A CRITICAL EXAMINATION OF THE MORO RESPONSE IN NEWBORN INFANTS—SYMMETRY, STATE RELATION, UNDERLYING MECHANISMS

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(Received 15 February 1994; accepted 14 December 1994)

Abstract—The primary purpose of the present study was to analyze quantitatively the vestibular evoked Moro response, and the symmetry of the movement pattern involved, as the traditional descriptions bring about. Another aim was to determine the segmental movements involved and determine whether the components of the Moro response are dependent on changes in the infant's behavioral state. Another question concerns whether the form of these movements changed over repeated trials on the same day, or from the first to the fifth day after birth. Vestibular evoked Moro responses of 52 neonates, 1–5 days of age, elicited in different behavior states (State 1–5), were examined and quantitatively analyzed. The response was evoked by a predefined, rapid, downward, vertical body motion, without any dorsiflexion of the infant's head. Optoelectronic device (SESPOT II) were used to monitor the arm/hand movement patterns involved in the response. The three-dimensional movement pattern in space, duration, velocity, latency, and the acceleration of both arms/hands were analyzed in relation to the infant's behavioral state. The response movements were structured into phases of abduction/extension, adduction/flexion and the extension/flexion of the fingers. The vestibular stimulation used was found to be sufficient for eliciting an adequate Moro response. The segmental movement pattern of the Moro response was found to be sensitive to the infant's behavioral state at the time when the response was elicited. This was found in the movement pattern, duration, latency, and the velocity of the response. The response was found to be asymmetrical, in 82% of the infants it was found to be a predominant shorter onset latency of the right arm, in 12% the opposite was found. These findings suggest that there is a fundamental, spinal asymmetry involved in the Moro response which is subject to supraspinal influences emanating from the vestibulospinal system. No differences were found between 1 and 5 days of age for any of the scoring categories, and no differences were found within groups over six successive trials.

Key Words: Moro response; newborn; reflex; state; vestibular; laterality.

INTRODUCTION

The Moro response is one of the most distinct and regular responses that can be elicited in the newborn infant. The normal response is characterized by sudden, symmetrical, extension/abduction movements of the arms, and extension of the fingers, followed by adduction of the shoulders and flexion of the arms. A Moro-like response was first described by Magnus and de Kleijn [13]. In his initial description of the response 1918, Moro [17] stressed the flexion/adduction ("umklammerung") phase of the response rather than the primary extension/abduction phase. Following Moro, most studies have been concerned with various methods of eliciting the response. In addition, the underlying sensory pathways have been a subject of considerable discussion in terms of whether they are primarily vestibular, proprioceptive, or exteroceptive in nature. Despite this attention, and the fact that the Moro
response is commonly used in neurological evaluations of the newborn infant, there is still little agreement about its basic nature. In part, this is due to a lack of adequate descriptions of the segmental movements involved relative to eliciting conditions and the behavioral state of the infant.

McGraw [14] in describing the list of effective methods for eliciting the response pointed out that it is the quality of suddenness in the stimulus which is important. It has also been suggested that the different modes of eliciting the Moro response merely vary the intensity of the response [18]. There are differences of opinion with regard to the mechanisms of the Moro response. According to Parmelee [20], the mode of elicitation determines to a large extent which afferent input is responsible for the resulting patterning of the response. He stressed that stimulation of more than just the semicircular canals of the vestibular apparatus is necessary for a strong Moro response, and that proprioceptive stimulation arising from movement of the neck seems to be very important. Peiper [21] held that the Moro response could be ascribed mainly to vestibular stimulation, whereas André-Thomas and Hanon [1] concluded that proprioceptive input from the neck joints is the main source of elicitation. Prechtl [23] favored the opinion of Peiper while at the same time emphasizing the state dependent nature of the response. Touwen [30], one of the first to control for state, showed that his three types of elicitation (head-drop, lift, and hit on the surface), did not have identical effects during development. This implies that they are based on different brain mechanisms or that their afferent input is not the same.

A normal Moro is commonly described as being a very symmetrical response. It becomes asymmetrical in the presence of brachial palsy and in the rare cases of neonatal hemiplegia or other pathological states [19]. Fractures of the clavicle or humerus or injury to the shoulder joint are also common causes of asymmetry [18]. To date, there have been no quantitative, systematic observations designed to examine whether the response is truly symmetrical in healthy, normal infants.

It is difficult to demonstrate reliable lateral differences in spontaneous hand/arm use in early infancy [27]. However, there is a considerable body of evidence pointing to postural biases and other motor asymmetries in human newborns (see [2] and [3] and [26]). For example, asymmetries have been found in various neonatal reflexes, which in most cases are generally stronger on the right side. These include the asymmetric tonic neck reflex (ATNR), the stepping and placing reflexes, and the grasping reflex. Not all studies have demonstrated a right-sided bias for the ATNR [4, 12], and the stepping reflex [22]. According to Liederman [12], a right-sided ATNR may only appear because the infant prefers to lie with the head to the right.

The most frequently reported postural asymmetry in newborns is their tendency to lie with their heads to the right in the supine position. Hopkins et al. [11] found this right-sided head-turning and maintenance bias in newborns within 1 hr of delivery. A similar bias has been reported for preterm infants 33–34 weeks gestation [6, 8]. This bias is present regardless of whether the infant was delivered vaginally or by means of caesarian section [31]. In a clinical context, Saint-Anne Dargassies [28] noted that prior head position was positively related to an asymmetry in the Moro response. According to the intriguing theory presented by Pervic [26], the origins of cerebral lateralization in humans derives from the asymmetric prenatal development of the vestibular organ (labyrinth), and that vestibular lateralization can be traced to the asymmetric positioning of the fetus in utero during the final trimester. According to Michel [15], the neonatal head orientation induces a lateral asymmetry in hand regard activity in the early infancy.
On the basis of Pervic [26] left-otolithic left dominance model of lateralization, and the many findings of lateral biases in the movements and postures of normal, healthy infants, one may expect to find that some of the kinematic parameters of a vestibular evoked Moro response have an asymmetrical bias. If, however, the predominantly rightward asymmetry of newborn's initial head posture induces the lateral biases observed in response, posture and asymmetrical arm/hand movements, then, if the newborn's head is kept in a midline position when the response is evoked, such biases should not be detectable.

In the present study, it was assumed that a vestibular stimulus without any proprioceptive inputs from the neck would be sufficient to elicit an adequate Moro response. Consequently, the main aim of the study was to provide a quantitative analysis of the vestibular evoked Moro response. Among other things, this analysis would reveal whether the arm movements elicited were symmetrical in nature. Another aim was to describe the segmental movements involved and whether their patterning was dependent on changes in behavioral state. Finally, it was asked whether the form of these movements changed, over repeated trials on the same day, or from the first to the fifth day after birth.

**METHOD**

*Subjects*

Fifty-two newborn infants, 31 boys and 21 girls, ranging in age from one (> 10 hr) to 5 days of age participated in the study. All infants were healthy with normal, single vaginal deliveries, a 1-min Apgar score of 8 or more, and no known medical problems during pregnancy. Their gestational ages ranged from 36 to 42 weeks (M = 39.6) and birthweights from 2330–4750 g (M = 3660 g). Two of the infants were born small-for-gestational-age. At the time of observation, the age distribution of the infants was as follows: 11 infants on day one, 12 on day two, 10 on day three, 11 on day four, and 8 on day five. The study was approved by the Ethical Committee of the Medical Faculty of Umeå University Hospital, and involved informed consent of the mother.

*Procedure and apparatus*

All infants were tested in a room adjacent to the delivery clinic at Umeå University Hospital. The infant was placed in a specially constructed chair, angled at 20° to the vertical, and testing began when he or she was in an appropriate state. Behavioral state was assessed both before the infant was placed in the chair and prior to each trial using Prechtl's [25] classification [State 1 (quiet sleep)—State 5 (crying)]. The infants were tested in various behavioral states. Depending on the infant's cooperation, six responses were evoked in succession.

The chair, mounted on a purpose-built table, ensured that the infant's head and trunk were maintained in the midline position while permitting the arms and legs to move freely. In order to evoke a Moro response, the chair could be triggered to move suddenly backwards a predefined distance by the experimenter at an appropriate moment (the displacement, velocity, and acceleration profiles of the chair movement are shown on the top of Fig. 1). The movement of the chair was produced by regulating high pressure air (two bars) taken from a movable tube. Two sensors controlled the distance between the start and stop of the chair movement, which could be adjustable between 1 and 20 cm. Based on a preparatory study, the displacement of the chair was fixed at 11 cm in the vertical plane. The maximum (peak) velocity of the displacement was 3.2 m set⁻¹, with maximum acceleration being 6 m sec⁻². The total duration of a displacement was 105 msec. Five seconds after displacement, the chair returned slowly to the starting position.

*Data extraction*

An optoelectronic device (SELPOT II) was used to monitor the Moro movements of both the infant's hands/arms. It consisted of a signal-emitting and a signal-receiving part. The signal emitting part used light emitting diodes (LEDs) emitting light in the infrared part of the spectrum. The signal-receiving part consisted of two cameras with open shutters and equipped with optoelectronic plates sensitive to the wavelength of the light emitted by the LEDs. In the present study, 5 LEDs were monitored. The LEDs used were about 6 mm in diameter with a half power angle of 60°. The system worked as follows. A LED and one of the cameras were always activated in a synchronized manner. The infrared, light projected on the optoelectronic plate of the camera, created a potential field and the system read off the X and Y coordinates of the center of that field. The signals were then AtoD converted and stored on the hard disc of a SMS 72/77 computer on line. The system worked sequentially. A LED would flash twice, once for each camera. When several LEDs were monitored during the same time period as in the present study, they were flashed in a specific repeated order. Before the data were analyzed, the recordings from the two
cameras were transformed into a single account of the event in Euclidian coordinates. Two LEDs were mounted on the dorsal side of each hand to monitor the spatial and temporal properties of the response. One LED was mounted on the chair at the same level as the infant's head to monitor the absolute onset of the chair movement. The SELSPOT cameras were placed above the subject, at an angle of 30° from the sagittal plane and at a distance of 1.2 m from the subject's arms. The accuracy of the system with this set-up corresponded to around 0.5 mm displacement in each of the three dimensions of space. Data were sampled at 400 Hz.

The SELSPOT data were collected in 3-sec periods. Just before each trial, the arms were placed in the same starting positions for all infants (slightly flexed on the stomach). The triggering of the SELSPOT system, at a time when the infant was in an appropriate state, denoted the start of each period, which occurred about 1 sec before displacement of the chair. Complete testing took about 5–10 min, with a minimum duration of 30 sec between trials. After each recording session, the data were transformed into three-dimensional coordinates and stored on a DEC11/77 computer for later analysis.

Video recordings (SONY Umatic, VO-5800PS) were made of all sessions. These recordings allowed checks to be made of the SELSPOT data wherever they appeared to be invalid. The video camera was placed 2 m above and in front of the infant at about 50° from the vertical plane. The recordings were also used to score the quality of the segmental (arm and finger) movements involved in the Moro response in a semi-quantitative way. Three categories of segmental movements were scored from the video recordings using the following rating scales.

A. Abduction/extension of the arms.
0. No reaction.
1. Slight abduction/extension of the arms, not surpassing 70–90° extension in the elbow joint, and 45° abduction in the shoulder joint.
2. Evident abduction/extension of the arms (more than 90 and 45°, respectively).
3. Complete abduction/extension of the arms.

B. Abduction/flexion of the arms.
0. No reaction.
1. Slight adduction/flexion of the arms.
2. Evident adduction/flexion of the arms.
3. Full adduction/flexion of the arms.

C. Finger movements.
0. No reaction of the fingers (compare with the starting position of the hand).
1. Extension of some fingers, with one or more fingers flexed.
2. Extension and spreading of fingers, with (in some cases) just a slight semiflexion of the outermost-phalang of the thumb and the index finger, like a C shape.
3. Evident extension and maximal spreading of all fingers.

Data analysis

The movement trajectories of the hands were visually inspected in all three dimensions (lateral, vertical and anterior displacement) and compared to the vertical displacement of the chair. Parts of recordings in which the LEDs were not reliably recorded or totally missing were excluded from further analysis. Such recordings were easily identified by their stepwise displacements and the non-correspondence between recordings from the two optoelectronic cameras on their common axis. The amplitude and the duration of the Moro responses were determined for each trial from the LEDs on the hands (one hand at a time) from the lateral trajectory displacement. The infants, for whom more than 50% of the SELSPOT recordings were of good quality, were included for further kinematic analyses. The maximum-velocity (velocity peak) and the onset latency of the Moro response for both arms were determined from frame-by-frame inspections of the three-dimensional velocity and acceleration profiles. The onset latency was defined as the time elapsing between the onset of the vertical chair movement and the onset of the lateral arm displacement. Given that the highest possible sampling frequency (400 Hz) was desirable, particularly for analyzing the onset latency of each arm no filtering was used.

RESULTS

Data from 250 trials were analyzed from 52 neonates. The majority of infants produced Moro responses on all six trials. Acceptable SELSPOT measurement quality was obtained for 225 trials. In 25 trials no bilateral Moro response was elicited. Nineteen of these types of responses were made when the infants were in State 5, two in State 1, two in State 3, and two in State 4. A typical kinematic example of a Moro response from an infant in State 3 is shown in Fig. 1.
Fig. 1. A Moro response of a boy 5 days of age evoked in State 3. Part (a) shows the vertical displacement of the chair (thick line) and the 3-D velocity of the chair displacement (thin line); (b) the 3-D acceleration of the chair; (c) shows the lateral displacement of the right hand (thick line) and its 3-D velocity (thin line); (d) the 3-D acceleration of the right hand; (e) shows the lateral displacement of the left hand (thick line) and its 3-D velocity (thin line); (f) the 3-D acceleration of the left hand. The broken lines indicate the onset of the chair displacement. The latency for the right arm is 85 msec and for the left arm 97 msec.
Table 1. The total mean scores from 52 infants Moro responses, for six successive trials, and for each of the following categories: abduction/extension of the arms (A), adduction/flexion of the arms (B) and finger movements (C)

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Note: Age = Days (1–5), (n) = number of infants, M = mean scores.

The semi-quantitative ratings for movement categories A, B and C were analyzed by three ANOVAs with a split-plot design in which the effect of age (1–5 days) were tested on categories (A, B, C) over trials (1–6). Table 1 gives the mean Moro response scores for each of the three categories and for each age group over each of the six trials. No significant effect of age (P > 0.05) was found for any of the three categories, and there were no significant differences within groups over trials.

A 5 x 3 ANOVA (state x category) was performed to test the effects of state on the three types of segmental movements. The average values of the A, B and C movement categories for the five states are shown in Fig. 2. Significant main effects of state were found for all three categories: category A, [F (4, 25) = 11.934, P < 0.0001]; category B [F (4, 25) = 18.111, P < 0.0001]; and category C [F (4, 25) = 11.757, P < 0.0001]. A post-hoc Scheffe test revealed significant differences between states for the abduction/extension movements: State 1 and 4 (F = 6.19), State 1 and 5 (F = 8.82), State 2 and 5 (F = 3.11), State 3 and 4 (F = 2.86), and between State 3 and 5 (F = 4.72). In State 4 and 5, abduction/extension of the arms was not so evident relative to the other states. The most prominent abduction/extension movements were found in State 1 and State 3 (see Fig. 2).

Significant differences (P < 0.05) for the adduction/flexion movements were obtained between the following states: State 1 and 2 (F = 14.04), State 1 and 3 (F = 9.54), State 1 and 4...
State 1 State 2 State 3 State 4 State 5

Fig. 2. Distribution of the mean scores of the Moro movement pattern, abduction/extension (A), adduction/flexion (B), and the finger reactions (C), where 0 indicates no reaction, and 3 an optimal reaction.

(F = 9.44), and between State 2 and 5 (F = 4.49). The adduction/flexion movements were very slight and, in many cases, almost nonexistent in State 1, while quite prominent and in some cases predominant (over the abduction/extension movements) in State 4 and 5.

For hand and finger movements, the most prominent extension of the fingers was found in State 3 and the most striking difference was obtained between State 3 and 5 (F = 9.31). Significant differences (P < 0.05) were also found between State 1 and 5 (F = 4.38), and State 2 and 5 (F = 7.95). Fisted hands and/or no reactions of the fingers were most common in State 5.

The average correlation, over the six trials, between abduction/extension movements of the arms and extension movements of the fingers ranged from 0.592 to 0.716 (Mean \( r_p = 0.656 \)). The mean correlation between abduction/extension and adduction/flexion of the arms was \(-0.061\).

As can be seen from Fig. 2, the most complete Moro responses were evoked in State 2 and State 3, with more incompleteness being evident in State 4 and 5. In all states, except 4, there was a tendency for the arms to react with more extension than flexion.

A one-way ANOVA was done to test the effects of state on duration time, which is the time from onset of the extension/abduction movements of the arms/hands to the finish of the flexion/adduction movements (startle movements and/or tremor, sometimes follow a Moro response were excluded from the duration time). A significant main effect of state was found \([F (4, 221) = 5.733, P < 0.001]\). The mean Moro durations were 1.56, 1.25, 1.44, 1.40 and 1.09 sec for State 1, 2, 3, 4, and 5, respectively. The most rapid response was seen in State 5, and the slowest response was seen in State 1. A post-hoc Scheffé test comparison of the mean duration times revealed significant differences (P < 0.05) for latency between State 1 and 5 (F = 3.244), State 3 and 5 (F = 3.099), and State 4 and 5 (F = 2.44). The average correlation between the right and the left hand/arm was 0.697.

Table 2 displays not only the mean durations, but also mean latencies and maximum velocities for right and left arms, relative to each of the five states. A one-way ANOVA revealed a significant effect of state on the latency of responding \([F (4, 211) = 11.165, P < 0.0001]\). Post-hoc comparisons indicate significant differences (P < 0.05) for latency.
Table 2. Mean durations of the Moro responses, mean latencies for onset of the right and left arms, and the mean maximum velocities (peak) for the right and left arms, for each of the five states

<table>
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<tr>
<th></th>
<th>State 1 M (S.D.)</th>
<th>State 2 M (S.D.)</th>
<th>State 3 M (S.D.)</th>
<th>State 4 M (S.D.)</th>
<th>State 5 M (S.D.)</th>
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<td><strong>Duration</strong></td>
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<td>1.25 (0.41)</td>
<td>1.44 (0.43)</td>
<td>1.41 (0.47)</td>
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<td>087 (027)</td>
<td>078 (022)</td>
<td>134 (032)</td>
<td>107 (056)</td>
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<tr>
<td><strong>Latency left</strong></td>
<td>165 (069)</td>
<td>097 (031)</td>
<td>101 (026)</td>
<td>129 (054)</td>
<td>123 (047)</td>
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<tr>
<td><strong>Max. vel. right</strong></td>
<td>650 (378)</td>
<td>574 (163)</td>
<td>662 (123)</td>
<td>590 (211)</td>
<td>563 (149)</td>
</tr>
<tr>
<td><strong>Max. vel. left</strong></td>
<td>652 (259)</td>
<td>549 (174)</td>
<td>462 (125)</td>
<td>576 (119)</td>
<td>598 (146)</td>
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*Note:* Duration = sec, latency = msec, max. vel. = mm sec$^{-1}$, S.D. = standard deviation.

between State 1 and 2, ($F = 5.61$), State 1 and 3 ($F = 4.658$), State 2 and 4 ($F = 4.236$), State 2 and 5 ($F = 2.933$), and State 3 and 4 ($F = 3.046$). The shortest latencies were found in State 3, ($M = 90$ msec), and the longest latencies in State 1, ($M = 154$ msec). A comparison of the latencies between the right and left arm showed a significant difference [$F(1, 106) = 136.52, P < 0.0001$]. The latencies were significantly shorter for the right arm. In 70% of trials, the latency for the right arm was shorter than for the left arm, in 7% they were equal, and in 23% those for the left arm were shorter than for the right arm. This right-sided asymmetry was rather stable over the six trials for the individual infant. Thus, 82% of the infants show a predominantly shorter latency for the right arm, 12% for the left arm, while in 6% no predominant side effects (or inconsistency) were evident. Of the six infants with shorter latencies on the left side, five where boys and one was a girl.

State did not have a significant effect on maximum (peak) velocity of the Moro response ($P < 0.05$). Maximum velocity displayed a rather high variability between subjects within each state (especially in State 1 and State 5). The two arms did not differ significantly in terms of peak velocity. The mean maximum velocity for the right arm was 579.3 mm sec$^{-1}$, as against 601.2 mm sec$^{-1}$ for the left. The average correlation between the right and left maximum velocities was 0.376. However, the maximum velocities (peak placement) were related to the side differences found for latencies time. Peak velocity occurred frequently in the extension/abduction phase of the Moro response in State 1, 2 and 3, most frequently in State 4, whereas in State 5 it was predominantly found in the flexion/adduction phase. Examples of the movement profiles and the three-dimensional velocity distributions of two Moro responses, one of an infant in State 1, and another of an infant in State 4, can be seen in Figs 3 and 4, respectively. The vertical and anterior movements of the arms for the same Moro response depicted in Fig. 4, are shown in Fig. 5.

**DISCUSSION**

There has been considerable debate as to whether the main afferent pathway of the Moro response originates in the neck proprioceptors or the vestibular receptors. The most common way to elicit the response in a neurological assessment is the “head-drop” method, done with a manual manoeuvre. This method stimulates both the semicircular canals of the vestibular system and the proprioceptive receptors of the neck. This, along with other manual techniques to evoke and assess the Moro response, have considerable scoring reliability problems [20]. The method and measurement technique used in the present study
for evoking, observing and scoring the response does not have such problems. Stimulus properties (intensity, length, velocity and acceleration) are the same for all infants. However, there is no dorsiflexion of the infant's head using the present method, which eliminates proprioceptive inputs from the cervical neck vertebrae. The whole body motion mainly provides vestibular input (at least in the initial phase of elicitation).

The present study provides further support for the view that the Moro response is mainly activated from the vestibular receptor systems. However, there appears to be a simultaneous on-going control of the two different phases of the Moro response. When the head and trunk are tilted backwards, extension/abduction movements of the arms are triggered mainly by the vestibular receptors. The vestibulospinal reflexes contract the limb muscles and sensitize the infant for subsequent disequilibrium. These positional changes of the arms, head and trunk, will provide a compensatory synergy (the adduction/flexion movements), triggered mainly by the proprioceptive receptors, and strongly influenced by the infant's state. The
flexion/adduction phase may also be influenced by other exteroceptive receptors than the neck proprioceptors, e.g. by somesthetic and tactile receptors from the back.

Another finding is that the normal Moro response has a rather clear asymmetry in the onset of the abduction/extension phase as revealed by the three-dimensional velocity and acceleration profiles derived from the SELSPOT measurements. To our knowledge, no other study has reported the presence of this particular asymmetrical bias in the Moro response. On the contrary, asymmetrical Moro responses have previously been related to various pathological conditions. However, Freudenberg [7] emphasized that the response in the arms could be asymmetrical if the head was turned to one side at the time when the stimulus was administered. In the present study, the heads of the infants were centered in the midline position both before and when the stimulus was applied, thus excluding a response asymmetry based on an asymmetrical position of the head. In more than 80% of the infants, it was found that the right arm started to move before the left, and in 12% the opposite was
It should be noted, however, that this asymmetry in the onset of arm movements is hardly detectable by the naked eye, due to the fact that the difference in timing is only about 0.02 sec. It is important to note that this asymmetry was stable within individuals across trials. These findings suggest that there is a fundamental, spinal asymmetry involved in the Moro response which is subject to supraspinal influences emanating from the vestibulospinal system.

Our finding, that at least one feature of the Moro response is asymmetrical, may be explained by Previc's [26] claim that vestibular lateralization may be due to a lateralized positioning of the fetus during the last trimester of pregnancy, which accordingly favors the development of a left-otolithic dominance and thereby promotes a contralateral right-sided bias in the movements and postures of the newborn. However, this explanation may not be the only one for the asymmetry found in the Moro responses. The development of the vestibular organ (membranous labyrinth) begins early in the fetal life [5]. According to Holt [10], the maturing ampullary crista becomes active as early as the eighth or ninth week of
fetal life and a feeble, Moro-like response (from vestibular receptors) can be elicited as early as the 9th–10th week of gestation. Hepper's et al. [9] observations, that the fetal thumbsucking is already predominantly right-handed from 15 weeks of gestation age, speaks for asymmetry, which, if so, will appear many weeks before a lateralized fetal position. The significance of early fetal hand positioning preference is, however, unclear.

Attempts at eliciting the Moro response in utero have not been successful [32]. This finding has plausibility in that if the vestibulum was fully functional before birth, then the fetus would react to most maternal movements—a situation that would quickly deplete fetal energy reserves. To some way, the change from the intra- to the extrauterine environment (when being exposed to the full force of gravity) triggers the onset of vestibular evoked responses such as the Moro.

Relationships between the infant's behavioral state and the segmental movements involved in the Moro response were clearly demonstrated in the present study. It was found that differences in response quality, latency and duration were a function of the infant's state. It was difficult to obtain a full-blown response when the infants were in an active awake state (State 4) or crying (State 5), and incomplete responses were most common in quiet sleep (State 1). The most stable and evident responses were found in State 3. The finger and hand movements were also found to be related to the state of the infant, but not as clearly as the arm movements. An explanation might be variations in the starting position of the fingers within each state. However, fisting of the hands (during the abduction/extension phase) was most common in State 5, whereas the clearest extension of the fingers was found in State 3. These differences are probably due to the elevated muscle power in the crying infant. The state dependency of the response was also demonstrated by the fact that the response strength, latency and other kinematic parameters such as movement amplitude did not change across trials as long as the infant's state remained constant. However, if state changed over trials, then the response was altered accordingly.

The present findings agree in general with those of Prechtl [24], who reported, for example, that the Moro response to stimulation of the labyrinth was maximally strong in State 1, as was found in the present study, but only for the extension/abduction movement pattern. In contrast, the flexion/adduction part of the response was consistently weak (or absent) in this state. Another contrast concerned the response pattern in State 2. Prechtl [24] proposed that in State 2 the Moro disappears, whereas we could elicit a regular and rather stable response in this state. Such contrasts may be related to differences in the procedures used to elicit the response. In the present study, the method of elicitation was probably much more sudden than if a response is evoked manually as in Prechtl's [24] case. It is also possible that the Moro response in State 2 may be dependent on the presence or absence of REM sleep.

As Parmelee [20], Mitchell [16] and Touwen [30] have maintained, the present data support the notion that the extensor abductor segments are the dominating phase of the response. This phase is also more stable between different states and within subjects, than the flexion/abduction phase. This indicates that there may be different, underlying neural mechanisms involved in the two phases of the Moro response. The findings of Schulte et al. [29], that the extension/abduction movement of the response is the first to be developed, as well as those of Touwen [30] and Parmelee [20], which revealed that the flexion/adduction is the first to abate and disappear, speaks for different stages of development in the two phases of the response.

Finally, the present study raises questions as to whether the asymmetry found in the Moro
response is predictive of later arm/hand preference, and how this response bias is related to other motor asymmetries in early infancy such as a lateral head position preference. These questions were beyond the scope of the present study, but deserve further investigation.

Acknowledgements—This research was supported by the Bank of Sweden Tercentenary Foundation. The author wishes to thank the mothers for participating with their infants in this project and the helpful personnel at the maternity ward at Umeå University Hospital of Sweden. She also expresses her gratitude to Claes von Hofsten and to Birgitt Rosblad for their help and constructive discussions during the ongoing study and to Brian Hopkins for his fruitful comments on the manuscript.

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