Minimizing the Risks of Sudden Infant Death Syndrome: To Swaddle or Not to Swaddle?

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Objective To evaluate the effects of swaddling on infant arousability, particularly the progression of subcortical activation (SCA) to full cortical arousal (CA), because impaired arousal may contribute to sudden infant death syndrome.

Study design Healthy term infants, who were routinely swaddled (n = 15) or unswaddled (n = 12) at home, were studied with daytime polysomnography at 3 to 4 weeks and 3 months after birth. When both swaddled and unswaddled, arousability was assessed with a pulsatile jet of air at the nostrils.

Results Larger increases in overall arousal thresholds (SCA plus CA) with swaddling were observed in infants who were easiest to arouse when unswaddled. Swaddling did not alter SCA or CA frequencies of routinely swaddled infants at either age. In infants who were naïve to swaddling, arousal thresholds were increased and CA frequency decreased during swaddled quiet sleep at 3 months.

Conclusions This study provides a scientific basis for assessing the safety of swaddling in infant care practice. The decreased cortical arousals observed in infants unfamiliar with swaddling may correspond to the increased risk of sudden infant death syndrome for inexperienced prone sleepers. *(J Pediatr 2009;155:475-81)*.

See editorial, p 461 and related article, p 505

Sudden infant death syndrome (SIDS) is one of the leading causes of infant death in western countries.[1] Epidemiologic studies identified prone sleeping as the major risk factor for SIDS.[2] In the 1990s worldwide public awareness campaigns began promoting supine sleeping to prevent SIDS. As a direct result, SIDS rates were reduced by more than 50% in most western countries.[2,3] However, the fall in the prevalence of prone sleeping has since plateaued, and many parents have become noncompliant with safe sleeping guidelines. Despite the well-documented risks of prone sleeping,[4,5] in some areas up to an alarming 25% to 30% of parents/caregivers continue to place their infants in this position to sleep.[6-8] Most of these caregivers report their babies "are more comfortable" or "sleep better that way," and some also describe excessive crying of babies in the supine position. As an alternative to prone sleeping, swaddling, or tight wrapping of infants has been recommended by some Australian SIDS organizations as a method of settling infants in the supine position. The popularity of infant swaddling has also recently increased in the United States.[9]

The final event leading to SIDS may involve an inability to arouse from sleep in response to a respiratory or cardiovascular challenge.[10,11] The arousal hypothesis is supported by postmortem identification of dysfunction in brain regions relevant to cardiorespiratory control and arousal from sleep in SIDS victims.[12] Furthermore, previous studies have reported decreased total arousability to various stimuli and altered brainstem-cortex arousal patterns in infants sleeping in the prone position, the major risk factor for SIDS.[13-15]

Infant swaddling minimizes arousals from sleep, crying time, spontaneous startles, and the progression to full arousal.[16-18] In contrast, other studies have reported that infants are more sensitive to auditory challenges in active sleep (AS) when swaddled.[19] During quiet sleep (QS), a state where infant arousability is already reduced,[20] potential effects of swaddling on induced arousability are unknown. Furthermore, although the most recent definitions for infant arousal responses recognize that the process of arousal represents a progression from subcortical activation (SCA) to full cortical arousal (CA),[21] the consequences of swaddling on this progression remain unstudied.

ANOVA	Analysis of variance
AS	Active sleep
CA	Cortical arousal
EEG	Electroencephalography
NS	Not significant
RM ANOVA	Repeated measures analysis of variance
SCA	Subcortical activation
SIDS	Sudden infant death syndrome
QS	Quiet Sleep

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Before widespread promotion of swaddling as a safe settling method, a fuller understanding of the effects of swaddling on infant arousability is needed. Thus the aim of this study was to evaluate the effects of swaddling on stimulus-induced arousal pathways during both AS and QS, both in infants who were routinely swaddled and those who were unswaddled at home. We hypothesized that swaddling would suppress infant arousability to somatosensory stimulation by minimizing the progression to full CA.

Methods

Twenty-seven healthy infants (17F/10M) were studied. All infants were born at term (range 38 to 41 weeks of gestation) and were of normal birth weight (mean ± SEM, 3462 ± 85 g) and 5-minute Apgar scores (median 9, range 9-10). None of the mothers smoked during pregnancy. The infants were all breast fed and routinely placed in the supine position to sleep at home.

Ethical approval for this project was obtained from the Southern Health and Monash University Human Research Ethics Committees. Participation was entirely voluntary, with no monetary incentive provided. Written informed parental consent was obtained before study commencement.

Polysomnography

Daytime polysomnography was performed at both 3 to 4 weeks (n = 27) and 3 months (n = 26) postnatal age, in a sleep laboratory where the ambient temperature was 23.0° ± 0.1°C and noise was minimal. A 16-channel polygraph (Model 78A; Grass Instrument Co., Quincy, Massachusetts), running at a sampling rate of 500 Hz, recorded electroencephalography (EEG), left and right electrooculography, mental-submental electromyography, electrocardiography, abdominal skin temperature (YSI 400 Series Thermistor; Mallinckrodt, Melbourne, Australia), thoracic and abdominal breathing movements (Piezo-electric sensors, Resp-ez; EPM Systems, Midlothian, Virginia), nasal/mouth airflow (BreathSensor thermistor; Nellcor Puritan Bennett Ltd, Eden Prairie, Minnesota), expired CO_2 (Capnocheck Plus; SIMS BCI Inc, Waukesha, Wisconsin), and blood oxygen saturation (BIOX 3700e pulse oximeter; Ohmeda, Louisville, Colorado). Electrodes and leads were attached during the routine morning feed, and the study began when the infant was asleep in the supine position in a bassinet.

Study Protocol

At each age, infants were studied both unswaddled and swaddled, with the starting condition randomized for the first study and reversed for the next. Infants were swaddled by a single investigator in a light muslin (cotton) wrap with their arms folded across the chest. With the wrap at clavicle level, it was firmly crossed over from side to side, with the larger edge tucked under the infant's back; the excess material was twisted at the feet, loose enough to allow a degree of hip flexion and abduction, then folded beneath the infant. Infants were then covered with a cotton baby blanket. When unswaddled, infants were covered with the same muslin wrap and blanket, but the covering was not wrapped tightly, and the limbs and torso were left unconstrained.

Sleep state was defined as AS, QS or indeterminate sleep, with standard criteria.[22] During both AS and quiet sleep, infant arousability was assessed with a pulsatile air-jet (3 Hz, for 5 seconds) delivered to the left and right nostrils alternately, as described in detail previously.[23] For each stimulus, baseline physiological measurements were obtained from the preceding 10 seconds, and responses were scored as nonarousal, subcortical activation (SCA), or cortical arousal (CA), with standard definitions.[21] This air-jet protocol produced similar arousal responses to those induced by mild hypoxia (15% inspired O_2) challenges throughout the first 6 months of life, both for total arousability[23] and also SCA/CA frequencies.[24]

Data Analysis

Mean arousal thresholds were determined with SCA criteria, so that CA was also captured by the arousal definition, making the arousal threshold inclusive of both SCA and CA. Regression analysis for percent change in arousal threshold between unswaddled and swaddled conditions was performed for each sleep state at each age studied, and the identity and slope of trend lines were compared between sleep states.[25] Non-arousal, SCA, and CA responses were expressed as percentages of total stimuli performed. Two-way repeated measures analysis of variance (RM ANOVA) was used to contrast effects of sleep state and swaddling on arousal thresholds and the frequency of each arousal response (SCA and CA). Two-way RM ANOVA was also used to test for effects on baseline physiological variables (10 seconds pre-stimulus; heart rate, respiratory rate, oxygen saturation, and abdominal skin temperature). Arousal data were also compared between infants who were routinely swaddled at home and those who were not using 2-way RM ANOVA (1 factor repetition) with Student Newman-Keuls post-hoc analysis to identify the source of differences detected by ANOVA.

Results

Overall Group

Effects of Swaddling on Overall Arousal Threshold.

Swaddling had no significant effect on arousal thresholds during AS or QS at 3 to 4 weeks (Figure 1, A). There was an overall effect of swaddling at 3 months, when infants were more difficult to arouse when swaddled ($P < .05$), although after post-hoc analysis this was significant only during QS ($P < .001$, Figure 1, B). At both ages, regardless of swaddling, arousal thresholds were higher during QS than AS ($P < .05$). A negative correlation was observed between the baseline (unswaddled) threshold and the change in threshold when infants were swaddled. This linear relationship was significant ($P < .05$) for both sleep states at 3 to 4 weeks (Figure 1, C) and at 3 months (Figure 1, D) when the slope in AS was greater ($P < .05$).

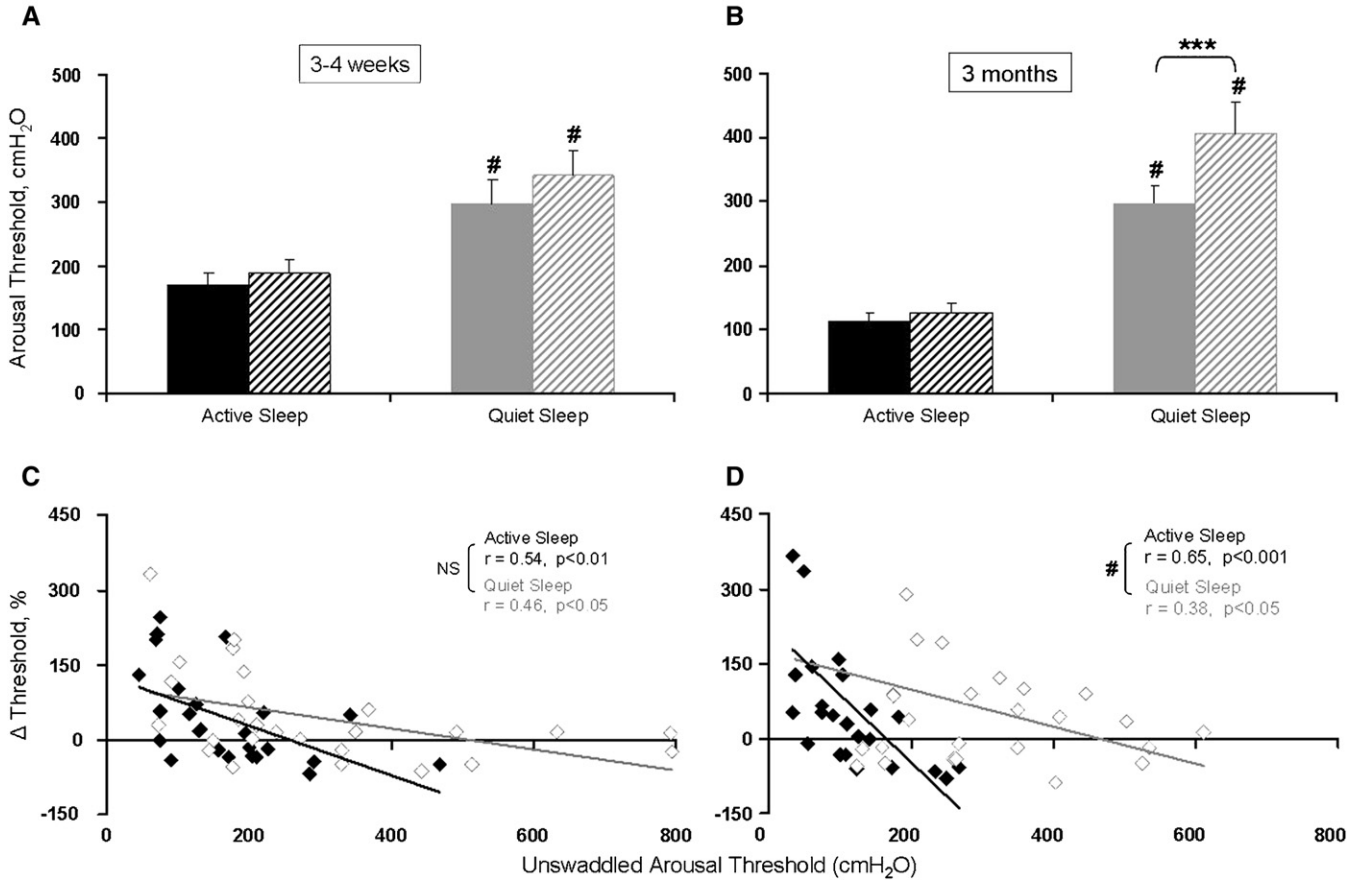

Figure 1. Mean unswaddled *(solid bars)* and swaddled *(striped bars)* arousal thresholds at **A,** 3 to 4 weeks and **B,** 3 months. Regression analyses of the change in threshold (swaddled minus unswaddled) with swaddling versus the baseline (unswaddled) threshold, during AS and quiet sleep at **C,** 3 to 4 weeks and **D,** 3 months. Symbols represent significant differences; $^{***}P < .001$, unswaddled versus swaddled thresholds; $^{\#}P < .05$, QS vs. AS; ^{NS} not significantly different. Note the overall trend for an increase in arousal thresholds with swaddling (**A** and **B,** $P < .05$ ANOVA), which reached significance in quiet sleep at 3 months (**B,** $P < .05$ SNK). Also note the greater swaddling-induced increases in arousal threshold in infants with lower baseline thresholds (**C** and **D,** $P < .05$).

Arousal Frequency. Nonarousal was the most frequently scored response, being observed in 62% ± 3% of tests. This was followed by SCA then CA with overall respective occurrences of 29% ± 2% and 10% ± 2% ($P < .05$). Figure 2 shows the response frequencies after division to account for sleep state and age. In QS, proportions of nonarousing tests and those that elicited SCA or CA were not different between unswaddled and swaddled conditions. During AS, CA was less in swaddled infants at 3 months (11% ± 2% swaddled vs 15% ± 3% unswaddled, $P < .05$).

There were more non-arousing stimuli during QS than AS at both 3 to 4 weeks and 3 months (Figure 2, $P < .05$). At 3 to 4 weeks, the frequency of SCA remained unaffected by sleep state, but at 3 months there were fewer SCA in QS compared with AS (26% ± 2% vs 33 ± 3%, Figure 2, $P < .05$). At both ages, CA in QS was less than in AS by approximately 8% ($P < .05$); this sleep state difference was absent when infants were swaddled at 3 months.

Duration of Cortical Arousals. At 3 to 4 weeks, the EEG desynchronization associated with CA was significantly shorter in duration when infants were swaddled compared with unswaddled during both AS (9.0 ± 1.0 seconds vs 13.2 ± 1.6 seconds, $P < .05$) and QS (5.1 ± 0.3 seconds vs 9.7 ± 1.4 seconds, $P < .05$). EEG desynchronization with CA was also consistently reduced during QS compared with AS at this age ($P < .05$). There were no effects of swaddling or sleep state on EEG desynchronization at 3 months.

Baseline Physiological Variables. There were no significant effects of swaddling or sleep state on baseline heart rate, oxygen saturation, or abdominal skin temperature (Table). When infants were swaddled, respiratory rate was increased by approximately 3 to 5 breaths/min ($P < .05$) in QS at 3 months and in AS at both ages. Respiratory rate was higher during AS compared with QS in both unswaddled and swaddled conditions ($P < .05$).

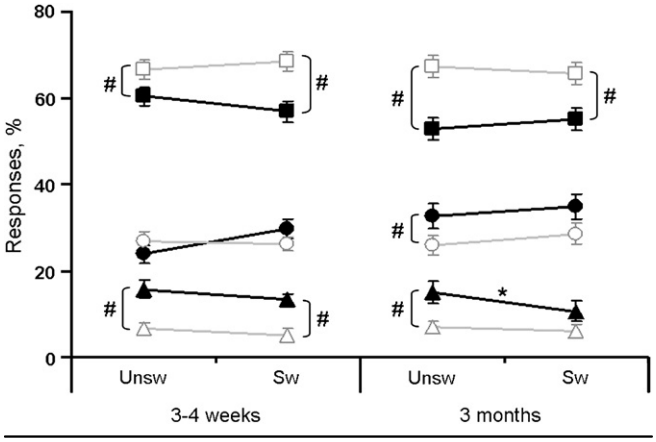

Figure 2. Infant responses to air-jet stimulation during AS *(black)* and QS *(gray)*; nonarousals *(squares)*, SCA *(circles)*, and CA *(triangles)*, each expressed as a percentage of total stimuli applied. Symbols indicate significant differences; $P < .05$, *unswaddled *(Unsw)* versus swaddled *(Sw)*, #AS versus QS.

Air-jet Stimulus. There were no differences in number of air-jet stimuli performed between sleep states (AS and QS) or conditions (unswaddled and swaddled) (Table). There were no differences between the stimulus pressures that elicited SCA and those that led to CA in either sleep state or condition at either age studied, except for a higher pressure for SCA than CA at 3 to 4 weeks during swaddled QS ($P < .05$). Overall, higher pressures were required to induce both SCA and CA during QS than in AS ($P < .001$). During QS at 3 months, higher pressures were required to elicit SCA when infants were swaddled compared with unswaddled.

Routine versus Naïve Swaddling

At 3 to 4 weeks, 15 infants were routinely swaddled at home, and 12 infants were not swaddled (denoted as naïve to swaddling). At 3 months, data from 18 routinely swaddled infants and 8 naïve to swaddling were available, with 1 unswaddled infant being unavailable for follow-up, and 3 whose parents changed to swaddling the infant between studies.

Effects of Swaddling on Arousal Threshold. Highest arousal thresholds were observed in the infants who were naïve to swaddling (Figure 3), with arousal thresholds being significantly elevated when swaddled at 3 months (536 ± 77 cmH_2O) than when unswaddled (275 ± 24 cmH_2O, $P < .001$) during QS. Infants who were naïve to swaddling were also less arousable when compared with the routinely swaddled group when swaddled (348 ± 60 cmH_2O, $P < .05$). Overall, QS was associated with higher arousal thresholds than AS ($P < .001$). In infants who were routinely swaddled at home, arousal thresholds were similar when unswaddled and swaddled, regardless of sleep state or postnatal age.

Arousal Frequency. There were no significant effects of swaddling on the frequencies of nonarousals (Figure 4, A) or SCA (Figure 4, B) in either routine or naïve to swaddling groups. At 3 months, swaddling in the naïve group was associated with decreased CA (4% ± 2%, Figure 4, C) when

Table. Baseline values of heart rate, respiratory rate, oxygen saturation, and abdominal skin temperature, with intensity of air-jet tests at both 3 to 4 weeks and 3 months (mean ± SEM)

	3 to 4 weeks		3 months	
	AS	QS	AS	QS
Baseline physiological variables				
Heart rate (beats/min)				
Unswaddled	135.4 ± 1.9	134.8 ± 2.0	121.7 ± 1.7	122.7 ± 1.7
Swaddled	133.4 ± 1.9	134.9 ± 1.9	123.9 ± 1.6	122.9 ± 1.6
Respiratory rate (breaths/min)				
Unswaddled	47.7 ± 1.6	43.0 ± 2.2*	40.0 ± 1.2	34.1 ± 1.3*
Swaddled	51.3 ± 2.2†	44.2 ± 2.3*	43.5 ± 1.4†	39.3 ± 1.9*†
Oxygen saturation (%)				
Unswaddled	94.3 ± 0.6	94.4 ± 0.3	95.0 ± 0.6	9.9 ± 0.3
Swaddled	94.0 ± 0.2	94.5 ± 0.3	94.9 ± 0.2	95.0 ± 0.4
Skin temperature (degrees Celsius)				
Unswaddled	36.2 ± 0.2	36.2 ± 0.2	36.2 ± 0.6	36.1 ± 0.2
Swaddled	36.3 ± 0.2	36.2 ± 0.2	36.3 ± 0.6	36.2 ± 0.6
Stimulus information				
Tests performed (no.)				
Unswaddled	17 ± 1	20 ± 2	13 ± 1	21 ± 2
Swaddled	22 ± 2	20 ± 1	16 ± 1	25 ± 1
SCA pressure (cmH_2O)				
Unswaddled	148 ± 21	302 ± 35*	117 ± 14	317 ± 34*
Swaddled	205 ± 26	368 ± 35*	150 ± 18	437 ± 48*,†
CA pressure (cmH_2O)				
Unswaddled	198 ± 21	333 ± 52*	115 ± 20	383 ± 62*
Swaddled	209 ± 25	256 ± 29‡	174 ± 23	410 ± 76*

AS, Active sleep; *QS*, quiet sleep; *SCA*, subcortical activation; *CA*, cortical arousal. Symbols represent statistically significant effects of swaddling (†$P < .05$, compared with unswaddled), of sleep state
(*$P < .05$, QS compared with AS), and of arousal type (‡$P < .05$, CA compared with SCA).

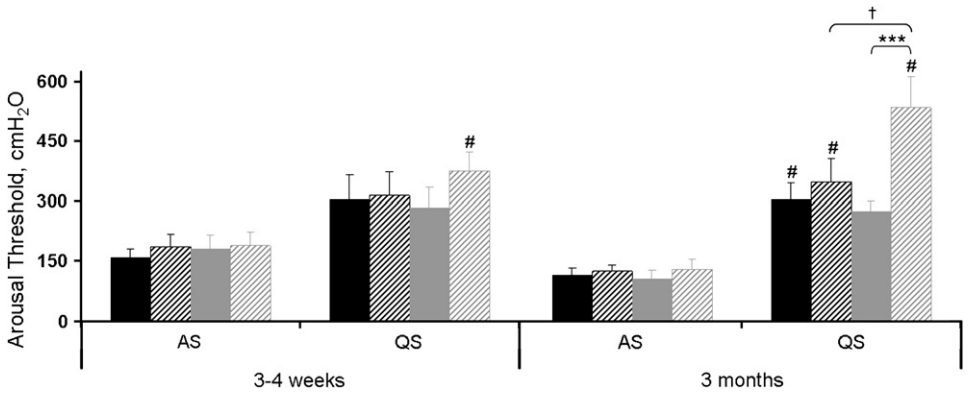

Figure 3. Mean arousal thresholds observed in unswaddled *(solid bars)* and swaddled *(striped bars)* sleeping conditions; data are shown for routine *(black)* and naïve *(gray)* swaddling groups. Symbols represent differences between groups; $^{\dagger}P < .05$, routine vs. naïve; $^{***}P < .001$, unswaddled versus swaddled; $^{\#}P < .05$, AS versus QS.

compared with the unswaddled condition (15% ± 5%, $P < .05$); the frequency of CA of the naïve group when swaddled was also lower than routinely swaddled infants when swaddled (13% ± 3%, $P < .05$). Generally, AS was associated with fewer nonarousals and more CA compared with QS ($P < .001$), in both routine and naïve groups.

Discussion

This study has provided detailed information of the effects of swaddling on arousability of infants who are routinely swaddled and those naïve to swaddling during the first 3 months of life. At 3 months postnatal age, swaddling increased arousal thresholds in QS and depressed full cortical arousal in AS. In addition, at both 3 to 4 weeks and 3 months, swaddling was more effective in decreasing arousability in infants who were more easily aroused from sleep when unswaddled; there were minimal or no effects in infants with high baseline arousal thresholds. Notably, of particular relevance to SIDS, at 3 months of age swaddling increased arousal thresholds in QS and decreased cortical arousal frequency in AS only in infants who were naïve to swaddling.

Infant arousal has been described as a hierarchy of responses, whereby full CA is preceded by a sequence of subcortical events, a breathing pause or sigh, a startle, and "thrashing" behavior, with each event stimulating the next in a chain of activation.[26] Our findings of decreased induced CA with swaddling during AS, along with those of a previous study that described decreased spontaneous startles during both sleep states,[18] support the contention that the motor restraint of swaddling decreases proprioceptive stimulation to the cortex via the brainstem by inhibiting this startle reflex.[17] Constant stimulation from the skin and thermal receptors may contribute somewhat to the calming effect of swaddling and the reduced startle responses.[17] This explanation does not account for the decreased arousability observed in our study, because infants were wearing the same clothing and were covered by the same bedding when both swaddled and unswaddled. Furthermore, abdominal skin temperatures remained unchanged between the 2 sleeping conditions.

The largest increases in arousal threshold with swaddling were observed in infants with the lowest baseline thresholds, that is, in those who were easiest to arouse from sleep when unswaddled. This negative correlation was significant in both sleep states at both ages studied, and it was strongest in AS at 3 months. AS is a state when infants are more arousable than when in QS, as we have previously reported.[13,20,23,27] This feature of AS has led us to suggest that any factor that impairs arousal may have more serious consequences than in QS.[27] In this study, minimal or no effects of swaddling were observed in infants with high unswaddled arousal thresholds regardless of the sleep state, suggesting that there is a physiological limit preventing further increases in arousal threshold. Such a limit may explain why the decrease in CA frequency observed when infants were swaddled was only observed during AS, when arousal threshold is lower than in quiet sleep. In contrast to our findings, 1 study using auditory stimulation during AS only found that arousability was increased when infants were swaddled.[19] The differences between these findings and ours are perhaps due to the broad age range of infants studied (up to 6 months) by Franco et al,[27] because during this period there is significant maturation of sleep architecture and arousal responses. In addition, unlike our study, the swaddling technique used involved sand bags to tightly wrap bed sheets, which would also prevent movement of infants' legs, as well as arms.

Our study demonstrated that swaddling did not affect baseline heart rate, temperature, or oxygen saturation, although respiratory frequency was increased. The increased respiratory frequency is consistent with previous studies[28,29] and is most probably due to restricted tidal volumes imposed by the firm wrapping. This respiratory rate increase is unlikely to represent a risk for the infant, because respiratory rates were within limits of normal variation for this age group.[30]

A unique aspect of this study was that the routine home practices of swaddling were addressed. Infants who were

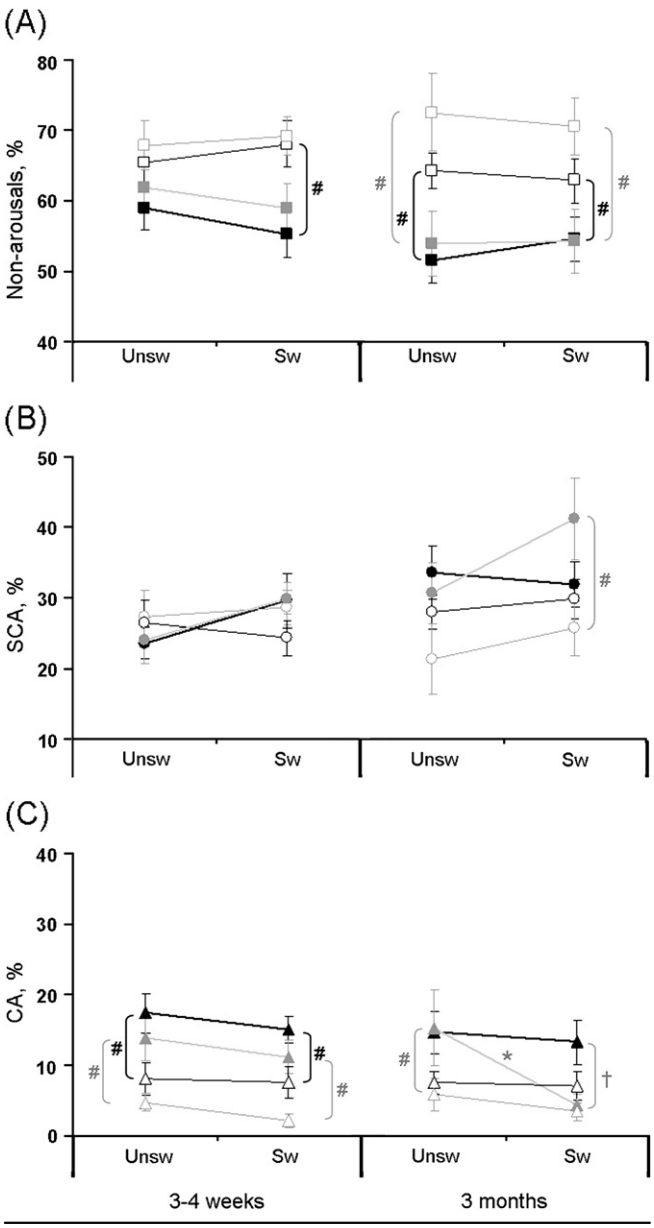

Figure 4. Infant responses to air-jet stimulation; **A,** nonarousals **B,** SCA, and **C,** CA during AS (*solid squares, circles,* and *triangles*, respectively) and QS (*open squares, circles,* and *triangles*) are expressed as percentages of total air-jet stimuli for both routine *(black)* and naïve *(gray)* swaddling groups. Note that the y-axis scales differ for each response. Symbols represent significant differences; $P < .05$, *swaddling and #sleep state.

swaddled at the beginning of all sleep periods at home were classified as "routinely swaddled." Lipton et al[17] previously showed that in terms of startle frequency, partial swaddling with free arm movement was similar to unswaddled conditions, so that infants who were routinely swaddled with arms free were included in the "naïve" group. It is important to note that the infants comprising the routine and naïve swaddling groups were not identical at 3 to 4 weeks and 3 months, because parents altered swaddling practices at home; between the 2 studies, 3 families ceased swaddling, and 7 families began routinely swaddling their infant, an anecdotal indication of the technique's settling success in these households. Perhaps the most important finding of our study was that the swaddling-induced changes in arousability at 3 months (the increase in arousal thresholds during QS and the decrease in CA during AS) occurred only in the infants who were unfamiliar with sleeping swaddled. This characteristic is notable for its similarity to the increased SIDS risk associated with naïve or inexperienced prone sleeping.[31] The coincidence merits attention, particularly because a decrease in spontaneous CA was documented in infants who later succumbed to SIDS.[11]

The relationship between SIDS and swaddling has changed over the years. Previous studies showed that swaddling infants potentiated the risk of SIDS associated with the prone sleeping position (from 3-fold to 12-fold increase in risk),[32] whereas firm wrapping in the supine position decreased the risk of SIDS.[33] A cotton sleeping sack was described as a preventative factor for SIDS in 1 study, although this was likely due to the decreased frequency of these infants turning prone; unlike most conventional swaddling methods, the sleeping sacks described by L'Hoir et al[34] did not prevent arm movements. Furthermore, in the mid nineties Fleming[35] and Blair found swaddling to be more common among SIDS victims (14%) compared with age-matched control infants (9%). Preliminary findings of a more recent study suggest this difference has since become more marked (24% SIDS infants were swaddled, compared with 6% of control). Although sleeping position was not addressed in the earlier study, most of the recently studied infants had been placed to sleep in the supine or lateral position; furthermore, swaddling remained a significant risk factor in a multivariate analysis, which included infants who were found prone (P.S. Blair, personal communication).

A failure to arouse from sleep has been strongly linked to SIDS, and this study has demonstrated that swaddling decreased infant arousability from sleep. This depression of arousal was most evident in infants who were more easily aroused from sleep when unswaddled, and this is likely the reason for recommendations of swaddling as a settling technique for infants in the supine position. Swaddling had no effect on arousal processes of routinely swaddled infants but decreased CA at 3 months in infants who were not familiar with being swaddled. Our study highlights the importance of scientific investigation of the mechanisms involved in reducing arousal when infants are swaddled, before recommending changes in infant care practices. Appropriate education of parents and caregivers is required, with emphasis on the potential adverse consequences of unaccustomed sleeping practices, particularly at the age of high SIDS risk. ■

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