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# Effect of External Motion on Correspondence Between Infant Actigraphy and Maternal Diary

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## Abstract

Correspondence between infant actigraphy and mother-recorded diary differed significantly when receiver-operator function area under the curve, correlation, and logistic regression were calculated with and without excluding periods of external motion. External motion occurred in 40% of recording time and significantly changed activity count per epoch.

### Keywords

Infant; sleep; actigraphy; instrumentation

## Introduction

The purpose of this research was to assess correspondence between actigraphy activity count and mother's diary recording of infant sleep and wake state with and without excluding periods of external motion. Infant sleep is a primary concern among parents and a frequent focus of behavioral research during the first months of life. Small, watch-like actigraphy monitors are relatively unobtrusive and easily employed in the study of infant sleep-wake pattern. Actigraphy monitoring is ideally suited to continuous monitoring in the newborn and young infant's naturalistic home environment (So, Adamson, & Horne, 2007). Additionally actigraphy has been successfully used in the study of hospitalized premature infants (Rivkees, Mayes, Jacobs, & Gross, 2004). Across infant, child, and adult age groups actigraphy is considered an appropriate approach for the study of sleep-wake schedule including circadian rhythm (Sadeh, Hauri, Kripke, & Lavie, 1995). External motion is a common experience for infants, related to either motion generated by another person (caregiver) or inanimate devices such as infant swings and "bouncers". Protocols suggest use of a log or diary to document and control motion and other artifacts in actigraphy records (Littner et al., 2003) however few reports describe the influence of external motion on recordings of infant activity.

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Sadeh and others (Sadeh, Acebo, Seifer, Aytur, & Carskadon, 1995) reported 95.3% overall agreement rate between observation-based sleep-wake scores and actigraphy from 2–2.5 hour recordings among 41 infants less than one year of age. Findings included, however, varied agreement rates across infant states and age, with increased age associated with improved performance. A study of parent diary combined with night time actigraphy in 66 infants (age 7–26 months) demonstrated strong correlation with sleep onset ($r = 0.88$) and sleep duration ($r = 0.74$) although parents' diaries underestimated night time awakenings and overestimated total sleep (Sadeh, 1996). While these and other studies speak to parent diaries collected in conjunction with infant actigraphy, there is little information documenting external motion influencing infant actigraphy and describing incorporation of such factors into analysis. In limited instances of previous research, epochs containing external motion were removed prior to analysis (Gnidovec, Neubauer, & Zidar, 2002; Wulff & Siegmund, 2000). Previous research examining actigraphy usage in infants has focused primarily on night time sleep or short daytime recordings, however there is further need to record infant actigraphy throughout the 24-hour period to portraydaily patterns.

## Methods

### Participants and Setting

Term gestation, singleton, normally developing infants were recruited through postpartum classes and community flyers. Eligibility criteria included uncomplicated pregnancy, vaginal birth, and 2–10 weeks of age. Thirty-one healthy infants completed study procedures in the home environment at mean (SD) postnatal age 55 ± 14 days. The sample included 14 female infants. Racial and ethnic distribution included: African-American, 1; Asian, 7; white, 21; Hispanic, 1. Twenty-eight infants (90%) were breastfed. The age range of 2–10 weeks was chosen because it is the most impressionable period for infant sleep-wake rhythm development (McGraw, Hoffmann, Harker, & Herman, 1999).

### Instruments and Procedure

Infant activity was recorded continuously in 15 second epochs over four to seven sequential 24-hour periods using an omnidirectional accelerometer-based activity monitor (Actiwatch 64, MiniMitter-Respironics, Bend, OR) applied to the infant's ankle. Two separate projects with identical actigraphy protocols (aside from total length of recording) provided data for this reported analysis. Agreement rates > 90% have been demonstrated between this instrument and polysomnography in infants less than 6 months of age (So, Buckley, Adamson, & Horne, 2005). The equipment chosen for this study records a digitally integrated measure of gross motor activity. Degree of motion and occurrence are represented as activity counts per epoch. The monitor specifications include: sensitivity, 0.01g; maximum sampling rate, 32 Hz. A commercially available software, Actiware-Sleep 3.4 (MiniMitter-Respironics, Bend, OR), can be used to score sleep-wake from the activity data. The software uses a validated weighted moving average algorithm (Oakley, 1997) in which activity counts recorded during the measured epoch are smoothed by the activity levels in the surrounding epochs to yield a total activity count. Based on user determined sensitivity threshold, total activity counts for a measured epoch exceed the threshold sensitivity, it is scored as awake; otherwise it is scored as sleep. For the current study, the raw activity counts from the actigraph were used for analysis because the algorithm moving average could not be applied over long periods of external motion. The scoring system also includes a filter that removes steady state acceleration such as riding in a car but does not adjust for other external motion experienced by infants.

Mothers used a diary divided into 15 minute epochs to indicate infant sleep and wake periods in addition to feedings, holding (animate motion), and forms of motion (inanimate motion) experienced by the infant. Parent diaries have been shown to be accurate in terms of schedule-

related events, such as sleep onset and duration, and correlation between actigraphy and diary in one previous study was reported to vary from r = 0.74 – 0.88 (Sadeh et al., 1995).

The study was approved by the institutional review board. Study initiation included obtaining written maternal consent and instruction regarding use of activity monitor and diary. Activity monitors were worn consistently, with brief removal for bathing.

### Analysis

Raw activity counts, originally recorded in 15 second epochs, were aggregated within subject over 15 minute periods to match diary intervals. Aggregation included total activity count and log mean of the count over each 15 minute interval. Animate and inanimate motion codes were combined to represent external motion. Total activity count per 15 minute epoch was compared across subject, including and excluding epochs containing external motion, by paired t-test. Correspondence between actigraphy and diary was examined within subject three ways (biserial correlation, receiver-operator area under the curve, and logistic regression). First the relation between actigraphy mean log value and dichotomous diary code (sleep, wake) was determined using Pearson point biserial correlation. The correlation coefficient summarizes the strength of relation between actigraphy activity count a continuous variable, and sleep-wake state recorded in the diary, a dichotomous variable. Second, area under the curve (AUC) was derived from receiver-operator characteristic function. AUC is a nonparametric omnibus measure of the general strength of the relation between the dichotomous diary sleep-wake states and actigraphy activity counts independent of the metric. Third, logistic regression was used to evaluate the ability to predict sleep-wake status, as recorded in the diary, from actigraphy activity count. Logistic regression parameters included percent of diary intervals correctly predicted. Parameters from each of the three assessments of correspondence, calculated within subject and including or excluding diary intervals containing external motion, were compared across subjects using paired t-test to evaluate the effect of external motion on correspondence between actigraphy and sleep-wake state recorded in the diary.

## Results

The mean percent of recording time involving external motion per subject was 40% (SD 11%). Approximately 75% of external motion involved holding by caregivers with the remaining 25% related to equipment such as infant bouncer, car seat, shopping cart, cradle, stroller, swing, and rocking chair. Sixteen percent of recording time associated with external motion occurred during night time (defined as 2000-0600).

External motion increased activity counts recorded by actigraphy. Total activity count per fifteen minute epoch was higher when periods of external motion were included in the analysis as compared to excluded (mean 2207 ± 568 vs. 2018 ± 599). Further, inclusion of periods of external motion in the analysis revealed higher activity counts during diary-recorded epochs of infant asleep compared with exclusion of external motion (mean 992 ± 403 vs. 803 ± 388).

The comparison of differing approaches to assessing correspondence revealed statistically significant differences when epochs containing motion were either included or excluded in the analysis (Table 1). When motion was excluded correspondence between actigraphy and diary improved. AUC, correlation coefficient, and prediction percent correct increased and additionally the logistic regression coefficient indicated improved predictability.

## Discussion

In this study we examined the effect of external motion on correspondence between actigraphy and diary in infants. Infants spent a considerable portion of each day receiving various forms

of external motion, both holding by caregivers as well as infant equipment. Few previous studies have documented such external motion among young infants. External motion experienced by infants increases activity counts during actigraphy recording. Correspondence between activity counts and diary differed significantly when epochs with external motion were included for analysis. These findings suggest that external motion is a major factor influencing the accuracy of actigraphy in infants and support the view that activity data recorded when infants were exposed to external motion should be excluded from the analysis. Actigraphy, when used as a sleep measure, differentiates sleep and wake based on recorded body movement. The present study is not a validation study as we did not compare actigraphy and polysomnography, the gold standard measure of sleep. However, this is the first study to evaluate the effect of external motion on actigraphy performed in young infants. Previous research has acknowledged the effect of external motion as well as other artifacts by excluding those epochs for analysis (Gnidovec et al., 2002; Wulff et al., 2000). Validation studies of infant actigraphy have typically been conducted over limited sleep periods in a laboratory setting. These studies have shown that actigraphy can appropriately provide activity counts when infants are not experiencing external motion. Use of actigraphy in the natural home environment to capture 24-hour activity and sleep-wake pattern raises questions about the influence of external motion.

Given that external motion is a predominant experience for infants including being held, rocked, and carried by another person, characterization of infant 24-hour sleep pattern using actigraphy should include recognition of the role of external motion. Parent diaries or sleep logs should include means to document holding and other forms of external motion. The extent of the impact of external motion on actigraphy raw activity counts might vary depending on the motion sources. Actigraphy could therefore underestimate sleep or overestimate awake when infants are exposed to external motion. Evidence confirms the need to combine infant actigraphy with diary recording to address the effects of external motion.

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**Table 1**

Comparison (mean (SD)) of within-subject correspondence between infant actigraphy and mother-recorded sleep-wake diary including and excluding external motion (n = 31).

| | External Motion | |
|---|---|---|
| | **Included** | **Excluded** |
| ROC-AUC | 0.844 (0.070) | 0.896 (0.0781)* |
| Pearson point biserial r | 0.470 (0.150) | 0.588 (0.172)* |
| LR-B | 1.091 (0.438) | 1.565 (0.685)* |
| LR-% correct | 77.5 (6.5) | 86.3 (7.9)* |

Note. Based on records ≥ four to seven days in length. ROC-AUC = area under curve from receiver-operator characteristic, LR-B = logistic regression coefficient, LR-% correct = prediction percent correct. The logistic regression coefficient B can be interpreted as a log odds ratio (OR) indicating the chance of correct prediction of diary sleep-wake status from activity count: motion included, mean OR 2.98; motion excluded, mean OR 4.78.

* paired t-test, $p < 0.000$