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THE ORGANIZATION OF SPONTANEOUS ARM AND FINGER ACTIVITY IN HUMAN NEWBORNS

by

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Abstract

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by

Susan P. Bewley

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To investigate the possibility that newborn spontaneous arm/finger activity is organized rather than random and diffuse, I videotaped 35 healthy full-term newborns (mean age, 38.1 hours) for five minutes, using two cameras located at right angles to each other, and coded all extensions and flexions of the infants' arms and fingers during that period. Based on an analysis of contingency coefficients, I found that (1) movement of the arm and movement of the fingers co-occurred at chance levels and (2) except in state 3, extension of the arm and extension of the fingers co-occurred significantly more often than would be expected by chance, as did flexion of the arm and flexion of the fingers, while arm extension/finger flexion and arm flexion/finger extension combinations occurred significantly less often. These findings indicate that organization is characteristic of newborn spontaneous arm and hand activity when state conditions allow it to emerge.

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Introduction

Overview

In attempting to understand the foundations of emerging perceptual/motor relations in human infants, developmentalists have typically excluded from consideration the spontaneous or unelicited upper-body activity of the newborn. Traditionally, such activity, and non-reflexive elicited activity as well, were described as random, diffuse and unorganized (Halverson, 1931; McGraw, 1941). It was assumed that cortical maturation was the means by which order would eventually be introduced into this chaos. Thus, neither spontaneous nor elicited non-reflexive activity was thought to be important to emergent organization of behavior. More recently, however, both theoretical and empirical considerations have produced a re-examination of that assumption.

Today, the spontaneous activity of the newborn is thought to be important for two reasons: (1) it exhibits organization, the presence of which sheds light on the processes involved in developing motor organization and (2) early temporally-organized activity itself is likely to influence the very form new structures take as development proceeds.

Temporally-organized activity in fullterm human newborns has been studied with regard to cyclic motility and lower-limb activity (kicking and stepping) but the spontaneous activity of the upper limbs has not been investigated for temporal organization. Since such organization, if it exists, would likely influence developing perceptual/motor organization, this study was designed to determine if such temporal organization exists in newborn arm and finger activity and, if so, whether or not it is related to other variables that might provide clues to its developmental course.

Definitions

Newborn behavior is typically divided into three categories: (1) "Spontaneous" or unelicited movement, generally defined as movement that occurs in the absence of any specific stimulus presented by a researcher and in the absence of any "obvious cues" from the environment, but occasionally more narrowly defined as movements of the limbs of animals whose spinal cords have been cut to prevent all sensory input from reaching those limbs (Robinson & Smotherman, 1992); (2) reflexes, which are well-defined, stereotyped, species-typical responses to specific stimuli (e.g., the sucking response, the Babinski response); and (3) elicited non-reflexive movements, movements that occur in response to a stimulus but which are not stimulus-specific, not necessarily well-defined or stereotyped, and do not reliably occur in response to stimulation (e.g., newborn "reaching" in the presence of a visual stimulus). The focus of the current study is the organization of spontaneous movements, in the general sense as defined above, in healthy fullterm human infants.

Theoretical Perspectives I: The Role of Spontaneous Activity in the Development of Motor Organization

The study of spontaneous movements in newborns has a two-part history, one which mirrors the two-part history of the study of spontaneous movements in embryos.

Some of the earliest investigations of the emergence of spontaneous activity in human embryos were conducted in the context of the now-outmoded nature/nurture controversy. The assumption was that if unelicited activity could be observed prior to the emergence of reflexive activity, it would support the view that a master plan for structural development existed in the genes and unfolded automatically, with no contribution from either the environment or the activity of the organism itself. Once a structure had thus developed, it would begin to function and exhibit whatever behavioral organization had been built into it as a result of the structure that had been dictated by the genes. The nervous system would continue to differentiate, and new functions would emerge, but the previously-existing activity of the organism would have no impact on this process. The alternate perspective was that, if reflexive activity emerged prior to unelicited activity, it would suggest that sensation, a physiological reaction to some form of energy impinging on a responsive sensory structure, was or could be implicated in the development of behavioral patterns through its influence on the organism's activity. This would open the door to the possibility that both environmental input and the activity of the organism itself (through self-stimulation, exercise, adaptation to feedback, etc.) could play a role in the development of the basic structures and behavioral organization of the organism.

Victor Hamburger, a major proponent of the master-plan perspective, believed, however, that observation of the order of emergence of spontaneous (in the general sense) and reflexive activity was not sufficient to support the genetic-blueprint explanation of the source of order and form in development. To provide a more rigorous test of the role of stimulation in the development of behavior, he removed parts of the spinal cord and peripheral sensory system of chick embryos prior to the onset of motility, to prevent all sensory input from reaching the lower limbs (Hamburger, Wenger & Oppenheim, 1966). He found that, up to embryonic day 15, the quantity of movement of the hindlimbs was the same in the experimental group as in controls who had spinal cord gaps but intact peripheral sensory systems. He concluded that such movements are the product of a pre-determined structure that develops without sensory input or feedback and that self-stimulation and other forms of experience are irrelevant to structural development. While this is clearly an overly-broad interpretation of the data, it does seem reasonable to conclude that sensory input and feedback were not required for the initial emergence of motility in chick embryos. In the context of the nature/nurture framework, this study seemed to provide decisive evidence for the "nature" position.

Similarly, both spontaneous and elicited non-reflexive movements of newborns were observed closely by researchers in the 1930's and 1940's, but dismissed when they appeared to exhibit no organization and no goal-directedness (Halverson, 1931; McGraw, 1941).

It should be noted that the terminology used to describe newborn spontaneous activity has changed somewhat over the years. In early reports, the term "unorganized" was used to suggest that the infant's unelicited activity was quantitatively random -- that is, that there were no systematic relations between one movement and another. The term "random" referred to the fact that both spontaneous and elicited non-reflexive activity in newborns showed no evidence of purpose or orientation to a goal. For example, dangling a pocket watch in front of an infant resulted in, at most, "random" arm-waving but nothing that looked like intentional directed reaching (McGraw, 1941). Today, the terms "organization" and "random" are both used to discuss quantitative temporal relations in activity, and the term "intentional" is used to describe volitional, purposeful behavior.

It should also be noted that the reports of the 1930's and 1940's on the nature of newborn spontaneous activity are based on clinical impressions. That is, investigators observed infants closely, but did not characterize, quantify and analyze their movements on a second-by-second basis. Nevertheless, newborn early spontaneous and elicited non-reflexive behavior was considered for subsequent decades to be irrelevant to the development of later voluntary, organized, controlled activities.

Though not mentioned by Hamburger et al. (1966), the results of their study described above also demonstrate that the observed motility is the product of local organization (the organized properties of the limb itself in the context of a particular environment) and not a central control mechanism. In retrospect, this finding seems to pre-figure more recent theoretical advances in the understanding of the development of behavioral organization.

In 1935, Nicola Bernstein (1967) published a paper on motor control in which he set out what has come to be known as the "degrees of freedom" problem. That is, the components of the motor system embody an incalculable number of "degrees of freedom." How does the central nervous system control all the parts of this system to produce rapid, accurate responses to a wide variety of complex tasks? Bernstein briefly considered this problem in terms of the development during childhood of highly skilled motor functioning, but his perspective had little impact on the major theoretical camps in this country at the time. Republished in 1967 in a collection of his papers (Bernstein, 1967), the "degrees of freedom" problem caught the attention of contemporary researchers. Thelen (1985) has outlined the current dynamic systems model of motor control, which takes into account the "degrees of freedom" problem and suggests that "coordinative structures" emerge during development. "Coordinative structures" are groups of components in the motor system that are linked to each other, so that the "degrees of freedom" each has is constrained by its functional association with other parts of the system. These coordinative structures presumably emerge during development, based initially on local organization of movement and random association of various movements in different parts of the body. Thus, in early spontaneous activity, we may be able to identify emerging relations that are in the process of becoming "coordinated."

Robinson and Smotherman (1989) have suggested that, if various parts of the body move on the basis of local properties, then it would be possible for movements in different parts of the body to become "organized," or systematically linked temporally, as a result of random association. That is, if two activities occur simultaneously often enough, they may become linked as a result of what was initially a random co-occurrence. This theory allows us to consider a process by which organization in behavior may emerge, a possibility not available in the unfolding-blueprint perspective.

If the intrinsic dynamics of moving body parts allow them to become associated with each other in systematic ways locally, without specific cortical control of each part of the system, then they are available to become the coordinative structures necessary to the dynamic systems perspective on the development of motor control. Once again, this approach allows us to leave behind the restrictive nature/nurture framework and consider development as an epigenetic process, where structure influences function and function influences structure, the brain influences behavior and behavior influences the brain, and new structures and new behavioral organizations emerge through interactions of active and passive elements of the entire system. This perspective directs our attention toward the processes of development as the source of understanding behavior.

Theoretical Perspectives II: The Role of Patterned Activity in the Development of Brain Organization

In considering how some aspects of the development of perception might be influenced by experience, Hebb (1949) proposed the concept of cell-assemblies -- groups of cells that end up firing together as a result of repeated co-activation in response to visual stimulation. They would come to do this as a result of changes at the synapse that increased the strength of the relationship between various neurons. Hebb discussed his theory specifically in terms of visual perception, but he was actually describing a general principle of the emerging organization of brain activity. This general principle is, if correct, inescapable. That is, if neurons do come into certain functional relations with each other as a result of repeated patterned afferent activity then, presumably, it would be impossible for patterned afferent activity not to have an impact on emergent functional relations in the brain. Regardless of the source of patterned activity arriving at the brain -- whether that source be a visual stimulus, an aural stimulus, a locally-organized pattern in elicited or unelicited gross motor activity, or anything else -- the organized nature of that activity would produce systematic changes in brain function.

In early infancy, the visual system and the gross motor system are both undergoing rapid change themselves and at the same time becoming integrated with each other. Presumably, the temporal organization of activity in each system contributes to the development of these relations. While there are no studies directly investigating that possibility, there exists a body of empirical evidence that points rather clearly to that suggestion.

Activity in the visual system. At birth, cortical cells in the visual system of kittens are responsive to stimulation from both eyes. Wiesel & Hubel (1963) occluded or sutured closed one eye in each of several kittens at the time of normal eye opening and continued this monocular visual deprivation for one to four months. When they subsequently opened the deprived eye and occluded the previously-open one, they found that the kittens had no visual placing response, their gait was odd-looking and hesitant, and their heads bobbed up and down in what the authors described as a "peculiar" manner. In addition, single-cell recordings from the visual cortex showed that no cells were responsive to the deprived eye and a small number of cells couldn't be driven by either eye. These results suggest that activity in the visual pathways after birth is necessary to maintain normal cortical function. But it would seem that activity in the visual system is not by itself sufficient for normal perceptual/motor development. Such activity must be coupled with activity in the gross motor system as well.

Self-produced activity in the gross motor system. Held & Hein (1963) raised pairs of kittens in the dark for 8 to 12 weeks, until they were big enough to manage the experimental conditions. Then they put each pair of kittens into an apparatus inside a lighted cylindrical chamber for three hours a day. The interior wall of the chamber was patterned in black and white stripes. The apparatus in this chamber consisted of a central post with a gondola attached to one side and a harness attached to the other side. One kitten was placed in the gondola and restrained by a neck yoke and body clamp, leaving the legs free to move but preventing locomotion. The other kitten was placed on the floor and harnessed to the gondola. This kitten was free to walk and, whenever it did, it moved the gondola and the passenger kitten as well. With this arrangement, both kittens experienced the same amount of movement and the same amount of movement-produced variation in the visual scene, but only the active kitten did so in the context of self-produced movement. Each day, the kittens were tested for the visually-guided paw placement response. On the first day that either member of the pair produced this response, both were tested on the visual cliff. In all 8 pairs, the active kitten descended to the shallow side of the visual cliff during each of 12 trials while the passive kitten chose the deep side about as often as the shallow, showing no evidence of discriminating the two. The authors concluded that self-produced movement and its own visual feedback are required for visually-guided behavior to develop. But again, it seems that activity even in both of these systems is not enough. It has to be temporally-organized. That's partly shown by this study, where the visual and gross motor activity have to be related to each other in time, but this study doesn't get at the issue of temporal organization of activity within each of the systems.

Temporally-organized activity. Luhmann, Greuel, Singer & Altmann (1987) raised kittens in the dark for 5 weeks and then introduced temporally-organized visual experience for 3 weeks, one to 3 1/2 hours a day. That organization was accomplished by fitting the kittens with goggles that were mounted with microprocessor-controlled shutters. That allowed the authors to provide visual stimulation to the two eyes in an alternating fashion. They found that when stimulation was presented to one eye and then the other in an alternating fashion, the rate of alternation had to be less than half a second (no more than 400/400ms) for normal binocular cell function to emerge. An alternation rate of as little as 500/500ms interfered with the development of binocular activity measured both behaviorally (jumping off a platform) and by means of single-cell recordings. In other words, even a slight alteration in the timing of visual activity resulted in a significant alteration in the developmental outcome.

To date, there are no studies investigating whether or not disruption of coordination in the gross motor system disrupts development of perception or perceptual/motor relations. The Held & Hein (1963) study showed that de-coupling gross motor activity from changes in the visual scene interfered with such development, but it didn't address the question of organization within the gross motor activity.

However, taken together, these studies seem to suggest that non-reflexive, non-elicited, temporally-organized activity is critical to normal perceptual/motor development in kittens.

If emerging coordinative structures play a role in the development of motor control, and spontaneous temporally-organized activity contributes to normal perceptual/motor development, then we should expect to find such organization emerging in the immature developing human.

Identifying Organization in Motor Activity

The basic characteristic of organization in motor behavior is temporal patterning of movement. Robinson and Smotherman (1988) have described three forms this patterning may take: (1) synchrony, where movement occurs in two or more parts of the body simultaneously, (2) asynchronous temporal patterning, as when behavior occurs cyclically, in regular bouts and (3) sequential ordering of specific movements in a chain that reliably recurs, as when hand-mouth contact is followed by sucking. The first form, synchrony, refers to simultaneous movement of any kind in different body parts, without regard to the nature of the movements, but of course specific movements in different body parts may be linked in this manner as well.

Emerging synchrony, the first type of organization delineated above, is a relatively new area of investigation with regard to human infants. Synchrony in developing state organization has been studied in the fetus (DiPietro, Hodgson, Costigan, Hilton & Johnson, 1996; Nijhuis, Prechtl, Martin & Bots, 1982), the preterm infant (Dreyfus-Brisac, 1970; Prechtl, Fargel, Weinmann & Bakker, 1979) and the fullterm infant (Prechtl, 1977), as well as in the context of relationships between fetal and newborn states (Pillai & James, 1990). Some data exists on emerging linkages of specific movements in specific body parts in human newborns (e.g., leg movements, Thelen & Fisher, 1982, 1983; Thelen, Fisher, Ridley-Johnson & Griffin, 1982; Thelen, Fisher & Ridley-Johnson, 1984) but no data exists on emerging relations between arm and finger movement during the first days of postnatal life.

Research on Spontaneous Motor Activity in Human Newborns

The resurgence of interest in spontaneous newborn activity over the past two decades has produced a large number of studies, but most are concerned with the amount or the quality of such activity, rather than its organization. For example, Erkinjuntti (1988) studied body movements during sleep in 16 healthy fullterms and 21 infants with abnormal neurological signs at birth. The infants were placed on a static charge sensitive bed (SCSB), a specially-constructed mattress that is capable of recording even very low-amplitude movements. The movements were then divided into three categories: (1) major movements (lasting more than 5 seconds), (2) minor movements (2-5 seconds) and (3) twitches (1 second or less). Thus, the authors were able to calculate the number and duration of such movements, but information on relationships among movements cannot be obtained by this method.

A slightly different approach to the quantification of newborn movement is to determine the frequency of specific types of movement. The type of movement selected depends, of course, on the question(s) that prompted the study. Researchers interested in the development of hand preference, for example, have investigated laterality of arm movement in newborns. Ottaviano, Guidetti, Allemand, Spinetoli and Seri (1989) conducted such a study, and recorded arm extension, arm flexion and movement of the arm toward the midline, for both right and left arms, and in both the absence and presence of a visual target. Whether or not this study can be considered a study of "spontaneous" movement is an open question, however, because the infants were strapped to a foam rubber mattress that was backed by a wooden board and slanted at a 30-degree angle. The mattress also contained a hollowed-out section for the baby's head, to reduce head movement. Thus, the infants were not free to move their bodies or heads spontaneously, and this is quite likely to have affected the arm movement observed. In any event, the researchers tabulated right-arm and left-arm movements, but did not report on relations between them, and did not record finger movements.

Typically, studies on spontaneous movement in newborns do not include descriptions of finger movement. One exception is a study by Konishi, Takaya, Kimura, Takeuchi, Saito and Konishi (1997), which investigated laterality of finger movements in preterm babies. The finger movements recorded were: (1) making a fist for at least 3 seconds, (2) opening all the fingers for at least 3 seconds and (3) other movement of the fingers. These movements were recorded for both the left and the right hand, but relations among these movements were not analyzed, and movement of the arms was not recorded.

One study that considered both arm and finger movement was reported by Thelen (1979). She had noted in the literature a variety of interpretations of the stereotyped behaviors exhibited by infants and children. Concluding that these behaviors could have developmental significance for both normally- and abnormally-developing babies, she attempted to describe such activities and delineate their developmental course in normal babies. She identified stereotyped behaviors by observing babies and noting those behaviors that were repeated "in the same form" (Thelen, 1979, p. 700) a minimum of three times in a brief period, with no other type of movement occurring between the repetitions. These criteria yielded 47 different stereotyped behaviors that occurred during the first year, including a number involving arms and fingers. However, relationships among the various arm and finger stereotypies were not investigated, and no data was reported for infants under the age of 6 weeks.

In addition to studies that focus on the amount of spontaneous movement exhibited by newborns, many investigations of the quality of infant spontaneous movements exist. Pediatric neurologists have long been interested in the amount of movement infants exhibit, the postures they adopt and the quality of muscle tone observed. However, it was Heinz Prechtl who eventually systematized the assessment of general movements in infants. In 1979, Prechtl, Fargel, Weinmann and Bakker presented data on the amount of general movement exhibited by low-risk preterms at various conceptional ages, and briefly described the quality of these movements: "unco-ordinated, slow, writhing movements of arms, legs and trunk, often including the head (p. 5)." In this paper, the authors also included data on respiration, posture of head, arms and legs, stretches, startles, twitches, cloni, mouth movements, slow and rapid eye movements, hand-mouth and hand-face contact, yawns, hiccups, sneezing, smiles and crying. Subsequently, Prechtl and his colleagues began to focus more closely on general movements, having come to believe that the quality of these movements is an important characteristic of the development of both normal and at-risk infants. Hopkins and Prechtl (1984) published a longitudinal study of 12 healthy, fullterm infants who were observed at 3, 6, 9, 12 and 18 weeks of age. In this paper, they provided a more complete description of the quality of general movements (writhing, fidgety, wiggling-oscillating, saccadic and swiping qualities were described), as well as the changes in quality of general movements that they observed over the first 18 weeks of life. In 1989, Cioni, Ferrari and Prechtl published data on the posture and movements of 10 healthy fullterms on the first and fourth days of life, again including both general movements and other types of movement. With the publication of this study, together with the above-mentioned papers, data was now available on the general movements of preterms, fullterm newborns and fullterm babies to 18 weeks of age. In 1990, Prechtl published an editorial in the journal Early Human Development in which he made the case for the assessment of general movements as a powerful diagnostic tool in the evaluation of at-risk infants. In the same issue of Early Human Development, Ferrari, Cioni and Prechtl (1990) published a study of the general movements of 14 low-risk and 29 high-risk preterms, showing that the assessment of the developmental course of general movements was a better predictor of later outcome than was the type or developmental course of brain lesions. Since then, numerous studies using this assessment procedure have been conducted with various sub-categories of at-risk infants. This methodology appears to differentiate quite well infants who will later have sub-optimal outcomes from those who will not. It is not designed to provide information about emerging organization in arm and finger activity, and does not. However, Prechtl (1990) has argued that the "writhing" quality of general movements seen in normally-developing babies contains a Gestalt quality of organization (despite his early description, quoted above, that defines these movements as "unco-ordinated"), and that the general movements of compromised babies do not contain this quality of coordination. Prechtl notes that, in the study of low-risk and high-risk preterms published by Ferrari, Cioni and Prechtl (1990), quantification of specific movements (e.g., patterns of finger movement) was not helpful in predicting outcome. However, perhaps investigating linkage among various types of movement would provide a clearer picture of the components of the Gestalt to which Prechtl refers.

Prechtl's method has also been used to study stability of individual differences in motility from fetal to postnatal life in healthy fullterms. Groome, Swiber, Holland, Bentz, Atterbury and Trimm (1999) investigated the duration of general movements in 22 fetuses between 38 and 40 weeks gestational age, and again postnatally when the babies were two to four weeks old. Because the authors were interested in stability of individual differences, each subject was videotaped (via ultrasound) three times prenatally and (directly) three times postnatally. For the fetuses, the presence of general movements was inferred from the presence of head movements, a method the authors had previously validated. For the newborns, a single video camera was positioned to capture the head and trunk movements of the infant, and presence or absence of general movements was scored accordingly. This study was carefully designed and rigorously controlled, and, for its purpose, provides much interesting information. However, once again, such a design cannot provide any insight into the organization of newborn movements.

Finally, Piek and Carman (1994) employed both Thelen's (1979) and Hopkins and Prechtl's (1984) categories to investigate the spontaneous activity of infants from two to 50 weeks of age. In addition, they recorded all other spontaneous movements not included in either Thelen's or Hopkins and Prechtl's catalogs. For all of these movements, they reported the frequency of bouts of movement, but did not analyze the relations among movements.

To date, only one study on temporal relationships between various types of arm and finger movement exists. Hayes, Plante, Fielding, Kumar & Delivoria-Papadopoulous (1994) studied the spontaneous activity, including arm and hand/finger movement, of premature infants at conceptional ages ranging from 25 to 34 weeks. They used direct observation, rather than videotaping the babies, and divided their hour-long observation period into 1-minute blocks. They then used a 1/0 time sampling method (1 minute of observation followed by 1 minute for recording the observations, then another minute of observation followed by a minute of recording, etc.). For each minute of observation, they recorded the presence or absence of each type of movement (arm, leg, facial, head, eye, etc.) regardless of how many times that movement occurred during the minute. Thus, the actual frequency of each type of movement was not recorded, and, as the authors note in their discussion, the question of whether or not any movement occurred simultaneously with any other movement, either at chance or greater or less than chance levels, cannot be addressed on the basis of this data.

One other set of studies suggests that systematic relationships between arm and finger movement might be found in infants in the early postnatal period. These studies are concerned with elicited non-reflexive upper body activity, rather than spontaneous movement. In this context, several investigators have attempted to elicit "reaching" or "pre-reaching" in newborns, with mixed results.

The study that initiated this line of investigation was conducted by Bower, Broughton and Moore (1970). They reported evidence of directed reaching in five infants aged 6-11 days, and further evidence of intention in the visually-guided reaching of 11 infants ranging in age from 8 to 31 days old. This study was quite controversial, because it appeared to have significant implications for our understanding of how developmental change occurs, how we conceive of a human newborn and how we investigate the emergence of perceptual/motor integration. That is, if human babies are born with the ability to focus on an object, decide to try to obtain it, and organize their behavior to that end, then they have cognitive and perceptual/motor functions that would seem to require little in the way of development post-natally. The finding of such abilities raised profound questions about what could be happening pre-natally to produce such a result.

Ruff and Halton (1978) attempted to replicate the first finding reported in the above study, and were unsuccessful. In both the original study and the attempted replication, the movement of the arm was the focus and no mention was made of finger activity. However, Bower (1972) had also reported that infants reached differentially towards objects and pictures, showing many more reaches toward objects than pictures, and in that report did suggest that the fingers of the reaching limb conformed appropriately to the size of the object to be apprehended. It was this study that prompted additional investigation of the relationship between arm movement and finger activity in the presence of a visual stimulus. DiFranco, Muir and Dodwell (1978) recorded the form of the hand (i.e., fisted, open or "shaped") in association with arm movement, but did not record the actual movement of the fingers in association with arm movement. Subsequently, Von Hofsten (1984) did provide some data on extension (but not flexion) of the fingers. He presented 1-week-old infants with a moving visual stimulus in two blocks of trials, the blocks separated by one minute during which the object was absent. He found that approximately 35% of forward arm extensions were accompanied by simultaneous finger extension when the infant was not looking at the object, and 40% of arm extensions were accompanied by finger extensions when the infant was fixating the object. No data is reported for finger extension in the object-absent condition. Because the focus of this study was forward arm extension, there was also no data reported for side extensions or for flexions, or for the finger activity associated with them. It was therefore not possible to determine whether or not the 35-40% figure represents a relationship exceeding chance levels.

One final activity of human newborns that suggests a relationship between arm and finger movement is the Moro response. This reflex would appear to demonstrate both synchrony and sequential ordering of movement in its characteristic abduction of the shoulders and extension of the elbows and fingers, followed by adduction of the shoulders and flexion of the elbows and fingers simultaneously in both arms in response to vestibular stimulation. While the apparent organization in this response has not been quantified and terms such as "simultaneous" and "organized" represent clinical impressions only, the response is extraordinarily robust and has been observed so often by so many pediatric neurologists that I view it as highly unlikely that a quantitative analysis would reveal that this response is not in fact well organized.

Perhaps the most important point about the observations of newborn "reaching" and the Moro response is that they represent what had been considered to be two distinct categories of behavior: primitive reflexes and elicited non-reflexive behavior. These were, and often still are, thought to be organized differently, to involve different mechanisms and to have different developmental courses. That they may exhibit similar properties of organization suggests that these categories may be simply different expressions of the same functional relations, elicited through different combinations of state, posture and stimulus. That is, while the neural pathways that trigger these behaviors may be different, the <u>form</u> the behavior takes may be similar because it depends on local properties of the system (relations among bones, joints, tendons, gravity, amount of energy being expended, etc.). Bernstein (1967) pointed out that this sort of phenomenon is characteristic of motor control. If this were the case, it would not be surprising to find that such organization also emerges in unelicited behavior, at least under some state conditions.

The Role of Infant State in Spontaneous Activity

In adults, a variety of different sleep and waking states have been identified. These states do not exist in their adult form in newborn infants, but the development of differentiated states begins prenatally and is well under way in fullterm infants at birth (Nijhuis, Prechtl, Martin & Bots, 1982). Most researchers agree that, at birth, five discrete states can be observed. Each state is characterized by distinctive cardiac, respiratory, and EEG patterns, and specific behaviors such as eyes open or closed, presence or absence of different kinds of vocalizations and presence or absence of gross motor activity. Although it is preferable to refer to infant states by number (state 1, state 2, etc.) to avoid imposing inappropriate qualitative adult characterizations on infant behavior, researchers typically use just such an "incorrect" shorthand to refer to infant states. State 1 is often called "quiet sleep," state 2 "active sleep," state 3 "quiet awake," state 4 "active awake," and state 5 "crying."

Many observers have noted that infant state plays a significant role in newborn spontaneous behavior. Wolff (1966) investigated a subset of spontaneous behaviors, those that exhibited "a coherent and recognizable configuration that remains stable from one day to the next[, i.e.,] ... startles, sobbing inspirations, facial twitches, rhythmical mouthing, and erections" (Wolff, 1966, pp. 11-12). He found that such activities were highly state-dependent, to the extent that some could only be observed in certain states and never occurred in others. Wolff also studied some additional "specific motor patterns" (p. 49) in relation to time since last feeding, but not in relation to state. He deliberately excluded all other unelicited motor behavior from consideration because he assumed that the rest of an infant's spontaneous behavioral repertoire was not characterized by any kind of organization.

Feldman and Brody (1978) investigated Wolff's "specific motor patterns," which included kicking, mouthing, tongueing, and hand-face and hand-mouth contacting, in relation to state. They found that these behaviors were also state-dependent, occurring most frequently in states 4 and 5.

A number of other investigators (e.g., Korner, 1969 and Prechtl & Beintema, 1964) have observed a systematic relationship between amount and kind of activity and infant states. While there are no studies of all spontaneous arm and finger activity in newborns in relation to state, it seems likely, from the studies of other types of newborn motor behavior, that the rate of occurrence of specific arm and finger activity will be different in different states. Such differences could result in different rates of co-occurrence of two particular behaviors in different states. For this reason, specific relations among behaviors could emerge in some states and not others.

The Current Study

On the basis of these considerations, Bewley and Turkewitz (1994) videotaped 6 healthy full-term infants in various states and found statistically significant state-dependent relations between arm extension and finger extension and between arm flexion and finger flexion in all of the infants.

In the current study, I attempted to replicate these initial findings with a larger group of babies and expand the analysis in two general areas: (1) I investigated whether or not this organization was related to birth weight, estimated gestational age or post-natal age and (2) derived a measure of "tightness of coordination" so that the quality of infants' spontaneous activity might be quantified for diagnostic purposes.

Method

Subjects

35 healthy, full-term newborns, 17 females and 18 males, participated in this study. They were all born between July 1997 and October, 1998 in the Weiler Hospital of Albert Einstein College of Medicine, Bronx, New York and met the following criteria: (1) the mother had been invited to have her infant in the study and had agreed, (2) there had been at least 6 pre-natal care visits, an uncomplicated pregnancy and vaginal delivery accompanied by no anesthetic or a local anesthetic only, (3) the infant's one-minute and five-minute Apgar scores were at least 8 and 9, respectively, (4) no special care, testing or observation was required, (5) estimated gestational age was 37 to 42 weeks (actual range 38 to 41 weeks, mean 39.7 weeks, s.d. .9), (6) birthweight was 2500 to 4200 grams (actual range 2925 to 3990 grams, mean 3417.6 grams, s.d. 273.4) and (7) the baby had not been circumcised within the preceding 24 hours. The infants' post-natal ages ranged from 17.5 hours to 49.7 hours, mean 38.1 hours, s.d. 8.1. All but 5 babies had post-natal ages between 24 and 48 hours.

Equipment

In order to obtain an accurate record of the infants' movements in three planes, I used two video cameras located at right angles to each other, one positioned at the head of the examination table and the other at the left side. The images from both cameras were fed into a mixer that created a split-screen video recording, enabling us to view the babies' movements from two different angles simultaneously. Time code was added to the video tapes subsequently.

Procedures

The babies were brought into a small nursery and placed on an infant examination table. They were dressed in T-shirts and diapers, and were swaddled from the waist down with their arms and hands free to move. They were videotaped for five minutes in a supine position with their heads initially centered in the midline position. Taping began without regard to the infant's state, which was later scored continuously from the videotape.

State classification system. My state classification system was based on that of Prechtl (1977) as follows:

State 1 - eyes closed, little or no gross motor behavior (startles may occur), no vocalizations.

State 2 - eyes closed, gross motor behavior present, no vocalizations.

State 3 - eyes open, little or no gross motor behavior, no vocalizations.

State 4 - eyes open, gross motor behavior present, no vocalizations.

State 5 - eyes open or closed, gross motor behavior present, vocalizations (crying).

Not all babies exhibited every state during videotaping. Table 1 shows the number of babies who contributed data for each state, along with their demographic characteristics. One-way analyses of variance revealed no differences among the state groups on any of these variables. Since some babies contributed to more than one state, there is a violation of the ANOVA requirement for independence. However, because of the small number of babies in that category, I believe this test produces a reasonable approximation here.

Table 1

Demographics by State.

	State			
	2	3	4	5
N	15	15	15	19
Mean BW in grams (S.D)	3481.8 (284.9)	3360.3 (308.3)	3358.3 (275.2)	3464.3 (271.9)
Mean EGA in weeks (S.D.)	39.5 (.9)	39.6 (.9)	39.9 (1.0)	39.7 (.8)
Mean PNA (Postnatal Age) in hrs. (S.D.)	35.2 (10.3)	41.1 (4.8)	38.6 (5.1)	36.3 (7.9)

Note. BW=birthweight; EGA=estimated gestational age; PNA=postnatal age.

Movement coding system. To determine the relationship between flexion and extension of the arms and fingers, I coded all of the flexions and extensions of the right arm and fingers on a second-by-second basis. A "flexion" of the arm was defined as a movement that decreased the angle of the elbow and an "extension" was defined as an increase in the angle. A "flexion" of the fingers was recorded when one or more of the fingers closed, and an "extension" when one or more of the fingers opened. Because infants can easily produce more than one discrete movement in the space of a second, I used the one-second time unit only as a basis for keeping track of where I was on the tape and determining reliability. The coding system itself was based on what I termed an "epoch of movement." An epoch began when the arm or one or more fingers began to extend or flex, or when the arm and at least one finger began to extend or flex simultaneously. The epoch ended when there was a change in the movement of either the arm or the fingers. For example, if a baby extended arm and fingers simultaneously, then flexed the fingers with the arm still extended but not moving, then flexed the arm without moving any of the fingers, and then fell still, four epochs of movement would be recorded. The first would be characterized as simultaneous extension of arm and fingers, the second as finger flexion only, the third as arm flexion only, and the fourth as no movement of either arm or fingers. If the first two epochs occurred in the same second (let us say, 5 minutes and 7 seconds after the hour), the third epoch occurred in the next second, and the fourth in the next, the code sheet would be marked as follows:

Minute:Second	Arm	Fingers
05:07	E	E
	N	F
05:08	F	N
05:09	N	N

With regard to finger movement, babies sometimes extend one or more fingers while simultaneously flexing one or more of the others on the same hand. (While this is difficult for adults to do, you may be able to create a sketchy version if you hold your fingers in a relaxed, slightly curled position and then try to extend your index finger and pinkie while simultaneously flexing the two middle fingers. Infants produce this and other such combinations with great speed and facility.) When the fingers moved in this way, the movement was coded as "mixed" and I intended to treat it as a separate category in subsequent analyses. However, there were so few of these movements (less than a dozen across all 35 babies) that this category was not further analyzed.

It should be noted that my concern was with the character of the movement and not with its final static position. For example, an extensor movement did not have to result in a fully extended arm or finger to be counted as an extensor movement, and a flexion of the fingers did not have to result in a tight fist to be counted as a flexor movement. The type of movement, and not its final outcome, was the focus.

Reliability. Two trained coders independently coded all of the movements of five infants (a total of 977 epochs of movement) and their agreement on the state and movements observed in each epoch was determined for each of the five babies. Agreement on all three elements of an epoch (state, movement of arm, movement of fingers) ranged from 81% to 88%. Cohen's kappa ranged from .76 to .86.

Results

The central questions of this study were (1) are there coordinated movements of the arm and fingers in the human newborn's spontaneous activity and (2) if so, are these relationships state-dependent? That is, does movement of the arm and movement of the fingers co-occur more often than would be expected by chance? Does extension of the arm occur with extension of the fingers at greater than chance levels, or does flexion with flexion? Does the infant's state influence whether or not such co-occurrence emerges? In terms of basic probability theory, these questions can be restated in the general form: given the frequency of behavior x and the frequency of behavior y, how often would we expect behavior x and behavior y to co-occur by chance if they were independent of each cther, and is the actual co-occurrence of these behaviors significantly greater (or less) than the expected chance co-occurrence?

Frequency of Movement

As is shown in Table 2, state influenced both the rate of movement and the proportion of arm-to-finger movement. The rates were much higher in states 4 and 5 than in any other state for both arm and finger movements. In addition, arm and finger movement occurred at nearly equal rates in state 5, while finger movement occurred at greater rates than did arm movement in all other states.

Table 2

Rate of Movement in Relation to State.

	State			
	2	3	4	5
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
Arm movements/sec.	.17 (.16)	.12 (.08)	.35 (.18)	.52 (.24)
Finger movements/sec.	.31 (.24)	.23 (.19)	.49 (.16)	.61 (.19)
Total movements/sec.	.48 (.39)	.35 (.18)	.84 (.30)	1.12 (.38)
Simult. movements/sec.	.12 (.12)	.05 (.05)	.24 (.16)	.34 (.18)

Co-occurrence of Movement

Chi-square analysis revealed that the co-occurrence of movement of the arm and fingers did not differ from chance levels for two-thirds (23 of 35) of the infants across states or within any state. For the remaining third, no clear pattern emerged. Table 3 is an example of a chi-square for a typical baby, showing no significant association between arm and finger movements across states. Table 4 provides a summary of these results, across states and within states. Appendix A shows detailed results of this analysis for each baby, across states and within states.

Table 3

Example of a Chi-square for a Typical Baby.

	Finger Movement	
Arm Movement	N	Y
N: Actual Expected	42 40.8	48 49.2
Y: Actual Expected	21 22.2	28 26.8

p=.67

Note. Y=Yes (movement occurred) and N=No (no movement occurred).

Table 4

Significant vs. Non-Significant Association.

	Across States	State 2	State 3	State 4	State 5
Association between arm and finger movements did not differ from chance.	25	12	11	11	17
Arm and finger movements co-occurred significantly more often than would be expected by chance.	10	3	1	4	2
Arm and finger movements co-occurred significantly less often than would be expected by chance	0	0	1	0	0
No arm movement occurred	0	0	2	0	0
Total	35	15	15	15	19

Note. Number of infants who showed a significant vs. non-significant association between arm and finger movements, across and within states.

Relationships between co-occurrence of movement and rates of movement. Did rate of movement influence association between arm and finger movement? A t-test revealed that babies who showed a significant association between arm and finger movement across and/or within any state had a higher mean rate of movement than babies who did not (mean=.78 vs. .52, t=2.21, $p<.05$).

Relationships between co-occurrence of movement and demographic variables, across states. It was revealed by t-tests that babies who showed no significant association between arm and finger movement did not differ from those who did on BW, but had a slightly lower mean EGA (39.4 weeks vs. 40.0 weeks, t=-2.03, $p=.05$) and a tendency toward a lower PNA (36.4 hours vs. 41.5 hours, t=-1.84, $p=.07$).

In other words, older babies were more likely to show a significant association between arm and finger movement than were younger babies.

Relationships between rates of movement and demographic variables, across states. There were no significant correlations between overall rate of movement, rate of arm movement or rate of finger movement with BW, EGA or PNA.

Summary of relationships between association of arm and finger movement, rates of movement and demographic variables, across states. Babies who moved more were more likely to show linkage between arm and finger movements, and babies who were older were more likely to show such linkage, but older babies did not move more than younger babies. Thus it seems that both rate of movement and age influenced linkage independently.

Relationships between co-occurrence of movement and rates of movement, within states. As can be seen in Table 4, the number of infants in each state who showed a significant association between arm and finger movement was too small to permit analysis of this variable in relation to rates of movement.

Relationships between co-occurrence of movement and demographic variables, within states. Again, as can be seen in Table 4, the number of infants in each state who showed a significant association between arm and finger movements was too small to permit analysis of this variable in relation to other variables.

Relationships between rates of movement and demographic variables, within states. There was a significant negative correlation between rate of movement and PNA in State 3. This was due to significantly decreasing finger movement as the babies got older. By contrast, arm movement in State 3 increased non-significantly as the babies got older. There was also a significant negative correlation between rate of finger movement and EGA in State 3. The relationship between total movement and EGA in State 3, however, was non-significant, though also negative. The relationship between arm movement and EGA in state 3 was positive and non-significant. In state 5, a positive relationship between EGA and rate of arm movement approached significance ($r=.42$, $p=.08$).

Summary of relationships between association of arm and finger movement, rates of movement and demographic variables, within states. Analyses of relationships between association of arm and finger movement and rates of movement or demographic variables within states could not be performed due to the small number of infants in each state who exhibited a significant association between arm and finger movements. With regard to relationships betweeen rates of movement and demographic variables, in general, there were small and non-significant positive relationships between rates of movement and EGA and PNA. The exception was state 3, where there were some negative relationships between rate of finger movement and age (both EGA and PNA). As age went up, finger movement decreased in state 3.

Co-occurrence of Specific Types of Movement

When either the arm or the fingers move alone, there is no opportunity for linkage among particular movements to develop. When both the arm and the fingers are moving, there is the possibility for relations among specific high-rate behaviors to become established. For that reason, I wanted to know what patterns might obtain when both the arm and fingers are moving. I therefore performed a separate analysis of only those epochs of movement in which both arm and fingers moved, and found that, for 22 of the 35 infants, the distribution of extensions and flexions was significantly different from what would be expected by chance. Moreover, the distribution revealed a most interesting pattern: extension of the arm was paired with extension of the fingers more often than would be expected by chance, and flexion of the arm was paired with flexion of the fingers more often as well. In addition, extension of the arm was paired with flexion of the fingers less often than would be expected by chance and flexion of the arm was paired with extension of the fingers less often than would be expected. I refer to this pattern (more extension/extension and flexion/flexion, less extension/flexion and flexion/extension) as the basic, or "canonical," pattern. Table 5 shows an example of this canonical pattern that was produced by a two-day-old infant boy in State 5.

Table 5

Example of Statistically Significant Canonical Pattern.

Movement of the Arm		Movement of the Fingers Extension	Flexion
Extension:	Actual	21	3
	Expected	8.7	16.0
Flexion:	Actual	6	47
	Expected	18.3	34.0

$p < .01$

In addition to the 22 infants for whom this pattern was statistically significant, 10 more infants showed this pattern non-significantly. Table 6 provides an example of this type of result, produced by a two-day-old infant girl in State 2.

Table 6

Example of Non-Significant Canonical Pattern.

Movement of the Arm		Movement of the Fingers Extension	Flexion
Extension:	Actual	8	5
	Expected	5.5	7.5
Flexion:	Actual	8	17
	Expected	10.5	14.5

$p = .08$

Chi square analysis revealed that there was no relationship between association of arm/finger movement and significance of the canonical pattern. That is, co-occurrence of arm and finger movements differed significantly from chance levels for a third of the babies, and not for the other two-thirds, but the distribution of significant and non-significant canonical patterns of arm/finger movements across these two groups did not differ from the distribution that would be expected by chance.

That is, despite the fact that typically there was no significant association between arm and finger movement, organization was found in the simultaneous movements of the arms and fingers. A reconsideration of Table 3 should clarify these findings. Table 3 shows the chi-square for one baby's arm and finger movements. For this baby and for the majority of babies, there was no significant association between arm and finger movements. However, when only those movements from the lower right-hand cell for each baby were considered, I found significant relationships between arm flexion and finger flexion and between arm extension and finger extension (the canonical pattern), for 22 babies and a non-significant canonical pattern for an additional 10.

Only 3 of the 35 infants did not show the canonical pattern. The exceptions were Baby 70, who was in state 3 throughout the taping, Baby 142 (state 5) and Baby 196 (state 2). As Table 7 shows, the canonical pattern generally holds for states 2, 4 and 5, but not for state 3. Appendix B shows the canonical/non-canonical patterns for each baby, across and within states. Appendix C shows detailed results for each baby across and within states.

Table 7

Summary of Canonical and Other Patterns.

	Across States	State 2	3	4	5
Canonical - Significant	22	5	1	12	12
Canonical - Non-Signif.	10	6	3	3	3
Non-Canonical	0	0	0	0	0
Neither Canonical nor Non-Canonical*	3	3	5	0	4
No Simultaneous Movements or Too Few to Analyze	0	1	6	0	0
Total	35	15	15	15	19

*These babies' arm and finger extensions and flexions co-occurred exactly as often as would be predicted by chance. That is, the probability of a distribution as different from the expected as this was 1.0 for these infants.

Although these results are quite robust, there is some degree of variability in the data. Only 3 babies did not exhibit the canonical pattern across states but, of those who did, almost a third showed non-significant patterns. This raises the question of the relationships between significant and non-significant patterns and rates of movement and demographic variables.

The Relationship between significant vs. non-significant canonical patterns and rates of movement, across states. The t-tests revealed highly significant differences (all $p<.01$) between significant vs. non-significant canonical patterns and rate of arm movement, rate of finger movement and overall rate of movement. Babies who moved more were likely to show statistically significant canonical patterns and babies who moved less were likely to show canonical but non-significant patterns.

The relationship between significant vs. non-significant canonical patterns and demographic variables, across states. There were no significant differences between significant vs. non-significant canonical patterns on BW, EGA or PNA.

Tightness of Coordination

The fact that almost a third of the babies who showed the canonical pattern across states showed a non-significant pattern also raises the question of the "tightness" of coordination and its relationship to other variables. For example, is there a relationship between such coordination and association of arm and finger movements? Do babies with lower birthweights or EGAs show "looser" organization of movement than larger, "older" newborns? Does post-natal age make a difference?

To investigate these questions, I derived a measure of "tightness of coordination" (TOC) for each baby by dividing the number of "coordinated" movements (arm extensions paired with finger extensions plus arm flexions paired with finger flexions) by the total number of paired movements. The resulting score was then used in various analyses to discover any relationships between coordination and other variables, as described below.

The relationship between TOC and presence or absence of a significant association between arm and finger movement, across states. A t-test showed that, across states, mean TOC did not differ on the basis of the presence or absence of a significant association between arm and finger movement.

The relationship between TOC and demographic variables, across states. Pearson correlations revealed that there was no relationship between TOC and BW or PNA. TOC and EGA were significantly negatively correlated ($r=-.36$, $p<.05$). A negative correlation between TOC and PNA approached significance ($r=-.31$, $p=.07$).

The relationship between TOC and association of arm and finger movement, within states. The number of infants in each state who showed a significant relationship between arm and finger movement was too small to permit this analysis (see Table 4).

The relationship between TOC and demographic variables, within states. TOC was not related to BW or EGA in any state. TOC was, however, negatively correlated with PNA in state 2 ($r=-.59$, $p<.05$) and state 4 ($r=-.56$, $p<.05$). In states 3 and 5, on the other hand, TOC and PNA were positively but non-significantly correlated [state 3 ($r=.60$, $p=.09$); state 5 ($r=.20$. $p=.42$)]. Table 8 shows the correlations, with number of cases and probability, between TOC and BW, EGA and PNA, across states and within states.

Table 8

Correlations between TOC and Demographic Variables.

	Across States	State 2	State 3	State 4	State 5
BW	-.02 (35) p=.90	-.21 (14) p=.47	.25 (9) p=.52	.27 (15) p=.32	.17 (19) p=.48
EGA	**-.36** (35) p=.04	-.37 (14) p=.19	-.28 (9) p=.46	-.34 (15) p=.22	.08 (19) p=.73
PNA	-.31 (35) p=.07	**-.59** (14) p=.03	.60 (9) p=.08	**-.56** (15) p=.03	.20 (19) p=.42

Note. Numbers in parentheses are the number of cases. Significant correlations are in boldface type.

Summary of relationships between TOC, association of arm and finger movement, rates of movement and demographic variables, across and within states. Across states, there were no significant relationships between TOC and arm/finger association or other variables, except for a significant negative relationship with EGA. Within states, there were few relationships between TOC and any other factor. The exception was state 2, where TOC was higher when the babies were younger (a significant negative relationship between TOC and PNA). In addition, in state 4, younger babies showed more TOC.

Gender Differences

Given that rates of movement had some influence on the organization found in newborns' movement, and a visual inspection of the data suggested that boys might have exhibited higher rates of movement than did girls, I analyzed the data for boys and girls separately. Sex differences of this kind are rarely found in newborns, and this comparison was therefore not a part of the original design of the study. As a result, there were very small N's for boys and girls in each state. Despite that fact, I include the results for boys and girls here, not only across states but within states, because they suggest further study with larger N's.

When girls and boys were analyzed separately, the boys showed all of the significant results described above for the demographic variables with the exception of the negative relationship between TOC and EGA, which was negative for boys but non-significant. Boys also showed a significant positive relationship between TOC and PNA in state 3 ($r=.87$, $p=.05$). There were no significant relationships for girls between TOC and any of the other variables across states or in any state. In addition, the correlations for girls were not always in the same direction (positive or negative) as those of the boys. Tables 9 and 10 show the correlations for boys and girls, respectively, between TOC and various demographic variables, across and within states.

Table 9

Correlations for Boys between TOC and Demographic Variables.

	Across States	State 2	State 3	State 4	State 5
BW	.10 (18) $p=.69$	-.41 (8) $p=.31$	.76 (5) $p=.14$	.11 (5) $p=.86$	.52 (11) $p=.10$
EGA	-.22 (18) $p=.37$	-.42 (8) $p=.30$	.10 (5) $p=.87$	-.42 (5) $p=.48$	.19 (11) $p=.57$
PNA	-.34 (18) $p=.17$	**-.74** (8) $p=.04$	**.87** (5) $p=.05$	**-.88** (5) $p=.05$	.16 (11) $p=.64$

Note. Numbers in parentheses are the number of cases. Significant correlations are in boldface type.

Table 10

Correlations for Girls between TOC and Demographic Variables.

	Across States	State 2	3	4	5
BW	-.28 (17) p=.28	.33 (6) p=.52	.22 (4) p=.78	.12 (10) p=.73	-.42 (8) p=.30
EGA	-.39 (17) p=.12	-.32 (6) p=.54	.72 (4) p=.28	-.20 (10) p=.58	-.32 (8) p=.44
PNA	-.17 (17) p=.50	.15 (6) p=.78	.76 (4) p=.24	-.28 (10) p=.44	.31 (8) p=.46

Note. Numbers in parentheses are the number of cases. There were no significant correlations for girls.

Given the gender differences described above, t-tests were performed to determine if boys differed from girls on any demographic variables, on rates of movement or on TOC across or within states.

Across states, the boys were, on average, several hours younger than the girls (boys' mean PNA=34.8 hours; girls' mean PNA=41.7 hours) and this difference was significant ($t=-2.74$, $df=33$, $p=.01$). The difference in EGA between boys and girls was slight (boys' mean EGA=39.3 weeks; girls' mean EGA=40.0 weeks) but it was significant ($t=-2.22$, $df=33$, $p<.05$). Boys and girls did not differ in BW, TOC or any rates of movement.

Within states, individual t-tests revealed that boys and girls who contributed data for a particular state did not differ on EGA or PNA for any state; boys who contributed data for state 5, however, were slightly younger on both measures and the differences approached significance. Boys who contributed data to states 4 and 5 were heavier than girls who contributed data for those states. For state 4, boys' mean BW was 3632.0 grams; for girls, it was 3221.5 grams ($t=3.83$, $p<.01$). For state 5, boys' mean BW was 3600.9 grams and girls' was 3276.5 grams ($t=3.13$, $p<.01$). Boys and girls did not differ on TOC in any state except state 3, where boys showed significantly more TOC than did girls ($t=4.7$, $df=7$, $p<.01$). Boys and girls did not differ on any rates of movement in any state.

Table 11 summarizes these gender differences across and within states.

Table 11

Summary of Gender Differences.

	Across States		Within States: State 2		State 3		State 4		State 5	
N	Boys 18	Girls 17	Boys 8	Girls 6	Boys 5	Girls 4	Boys 5	Girls 10	Boys 11	Girls 8
BW: Mean	3477.5	3354.2	3494.4	3427.8	3296.0	3276.3	3632.0	3221.5**	3600.9	3276.5**
(S.D.)	(297.6)	(237.5)	(319.0)	(266.7)	(245.1)	(389.1)	(245.1)	(169.4)	(237.3)	(200.2)
EGA: Mean	39.3	40.0*	39.3	39.5	39.4	40.3	39.4	40.1	39.5	40.1
(S.D.)	(.8)	(1.0)	(.9)	(1.1)	(.5)	(1.0)	(.9)	(1.0)	(.8)	(.6)
PNA: Mean	34.8	41.7*	30.9	40.8	41.9	39.7	35.6	40.1	33.5	40.2
(S.D.)	(9.1)	(5.0)	(11.7)	(6.0)	(2.6)	(5.6)	(5.4)	(4.4)	(8.6)	(5.1)
TOC: Mean	.77	.73	.76	.73	.73	.44**	.84	.79	.74	.76
(S.D.)	(.10)	(.11)	(.13)	(.06)	(.09)	(.10)	(.10)	(.08)	(.17)	(.11)

* $p<.05$. ** $p<.01$

Note. Boldface type indicates a significant difference between boys and girls.

Summary of Results

In summary, the following relationships were found:

(1) For two-thirds of the babies, there was no significant relationship between arm movement and finger movement across or within states. Babies who moved more were more likely to show a significant association, as were babies who were older (in terms of both EGA and PNA). However, older babies did not move more, suggesting that age and rate of movement influence arm/finger association independently.

(2) The results for state 3 were strikingly different from the findings across states. In state 3, there was a significant negative correlation between rate of movement and PNA, while across states there was no relationship between rate of movement and PNA. This negative relationships was due to the fact that finger movement in state 3 decreased as PNA increased. There was also a significant negative correlation between rate of finger movement and EGA in state 3.

(3) Despite the fact that the majority of infants showed no significant relationship between movement of the arm and movement of the fingers, 32 of the 35 infants showed a canonical pattern of relationships between flexion and extension of arm and fingers when both arm and fingers were moving. For 22 of the infants, this pattern was statistically significant. Babies who

moved more were likely to show statistically significant canonical patterns and babies who moved less were likely to show canonical but non-significant patterns. Unlike the findings regarding association of movement of the arm and fingers, where age was related to a significant association, there were no relationships between significance of canonical pattern and any demographic variable (BW, EGA or PNA).

(4) TOC was not related to presence or absence of an association between arm and finger movement, across states.

(5) TOC and EGA were significantly negatively correlated across states but not in any individual state. That is, babies who were born slightly earlier showed tighter coordination than babies who were born later.

(6) TOC was significantly negatively correlated with PNA in states 2 and 4 overall and for boys, but the relationships were non-significant for girls. Here again, younger babies showed tigher coordination than did older babies.

(7) TOC was positively correlated with PNA in states 3 and 5 overall and for both boys and girls, but this relationship was significant only for boys in state 3.

(8) Overall, boys were significantly younger than girls, and had been born slightly earlier. Boys and girls did

not differ on association of arm and finger movement, BW, rates of movement, or TOC.

(9) Within states, boys and girls did not differ on EGA, PNA or rates of movement in any state, although boys showed significantly more TOC in state 3 than did girls. Boys who contributed data to states 4 and 5 were significantly heavier than the girls who contributed data to these states, but BW was not associated with any measure of organization.

Across states summary. Across states, higher rates of movement were related to a significant association between arm and finger movement, and to a statistically significant canonical pattern of simultaneous arm/finger movement. Age (EGA and PNA) was related to association between arm and finger movement, but not to significance of the canonical pattern. Rate of movement and age were not correlated, suggesting they influenced the association between arm and finger movement independently. Age (EGA only) was negatively related to tightness of coordination. Boys were significantly younger than girls in terms of both EGA and PNA, but they did not show greater rates of movement or more arm/finger association, were not more likely to exhibit a statistically significant canonical pattern and did not show more TOC across states. This suggests that the sex differences found within states, as noted below, may be statistical artefacts due to small N's.

Within states summary. Relationships between other variables and association of arm and finger movement could not be analyzed within states due to the small number of infants who showed a significant association between arm and finger movement. Similarly, relationships between other variables and significance of canonical pattern could not be analyzed due to the small number of babies who showed non-significant canonical patterns. Tightness of coordination was significantly negatively correlated with PNA in states 2 and 4, and non-significantly positively correlated with PNA in states 3 and 5. In states 2 and 4, the negative correlation was non-significant for girls. However, boys and girls did not differ on EGA, PNA or rates of movement in any state.

Discussion

The issues that prompted this study were whether or not newborn spontaneous arm and finger activity is random, diffuse and unorganized and, if not, what kinds of patterns emerge and under what state conditions they do so. My main findings were that (1) in general, finger movement and arm movement co-occurred at chance levels and (2) when both the arm and fingers were moving, arm extension/finger extension and arm flexion/finger flexion co-occurred at significantly above chance levels and at relatively high absolute rates, while arm extension/finger flexion and arm flexion/finger extension co-occurred at significantly below chance and relatively infrequently except in state 3, where generally all types of co-occurrence were at chance levels and similar frequencies. Thus, for the majority of infants, movement in each part of the limb was independent of movement in the other but, when both were in motion, the type of movement of one was not independent of the type of movement of the other, except in state 3. These findings indicate that, like reflexive and perhaps non-reflexive elicited activity, newborn spontaneous arm and finger activity exhibits organization, and that infant state is a factor in its organization. This suggests that organization seen under eliciting conditions may be, in part, a general property of the moving arm and fingers and not a reflection of "hardwired" pathways programmed to respond to specific stimuli in specific ways.

A consideration of the state findings helps to clarify these results. When the arm and fingers were moving at roughly similar rates, as they were in states 4 and 5, a synergistic pattern emerged. It would seem that under these conditions the extension/extension and flexion/flexion pairs represent more stable configurations than do the opposite pairings. However, when the arm and fingers are moving at very different rates, as they were in state 3, with high rates of isolated finger movements and low rates of arm movement, there is less opportunity for stable relations between any two movements in the two different parts of the limb to emerge.

Assuming that the level of arousal in state 3, "quiet awake," is lower than that in state 2, "active sleep," it may be that higher levels of arousal in states 2, 4 and 5, while not "causing" these relations, do enable them to emerge. That is, when the level of arousal is high enough to get the arm moving at rates comparable to that of the fingers, synergistic relations can emerge. This possibility is partially supported by data on the newborn "stepping" response. Thelen, Fisher, Ridley-Johnson and Griffin (1982) found a highly significant correlation between arousal and number of steps in a sample of 65 infants tested at a mean post-natal age of 43.2 hours. While these authors did not count <u>all</u> the movements the babies made, and we therefore don't know if they made more non-stepping (non-organized) movements with their legs at lower levels of arousal and fewer such "non-organized" movements at higher levels of arousal, the data reported does show clearly that there were more organized movements at higher levels of arousal.

Whether or not state 3 is different from the other states in more than simply amount of movement is an open question, of course. Since there is less movement in state 3 than in states 2, 4 or 5, and only 9 infants in this study exhibited enough simultaneous arm and finger movement to analyze, these results should be replicated with a larger number of infants in state 3 before a firm conclusion can be drawn.

Three findings suggest that the organization generally found in this study is in a state of developmental transition. First, roughly a third of the infants differed from the majority on amount of simultaneous movement of arm and fingers. Second, there were significant <u>negative</u> relationships between post-natal age and coordination in states 2 and 4, while these correlations were generally non-significant but <u>positive</u> in states 3 and 5. Third, the effect of post-natal age on coordination was more apparent for boys than for girls. All of these findings represent a degree of variability that suggests a transitional period.

The Majority vs. The Minority. Although arm and finger movements occurred independently of each other in approximately 2/3 of the cases, they co-occurred significantly more often than would be expected by chance in the other third. For those infants whose arm and finger movements were independent of each other, both EGA and PNA were slightly lower than for those whose arm and finger movements co-occurred significantly more often than would be expected by chance. Although the finding for EGA was significant, the actual difference was quite slight (mean EGA (39.4 weeks vs. 40.0 weeks). Given that there was so little variability in EGA in this sample of babies, I believe this difference must be viewed with caution. With a miniscule amount of variability, even a slight difference in means would be statistically significant. In addition, EGA is truly and notoriously estimated gestational age, so with differences this slight, I believe it would be unwise to make too much of this finding unless it is replicated with a broader range of estimated gestational ages.

However, I believe it is reasonable to consider more seriously the difference found in PNA (36.4 hours vs. 41.5 hours, $t=-1.84$, $p=.07$). Although this difference only approaches significance, it suggests that there may be rapid post-natal change in association of limb movements as newborns adjust to the extra-uterine environment. The work of Thelen and her colleagues (Thelen, Fisher & Ridley-

Johnson, 1984; Thelen, Fisher, Ridley-Johnson & Griffin, 1982) strongly implicates gravity as a factor in infants' ability to exhibit coordinated activity, and the sudden change in the infant's relationship to gravity that is introduced at birth could, presumably, disrupt pre-natally existing relationships temporarily.

An alternate possibility is that linkage between movement of the arm and movement of the fingers does not exist prenatally, and begins developing quite rapidly in the first few days of extrauterine life.

The fact that there was no relationship between presence or absence of a significant association between arm and finger movements and TOC may seem counterintuitive, but this finding is in line with the possibility suggested by one of Thelen et al.'s reports that the amount, but not necessarily the organization, of activity is associated with level of arousal (Thelen, Fisher, Ridley-Johnson & Griffin, 1982). That is, even when some aspects of behavior are somewhat depressed, the intrinsic dynamics of the moving system may still be quite powerful.

Tightness of Coordination and Post-Natal Age. It is by now well-established that development does not take place in a linear fashion, with infants simply becoming "more" or "better" day by day, as they grow up. Rather, development is full of "regressions," spurts, periods of increased variability (periods of development that are characterized by less stability in the organization of a particular set of behaviors than previously) leading to reorganizations, and so on. With regard to motor behavior in particular, such "messiness" in the developmental course is well-documented both for the "stepping" response and for "reaching" behavior.

With regard to newborn "stepping," Thelen and Fisher (1982) found that newborn stepping and supine spontaneous kicking are the same movement when joint angles were measured, EMG records compared, and temporal structure of the two actions analyzed. Nevertheless, the developmental course of kicking was different from that of stepping. For kicking, there were high correlations between the angular rotations of hip, knee and ankle joints at 2 weeks PNA, and even higher correlations at 4 weeks. Disassociation of joint angles began around two months, and increased between 4 and 6 months (the time span differed for different joint pairs). This disassociation proved to be temporary, however. Between 5 and 8 months, the correlations among joint angles increased again, but this change was also temporary. By 10 months, the correlations were reduced dramatically, and the correlation between hip and knee was negative. For stepping, 2-month-olds showed simultaneous flexion of all three joints (which gives the "stepping" response its characteristic "marching" appearance). The stepping response disappears altogether shortly after two months; toward the end of the first year, a few weeks before upright locomotion emerges, infants again start stepping if held in an upright position. This behavior was found to be very different from newborn stepping, however. At 10 months, the relationships were in a transitional phase, and at 12 months, when the infants were walking, the early relationships were absent entirely, replaced by more complex relationships that more closely approximated normal adult gait (hip flexion precedes knee flexion and ankle initially extends rather than flexes). Thus, the early tight coordination revealed in both spontaneous kicking and in supported stepping proceeds through various phases of tight and loose linkage to arrive at the final adult form that is characterized by both more flexibility and more complexity in the interactions of the muscle systems involved.

Spontaneous arm and finger movement that occurs in the supine position may be analogous to supine spontaneous kicking, while visually-elicited reaching in constrained and supported infants may be analogous to supported stepping in newborns. Like stepping, reaching, when found at all, reportedly disappears temporarily and then reappears in a new form. Thus, the relationship between spontaneous arm and finger activity and eventual reaching may be similar to that of kicking and eventual walking. That is, locally organized synergies may exist in spontaneous activity prior to their integration into a later complex, voluntary behavior, and this local organization may proceed through various stages of tighter and weaker linkage.

Here, there were significant negative relationships between post-natal age and coordination in states 2 and 4, while these correlations were generally non-significant but positive in states 3 and 5. It may be that tightness of coordination is proceeding through a "loosening" phase in the first few days of postnatal life. Why, then, might we see positive relationships in states 3 and 5 between PNA and coordination? One intriguing possibility is that state 5 does not appear to exist prenatally, and the appearance of state 3 prenatally is currently in dispute. Nijhuis et al. (1982) have reported the presence of state 3 at 38 and 40 weeks EGA, while Pillai and James (1990) failed to observe it prenatally and suggest it emerges only in the extrauterine environment. If states 3 and 5 are in the process of becoming organized themselves immediately after birth, then movements associated with them might be different from those associated with the more mature states, 2 and 4. Alternatively, states 3 and 5 seem to represent extremes on the continuum of arousal, with state 3 being lowest and state 5 highest. It may be, then, that there are two different explanations for the way in which these states are related to coordination, and what the developmental course of that coordination in each state may be.

Whether or not organizational characteristics of newborn arm and finger activity are tied to level of arousal, it is clear that such activity is neither random nor strongly synergistic in the first few prenatal days. Movement of the arm and movement of the fingers are generally not linked, and may never be, allowing flexibility in the overall system. However, when the arm and fingers do move together, there is usually some organization, some tendency of the system to function in an organized manner. This organization is "loose" enough to allow modification by the task.

These results may shed some light on some of the previously contradictory findings with regard to newborn reaching, e.g., McGraw (1941), Halverson (1931), Piaget (1963) and Bower (1972). While arm and finger movement are generally not linked by 48 hours of age, when they do move together, that movement is likely to be organized. Thus, if a visual stimulus elicits movement, it's likely that that movement will exhibit arm extension/finger extension and arm flexion/finger flexion relations. The newborn engages in a sea of movement that includes isolated arm movements, isolated finger movements, and arm-and-finger moving together, and, within that sea, some organization exists and is therefore available to become linked, eventually, with other systems, e.g., the visual system, but perhaps also the auditory system or other systems.

The linkages found within the spontaneous activity of newborns suggests an alternative to maturation as a means by which infant activity changes over time in complexity, organization and flexibility. The dynamics of the system result in organized behavior that represents a reduction in the degrees of freedom, without requiring that the newborn possess sophisticated cognitive abilities or highly skilled motor functioning. The infant's tendency to extend arm and fingers simultaneously, and flex the arm and fingers simultaneously as well, provides her with a way to "accidentally" begin coming in contact with elements of her environment. These accidental encounters may provide a substrate for the beginnings of exploration, much as Piaget (1963) suggested, while allowing the baby to remain a baby, and not the sophisticated cognitive creature suggested by Bower (1972).

Appendix A

Relationship between Arm and Finger Movements

N refers to epochs of movement, not total movements, and includes epochs of NN. An empty cell indicates that the baby was never in the state. "No stats" indicates that the baby was in the state but did not produce enough movements for analysis to be possible. Probabilities derived by Fisher's Exact Test are indicated with a dagger (†). All others are Pearson's chi square probabilities. When a significant difference was found, or the difference approached significance, "less" or "more" indicates the direction of difference from chance.

		States			
Baby No.	Across States	2	3	4	5
Co-occurrence of arm and finger movements not significantly different from chance across states or within any state:					
54	n.s.		n.s. † n= 11		n.s. n= 81
57	n.s. n= 83 p=.06 (more)	n.s. n= 82 p=.07 (more)			
58	n.s. n=139	n.s. n=105			n.s. n= 34
66	n.s. † n= 49	n.s. † n= 48			
70	n.s. n= 79		n.s. n= 79		
72	n.s. n=235 p=.06 (more)	n.s. † n=195			n.s. † n= 40
87	n.s. n=307			n.s. † n= 39	n.s. n=268
88	n.s. n=225		No stats n= 18	n.s. n=146	n.s. n= 61
94	n.s. n= 88			n.s. n= 34	n.s. n= 54
110	n.s. n=259	n.s. † n= 45			n.s. n=214
116	n.s. n=222		No stats n= 24	n.s. n=198	

(Table continues)

		States			
Baby No.	Across States	2	3	4	5
131	n.s. n=179	n.s. n=179			
133	n.s. n=140 p=.09 (less)		n.s. (less) n=140 p=.09		
134	n.s. n=136		n.s. n=136		
135	n.s. n= 96	n.s. n= 81	n.s. † n= 15		
142	n.s. n=110	n.s. † n= 36			n.s. n= 74
149	n.s. n=244	n.s. † n= 24	n.s. † n= 19	n.s. n= 64	n.s. n=137
153	n.s. n=113			n.s. n=113	
154	n.s. n=221			n.s. n=166	n.s. n= 55
173	n.s. n=250			n.s. n=195	n.s. n= 55
187	n.s. n=142 p=.07 (more)		n.s. n=142 p=.07 (more)		
195	n.s. n=171		n.s. n=154	n.s. † n= 17	
196	n.s. n= 46	n.s. † n= 46			
Co-occurrence of arm and finger movements significantly different from chance across states but not within states:					
139	More n=213 p=.01		n.s. † n= 21	n.s. n=127 p=.08 (more)	n.s. n= 65
171	More n=288 p=.03	n.s. n=232			n.s. † n= 56 p=.09 (more)

(Table continues)

		States			
Baby No.	Across States	2	3	4	5
Co-occurrence of arm and finger movements not significantly different from chance across states but significantly different in one state:					
140	n.s. n=190		Less † n= 32 p=.03	n.s. n= 97	n.s. n= 61
144	n.s. n=310			More n=128 p=.01	n.s. n=182
Co-occurrence of arm and finger movements significantly different from chance across states but not in at least one state:					
69	More n=183 p=.001	More n=134 p<.001	n.s. † n= 28		n.s. † n= 21
95	More n=232 p<.01	n.s. † n= 15	n.s. † n= 34	More † n= 15 p<.01	More n=168 p<.001
147	More n=213 p=.05			More n=178 p=.04	n.s. † n= 35
Co-occurrence of arm and finger movements significantly different from chance "across states," i.e., within the one state exhibited:					
60	More n=166 p=.01		More n=166 p=.01		
93	More n=289 p=.01				More n=289 p=.01
174	More n= 78 p<.01	More n= 78 p<.01			
180	More n= 62 p=.03	More n= 62 p=.03			
197	More n=203 p=.02			More n=203 p=.02	

Appendix B

Relationships Between Simultaneous Arm and Finger Movements

This table presents the relationships between simultaneous arm and finger movements only. N=number of simultaneous movements. The "canonical" pattern consists of more occurrences of arm extension/finger extension and arm flexion/finger flexion, as well as fewer occurrences of arm extension/finger flexion and arm flexion/finger extension, than would be expected by chance. An empty cell indicates the baby was never in the state. "N=0" indicates that the baby was in the state, but there were no simultaneous movements. Probabilities derived by Fisher's Exact Test are indicated with a dagger (†). All others are Pearson's chi square probabilities.

		States			
Baby No.	Across States	2	3	4	5
54	Canonical ** n= 22		n= 2		Canonical ** † n= 20
57	Canonical ** † n= 17	Canonical ** † n= 17			
58	Canonical * † n= 28	Canonical ** † n= 22			n= 6 p=1.0 †
60	Canonical ** n= 40		Canonical ** n= 40		
66	Canonical n= 5	Canonical n= 5			
69	Canonical ** n= 64	Canonical ** n= 53	n= 2		Canonical ** † n= 9
70	n= 10 p=1.0		n= 10 p=1.0		

(Table continues)

Baby No.	Across States	States 2	3	4	5
72	Canonical ** † n= 25	Canonical ** n= 16			Canonical † n= 9 p= .08
87	Canonical ** n= 90			Canonical * † n= 12	Canonical ** n= 77
88	Canonical ** n= 32		n= 0	Canonical * † n= 19	Canonical n= 13 p=.10
93	Canonical ** n=137				Canonical ** n=137
94	Canonical ** n= 32			Canonical * † n= 10	Canonical ** n= 22
95	Canonical ** n= 91	† n= 4 p=1.0	† n= 4 p=1.0	Canonical † n= 12	Canonical ** n= 71
110	Canonical * n= 82	† n= 4 p=1.0			Canonical * n= 78
116	Canonical n= 28		n= 0	Canonical n= 28	
131	Canonical † n= 24 p=.09	Canonical † n= 24 p=.09			
133	Canonical † n= 22		Canonical † n= 22		
134	Canonical † n= 16		Canonical † n= 16		
135	Canonical † n= 14 p=.09	Canonical † n= 12 p=.06	n= 2		

(Table continues)

		States			
Baby No.	Across States	2	3	4	5
139	Canonical ** n= 70		† n= 6 p=1.0	Canonical ** n= 38	Canonical ** n= 26
140	Canonical ** n= 38		n= 0	Canonical ** † n= 24	Canonical † n= 14
142	† n= 16 p=1.0	n= 1			† n= 15 p=1.0
144	Canonical ** n=137			Canonical ** n= 38	Canonical ** n= 99
147	Canonical ** n= 64			Canonical ** n= 48	Canonical * † n= 16
149	Canonical ** n= 89	Canonical † n= 9	† n= 5 p=1.0	Canonical * † n= 21	Canonical ** n= 54
153	Canonical ** † n= 21			Canonical ** † n= 21	
154	Canonical ** n= 57			Canonical ** n= 41	Canonical ** † n= 16
171	Canonical ** n= 98	Canonical ** n= 66			n= 32 p=1.0
173	Canonical ** n= 60			Canonical ** n= 48	† n= 12 p=1.0
174	Canonical n= 38 p=.08	Canonical n= 38 p=.08			
180	Canonical † n= 26	Canonical † n= 26			

(Table continues)

		States			
Baby No.	Across States	2	3	4	5
187	Canonical n= 45 p=.08		Canonical n= 45 p=.08		
195	Canonical n= 30		n= 24 p=1.0	Canonical † n= 6	
196	† n= 4 p=1.0	† n= 4 p=1.0			
197	Canonical ** n= 65			Canonical ** n= 65	

*Chi square $p<.05$. **Chi square $p<.01$.

Appendix C

Conjunction of Flexion and Extension

in Epochs of Simultaneous Movement

Chi square probabilites derived by Fisher's Exact Test are indicated with a dagger (†). All others are Pearson's chi square probabilities. An empty cell indicates the baby was never in the state, or there was an empty row or column in the chi-square and no analysis was performed.

		FINGERS									
		Across States		State 2		State 3		State 4		State 5	
Baby	ARM	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex
54	Ext	9	2 **							8	1 **†
	Flex	2	9							2	9
57	Ext	5	1 ** †	5	1 **†						
	Flex	1	10	1	10						
58	Ext	8	5 * †	7	3 **†					1	2
	Flex	2	13	1	11					1	2
60	Ext	13	5 **			13	5 **				
	Flex	6	16			6	16				
66	Ext	2	0	2	0						
	Flex	1	2	1	2						
69	Ext	23	4 **	18	4 **					5	0 **†
	Flex	10	27	8	23					0	4

(Table continues)

		FINGERS									
		Across States		State 2		State 3		State 4		State 5	
Baby	ARM	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex
70	Ext	1	4			1	4				
	Flex	1	4			1	4				
72	Ext	8	1 ** †	6	1 **†					2	0
	Flex	2	14	1	8					1	6
87	Ext	24	4 **					3	1 *†	21	3 **
	Flex	6	55					0	8	6	47
88	Ext	12	1 **					8	0 **†	4	1
	Flex	4	15					2	9	2	6
93	Ext	50	16 **							50	16 **
	Flex	13	58							13	58
94	Ext	15	3 **					5	1 *†	10	2 *
	Flex	1	13					0	4	1	9
95	Ext	31	8 **	1	1	2	1	3	2	25	4 **
	Flex	12	40	1	1	0	1	2	5	9	33
110	Ext	22	19 *	1	1					21	18 *
	Flex	12	29	0	2					12	27
116	Ext	9	5					9	5		
	Flex	6	8					6	8		

(Table continues)

		FINGERS									
		Across States		State 2		State 3		State 4		State 5	
Baby	ARM	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex
131	Ext	6	3 †	6	3						
	Flex	4	11	4	11						
133	Ext	11	1 ** †			11	1 **†				
	Flex	2	8			2	8				
134	Ext	6	4 †			6	4				
	Flex	1	5			1	5				
135	Ext	4	1 †	4	0						
	Flex	2	7	2	6						
139	Ext	24	4 **			1	2	13	0 **	10	2 **
	Flex	14	28			2	1	8	17	4	10
140	Ext	15	3 **					12	2 **†	3	1
	Flex	6	14					2	8	4	6
142	Ext	2	1 †							1	1
	Flex	6	7							6	7
144	Ext	45	12 **					13	3 **	32	9 **
	Flex	13	67					3	19	10	48
147	Ext	25	4 **					19	2 **	6	2 *†
	Flex	4	31					3	24	1	7

(Table continues)

		FINGERS									
		Across States		State 2		State 3		State 4		State 5	
Baby	ARM	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex
149	Ext	30	15 **	2	3	1	2	9	4 *†	18	6 **
	Flex	8	36	0	4	1	1	1	7	6	24
153	Ext	9	1 ** †					9	1 **†		
	Flex	1	10					1	10		
154	Ext	21	7 **					15	6 **	6	1 **†
	Flex	5	24					4	16	1	8
171	Ext	25	19 **	19	13 *					6	6
	Flex	16	38	6	28					10	10
173	Ext	17	10 **					14	8 **	3	2
	Flex	7	26					4	22	3	4
174	Ext	8	5	8	5						
	Flex	8	17	8	17						
180	Ext	6	4 †	6	4						
	Flex	4	12	4	12						
187	Ext	14	6			14	6				
	Flex	11	14			11	14				
195	Ext	8	4			5	4	3	0		
	Flex	8	10			7	8	1	2		

(Table continues)

		FINGERS									
		Across States		State 2		State 3		State 4		State 5	
Baby	ARM	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex	Ext	Flex
196	Ext	1	1 †	1	1						
	Flex	0	2	0	2						
197	Ext	17	8 **					17	8 **		
	Flex	6	34					6	34		

*Chi square $p<.05$. **Chi square $p<.01$.

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