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Research Article

Validation of Actiwatch for Assessment of Sleep-wake States in Preterm Infants

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S U M M A R Y

Purpose: The purpose of this study was to validate the Actiwatch with behaviorally determined sleep–wake state in preterm infants and to explore the influence of postmenstrual age on the accuracy of Actiwatch.
Methods: A prospective and comparative research design was used. Twenty-four preterm infants with postmenstrual age ranging from 28–38 weeks were studied. The infants were studied for 2 hours between two feedings. Infant's sleep and wake state was measured every 30 seconds using Actiwatch and the Anderson Behavioral State Scale simultaneously.
Results: Actiwatch demonstrated high agreement, sensitivity, and predictivity of sleep state, when validated with the Anderson Behavioral State Scale at the setting of high and automatic activity thresholds, and was not influenced by the infant's postmenstrual age. However, lower specificity and predictivity were found in the wake state, and influenced by postmenstrual age.
Conclusion: Results of this study suggest that high activity thresholds are the most accurate for determining sleep state in preterm infants, and health care professionals must take the limitations into consideration while using the Actiwatch to assess wake states.

Introduction

Sleep-wake patterns of preterm infants reflect the maturity of the central nervous system, and serve as an indicator of behavioral development (Gertner et al., 2002; Holditch- Davis, Belyea, & Edwards, 2005; Soubasi et al., 2009; Wikström et al., 2012). Clinicians also used sleep–wake patterns to detect if the infant is under stress. Many factors could interfere with sleep–wake states. Preterm infants had more active wake state and less quiet sleep when under stressful environment, such as noise and bright light (Bertelle, Sevestre, Laou-Hap, Nagahapitiye, & Sizun, 2007). Infants also would have heightened wake states after a painful procedure (Holsti, Grunau, Oberlander, & Whitfield, 2005). Therefore, to assess sleep-wake patterns can help caregivers better understand preterm infant's responses to the environmental stimulus and pain. Disrupted sleep patterns and frequent night awakenings of preterm infants produce psychological stress in 20–30% of parents (Feldman, 2006; Korja et al., 2008). It is necessary to promote optimum sleep–wake patterns of preterm infants. Therefore, an objective and precise instrument for measuring sleep pattern of preterm infants is required.

Sleep–wake patterns of preterm infants can be measured with observation of behaviors and physiological variables. Those variables include physical activities, breathing patterns and eye movements (Holditch-Davis, Brandon, & Schwartz, 2003). The Anderson Behavioral State Scale (ABSS), developed by Anderson in 1978, is appropriate for assessing preterm infant's sleep patterns (Medoff-Cooper, Bilker, & Kaplan, 2010). However, behavioral observations require direct and continuous observation, and it is liable to cause observer fatigue. Therefore, behavioral observations may only be appropriate for short term use.

Polysomnograph (PSG) and the Actiwatch are two physiological measurements commonly used to assess sleep patterns in adults and children (Hyde et al., 2007). PSG is the gold standard in sleep assessment (So, Buckley, Adamson, & Horne, 2005). However, PSG requires electrodes and monitoring equipment, which is expensive and impractical for long term monitoring, and not feasible for healthcare providers. The Actiwatch uses an accelerometer to

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detect and log wrist movements, known as actigraphy. The actigraphy continuously records the occurrence of limb movements and sums the number of movements for a given period. The small size of the Actiwatch, similar to a wrist watch, allows a noninvasive and continuous measure that can be used for prolonged periods of time in a variety of situations. Compared to PSG, the Actiwatch is more appropriate for long term monitoring of sleep-wake patterns (Hyde et al.; So et al., 2005). Previous studies showed agreement of 87–95% between behavioral observations and the Actiwatch for sleep measurement of term infants after the third month of life (Gnidovec, Neubauer, & Zidar, 2002). As the infant's age increases, agreement increases (Gertner et al., 2002; Gnidovec et al., 2002). Another study (So et al.) also indicated that the overall agreements between Actiwatch and PSG reached 89–94% in infants under 6 months of age.

The sleep–wake patterns of preterm infants are less mature and more poorly developed than those of term infants. In preterm infants, active sleep decreased with postmenstrual age (PMA) while quiet waking, active waking and quiet sleep increased (Holditch-Davis, Scher, Schwartz, & Hudson-Barr, 2004). Preterm infants demonstrate various sleep–wake patterns during the period from birth to term equivalent age. However, validation of the Actiwatch has not been established for preterm infants. Moreover, it is not clear whether the validity of Actiwatch varies by different PMA. Thus, this study aimed to investigate the agreement between Actiwatch and ABSS in assessing sleep–wake patterns of preterm infants. The specific objectives of this study were to investigate (a) the agreement rate between Actiwatch and ABSS in assessing sleep–wake patterns of preterm infants, (b) the sensitivity, the specificity and the predictability of Actiwatch in assessing sleep–wake patterns of preterm infants, and (c) the accuracy of Actiwatch on different PMA groups.

Methods

Study design

A prospective, comparative research design was used. Sleep–wake patterns were assessed during the 2-hour interfeeding intervals using Actiwatch (Mini Mitter Company Inc., Sunriver, OR, USA) and the ABSS.

Setting and sample

A convenience sample of preterm infants was recruited from the neonatal intensive care unit and sick baby room of a medical center in Southern Taiwan. Inclusion criteria were (a) having no neurological problems and (b) being born between 23–37 gestational weeks. Exclusion criteria were (a) severe illness or congenital abnormality, (b) treated with sedatives or (c) restrained. Gertner et al. (2002) indicated a reduction in total sleep time over 32–36 weeks' gestational age. In accordance with this suggestion we grouped the included preterm infants into three groups: PMA less than 32 weeks, PMA between 32 and 36 weeks, and PMA more than 36 weeks. PMA is the corrected age of infants; it is equal to gestational age plus postnatal age. In this study, we used postmenstrual age to reflect the maturation of infants.

According to a previous study (So et al., 2005), the response within each subject group were normally distributed with a standard deviation of 1.3. The difference of means in agreement rate is 2.2. We set the statistical power at 0.8 and the type I error probability at .05. The Power and Sample Size Calculation Software, version 3.0 (Power and Sample Size com., Atlanta, GA , USA), was used to calculate the sample size. Result showed that seven participants for each group were required.

Ethical consideration

The study was approved by the Human Experiment and Ethics Committee. Parental written informed consent was obtained. The following information was verbally explained and also included as part of the consent form: (a) participation was voluntary, (b) the preterm baby would not be individually identified in any way, (c) participation could be discontinued at any time, (d) status of participating in this study would not affect the medical care they received, and (e) the original test data would be reviewed only by the researcher. Consent forms were obtained after the parents had decided participation in the research was in alignment with his or her values and goals.

Instruments

Actiwatch

The Actiwatch was used to record wrist motion of preterm infants during wake and sleep periods. The fundamental scientific principle of the Actiwatch is that a miniature piezo-electric transducer produces a voltage in response to a change in motion. The Actiwatch accelerometer sensitivity is 0.05 g-force; it weighs 16 g, and has a nonvolatile memory of 64 KB. Data from the Actiwatch were coded into sleep and wake in a 30-second epoch using commercially available software (Actiware version 5.0; Mini Mitter Company Inc., Sunriver, OR, USA). The voltage is amplified, digitized and then recorded on the device in nonvolatile memory. Later, the recorded data are transferred to a personal computer and can be subsequently analyzed to quantify activity during intervals characteristic of both wake and sleep. Actiwatch codes all epochs as wake is determined by comparing activity counts for 2 minutes surrounding the epoch. Actiwatch can distinguish sleep from wake using algorithms to quantify the reduced movement associated with sleep (So et al., 2005). If the counts exceed the threshold, the epoch is coded as wake. If it falls below, or is equal to the threshold, the epoch is coded as sleep. The Actiwatch software provided the wake threshold with low, medium, and high mode at activity counts of 20, 40, and 80 respectively. Another threshold of activity counts was the automatic setting mode, the formula was the mean activity counts in active period multiplied by 0.888 per epoch length. Actiwatch and PSG reached 89–94% agreement in infants under 6 months of age (So et al.).

Anderson Behavioral State Scale

The ABSS was adapted from the scale of Pamelee and Stern (as cited in Gill, Behnke, Conlon, McNeely, & Anderson, 1988); it was designed to measure the sleep-wake state of preterm infants using 12 detail behavioral sleep descriptors. Each state is judged by the criteria of body movement, regularity of respiration, openness of eyes, and muscle tension. The behavioral states were assessed as follows: 1 = regular quiet sleep, 2 = irregular quite sleep, 3 = active sleep, 4 = very active sleep, 5 = drowsy, 6 = alert inactivity, 7 = quiet awake, 8 = active, 9 = very active, 10 = fussing, 11 = crying, and 12 = hard crying. Interobserver reliability was reported among two observers (r = .95) for the instrument standardization (Medoff-Cooper, McGrath, & Bilker, 2000). In the current study, infant behavioral states were observed and coded at bedside immediately by one researcher every 30 seconds.

A 5-day program was devoted to train the researcher to assess preterm babies with ABSS. A didactic session was provided by a clinical nurse specialist, who had 10 years of preterm baby experience and had been trained with using ABSS. Assessment techniques and coding methods were demonstrated with videos. Case presentations and follow-up discussion were used to illustrate assessment techniques and correct coding responses. Assessment results of ABSS from the nurse specialist served as the gold standard, and the results of ABSS from the researcher were compared with those of the nurse specialist. Practices of ABSS assessment continued until the agreement between the research and the clinical nurse specialist reached 90% agreement.

For assessing the inter-rater and intra-rater reliability, infants were videotaped simultaneously. Data of three preterm infants (6 hours) were randomly selected from each of the three PMA groups. The inter-rater agreement between the researcher and another trained researcher was 93.1%, and the intra-rater reliability agreement was 92.8%.

Data collection

The study involved coding of sleep–wake state using behavioral observations and the use of Actiwatch for 2 hours between two feedings. Prior to the placement of the Actiwatch, the time on the Actiwatch was synchronized to the time on the video recording. The Actiwatch was placed in a self-designed soft bandage and positioned on the infant's right wrist. Infant's sleep and wake state was measured continuously using Actiwatch and the ABSS simultaneously.

Data analysis

Data of behavioral observations and Actiwatch were reduced to binary form (0 = wake state, 1 = sleep state). The ABSS was categorized to sleep (state 1–4) and wake (state 5–12) states. Analysis of sleep–wake state was carried out by the researcher blinded to the knowledge of Actiwatch data.

The agreement rate, sensitivity, specificity, positive predictive value of sleep (PPVS), and positive predictive value of wake (PPVW) were analyzed using SPSS (Version 15.0; SPSS Inc., Chicago, IL, USA) software. Agreement rate was defined as the proportion of concordant codes of ABSS and Actiwatch both sleep and wake. Sensitivity was the ability that the Actiwatch measured true sleep state, counted as the number of epochs that the Actiwatch correctly coded as sleep divided by the total number of sleep epochs as coded by the ABSS. Specificity was the ability that the Actiwatch measured true wake state, counted as the number of epochs that the Actiwatch correctly coded as wake divided by the total number of wake epochs as coded by the ABSS. PPVS was calculated as the concordant number of sleep coded by ABSS and Actiwatch divided by the total number that the Actiwatch coded as sleep. PPVW was calculated as the concordant number of wake coded by ABSS and Actiwatch divided by the total number that the Actiwatch coded as wake.

One way analysis of variance was used to compare differences of the agreement rate, the sensitivity, the specificity, PPVS, and PPVW of the Actiwatch between three levels of thresholds and between three groups of postmenstrual age. Bonferroni adjustment was the choice of method for post hoc analysis. Bonferroni test could control the familywise error by correcting the level of significance for each test (Field, 2009).

Results

General characteristics of preterm infants

The sample comprised 24 preterm infants, 12 each for male and female. The studied infants were born with an average gestational age of 31.4 weeks (SD = 3.6), mean birth weight of 1,433 g (SD = 590), and the median of Apgar scores were 8 (range 3–9) and 9 (range 6–10) at 1 and 5 minutes after birth, respectively. The gestation age at time of study was 34.6 weeks (SD = 2.6). Seven infants (29.2%) were of 28–31 weeks of PMA, nine infants (37.5%) were of 32–35 weeks, and eight infants (33.3%) were of 36–38 weeks (Table 1).

Sleep–wake states using Actiwatch and ABSS

A total of 6,547 records, average 272.79 records for each infant were collected. With ABSS, 4,957 (75.7%) sleep states and 1,590 (24.3%) wake states were identified. Table 2 presents the sleep and wake states measured with ABSS and Actiwatch at different activity thresholds.

Agreement, sensitivity, specificity, and positive predictive value of sleep and wake state

Table 3 demonstrates the accuracy of Actiwatch as validated with the ABSS. Agreement rate between Actiwatch and ABSS ranged from 68.23% to 81.30%. Significant difference in agreement rate was found among four different thresholds. The Bonferroni adjustment post hoc comparison revealed that agreement rate at the automatic and the high activity threshold were significantly higher than that at the low activity threshold ($p < .001$).

The sensitivity ranged from 70.96% to 96.82% when sleep states were assessed using Actiwatch. Significant differences in sensitivity were found among different thresholds. The Bonferroni adjustment post hoc comparison revealed that sensitivity at the automatic setting was significantly higher than that at the medium and low activity thresholds ($p < .001$). Sensitivity of the high activity threshold was also significantly higher than that at the low activity threshold ($p < .001$).

The specificity ranged from 28.83% to 60.02% when Actiwatch was used to distinguish the wake state. Significant difference in specificity was found among different thresholds. The Bonferroni adjustment post hoc comparison revealed that specificity at the low activity threshold was significantly higher than that at the automatic activity threshold ($p < .001$).

Actiwatch revealed high and similar positive predictive value for sleep at all four activity threshold values, ranging from 81.18% to 85.34%. No significant difference in PPVS was noted among different activity thresholds. Positive predictive value for wake state ranged from 40.88% to 66.17%. Significant difference in PPVW was found among different thresholds. The Bonferroni adjustment post hoc comparison revealed that PPVW at the automatic activity threshold was significantly higher than that at the low activity threshold ($p < .05$).

Accuracy of Actiwatch on different PMA groups

There was no significant difference in AR, sensitivity, PPVS and PPVW at all thresholds among the three PMA groups. However,

Table 1 *General Characteristics of Preterm Infants (N = 24).*

Characteristics	$M \pm SD$ or median or n (%)	Maximum	Minimum
Gestational age at birth (week)	31.4 ± 3.6	36.7	23.7
Birth weight (g)	1,433 ± 590	2,615	660
Apgar score (at 1st minute)	8 (median)	9	3
Apgar score (at 5th minute)	9 (median)	10	6
Body weight (g)	1,696 ± 470	2,604	825
Postmenstrual age (week)	34.6 ± 2.6	38.0	29.9
28–31	7 (29.2)		
32–35	9 (37.5)		
36–38	8 (33.3)		
Sex			
Male	12 (50)		
Female	12 (50)		

Table 2 *Sleep–wake States Using Actiwatch and ABSS (total observations N = 6,547).*

Threshold (No. of counts of activity)			ABSS	
			Sleep	Wake
			n (%)	*n* (%)
Actiwatch	Low (20)	Sleep	3,641 (55.6)	618 (9.4)
		Wake	1,316 (20.1)	972 (14.8)
	Medium (40)	Sleep	4,113 (62.8)	675 (10.3)
		Wake	844 (12.9)	915 (14.0)
	High (80)	Sleep	4,461 (68.1)	805 (12.3)
		Wake	496 (7.6)	785 (12.0)
	Automatic	Sleep	4,825 (73.7)	1,094 (16.7)
		Wake	132 (2.0)	496 (7.6)

Note. ABSS = Anderson Behavioral State Scale.

significant differences in specificity were found at the low and medium activity thresholds among the three PMA groups. The Bonferroni adjustment post hoc comparison revealed that the specificity of Actiwatch in PMA 32–35 weeks and 36–38 weeks were significantly higher than that of 28–31 weeks at the low and medium activity thresholds ($p < .001$). Table 4 presents the accuracy of Actiwatch on different PMA groups.

Discussion

Accuracy of Actiwatch

The current study revealed that Actiwatch, validated with ABSS, achieved high AR at the setting of high and automatic activity thresholds. However, the low activity threshold demonstrated lower agreement rate. This finding is similar to that of a previous study (So et al., 2005) which investigated the agreement rate between Actiwatch and polysomnography in infants up to 6 months of age and found high agreement rates with the automatic and the high activity threshold. The results indicated that the automatic and the high activity threshold are more appropriate for assessing sleep and wake states in preterm infants than the other settings.

PPVS were high in all threshold settings; all were above 80%, and were not differed from threshold settings. The Actiwatch demonstrated high sensitivities for sleep state at high and automatic activity thresholds, but not at the low threshold, which were also similar to results from previous studies (Hyde et al., 2007; So et al., 2005). This finding might be related to the relatively more active sleep states of preterm infants which has slight limb movement and is easy to be misinterpreted as a wake state at the low activity threshold. Unlike ABSS, Actiwatch cannot discriminate different sleep phases based on eye movement, facial expression, respiration and activity of extremities. When ABSS coded as active sleep and very active sleep states, Actiwatch may indicate wake. Therefore, setting an appropriate activity threshold setting is crucial when using Actiwatch in the assessment of sleep in preterm infants. The automatic and high activity thresholds of Actiwatch had the optimal results of measuring sleep state in preterm infants.

This study showed low specificity of wake state and low PPVW. These findings echoed results from previous studies with infants up to 6 months of age (Gnidovec et al., 2002; So et al., 2005) and in children (Hyde et al., 2007; Insana, Gozal, & Montgomery-Downs, 2010; Sadeh, Acebo, Seifer, Aytur, & Carskadon, 1995). This finding could have been because Actiwatch could not differentiate the quiet wake state, such as drowsy, alert inactivity and quiet awake in preterm infants. Actiwatch might misinterpret these active states as sleep state, which further resulted in low specificity and PPVW. Furthermore, the majority of the state of the preterm infants in this study was sleep state (75.7%) and only 24.3% was in the wake state. These findings were consistent with that of a previous study (Graven & Browne, 2008), which showed that the amount of sleep accounted for 70% of the sleep–wake pattern in preterm infants up to 37 weeks. The relatively low percentage of wake states in the preterm infants might also cause low specificity and PPVW.

The automatic thresholds and the low thresholds presented contrary results on specificity and PPVW on the wake pattern of preterm infants. While automatic thresholds of Actiwatch had better PPVW, the low thresholds had better specificity. Compared to automatic and low thresholds, the medium and high threshold can obtain relatively reliable specificity and PPVW. Therefore, medium and high thresholds could be better choices of thresholds for measuring wake state in preterm infants.

Accuracy of Actiwatch on different PMA groups

This study showed no significant difference in agreement rate at any thresholds among the three study groups. In contrast to previous studies, our result indicated no difference in agreement rate among the different PMA groups. Previous studies investigated infants up to 6 months of age, and found better accuracy of Actiwatch with older infants (Gnidovec et al., 2002; So, Adamson, & Horne, 2007). Age differences may play a role in the discrepancy of results from this study. The study of Gnidovec et al. indicated that the agreement rate of Actiwatch in infants aged 1 month, 3 months, and 6 months were 72.0%, 87%, and 95.0%, respectively. The maturity of sleep–wake patterns varied among these infants, resulting in inconsistency in agreement rate. However, infants of

Table 3 *Results of Actiwatch Validating with ABSS at Different Activity Thresholds (total observations N = 6,547).*

Variables	Threshold value ($M \pm SD$)				F[a] (post hoc)[b]
	(1) Low	(2) Medium	(3) High	(4) Automatic	
AR	68.23 ± 10.65	75.42 ± 10.05	79.29 ± 11.20	81.30 ± 11.83	6.65** (3) > (1), (4) > (1)
Sensitivity	70.96 ± 18.93	80.93 ± 13.97	88.49 ± 11.08	96.82 ± 3.85	16.84** (3) > (1), (4) > (1), (4) > (2)
Specificity	60.02 ± 19.53	51.18 ± 17.44	45.60 ± 10.59	28.83 ± 3.74	5.30** (1) > (4)
PPVS	85.34 ± 14.21	85.34 ± 13.04	84.25 ± 13.45	81.18 ± 13.74	0.50
PPVW	40.88 ± 19.34	45.76 ± 19.62	56.40 ± 14.35	66.17 ± 16.65	2.87* (4) > (1)

Note. AR = agreement rate; PPVS = positive predictive value for sleep; PPVW = positive predictive value for wake.
* $p < .05$. ** $p < .001$.
[a] Results of one way analysis of variance.
[b] Results of least significant difference post hoc analysis.

Table 4 *Accuracy of Actiwatch on Different PMA Groups (total observations N = 6,547).*

Variables	(1) 28–31 weeks *M* ± *SD*	(2) 32–36 weeks *M* ± *SD*	(3) 36–38 weeks *M* ± *SD*	*F*[a] (post hoc)[b]
AR				
Low	70.78 ± 8.34	66.43 ± 11.59	68.02 ± 12.21	0.31
Medium	77.95 ± 7.61	73.19 ± 12.36	75.71 ± 9.73	0.43
High	80.45 ± 8.76	77.68 ± 14.17	80.10 ± 10.57	0.14
Automatic	84.46 ± 10.08	76.05 ± 13.44	84.44 ± 10.46	1.48
Sensitivity				
Low	78.53 ± 9.89	70.56 ± 18.4	64.79 ± 14.60	0.99
Medium	88.37 ± 7.00	78.73 ± 11.43	76.89 ± 19.22	1.50
High	92.83 ± 9.42	87.59 ± 8.86	85.70 ± 14.44	0.81
Automatic	97.61 ± 2.18	95.56 ± 5.40	97.54 ± 2.83	0.76
Specificity				
Low	33.91 ± 13.77	72.87 ± 16.54	68.41 ± 14.52	5.41* (2) > (1), (3) > (1)
Medium	24.60 ± 12.10	65.79 ± 15.56	58.00 ± 18.83	7.54** (2) > (1), (3) > (1)
High	29.06 ± 12.60	59.74 ± 17.98	44.18 ± 17.13	2.20
Automatic	12.20 ± 9.46	34.01 ± 11.64	37.54 ± 19.03	2.87
PPVS				
Low	86.56 ± 10.31	82.77 ± 17.86	87.18 ± 13.93	0.22
Medium	85.99 ± 10.58	82.61 ± 17.25	87.84 ± 10.27	0.33
High	85.87 ± 10.80	81.40 ± 17.31	86.05 ± 11.63	0.31
Automatic	85.45 ± 11.27	75.20 ± 15.70	84.15 ± 12.45	1.43
PPVW				
Low	26.64 ± 13.00	57.17 ± 11.55	35.03 ± 15.58	2.73
Medium	35.01 ± 18.73	59.56 ± 19.97	39.64 ± 17.30	1.71
High	44.89 ± 12.14	65.48 ± 10.70	56.28 ± 12.24	0.69
Automatic	49.16 ± 15.17	84.49 ± 21.15	60.44 ± 17.34	2.18

Note. PMA = postmenstrual age; AR = agreement rate; PPVS = positive predictive value for sleep; PPVW = positive predictive value for wake.
**p* < .05. ***p* < .01.
[a] Results of one way analysis of variance.
[b] Results of Bonferroni adjustment for post hoc analysis.

this study aged 29–38 weeks of PMA, an age with less mature and stable in the sleep–wake patterns. Thus, they might have been too young to distinguish sleep–wake states. This study showed that the AR ranged from 66.43% to 84.46% at all thresholds in the three study groups; these findings were different from those of Gnidovec el al., in which the agreement rate of 1-month infants was lower than those of 3 months and 6 months. Therefore, these findings suggest high accuracy can be expected when Actiwatch is used in infants with mature and stable sleep-wake patterns. Yet, decrease in accuracy may be found in infants whose sleep–wake patterns are not well developed.

Our study showed there were no significant differences in high sensitivity and PPVS in any of the thresholds among the three PMA groups. These findings were consistent with those of previous studies (Hyde et al., 2007), which indicated the PPVS and sensitivity were all high in those aged between 1 and 12 years. Infants of this study with an age of 29–38 weeks of PMA were still showing high sensitivity and PPVS. Therefore, the Actiwatch may be a useful tool in pediatric sleep assessment.

This study showed no significant difference in PPVW in any of the thresholds among the three PMA groups. However, the low and the medium activity thresholds recorded significantly lower specificity than the automatic threshold did when Actiwatch was used in PMA of 28–31 weeks. This finding might be related to the more active sleep states in preterm infants younger than 32 weeks of PMA. When set at the low and the medium activity thresholds, the Actiwatch easily misinterpreted active sleep states as wake states. Therefore, researchers should avoid using low or medium activity threshold setting to detect wake state in preterm infants younger than 32 weeks of PMA.

Sleep–wake patterns of preterm infants have been found to be a crucial factor of developmental outcomes (Gertner et al., 2002; Holditch-Davis et al., 2005). However, delays in structural and functional brain development during the 40th week of postmenstrual age have been observed in preterm infants. Previous studies revealed that the sleep–wake pattern can be regulated by various interventions (Bhat et al., 2006; Rivkees, Mayes, Jacobs, & Gross, 2004). In order to reveal the development of the brain and the effect of intervention, an objective and precise instrument for measuring sleep pattern of preterm infants is required. This study showed that Actiwatch demonstrated high agreement, sensitivity, and predictivity of sleep state, validated with the ABSS at the setting of high and automatic activity thresholds, and was not influenced by the infant's PMA. However, better specificity and better predictivity of wake state were found in medium and high threshold settings, and not influenced by the PMA. Furthermore, the Actiwatch is noninvasive and allows for the continuous measurement of sleep state in a variety of situations. Therefore Actiwatch is a suitable instrument for assessing premature infants' sleep–wake states. Based on the result of the current study, setting at the high activity threshold is more appropriate for assessing sleep–wake states in preterm infants.

There are several limitations in this study. First, the Actiwatch was unable to differentiate either quiet wake and sleep or active sleep and wake states. Thus, it easily confuses sleep and wake states. Second, the preterm infants was in sleep state the majority of time. Thus, the Actiwatch not coding wake as valid as it did sleep may have been due to the smaller number of wake states. Therefore, future studies can take into consideration recording longer periods of sleep–wake states, and combining diary use with Actiwatch in preterm infants. Despite these limitations, our study supports the suggestion that Actiwatch provides a useful tool for the noninvasive measurement of sleep and wake states in preterm infants.

Conclusion

Actiwatch demonstrated high agreement, sensitivity, and predictivity of sleep state, validated with the ABSS at the setting of high and automatic activity thresholds, and was not influenced by the infant's PMA. However, better specificity and better predictivity of wake state were found in medium and high thresholds, and not influenced by the PMA. In consideration of the agreement, the sensitivity, the specificity, the PPVS, the PPVW and the PMA, the findings of this study suggest that the high activity threshold would be the most accurate setting for determining sleep state in preterm infants.

Conflict of interest

None of the investigators in this study have conflicts of interest in any form with Actiwatch or Actiware version 5.0.

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