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Original Article

Criteria for nap identification in infants and young children using 24-h actigraphy and agreement with parental diary

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ABSTRACT

Study Objectives: The study aimed to determine if an automated algorithm, capable of batch scoring, could extract naps and other 24-h sleep–wake variables from actigraphy without the need for parental sleep diaries, which rely heavily on parental awareness of child sleep.
Design: A cross-sectional design was used for the study.
Setting: The study examined healthy infants/children in their home setting.
Participants: A total of 160 infants/children in five age groups (6 months, and 1, 2, 3½ and 5 years) participated in the study.
Measurements and Results: Participants wore actigraphs for 5–7 days, and parents completed sleep diaries over 2 consecutive days. Three criteria were applied to find the minimum sleep time (20, 30 and 40 min) yielding the best nap agreement between diaries and actigraphy for nap/no-nap identification. Best agreements were 72.1% (20 min minimum), 78.4% (20 min), 91.0% (30 min) and 93.3% (30 min) for ages 6 months, 1, 2 and 3½ years, respectively. Kappa statistics classified nap–nap agreement as 'slight' for 6-month data but 'moderate' or 'almost perfect' for older age groups. The number of daytime naps extracted at each age group yielded no significant discrepancies between the methods. Diaries generally returned significantly earlier sleep onset, later sleep offset, longer sleep duration and fewer night wakings at 6 months and 1 and 2 years, but this was not significant at 3½ or 5 years of age.
Conclusions: Minimum age-specific sleep time thresholds are recommended to improve nap identification in actigraphy across infant and toddler age groups. The findings strengthen our confidence in the ability to collect actigraphy data in the absence of parental diaries, in 3½- and 5-year-olds, at least.

1. Introduction

In the first few years of life, changes in children's sleep patterns are characterized by consolidation of overnight sleep and a gradual decrease in daytime naps [1]. The age at which children discontinue naps is generally around 3–5 years [2,3], but culture has a strong influence [4]. Of clinical interest is the evidence that parents of young children struggle with nap issues such as irregular nap schedules [5] and/or negatively perceiving and even purposefully preventing naps [6]. Surprisingly though, parents do not relate daytime napping behaviour with the presence of a sleep problem [7]. Night-time sleep has been suggested to be the more important variable for development [8]. Napping during the day in preschool children has been demonstrated to reduce the drive to sleep at night, reducing nocturnal sleep duration [6,9,10] and resulting in more frequent night wakings [10]. Thus, an interaction between daytime napping and night-time sleep clearly exists, emphasizing the importance of capturing 24-h sleep–wake variables to accurately assess sleep patterns in infants and young children.

An objective measure like actigraphy is ideal for collecting individual and population-level sleep data. Substantial age-independent variability in napping exists within populations [11]. However, within infant and early childhood sleep, identification of daytime naps by actigraphy remains one of the most understudied areas of actigraphy measurement. No actigraphy guidelines exist for daytime naps, and thus non-validated night-time rules have been used [12]. This poses considerable difficulties because accelerometers infer sleep based on the absence of activity rather than being a direct measure of sleep per se. While this poses relatively few difficulties with night-time sleep, when it can be realistically inferred that children are indeed sleeping, it is more problematic during the day, when an absence

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of activity could just as easily be non-wear time. This study has used accelerometry by taking up waist-worn devices to integrate sleep and physical activity measures within that device. Our work has focused on developing a new count-scaled algorithm and MATLAB script that produces outputs demonstrated to enhance the utility and accuracy of both sleep [13] and activity measures [14]. The algorithm was initially developed for use with the Actical device (Mini-Mitter Co., Inc., Bend, OR, USA), the physical activity counterpart of the Actiwatch sleep device, and validated against polysomnography (PSG) within infant nap studies under conditions where sleep was disturbed [13]. The MATLAB script has since been expanded for analyses of both physical activity and sleep over 24 h. The algorithm and programming (software) accommodate automated batch scoring providing a major time advantage over other commercially available software for which sleep filters for each day and for each participant have to be individually entered into the program before scoring.

Use of an automated algorithm negates the need for parent-completed diaries/logs to indicate bedtimes and wake times. These are often unreliable and challenging to obtain, particularly when 24-h sleep–wake diaries are required, and made more difficult by having to adhere to this over several consecutive days [15]. Limitations with regard to accuracy are compromised by parents' perceptions and expectations of their child's sleep (realistic or otherwise) [16,17]. Furthermore, parents may only become aware of sleep times and night waking if the child fails to fall asleep independently and cries out on waking during the night and requires attention.

The aims of this study were (1) to determine if an automated algorithm, capable of batch scoring, could score naps and other 24-h sleep–wake variables from actigraphy without the need for parental sleep diaries and (2) to describe the agreement between 24-h sleep–wake outputs produced by the algorithm compared with that obtained from sleep diaries.

2. Methods

2.1. Participants

The participants were 160 infants and children studied at ages 0.5 years ($n = 39$), 1 year ($n = 31$), 2 years ($n = 30$), 3½ years ($n = 41$) and 5 years ($n = 33$). The study was performed on 14 infants at two time points (2 and 5 years, respectively). All excluding those aged 1 year were a subsample randomly selected each time from a larger pool of participants undergoing actigraphy and diary sleep measurement as part of a randomized controlled trial for the prevention of overweight in infancy [18]. The 1-year data were collected from a separate study targeted to fill this age gap and recruited from a list of parents who enrolled their infant at birth giving consent to be contacted for future research. Infants were excluded if they lived outside the study area, were born before full term (36.5 weeks), or if a congenital abnormality or a physical or intellectual disability likely to affect feeding, physical activity or growth was identified. Demographic information was collected via questionnaire and the New Zealand Deprivation Index was used to determine neighbourhood deprivation based on participants' current address [19]. Meshblocks (small geographical areas containing a median of 87 people) receive deprivation scores between 1 and 10, where 1 indicates an area is one of the 10% least deprived, and 10 indicates an area is one of the 10% most deprived, with this classification based on measures of income, employment, education and access to transportation. Height and weight of the infant/child were measured using standard techniques during clinic or home visits as described previously [18]. Ethical approval was granted from the New Zealand Lower South Regional Ethics Committee (LRS/08/12/063) and the University of Otago Ethics Committee (13/251).

2.2. Actigraphy

All infants/children wore an Actical accelerometer (Mini-Mitter Co., Inc., Bend, OR, USA) for 5–7 days (continuously) fitted on the shin of 6-month and 1 year-old infants, and over the right hip of 2-, 3½- and 5-year-old children. The accelerometers were initialized using 15-s epochs. This epoch length was chosen because of higher accuracy recorded in PSG nap validation studies compared with 30 or 60-s epoch lengths [13]. A valid day was defined as at least 8 h of wear time (while awake), and participants were excluded from the analysis if fewer than 2 valid days of wear were obtained that did not correspond with the diary data [20]. Data were cleaned and scored using an automated script developed in MATLAB (MathWorks, Natick, MA, USA). The programme was initiated using a 'time flag' for sleep onset and sleep offset, approximately half an hour before the average bedtime and wake times for our data set but could be modified accordingly. To detect sleep and wake states the count-scaled algorithm was used, where a weighted sum of the activity in the current minute, the preceding 4 min and the following 2 min was computed and then compared with the sleep–wake threshold of 1 (<1 = sleep). The count-scaled algorithm detects wake 'events' as the last of 15 continuous minutes of sleep followed by 5 min of awake and sleep 'events' as the start of 15 continuous minutes of sleep preceded by 5 min of awake. To detect the bedtime sleep 'event', the programme used the algorithm by first moving forward 3 h to detect the first sleep-onset event. If sleep was not detected in those 3 h, the programme moved 2 h backwards to identify the last sleep-onset event. If a sleep minute was not detected within the 3 h after or 2 h before the time flags, the file was reprocessed using observer-identified time flags. To detect sleep offset (wake event), the programme performs in a similar way but attempts to detect a wake time rather than a sleep time. Non-wear time applies to the period of time between sleep offset (morning wake) and bedtime and was defined as 20 min of consecutive zeros. Standard sleep–wake variables including nap counts and onset and offset were calculated using the automated script within MATLAB. A sleep period was defined as at least 20 min of sleep, preceded by 5 min of awake with the sleep period altered for nap detection as described for nap sleep time thresholds in the next section.

2.3. Sleep diary

Parents were asked to complete a 48-h diary coinciding with 2 consecutive days of actigraphy and starting at 6 am and no earlier than the second day of accelerometry wear. Time was displayed horizontally in 5-min grid blocks. A parent (usually the mother) was asked to indicate by an arrow the time the infant/child went to sleep and awoke, including daytime naps. Grid block counts with sleep and wake coding were then entered into a spreadsheet set up to automatically calculate standard sleep–wake variables including sleep offset and onset times, sleep duration, overnight wakings and number of naps and timing. When the infant/child was in the care of someone other than the parent during the day or night, the parent was instructed to ask the carer to fill out the diary for that period.

2.4. Nap concordance

A nap was assigned a category of '1' and no nap, a category of '0'. Each child at each age group and on each day was assigned an opportunity for a morning nap (starting before 12 pm) and afternoon nap (from 12 pm onwards). Corresponding naps between diary and actigraphy data were searched for and scored as matches if they started within ±30 min of each other and/or overlapped in timing by ≤30 min. If more than one nap occurred in the morning or afternoon, that nap and corresponding data were also scored.