray CE, Poitras VJ, et al. Combinations of physical activity, sedentary behaviour and sleep: relationships with health indicators in school-aged children and youth. Appl Physiol Nutr Metab. 2016; 41(6 Suppl 3):S283–S93. doi: 10.1139/apnm-2015-0626.
[9] Horwood L, Mok E, Li P, et al. Prevalence of sleep problems and sleep-related characteristics in preschool-and school-aged children with cerebral palsy. Sleep Med. 2018;50:1–6. doi: 10.1016/j.sleep.2018.05.008.
[10] Newman CJ, O'Regan M, Hensey O. Sleep disorders in children with cerebral palsy. Dev Med Child Neurol. 2006;48(7):564–568. doi: 10.1017/S0012162206001198.
[11] Brossard-Racine M, Hall N, Majnemer A, et al. Behavioural problems in school age children with cerebral palsy. Eur J Paediatr Neurol. 2012;16(1):35–41. doi: 10.1016/j.ejpn.2011.10.001.
[12] Galland BC, Elder DE, Taylor BJ. Interventions with a sleep outcome for children with cerebral palsy or a post-traumatic brain injury: a systematic review. Sleep Med Rev. 2012;16(6):561–573. doi: 10.1016/j.smrv.2012.01.007.
[13] Pavão SL, Rocha NACF. Sensory processing disorders in children with cerebral palsy. Infant Behav Dev. 2017;46:1–6. doi: 10.1016/j.infbeh.2016.10.007.
[14] 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. 2016;41(6 Suppl 3):S311–S327. doi: 10.1139/apnm-2016-0151.
[15] Krietsch KN, Armstrong B, McCrae CS, et al. Temporal associations between sleep and physical activity among overweight/obese youth. J Pediatr Psychol. 2016;41(6):680–691. doi: 10.1093/jpepsy/jsv167.
[16] Huang WY, Ho RST, Tremblay MS, et al. Relationships of physical activity and sedentary behaviour with the previous and subsequent nights' sleep in children and youth: a systematic review and meta-analysis. J Sleep Res. 2021;30(6):e13378. doi: 10.1111/jsr.13378.
[17] Lin Y, Tremblay MS, Katzmarzyk P, et al. Temporal and bi-directional associations between sleep duration and physical activity/sedentary time in children: an international comparison. Prev Med. 2018;111:436–441. doi: 10.1016/j.ypmed.2017.12.006.
[18] Mcneil J, Tremblay MS, Leduc G, et al. Objectively-measured sleep and its association with adiposity and physical activity in a sample of Canadian children. J Sleep Res. 2015;24(2):131–139. doi: 10.1111/jsr.12241.
[19] Verschuren O, Gorter JW, Pritchard-Wiart L. Sleep: an underemphasized aspect of health and development in neurorehabilitation. Early Hum Dev. 2017;113:120–128. doi: 10.1016/j.earlhumdev.2017.07.006.
[20] Brazendale K, Beets MW, Weaver RG, et al. Comparing measures of free-living sleep in school-aged children. Sleep Med. 2019;60:197–201. doi: 10.1016/j.sleep.2019.04.006.
[21] Smit DJ, Zwinkels M, Takken T, et al. Sleep quantity and its relation with physical activity in children with cerebral palsy; insights using actigraphy. J Paediatr Child Health. 2020;56(10):1618–1622. doi: 10.1111/jpc.15055.
[22] Verschuren O, Hulst RY, Voorman J, et al. 24-hour activity for children with cerebral palsy: a clinical practice guide. Dev Med Child Neurol. 2021;63(1):54–59. doi: 10.1111/dmcn.14654.
[23] Evenson KR, Catellier DJ, Gill K, et al. Calibration of two objective measures of physical activity for children. J Sports Sci. 2008;26(14):1557–1565. doi: 10.1080/02640410802334196.
[24] Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Med Sci Sports Exerc. 2005;37(11 Suppl):S523–S530. doi: 10.1249/01.mss.0000185658.28284.ba.
[25] Sadeh A, Sharkey M, Carskadon MA. Activity-based sleep-wake identification: an empirical test of methodological issues. Sleep. 1994;17(3):201–207. doi: 10.1093/sleep/17.3.201.
[26] Trost SG. State of the art reviews: measurement of physical activity in children and adolescents. Am J Lifestyle Med. 2007;1(4):299–314. doi: 10.1177/1559827607301686.
[27] Clanchy KM, Tweedy SM, Boyd RN, et al. Validity of accelerometry in ambulatory children and adolescents with cerebral palsy. Eur J Appl Physiol. 2011;111(12):2951–2959. doi: 10.1007/s00421-011-1915-2.
[28] O'Neil ME, Fragala-Pinkham MA, Forman JL, et al. Measuring reliability and validity of the ActiGraph GT3X accelerometer for children with cerebral palsy: a feasibility study. J Pediatr Rehabil Med. 2014;7(3):233–240. doi: 10.3233/PRM-140292.
[29] Xue B, Licis A, Boyd J, et al. Validation of actigraphy for sleep measurement in children with cerebral palsy. Sleep Med. 2022;90:65–73. doi: 10.1016/j.sleep.2021.12.016.
[30] Meltzer LJ, Montgomery-Downs HE, Insana SP, et al. Use of actigraphy for assessment in pediatric sleep research. Sleep Med Rev. 2012;16(5):463–475. doi: 10.1016/j.smrv.2011.10.002.
[31] Hulst RY, Gorter JW, Obeid J, et al. Accelerometer-measured physical activity, sedentary behavior, and sleep in children with cerebral palsy and their adherence to the 24-hour activity guidelines. Dev Med Child Neurol. 2023;65(3):393–405. doi: 10.1111/dmcn.15338.

[32] Simard-Tremblay E, Constantin E, Gruber R, et al. Sleep in children with cerebral palsy: a review. J Child Neurol. 2011;26(10):1303–1310. doi: 10.1177/0883073811408902.
[33] Horwood L, Li P, Mok E, et al. Behavioral difficulties, sleep problems, and nighttime pain in children with cerebral palsy. Res Dev Disabil. 2019;95:103–500.
[34] O'Brien LM. The neurocognitive effects of sleep disruption in children and adolescents. Sleep Med Clin. 2011;6(1):109–116. doi: 10.1016/j.jsmc.2010.12.007.
[35] Romanos M, Gerlach M, Warnke A, et al. Association of attention-deficit/hyperactivity disorder and atopic eczema modified by sleep disturbance in a large population-based sample. J Epidemiol Community Health. 2010;64(3):269–273. doi: 10.1136/jech.2009.093534.
[36] Reynolds S, Lane SJ, Thacker L. Sensory processing, physiological stress, and sleep behaviors in children with and without autism spectrum disorders. OTJR. 2012;32(1):246–257. doi: 10.3928/15394492-20110513-02.
[37] Meltzer LJ, Walsh CM, Traylor J, et al. Direct comparison of two new actigraphs and polysomnography in children and adolescents. Sleep. 2012;35(1):159–166. doi: 10.5665/sleep.1608.