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The accuracy of reaching in the dark in 7-month-old infants.

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THE ACCURACY OF REACHING IN THE DARK IN 7-MONTH-OLD INFANTS

A Thesis Presented

by

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ABSTRACT

THE ACCURACY OF REACHING IN THE DARK

IN 7-MONTH-OLD INFANTS

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The accuracy of 7-month-old infants' auditory localization was tested by examining their ability to reach for sounding objects in the dark. Infants were presented with a rattle, which had a finger puppet attached to it. Five identical rattles were positioned at midline, 30 and 60 degrees left and right. Each trial consisted of the experimenter bringing one rattle within the infant's reach and shaking it manually for 20 seconds or until the infant removed the object from the rattle. Each session began with 5 "warmup" trials in the light, one trial for each position. Following warmup, each rattle was presented 3 times, once in the light and twice in the dark. Dark and light trials were the same, except the experimenter switched the room lights off immediately

before the rattle was activated. The entire session was videotaped with an infrared camera. The room lights went on during the inter-trial intervals. Two silent control trials provided a baseline measure of arm activity in the dark.

When infants reached in the dark, their hand entered the correct sector, contacted or grasped the object 85% of the time, with incorrect reaches occurring on 15% of the trials. Reaching was 95% accurate on light trials. On 72% of the total dark trials and 90% of the light trials, the first head movement was an orientation toward the correct sector after trial onset. On trials when no reaching occurred, infants oriented their heads toward the activated rattle 80% of the time. These results suggest that; 1) reaching in the dark may represent a form of object permanence and 2) sound was sufficient to guide the infants' hand in auditory space, so neither sight of their hand nor sight of the object was necessary for accurate reaching.

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CHAPTER I

INTRODUCTION

Historically, the understanding of perceptual development has been dominated by two opposing views: empiricism and nativism. William James (1890, as cited in Lipsitt, 1971), an empiricist, described the situation of the young infant as one of complete chaos:

> "...assailed by eyes, ear, nose, skin and entrails at once, (the newborn) feels that all is one great blooming, buzzing, confusion."

In contrast, extreme nativists argue that the newborn enters the world with the perceptual abilities of an adult.

Currently, modified versions of these positions concerning the development of an infants' spatial representation exist. Piaget (1952) advocates the empiricist's position of the gradual emergence of perceptual organization. Although auditory, visual and tactual stimulation can elicit a few reflexes at birth, little perceptual coordination exists. An infant constructs a multimodal representation of space by actively exploring natural associations between objects and events. Piaget refers to the process by which this occurs as "reciprocal assimilation".

Bower (1974, 1979), assuming a nativist perspective,

advocates that the newborn is equipped with the initial unity of perceptual sensory systems. At birth, the infant is capable of responding to amodal properties of stimuli (e.g., intensity, location in space, movement), but the newborn cannot differentiate with respect to the modality of the input. With experience and maturation, the integrated sensory systems become increasingly differentiated.

Both positions suggest that the infant constructs auditory and visual space through sensory modalities. Regardless of one's theoretical perspective (i.e., Bower 1974, 1979; Piaget 1952), one reasonable hypothesis is that the maturation or gradual emergence of cross-modal organization, during the first 7 months of life, would provide the infant with a more sophisticated representation of space. In this thesis, I will define the infant's ability to perceive 3-dimensional space as Yonas and Pick (1975, p. 3) did: The ability to "identify the direction and distance of objects (and events) from himself and from each other". Yonas and Pick (1975) attribute to the infant some knowledge of a 3-dimensional environment which is similar to that of an adult's. Initially, the child enters the world with a crude sense of his physical position in reference to his environment. As the child's spatial perception approaches that of an adult's, his/her behavioral responses could be expected to become more efficient and effective.

The presence of a spatial response in an infant (i.e., head orienting towards a sound or an object, reaching towards an object) would imply the existence of some form of spatial representation. One way of examining the degree to which an infant's spatial map is developed, would be to focus upon the infant's ability to localize sound. Auditory localization involves the detection of a sound's location with respect to an ego-centric coordinate system. Therefore, this perceptual ability demonstrates that the organism must have some sense of spatial orientation in order to determine the location of the origin of a sound in relation to itself.

The present study attempted to determine the accuracy of auditory localization in 7-month-old infants by examining their ability to reach for sounding objects in the dark. A number of investigators have demonstrated that newborns reliably orient their heads in the direction of a sound source (Clifton, Morrongiello, Kulig & Dowd, 1981a; Muir and Field, 1979). However, the response of head turning is limited in the degree to which it represents an accurate measure of auditory localization. Head orienting is a directional response, but not necessarily a spatial response. Yonas (1979) has examined infants' sensitivity to spatial information through the use of the reaching response. He and his colleagues have indexed the development of infants' spatial abilities by measuring their sensitivity to binocular, kinetic and

pictorial cues (see review, Yonas & Granrud, 1985). If an infant's spatial abilities could be measured auditorily in the same manner, a direct observation and more precise measure would be provided of an infant's ability to locate the coordinates of a sound source in auditory space. The next chapter reviews the literature on auditory localization and the development of reaching, in order to demonstrate the advantage of utilizing both behavioral responses (i.e., head turning and reaching) in determining the accuracy of auditory localization.

CHAPTER II

LITERATURE REVIEW

Auditory Localization

Locating the source of a sound in space relies on two major binaural cues: 1) differential intensity at the two ears which result from the head acting as a sound shield and 2) differences in phase which occur because of the difference in the time-of-arrival of the sound to each ear (Green, 1976). The frequency composition of a sound determines the availability of these binaural cues. Both cues are available at some degree in most frequencies. For low-frequency sounds (less than about 1500 Hz), the listener uses time-of-arrival differences, while for high-frequency sounds (greater than 1500 Hz) the listener depends on interaural intensity. Neither binaural cue (i.e., intensity or time-of-arrival difference) is maximally accessible when sounds are composed of frequencies ranging from about 1500 to 3000 Hz. Thus, sounds in this frequency range have been found to be the most difficult for adults to localize (Mills, 1972).

The ability to localize a sound in space is adaptive for

survival in most organisms. From this perceptual ability, one could infer the existence of some knowledge of a spatial map in the organism. The human neonate displays some rudimentary form of this ability. However, the response repertoire of an infant under 6 months of age appears to be limited to eye movements (Mendelson & Haith, 1976) and head turns (Clifton, Morrongiello, Kulig & Dowd, 1981b; Muir & Field, 1979); Other possible responses (e.g., locomoting or verbally identifying) are not yet developed.

A number of studies primarily concerned with the coordination of the auditory and visual sensory systems in newborns have recorded eye movements. They have demonstrated that newborns will flick their eyes towards a sound of moderate intensity, when the sound is presented off midline (i.e., laterally to the right or left) (Crassini & Broerse, 1980; Turkewitz, Birch, Moreau, Levy & Cornwell, 1966; Wertheimer, 1961). Mendelson & Haith (1976), using the stimulus of a woman reading poetry, reported that newborns initially scan in the direction of the stimulus and then scan in the contralateral direction.

A few studies have failed to demonstrate occular orientation to a sound source (Butterworth & Castillo, 1976; McGurk, Turnure & Creighton, 1977). Their findings (or lack of) seem to be attributed to the duration of the sound stimulus that was used. Both of these studies relied on brief clicks as a stimulus (11 and 500 msec in

duration). Clarkson and Clifton (1986) have found that newborns do not orient their heads nor show a heart rate response to sounds of 14 and 500 msec in duration. Thus, infants may not have appreciated where the sound was coming from.

The head turning response has been used extensively as a measure of auditory localization. Early clinical studies gave some indication that newborns would orient towards a sound source (Hammond, 1970; Wolff, 1959). Brazelton's (1973) Neonatal Assessment Scale included items that tested auditory localization. He and his colleagues reported that newborns would orient and look at a sounding object. However, a number of factors were not controlled for in administering these items on the exam, such as experimenter knowledge of the location of the sound and the balance of visual cues.

The auditory localization item of the Brazelton Neonatal Assessment Scale (Brazelton, 1973) consists of the experimenter holding the newborn with one hand, while shaking a rattle off midline with the other for a few seconds. Muir and Field (1979) used this procedure to investigate sound localization, but added several important controls: 1) presentation of the tape-recorded rattle sound over loudspeakers located 90 degrees on either side of the baby's midline, 2) masking earphones worn by the experiementer holding the baby in order to prevent a bias towards the direction

of the sound's origin and 3) two "blind" observers (i.e., unaware of the type of trial (experimental vs control) or the location of the sound) who independently scored videotapes of the newborns' behavior.

Muir and Field (1979) demonstrated that newborns reliably orient their heads in the direction of the rattle sound. The 2 to 4 day old infants made ipsilateral head turns on 74% of the experimental trials which consisted of a 20 second stimulus presentation. During the control trials, which consisted of a 20 second silent interval, infants responded at a lower rate (40%) and showed a right bias during these head turns. Infants also made larger head turns on the sound trials than they did for silent control trials. The latency to respond averaged about 2.5 seconds, while the latency to complete the response averaged 3.5 seconds. Several components of the procedure seem essential for "optimal" responding. These include the frequency range of the stimulus (Morrongiello & Clifton, 1984), the newborns' position (i.e., semisupine), an alert state, a period of sufficient duration for the response to be made (Clifton et al., 1981b; Muir & Clifton, 1985) and the density of presentation (i.e., correct head turning increases linearly as the lateral stimulus presentation probability increases)(Clarkson, Morrongiello & Clifton, 1982).

Clifton et al. (1981b) adopted the procedure used by Muir &

Field (1979) and replicated the finding that newborns reliably turn their heads in the direction of a tape-recorded rattle sound (58% response rate, 95% correct). They also reported that the latency to respond and to complete a turn is quite slow (i.e., 4 seconds and 5.5 seconds, respectively). While Muir and Clifton and their respective colleagues have reported strong evidence of auditory localization in newborn and 5-month-old infants, they have also found through cross-sectional and longitudinal studies, that there is a decrease in responding during the second to the fourth month of life (Clifton, Morrongiello & Dowd, 1984; Clifton et al., 1981a & b; Clifton, Muir, Clarkson, Ashmead & Sherrif, 1985; Field, Muir, Pilon, Sinclair & Dodwell, 1980; Muir, 1985; Muir, Abraham, Forbes & Harris, 1979). Head turning toward sound drops to chance level and contralateral head turns increase between the ages of 6 and 9 weeks.

In an attempt to increase the frequency of the response rate during this period, Muir et al. (1979) manipulated the stimulus (i.e., by presenting novel sounds and familiar voices) and eliminated visual distractors by testing in the dark. These modifications were not successful in reestablishing the frequency and accuracy of head turning, which was observed during the first month of life. In contrast, Clifton, Morrongiello & Dowd (1984) were able to successfully manipulate the sound stimulus. Six to

8-week-old-infants responded with ipsilateral head turns on 42.5% of the test trials when a tape recorded voice greeted the infant (e.g., "Hello, baby! How are you?"), but they did not respond when trains of square-wave clicks were used as the stimulus.

Field, DiFranco, Dodwell & Muir (1979) also reported that 2.5 month olds would respond correctly on 75% of the trials to a tape-recorded female voice with head and eye movements. The discrepancy between the Field et al. (1979) and Muir et al. (1979) findings may be attributed to the degree to which the loudspeakers were located off of the midline (45 degrees vs 90 degrees, respectively)(Aslin, Pisoni & Jusczyk, 1983).

To summarize, Muir and Clifton and their respective colleagues (see Muir & Clifton, 1985) have concluded that although head turning becomes a "fragile response" 6 to 9 weeks after birth, it can be elicited by certain stimuli. They also report that at about 4.5 to 5.5 months of age, the head turning response reappears, and seems to be qualitatively different. The frequency of responding returns to its previous level and head orienting becomes more sophisticated in that motor control is improved, and the latency to respond decreases by 1 to 2 seconds. Developmental changes have also been reported for the amplitude of head turning. The magnitude of a head turn toward sound located 90 degrees off midline increases from 52 to 85 degrees between 2 and 5 months of

age. (Clifton et al., 1985).

Muir and Clifton (1985) attempted to explain this transformation in infant head turning to sound in terms of maturation of the central nervous system. The newborn's head turning to sound is characterized as a reflexive neonatal response. Examples of this category include the Moro, stepping and palmar grasp reflexes. The newborn's stepping reflex diminishes at about 3 to 4 months of age and is later replaced by voluntary walking (Taft & Cohen, 1967). The classic interpretation of this behavioral progression is that as the nervous system matures, there is suppression of subcortically controlled early reflexes with the transition to cortical control of behavior around 2 to 4 months of age (Gibson, 1981; Lipsitt, 1976; McGraw, 1943). Therefore, Muir and Clifton (1985) proposed that the newborn's "reflexive" head turn may represent an attempt to maximize binaural stimulation (i.e., intensity and time cues), rather than reflecting knowledge of a sound's position in auditory space. It may not be until the reappearance of the head orienting response at 5 months, that the infant perceives the true spatial coordinates of a sound's origin in relation to its own body and head. However, this has not been measured directly.

Whether or not an infant has the ability to precisely locate the origin of a sound is still unknown. The existing literature on

auditory localization in infancy has primarily focused on the division of space in terms of hemifields. A sound has been presented from only one side and head turns have been judged "correct" right or left. Very few studies have examined the accuracy of localization within the hemifields. Forbes, Abraham and Muir (1979), using the head turning paradigm, attempted to determine whether newborns (3 days old) could respond differentially (or with some degree of precision) within the hemifields. The infants were tested in an almost completely dark room in order to eliminate visual distractors. A tape-recorded rattle sound was presented through 1 of 5 speakers arranged in a perimeter approximately 25 cm from the infant's head. The loudspeakers were positioned at midline, 45 degrees right and left and 90 degrees right and left. The sound was presented twice at each location and there were two silent control trials. The camera was positioned behind the infant, pointing at the crown of the infant's head. A black line was placed along the midsagittal suture on the crown of the baby's head. The amplitude of a head turn was based on the degree of head rotation. This was measured by placing a protractor on the video screen along the black line. The protractor allowed for the head rotation area (0 to 90 degrees) to be divided into 4 equal sectors (22.5 degrees per sector).

Newborns were found to respond 90% of the time towards a

sound which was located 90 degrees from the midline. However, the frequency of responding to the 45 degrees position was equivalent to the midline position and control trials. A difference in the magnitude of head turning was reported between the midline and the 45 degree position, with larger head turns for the 90 degree position. The maximum head rotation to these positions (i.e., midline, 45 and 90 degrees) averaged 26, 53 and 68 degrees, respectively. Thus, Forbes et al. (1979) concluded that newborns respond differentially within the hemifields, although they are less accurate when the sound is positioned at 45 degrees (responding at chance level) than at 90 degrees.

Forbes (1981, see Muir, 1985) modified his procedure to test 4.5 month olds. The infants sat on their mother's lap. The mother wore headphones, which simultaneously presented the stimulus to both ears in order to prevent them from knowing where the sound was being presented. The speakers were located at midline, 30 degrees right and left and 60 degrees right and left. Forbes measured the degree of head rotation with the use of vector geometry. The baby's face represented a flat plane with the nose projecting out from this plane. The distance between the infant's nose and the horizontal axis (i.e., the infant's cheeks) was measured and converted into degrees of rotation from the midline. Forbes reported that the average head turn to the 30 degree and the 60

degree positions was 30 degrees and 48 degrees, respectively. Thus, Forbes (1981) concluded that 4.5 month olds responded with a higher frequency and with a greater degree of differentiation between the two positions within the hemifield than newborns did.

Forbes' studies (1981, Forbes et al., 1979), showed that infants from birth on are capable of responding differentially within a hemifield. However, head turning is not a precise measure of sound localization because the response as displayed by adult humans and animals only requires general orientation towards the sound. Hafter, Carrier & Stephan (1973) suggest that head orienting usually serves the purpose of bringing the sounding object in line with the eyes or body, allowing the eyes to search the area. Thus, the center of the head does not have to be lined up squarely with the sound's position, as eye movements may complete the infant's orientation toward the sound. A more precise measure of sound localization is needed if the accuracy at several locations is to be assessed. Measuring head turning in any way, (i.e., not just by the position of the nose), is not adequate. In contrast, eye movements toward an object must be very precise in order for the organism to foveat the object and allow visual scrutiny.

The animal literature indicates that the auditory cortex is not necessary in order to localize the correct hemifield when the

sound originates from two possible sources. Animals with lesions down the entire auditory pathway to the superior olive, which is the most peripheral nucleus where binaural interaction occurs, retain the ability to orient their heads correctly to a sound source (Masterton, 1974; Masterton, Thompson, Bechtold & RoBards, 1975). The most primitive ability in the sound-localization capacity is the ability to "home in" on a sound (Jenkins & Masterton, 1979). A number of studies have demonstrated that bilateral ablations of the auditory cortex prohibited dogs (Heffner, 1978), monkeys (Heffner & Masterton, 1975) and cats (Neff & Diamond, 1958; Neff, Fisher, Diamond & Yela, 1956; Strominger, 1969) from locomoting to a sound source. However, animals still had the ability to correctly key press (Heffner & Masterton, 1975) or head orient (Heffner, 1978; Thompson & Masterton, 1978; Thompson & Welker, 1963) in the correct direction of the sound source, although this ability was impaired compared to normal animals. Investigators have suggested that bilateral auditory cortex lesions result in an auditory-motor deficit (Heffner, 1978; Heffner & Masterton, 1975). The auditory cortex seems necessary when a response requires locomoting to a sound's location, but not for discriminating acoustic cues (i.e., phase and intensity disparities).

Clifton et al. (1981a) has suggested that head orienting can

not and does not allow us to infer that the infant posseses a sophisticated adult-like map of auditory space. The spatial knowledge necessary to orient towards a sound seems to differ from the knowledge that is required to physically locate a sounding object. Head orienting is a directional response, but not necessarily a spatial response. Therefore, by relying on the head turning response, Forbes (1981; Forbes et al., 1979) may have overestimated the infant's ability to precisely locate the origin of a sound.

Yonas and Granrud (1985) make a distinction which is analogous to the limitations of head orienting. They argue that eye movements can indicate infants' sensitivity to radial direction, but cannot indicate sensitivity to depth. Reaching is a spatially appropriate behavior which demonstrates the infant's sensitivity to the spatial layout of visual objects. Yonas and his colleagues (1979; Gordon & Yonas, 1976; Yonas, Cleaves & Pettersen, 1978) have used reaching to index the development of infants' sensitivity to binocular, kinetic and pictorial cues (see review, Yonas & Granrud, 1985). Yonas and Granrud (1985) state that "the most compelling demonstration of infants' sensitivity to the spatial information carried by a given depth cue would be a reach directed to the precise location of an object" (p. 319). A possible means by which to determine if a 7 month old perceives a

sound source as having a particular set of coordinates in auditory space, would be to elicit the reaching response, in addition to head orienting, in the absence of visual cues. Reaching for a sounding object in the dark offers a more precise measure than head orienting, of an infant's ability to accurately localize a sound source in auditory space. In the next section, I will review the literature on the development of reaching and provide evidence suggesting that the behavior of reaching toward an unseen sounding object can be used to investigate sound localization.

The Reaching Response

A. The development of reaching behavior. The presence of visual-motor coordination at birth is an issue which is still being debated (Bower, 1974; Bruner, 1973; Bushnell, 1981; von Hofsten, 1982; Lockman & Ashmead, 1983; McDonnell, 1979). A number of investigators have documented that young infants display behaviors which suggest the presence of reaching (Bower, 1974; Bruner & Koslowski, 1972; DiFranco, Muir & Dodwell, 1978; von Hofsten, 1979, 1982; McDonnell, 1979; Radar & Stern, 1982; White, Castle & Held, 1964). However, these behaviors are not considered to be visually guided reaches and have been referred to as "prefunctional" reaches (von Hofsten, 1982), reaching-like arm movements (Radar & Stern,

1982), "pre-reaching" (Trevarthen, 1975), "preadapted patterns of manipulatory activity" (Bruner, 1973) and "swiping" (White et al., 1964). Gibson & Spelke (1983) refer to these behaviors as representing "an intimation of coordinated looking and reaching" (p. 7). "Prereaching" behavior is defined in terms of arm movements, which do not include catching, grasping and manipulative hand movements (von Hofsten, 1982; Trevarthen, 1974). However, prereaching includes elements of reaching which resemble the anticipation of a grasp such as opening the hand during a forward extension and slowing down the hand near the object (von Hofsten, 1982).

Bower (1974, 1979) proposed that some degree of visuo-motor coordination is present at birth. Bower (1974) indicated that the "most basic characteristic" of reaching is directionality. He also stated that a correlation between the object position and the destination of a reach would support his hypothesis that neonatal arm activity is not random. Bower, Broughton and Moore (1970a) reported that neonates 7 to 14 days old had demonstrated successful visually elicited reaching towards objects located at various positions (i.e., midline, ±30 ,±60 degrees) around the infant. They reported a high incidence (70%) of arm extensions which were within 1.5 cm of the target object. Infants oriented their hand and arms (i.e., ballistic movements) in the appropriate direction

but contact did not always occur. Later, Bower (1974) reported that 40% of all the extensions made direct contact with the target. In another study, Bower, Broughton and Moore (1970b) found that 6 to 20 day old infants were capable of an adaptive avoidance response to approaching objects. The response was influenced by the speed of the approach and the closeness of the object to the infant. Bower (1974) argued that the reaching in this early period of life is visually initiated, but not visually guided.

Ruff and Halton (1978) attempted to replicate the Bower et al. (1970a) study. A baseline of the frequency of extensions in the absence of a visual stimulus was obtained. Seven to 15 day old infants were presented with a small sphere at various locations: midline, 45 degrees left and 45 degrees right. The number of extensions in the presence of the object was compared to the baseline for each infant. They reported half of the percentage that Bower et al. (1970a) reported as contacts and near contacts to the target (i.e., 36% of the total number of extensions). In addition, the overall "hit" rate (i.e., actual contacts) was only 7% of all arm extensions, with only one infant making contact with the stimulus when it was positioned at midline. Extensions were found to be equally likely in the presence or absence of the stimulus. Thus, in light of the high frequency of misses and the high frequency of reaching without a visual stimulus, the authors

concluded that reaching was not visually directed or intentional at this young age, but rather was occurring by chance. Other investigators have also failed to replicate Bower's findings (Ashmead, Lockman & Bushnell, 1980; DiFranco et al., 1978; Dodwell, Muir & DiFranco, 1976; Radar & Stern, 1982). However, a series of studies by von Hofsten will be described below in which he found that infants do make directionally appropriate arm movements to visual objects, although it appears the percentage of accuracy and frequency of reaching is lower than Bower et al. (1970a) had originally reported.

Von Hofsten (1982) examined newborns' arm and hand movements toward a slow moving object. A spherical tuft was presented at eye level and 12 cm away from the infant. The object moved along a horizontal circular path in a continuous (velocity 3.7 cm/sec) or irregular start and stop (velocity 7.4 cm/sec) motion. Five to nine day old infants displayed a greater activity level when the stimulus was absent (418 movements) rather than when it was present (346 movements). However, there was no difference in the absolute frequency of forward extensions when the target object was present or absent. The proportion of fixated extensions was almost twice the proportion of nonfixated extensions, when the object was present. Von Hofsten (1982) suggested that earlier studies (DiFranco, Muir, & Dodwell, 1978; Ruff and Halton, 1978) failed to

show a difference in arm movements with the presence or absence of the target object, because the increase in arm extensions to the object was hidden by the decrease in overall arm movements in the presence of the object. Von Hofsten (1982) also reported that when the infant fixated on the object, forward arm extensions were more accurate (i.e., aimed closer to the target), than other movements (i.e., nonfixated, closed eyes, indeterminate gaze). With the better aimed extensions of the fixated movements, the hand slowed down as it approached the object and clustered closer around the object. However, only 9% of the total number of reaches resulted in contact with the object (22 out of 232 reaches, 12 involved fixations and the other 10 did not). Thus, Von Hofsten (1982) suggested that a rudimentary (or primitive) form of visuo-motor coordination exists in the neonate and appears to have an orienting function.

Recently, Von Hofsten (1984) has examined the developmental changes of prereaching movements during the first four months of life. He reported that there is a decline in prereaching behavior at seven weeks of age. The number of fixated movements significantly decreased at 7 weeks and then steadily increased from the tenth to the nineteenth week of life. According to von Hofsten, 7-week-old infants do not lose interest in the object, but their visual attention to the object may inhibit prereaching in

some way. Von Hofsten (1984) explained this in terms of a state change. The excitement of the stimulus presentation may inhibit reaching.

Von Hofsten described developmental changes in the topography of the infant's hand movements. The arm initially is extended with an open hand, and then shifts to form a fist during the extension. Of the reaches which do occur at 7 weeks, there is a dramatic increase in fisted reaches, which then decreases after this period. The frequency of the hand opened before an extension begins to decrease from the fourth to the seventh week, and then increases (no difference was found between fixated and nonfixated movements). The hand opened during a reach decreases from 1 to 7 weeks of age, then increases for fixated extensions after the seventh week. By the tenth week, prereaching activity then returns to its previous level and the hand reopens during the extension, but only when the infant fixates on the object.

Von Hofsten (1984) defined this decrement in prereaching behavior as a critical period in development, after which the response returns at a more mature or sophisticated level. As earlier investigators had reported (Trevarthen, 1974; White, Castle & Held, 1964), at 2 months of age, the "extension synergy" (i.e., forward extension of the arm and opening of the hand) is broken up. Von Hofsten (1984) suggests that "the dissociation between arm

and hand movements at 2 months of age and the inhibition of directed reaching may indicate that the cortically "distal" motor system has started functioning but is not yet synchronized with the proximal motor system" (p. 387). Thus, through maturation, the behavior is reorganized. Infants will only extend their arms when they have fixated on the object. The hand opened during the extension represents a preparatory movement for the manipulation of the object. The developmental changes in reaching behavior may be analogous to the changes in the head turning response in auditory localization described earlier, in which the response declines from two to four months of age and then returns with fewer errors and shorter latencies (Muir & Clifton, 1985).

Another area which is still in question, is whether infants' prereaching behavior is sensitive to spatial information such as dimensionality. Bower has reported that prehension in infants (7 to 14 days) will be elicited by three dimensional objects, but not by two dimensional representations (Bower et al., 1970a). In contrast, DiFranco, Muir and Dodwell (1978) found no difference in neonatal (7 to 21 days old) reaching behavior toward objects or pictures of objects. Radar and Stern (1982) also reported that visually elicited prereaching responses in infants (8 to 16 days of age) did not differ between two dimensional and three dimensional objects.

In older infants (13 to 25 weeks), Field (1976b) examined reaching and visual attention to solid objects vs pictures of objects. Although these infants reached indiscriminately to solid objects and 2-dimensional representations of those objects, their visual attention was greater to 3-dimensional objects. Field (1976b) argued that the insensitivity of reaching to dimensionality reflects the immaturity of motor control and the "rather compulsive nature of visually elicited reaching behavior" in prereaching infants (p. 448).

From these studies, we can conclude that while the probability of prehensile activity increases when a visual stimulus is presented, the very young infant's reaching is not sensitive to dimensionality. Field (1976b) did find, however, that at 15 weeks of age, infants were sensitive to depth. Subjects curtailed their reaching attempts when the physical distance of the stimulus changed from within reach (13 cm) to beyond reach (52 cm). Gordon and Yonas (1976) have also reported that the duration and number of reaches decreased when infants were presented with objects beyond reach. Yonas, Sorknes & Smith (1983) found that when given a choice between two objects, infants by 20-22 weeks of age would consistently reach for the object that was physically closer. This preference becomes less pronouced when the separation between the objects diminishes.

Although perspectives differ on the existence, definition, sensitivity and continuity of prereaching behavior, there is general consensus that visually guided reaching first appears between 4 and 5 months of age (Bower, 1974; Von Hofsten, 1979; McDonnell, 1979; Piaget, 1952). White, Castle and Held (1964) have reported that visually directed reaching occurs just prior to five months of age. In a normative study of the development of reaching, infants were observed during the first 6 months of life. They reported that infants exhibit an orderly developmental sequence, which begins with swipes at 2 months of age and culminates to visually directed reaching. Von Hofsten (1979; 1982; von Hofsten and Linghagen, 1979), on the other hand, reported prereaching behavior in newborns and visually guided reaching at about 4 months of age.

Von Hofsten and Lindhagen (1979) examined 12 to 24 week old infants' prehensile responses to moving objects. They found that infants, at about 18 weeks of age, could successfully reach for a moving object if they were capable of reaching to a stationary object. Infants were capable of catching an object that moved a distance equal to twice the length of their arm in one second (velocity 30 cm/sec). In a closer analysis of these data, Von Hofsten (1980) reported that the infants made predictive prehensile movements to the anticipated position of the object, rather than

the position of the object prior to initiation of the reach. For a slow moving object (velocity 3.4 cm/sec), infants used the ipsilateral hand most often. The contralateral hand dominated in the two faster conditions (15 or 30 cm/sec). Between the ages of 18 and 36 weeks, this predictive skill did not increase. Rather, motor development improved so that the number of steps per reach decreased and the arm transport stabilized. Von Hofsten (1980) hypothesized that the infant has "prewired components" for predictive prehensile movements. Successful reaching for moving objects indicates that infants are capable of "time-coordinating" their behavior with external events in the environment.

To summarize, the ability to grasp a moving object is an early achievement. Infants master this task at the same time successful reaching for stationary objects is accomplished. By 4 to 5 months of age, reaching is visually guided and goal directed. The infant will reach for an object that is within reach, grasp the object, and then mouth the object for further exploration.

B. <u>The differences between prereaching and reaching behavior</u>. Intentionality is measured by the ability to: A) anticipate an outcome, B) select from alternatives a means by which to achieve an end state, C) determine an end state and D) if a deviation does occur, the means to substitute an alternative in order to correct for it (Bruner, 1973). The capacity of all of

these abilities is present at birth. Bruner (1973) views the infant as having the capacity at birth to be aroused by an intention, triggered by an object in the environment. Initially behavior occurs by instinct or reflex, then it is converted into intentional action. He proposed that there is a "construction of behavior rather than the acquistion of response" (p. 6). Bruner hypothesized that "preadapted patterns of manipulatory activity" (i.e., prereaching) is made up of a loosely ordered sequence of subroutines (e.g., 1= prolonged looking, 2= action of mouth and tongue, 3= arm movements). Through practice, feedforward and feedback, these subroutines undergo alterations, reorganization and modularization (i.e., shorter latency and greater efficiency in execution). A new pattern or higher-order action emerges in the form of visually guided reaching, in which there is less variability and greater accuracy. As this new pattern is repeatedly executed, modifications continue. Rather than engaging in forward ballistic arm movements, by 6 or 7 months, infants are reaching in two steps. Initially, the infant extends the hands out to the plane of the object, which is then followed by the anticipatory hand-closure pattern. Bower (1974) also described this pattern. He stated that reaching develops from a unitary movement (reach-grasp), into two separate elements of reaching and then, the grasp. The reach is visually initiated and the grasp is visually guided. Older infants touch the object before grasping.

Von Hofsten (1979; 1980; 1982; 1984; von Hofsten and Lindhagen, 1979), as noted earlier, has examined the development of visually directed reaching in depth. He has found that from 12 to 36 weeks of age, the number of movement elements per reach decreases. The duration of approach to the object has also decreased with age. Zig-Zag and large roundabout movements disappear by 24 weeks of age. The first visually elicited step of a reach also begins to play a major role. As the infant develops, the duration of the first step increases. The power of the reach and the approach is concentrated in this first movement. The steps which follow tend to decrease in duration and focus on increasing the precision of the movement. Von Hofsten (1979) attributes the large number of movements and the imperfections in prereaching behavior to the immaturity of the motor system rather than limitations on the infant's anticipatory ability. Eighteen and 36 week olds are equally accurate in their reaches ahead of a moving object, suggesting that infants may be prewired with this ability. Von Hofsten states that the transition from prereaching to reaching occurs at about 4 months of age.

Bushnell (1985) discussed three distinctions between prereaching and reaching behavior. The most obvious difference is that prereaching is less accurate than reaching. Prereaching is also characterized as visually elicited or triggered and tends to

be ballistic, while reaching is visually guided. The third distinction focuses on three factors: 1) the seen-target (i.e., visually localized target), 2) the seen-hand (i.e., visually localized hand) and 3) the felt-hand (i.e., proprioceptively or kinesthetically localized hand). Bushnell argued that successful or aimed prereaching involves matching the seen-target and the felt-hand, while reaching involves the seen-target and the seen-hand. Newborns and very young infants rely on an innate visuo-motor spatial coordination, while older infants assess the "gap" between the seen-target and the seen-hand and work towards reducing the distance. Bushnell (1985) supported her hypothesis by providing interpretations of a number of studies.

Lasky (1977) examined the effects of visual feedback of the hand on reaching and retrieving behavior in 2.5 to 6.5 month old infants. In the experimental condition, a mirror occluded the sight of the hand. In the control condition, the hand was visible. The rate of reaching and retrieving in 5.5 and 6.5 month old infants was disrupted, but not inhibited entirely, in the experimental condition. From the amount of hand gazing that occurred in this condition, Lasky (1977) hypothesized that older infants' behavior was disrupted because the expectation of visual feedback was not met. The young infants' reaching and retrieval was not as disrupted by the lack of visual feedback as the older

infants. Lasky (1977) states, however, that "it is unclear what conclusions can be drawn concerning visual feedback of the hand and visually guided reaching and retrieval in very young infants (younger than 5.5 months)", because some of the infants were "non-reachers" and their contacts may have been by chance (p. 116).

Lasky's (1977) findings suggest that older infants are utilizing the sight of the hand during a reach. He reported that there was greater accuracy in reaching when visual feedback from the hand was present. McDonnell (1975) reported that 4 to 10 month old infants, wearing distorting prisms, also use visual feedback of their hands to correct inaccurate reaches. From these studies, Bushnell (1985) concluded that older infants (i.e., 4 to 6 months), during a reach, were dependent on visual feedback from the hand. However, the infants in Lasky's (1977) & McDonnell's (1975) studies may have been reacting to the strangeness of the visual environment. Very few infants, if any, have experience in situations that occlude or distort sight of their hand.

Earlier investigations also reported that prereaching infants monitor their hand and the object during an extension (Bower, 1974; Piaget, 1954; White, Castle & Held, 1964). Von Hofsten and Lindhagen (1979) reported that their infants at 12 to 36 weeks of age (from prereaching to reaching), always fixated the moving

object when reaching for it and never looked back and forth from the hand to the object. Bushnell (1985) argued that although the target object was fixated rather than the hand, the hand was still within the visual field during the reach. However, whether the reach was guided by the seen-hand or the felt-hand cannot be determined.

Bushnell (1985) proposed that at the point of transition from prereaching to reaching (i.e., between 4 and 6 months), infants are sensitive to visual feedback of the hand during the reach. Later, visual guidance becomes less important. McDonnell and Abraham (1977) observed prehensile activities of infants wearing laterally displacing prism glasses and suggested that visually guided reaching peaks at about 7 months of age (i.e., fewer prism adaptations). By 9 months of age, infants are less dependent on visual feedback. Bushnell (1982; Lockman, Ashmead & Bushnell, 1984) also noted in her own work, that infants near the end of their first year of life only monitor their reaching in certain circumstances. Less attention is paid to the seen-hand and the seen-target.

Bushnell (1985) hypothesized that the decline in visually guided reaching is due to the overlearning of the skill. The repetition and mastery of reaching causes it to become "automatic" or unconscious, requiring little or no attention. Von Hofsten's

(1979) observations have indicated that the reaches of 4 and 5-month-old infants involve 3 or more movements and consist of many "zig-zag movements", while 9-month-olds reach with a unitary, direct and rapid movement. Thus, reaching is much more stabilized. Bushnell (1985) suggested that once this skilled once-aimed movement is "unleased", "no additional" assessments of the gap between the seen-hand and the seen-target are necessary. The constant monitoring of the gap is not necessary because the infant "knows" how to get the seen-hand to the seen-target.

In summary, Bushnell (1985) argued that between 4 and 6 months of age, the transition from visually elicited to visually guided reaching has just occurred and constant monitoring of the gap between the seen-hand and the seen-target is critical for a successful reach. By 9 months of age, the reaching response is well practiced and possibly overlearned. Thus, little attention to the seen-hand and seen-target is necessary, which Bushnell (1985) speculated may bring about the decline in visually guided reaching. According to Bushnell's hypothesis, an infant would not be capable of accurately reaching in the dark to a sounding object until 9 months of age. One would not expect a 6.5 to 7-month-old to be able to successfully reach out in the dark for a sounding object because the seen-hand-seen-target gap could not be monitored or assessed.

Reaching in the Dark

Bower and his colleagues (Bower & Wishart, 1972; Wishart, Bower & Dunkeld, 1978) have examined the infant's ability to reach for an object in the light and in the dark. Bower and Wishart (1972) reported that 5 month old infants will search in the dark and make contact with an object when it is presented in the light and then the lights are suddenly switched off. Harris (1983) pointed out, however, that it is not clear if the infant's arm extensions were initiated before the lights were extinguished or whether manual contact occurred because of random flailing in the dark.

Wishart et al. (1978) expanded their procedure in a second study to include auditory-motor coordination. They report 3 experiments in this paper. In experiment 1, the task involved reaching to a silent object in the light. The same object was then sounded in the dark (4 bursts per second of noise, having a center frequency of 800 Hz). The object was only presented at midline. In experiment 2, the object position was varied (i.e., midline, 30 degrees left and 30 degrees right). The third experiment involved a silent object being presented in the light and then the lights

were switched off. Thus, the infants were supposedly reaching to the visual trace of the object. In full illumination, the hit rate demonstrated the accuracy of visual-motor coordination. In the dark, the hit rate in experiment 1 and 2 measured the accuracy of auditory-motor coordination. Bower (1982) suggested that the same motor behavior is required in both conditions. He did not differentiate between the seen and the felt hand.

The results of these studies demonstrated that, at positions off the midline, auditory-motor behavior was less accurate than visual-motor behavior in infants below 6 months of age. Wishart et al. (1978) also demonstrated that reaching at midline in the dark peaks at 5 months, then there is a sharp decline until 9 months of age. Bower (1982) stated that detection of the midline sound source is an "unlearned ability" in the human infant. Detection of sound sources to the right and left are also present at birth. However, "precise localization to the right or left is not present at birth and seems to develop during infancy" (Bower, 1974, p. 34). It should be noted that Bower neglected to include critical details in his studies such as what behavioral response constituted a reach and how the accuracy of that reach was scored (i.e, contact or near contact with the object, etc). He also failed to provide complete interpretations of his findings. Thus, it is difficult to draw conclusions from these data.

Wishart's et al. (1978) results represent the findings one would expect according to Bushnell's (1985) model. Reaching is not visually guided before 5 months or after 9 months of age. Thus, reaching is not disrupted in the dark for these age groups. However, we would expect the hit rate to be much higher in 9 month olds (i.e., reaching is much more accurate than prereaching behavior). The period in which Wishart et al. (1978) reported a sharp decline in reaching in the dark (i.e. between 5 and 9 months of age), is also the period that Bushnell (1985) describes as the most sensitive to visual feedback of the hand. Thus, one would expect reaching in the dark to be disrupted.

In contrast to the Wishart et al. (1978) findings and Bushnell's (1985) hypothesis, Muir, Clifton, Clarkson & Sherrif (1983) have observed reaching in the dark in 2 to 6 month old infants. In a longitudinal study, reaching in the dark as well as in the light was examined in seven infants from 8 to 25 weeks of age. The objects were presented 45 degrees left or right of the midline, just below shoulder level and within reach. The same two positions were used on every trial. In the dark, there were four types of trials: sound alone, luminous objects alone, a luminous object with sound directly behind it and conflict trials in which a sounding object was presented on one side and a luminous object on the other. From my own informal observations of the videotapes,

infants appear to be capable of localizing sounds presented in the dark. Infants reached for the sounding object on sound alone trials. During conflict trials, infants tended to grasp the luminous object first and then grasp the sounding object. A few infants, when presented with the luminous object and sound together on the same side, reached beyond the luminous object to the sounding object.

This preliminary evidence indicates that 6-month-old infants do reach to sounding objects the dark. However, the limitations of this study were that there were only two sound alone trials per session and that the objects and sounds were always presented in the same two positions trial after trial, week after week. Therefore, it can not be determined if, when the infants did begin to reach, around 5 to 6 months of age, they were actually utilizing sound cues or whether they had expectations of the position and presence of an object due to past experience.

In a subsequent investigation, Stack, Muir, Sherriff & Roman (1986) eliminated the light sequence and focused on reaching in the dark. In two cross-sectional experiments, reaching in the dark to auditory and visual stimuli was examined in infants from 2 to 7 months of age. In experiment 1, the same stimuli and four types of trials were used as in the Muir et al. study (1983). The objects were also presented in the same positions. Stack et al. (1986)

reported that there were very few responses on auditory alone trials. The higher response rate in the Muir et al. (1983) study may be attributed to the light sequence infants had experienced prior to testing in the dark.

In experiment 1 of the Stack et al. (1986) investigation, when a reach did occur, the latency to initiate a response was significantly slower for auditory alone than for visual alone or visual-auditory paired trials (i.e., 15 vs 7 seconds, respectively). As age increased, the quality of the reach improved. Reaches were aimed significantly better toward the visual target than toward the auditory target. Reaching toward the auditory target involved more groping. In contrast to the Wishart et al. (1978) findings, no dramatic decline in reaching was found after 5 months of age to the auditory stimulus.

Experiment 2 in Stack et al. (1986) examined the effects of target position and "visual priming". The authors suspected a practice effect because infants had repeated exposure to only two positions. In addition, they were concerned that reaching on the auditory alone trials may have been enhanced or primed by the combined auditory-visual trials. Half of the infants received 5 trials of the auditory stimulus alone followed by 5 trials of the visual stimulus alone. The other half received the two blocks of trials in the reverse order (i.e., 5 trials of visual alone

followed by 5 trials of auditory alone). The stimuli were presented at midline, 30 and 60 degrees, left and right.

The results of experiment 2 were similar to the first study. There were very few reaches on auditory alone trials. The latency to respond to the auditory stimulus was slower than to the visual stimulus. The quality and frequency of reaches improved with age to the visual stimulus, but remained the same for the auditory stimulus. Seven-month-olds showed more overall reaching and were more accurate than 5-month-olds to the visual stimulus. However, reaching was significantly poorer on auditory alone than visual alone trials for both groups. No order effect was found.

The frequency and accuracy of the reaching response was greater in experiment 1 for visual and auditory targets. Stack et al. (1986) proposed that this could be due to visual priming, although there was no order effect. The sound and the luminous object were not paired together in experiment 2. Therefore, the infant may not have associated a sound in the dark with a physical object in space, which could account for the very poor response rate to the auditory alone trials. This interpretation may be supported by the seemingly higher response rate in the Muir et al. (1983) study than the Stack et al. (1986) study. In the Muir et al. (1983) study, infants had experience with reaching in the light prior to the dark testing. Therefore, they did have practice

and could have made a stronger association between the object and its sound. An alternative explanation would focus on the extinction of the response. In experiment 2, infants received 5 auditory alone trials, while in experiment 1 they received only two of these trials. If the initial reaches did not result in contact, the response may have extinguished over trials.

The Muir et al. (1983) and Stack et al. (1986) studies encourage the expectation that infants at 6 months of age will reach out for a sounding object in the dark, under certain conditions. Muir's procedure is appealing in: 1) the unique information concerning sound localization abilities that the reaching response provides, 2) its relevance for the infant's ability to use sound cues to guide reaching, and 3) its implications for the infant's concept of an unseen object. An infant reaching in the dark to a sound would imply that the infant is reaching for an object and possibly has an understanding of some form of object permanence.

Searching For Sound

Reaching for an object that cannot be seen but can be heard has been investigated in two situations: reaching in the dark, as

discussed in the previous section, and the Piagetian task of search for a hidden object. The question posed in the latter situation was whether a sound from the hidden object would aid the infant's search. The conclusion derived from search studies has been that infants fail to use sound cues in their search behavior until the end of their first year (Piaget's stage IV-8 to 12 months of age).

Freedman, Margileth, Fox-Klenda and Miller (1969), using a standard Piagetian task of object permanence, found that 5 to 12-month old infants would search for soundless objects they saw being hidden before searching for an object they could hear but not see. They reported that infants did not begin to search for a sounding object hidden by a barrier until their 8th to 11th month of life. Thus, the authors concluded that sound cues alone are ineffective in eliciting search behavior for objects until the infant enters stage IV.

Bigelow (1983), also using a standard object permanence task, investigated infants' use of sound to guide search behavior. Her results are consistent with those of Freedman et al. (1969). Infants began to use sound to direct their search behavior in stage IV. Bigelow also found that the use of sound to locate a surreptitously hidden sound-producing object appeared earlier than the use of sound to locate objects in displacement tasks. These findings are in agreement with Uzgiris and Benson (1980, as cited

in Bigelow, 1983), who found that a larger number of infants were more successful searching for objects they heard but did not see hidden, than searching for objects they saw hidden but only heard being displaced to another location. Sound was found to be more effective in guiding search behavior if the infant was given the opportunity to manipulate the object and see the object produce the sound before it was hidden. Harris (1971) also found that 8-month-old infants would search more for an object if they had first manipulated it. Thus, it seems touch influences or may "motivate" the infant's search behavior.

One study has reported results contrary to the above studies. Ginsburg and Wong (1973) found that sounding objects enhanced 6 month old infants' search for a target object when they watched it being hidden. All of the infants were pretested to ensure that they were incapable of searching for nonsounding hidden objects. The infants were given the opportunity to manipulate a sounding object (music box), which was then placed in front of them and covered with a white cloth. The object was always covered from the back to the front in relation to the infant. Infants searched for this sounding hidden music box. The authors suggested that the continuous auditory cue during the hiding procedure maintained the infants' attention and signalled the object's continued presence. From the work of Harris (1971) and Uzgiris and Benson (1980), it

would seem that the manipulation of the object prior to it being hidden may have also contributed to the enhancement the infants' search behavior.

Infants who would seem to be the most dependent on sound cues are those without sight. One would expect blind infants to utilize sound cues earlier than sighted infants. Selma Fraiberg (1977; Adelson & Fraiberg, 1974) has done a substantial amount of research with blind infants. A portion of her investigation has focused on the coordination of the hand and ear. She indicated that the age range of stage IV (8 to 11 months) is almost identical to the age range in which blind infants begin to retrieve sounding objects. Fraiberg divided the hand-ear coordination of blind infants into two major stages: Stage 1- midline reach to a sound cue following a tactile cue and Stage 2- midline reach for an object based on sound cue alone (Fraiberg, 1977; p. 16). In Stage 1, the blind infant retrieves the toy from the midline after it has been removed from his hand. At this stage, the infant cannot retrieve the toy on sound alone. Stage 2 is achieved when the infant can retrieve the object at midline based on sound cues alone (i.e., having no prior contact with the object). Fraiberg tested ten blind infants. The median age at which the infants had reached Stage 2 was 8 months and 27 days, and the range was 0:06:18 to 0:11:01 (Fraiberg, 1977; p. 166).

Fraiberg (1977) stated: "The child who reaches directionally and attains the sound toy in the "expected" place, localizes sound at its variable source and infers it substantially from its sound attributes--which we may take as an elementary demonstration of the toy's "permanence" and so with greater confidence credit this performance as an equivalent to Piaget's Stage 4." (p. 168). Therefore, sighted and blind infants appear to be developing in parallel in terms of the effectiveness of sound cues in obtaining an object. Bower (1982) stated that vision does not link audition and prehension in sighted infants, because sighted and blind infants demonstrated similar reaching behavior at the same point in development. Fraiberg (1977) indicated that a third stage seemed to exist in blind infants involving directional reaches to sound cues only. However, this stage was not studied systematically.

In summary, the studies which have examined the influence of sound on search behavior have found that sound is not an effective cue until the infant is about 8 months of age. Therefore, although the reaching in the dark studies suggest that younger infants may be capable of localizing a sounding object in the dark, the studies which focus on searching for a hidden object and Bushnell's (1985) argument of the necessity of visual feedback from the hand, would suggest that they are not. The studies reviewed in this section, however, have all utilized a standard Piagetian task of object

permanence. Therefore, the nature of the situation may be a critical factor in determining the effect of sound on reaching or search behavior.

The Nature of the Transition in the Occlusion of Objects

Infants 4 to 5 months of age will move an object they are holding into their visual field (Bower et al., 1970a; Piaget, 1952; White, Castle & Held, 1964) or reach in the dark (Bower & Wishart, 1972; Hood & Willatts, 1986; Stack et al., 1986; Wishart, Bower & Dunkeld, 1978), but will not remove an object they have clasped from underneath an opaque cloth. Reaching in the dark implies that the young infant understands some form of object permanence (Hood & Willatts, 1986). The manner in which an object disappears may be an important factor in whether or not an infant will search for a hidden object or a sounding object. Object permanence, according to Piaget (as cited in Harris, 1983), is the ability to interpret the covering of an object as a temporary occlusion rather than its annihilation (e.g., bubble bursting).

Gibson (1969) argued that an infant who perceives the difference between an object that instantly disappears (i.e.,

annihilation) and an object that gradually is covered, can expect or predict the annihilated object to cease to exist and the occluded object to reappear. Gibson focused on the infant's perception of the occlusion rather than the infant's ability to find the object. Thus, an infant's expectations are dependent upon his/her perception of the event. In agreement with this perspective, Harris (1983) argues that Piaget has misstated the question. The infant is not faced with whether the object exists or not (after its disappearance), but rather where is the object now that there has been this change of events. Therefore, an infant may not perceive the sudden loss of light as an object's annihilation, but rather a "new" situation in which he/she must locate the object. If this were the case, we would expect reaching in the dark from infants who were capable of successfully reaching for objects in the light.

Proposed Research

Auditory localization involves the detection of a sound's location with respect to an ego-centric coordinate system. This perceptual ability enables the organism to determine the origin of a sound in 3-dimensional space. Muir and Clifton and their respective colleagues have demonstrated that infants reliably orient their heads in the direction of a sound source. However, the head orienting response is limited in the degree to which it

represents an accurate measure of auditory localization. Clifton et al. (1981) suggested that head orienting does not allow us to infer that the infant possesses a map of auditory space. Head orienting is a directional response, but not necessarily a spatial response. Yonas and Granrud (1985) make a distinction which is analogous to the limitations of head orienting. They argue that eye movements can indicate infants' sensitivity to radial direction, but cannot indicate sensitivity to depth. They state: "The most compelling demonstration of infants' sensitivity to spatial information carried by a given depth cue would be a reach directed to the precise location of an object" (p. 319). Yonas and his colleagues have used reaching to index the development of infants' sensitivity to binocular, kinetic and pictoral cues. As the arm transport stabilizes by 6 months of age, the precision of the infant's ability to localize may become more measurable with the use of both the reaching response and head orienting. By examining an infant's motor responses to localize sounds in the dark at several positions within a hemifield, more information may be provided to enhance our understanding of an infant's spatial sensitivity.

The present study was primarily a descriptive study, that focused on whether infants can utilize sound cues to accurately localize the position of a sounding object in the dark. The

literature that was reviewed yields conflicting predictions of infants' performance on this task. Bushnell (1985) would hypothesize that without the visual cues to monitor the seen-hand-seen-target gap, infants cannot accurately reach for an object in the dark until approximately 9 months of age. She supports her hypothesis with studies (Lasky, 1977; McDonnell, 1975) which have manipulated the infant's visual field (i.e., distorting prisms). Investigations which have utilized sound in the standard Piagetian task of object permanence would also predict that 7-month-old infants would not be able to accurately reach in the dark to a sounding object. However, the Muir et al. (1983) and the Stack et al. (1986) studies would allow one to entertain the idea that infants may be capable of this task. As was proposed in the last section, the manner by which an object disappears may account for the differences in the prediction of infants' reaching performance in the dark.

The rate of performance in the Stack et al. (1986) study was poor in the auditory alone condition. Therefore, the present study attempted to provide optimal conditions in order to establish a high rate of responding. The session began with a warmup of reaching in the light to a sounding object. The warmup acted as a screening procedure to establish if infants were capable of grasping the stimulus. The warmup also familiarized the infant

with the sounding object. The infant was given the opportunity to manipulate the object which was attached to the rattle. Harris (1971) found that infants would search more for an object if they had manipulated it before it was hidden. Thus, the intent of the familarization was to increase or establish motivation in the infant to reach for the object in the dark. During the test session, light trials were interspersed between dark trials in order to determine if the infant was on task.

The stimulus which was chosen was another means by which to maximize responding. The Brazelton rattle was chosen from a practical rather than a theoretical stand point because, A) it is a broadband sound (i.e., easily localized) and B) it is the same stimulus that was used in the Muir et al. (1983) and the Stack et al. (1986) studies, which also involved reaching in the dark. Although it is difficult to specify the acoustic parameters of this stimulus, it has been shown in a number of studies to reliably elicit headturning in infants from birth to 6 months of age (Muir & Clifton, 1985). For this reason, the rattle has been used in the majority of recent studies of sound localization in infants.

Anticipated Behavior

Reaching in the light, during the test session, represented a baseline of infants' ability when visual cues were available. It

is predicted that infants capable of reaching towards a sounding object in the light, will be capable of reaching towards a sounding object in the dark. Overall, infants will perform better on light trials, because visual cues are available. Infants will display a higher frequency and greater accuracy of reaching in the light than in the dark. When infants reach in the dark, they will be within 15-degrees of where the rattle is activated, rather than displaying flailing or groping in search of the sounding object. The latency to contact the sounding object will be shorter for light trials. Out of the total number of contacts, light trials will be more likely to end with the removal of the object from the rattle.

A rattle position effect is anticipated on dark trails. The natural position of the arms at rest would seem to indicate that the extreme positions are more accessible to the infant. In the dark, infants will display a higher frequency of reaching at the extreme position of each hemifield, rather than at midline, because it would require additional effort. Thus, more errors are also expected at these positions (i.e., $\pm$ 60 degrees).

Similarities in behavior between light and dark trials are also anticipated. Infants at 7 months of age will initially orient their heads in the direction of the sounding object in the light and in the dark, regardless of whether or not a reach is made. Infants will also reach for the sounding rattle with the hand that

is closest to the object in the light and in the dark.

CHAPTER III

METHOD

Subject

Fifty one infants, following a normal course of development were recruited from published birth announcements via a letter and a follow-up telephone call. Twenty infants (8 male and 12 female) ranging in age from 27 to 30 weeks old (mean age 28.2 weeks) completed the session. Parents brought their infants to a laboratory in the psychology building, where they were asked to sign a consent form allowing their infant to participate. As infants were scheduled for testing, they were randomly assigned to one of five rattle rotation sequences. Additional infants were tested but eliminated from the sample because of failure to reach for the object in the light during pretest trials (3), fear of the dark (2), ear infections (1), having received medication the day of the test session (1) and the mother talking (1) or holding the infant improperly (1) throughout the test session. In addition, 22 infants partially completed the session, but became fussy.

All subjects met the following criteria, verified by the parental interview that was given on the test date: A) no ear

infections or colds on the test date, B) no history of chronic ear infections, C) no suspicion of hearing loss, D) no preterm infants, E) no medication on the test date and F) following a normal course of development. At the end of the session, each infant received a certificate of appreciation and a child's picture book.

Stimulus

The stimulus was a Brazelton type rattle (plastic rectangular container (4 x 4 x 7.5 cm) 1/3 filled with popcorn kernels), which was manually shaken. A spectrographic analysis has revealed the Brazelton rattle to be a broadband stimulus comprised of frequencies ranging from 50 to 7000 Hz (peak frequency =2700 Hz) (Clifton et al., 1981).

A plastic Sesame Street Big Bird finger puppet (Gabriel No. 53177) (approximately 3 x 2.5 x 8 cm, excluding the beak), was backed with velcro and attached to the front of the rattle. This brightly colored object was small enough so that the infant could easily grasp and detach it from the velcro strip on the rattle. This removable aspect of the toy was expected to motivate the infant to reach and grasp the object. Rhythmic shaking of the rattle produced sound peaks around 78-80 dBA over a background

noise level of 29 dBA.

Apparatus

The apparatus consisted of five rattles, each mounted on a rod (diameter 0.8 cm, length 76 cm), which was fastened to a hinge that allowed the rattle to be moved up and down. The experimenter manipulated the long rod in order to produce movement of the rattle. Mounting the rattle on the rod maintained the rattle's position during testing (i.e., a specific distance from midline and at the infant's shoulder level). This handle for the rattle had .25 cm holes placed approximately 2.5 cm apart along its entire length. The design of the handle allowed for the rattle's distance from each infant to be adjusted, so that an arm extension would bring the infant's hand into contact with the rattle. Curtain weights were fastened to the end of each of the handles. The weights kept the rattles in the air, above the infant's head and out of reach, when they were not being activated.

The base of the apparatus was made of plywood (110.5 x 44 cm), which had a curved elevated rim (2 x 6.5 cm) attached along its entire length. The curve , which was positioned 10.5 cm from the back edge of the base, was concave from the perspective of the

infant. The base and the rim were covered with a white cotton cloth. Five wooden rods (diameter 0.8 cm, length 31 cm) were inserted (1.5 cm) vertically into the curved rim of the base. They were positioned at midline (0 degrees), ± 30 degrees and ±60 degrees. A wooden hinge (13.5 x 3 x 4 cm) was attached to each of these vertical rods, approximately 2 1/2 inches from the top of the rod. A rattle handle was threaded through each of these hinges.

The base of the apparatus was divided into eight 15-degree sectors, radiating out from the infant's body. The boundaries of these sectors were marked off with charpak tape. These sectors were used to judge the accuracy of the infant's reach. Each rattle was flanked by two sectors, with the exception of rattles 1 and 5. These rattles only had one of their sectors marked on the apparatus. Thus, the missing sectors were estimated. The sectors which flanked the activated rattle during a particular trial were designated as correct sectors for that trial. Therefore, if an infant reached within those particular sectors, he/she would have been judged as making a correct reach. The target area for a correct response was approximately 4 cm on all sides of the rattle. A reach was defined as the extension of the forearm away from the body, in a forward motion, in the direction of the apparatus.

The apparatus was mounted on a wooden box (64 x 41.5 x 38.5

cm) with wheels so that it could be moved easily to maintain the angle positions in relation to each infant. The wooden box was raised 7 cm off the ground. All of the rattles were presented in the same plane, at shoulder level and within the infant's reach.

The entire session was videotaped with an infrared sensitive camera (Panasonic model WV-1850). It was positioned directly over-head and 130 cm from the top of the apparatus. The infrared light source was also positioned directly over-head and 37 cm to the left of the camera. The video camera signal was fed through a video timer (For.A model VTG-33), into a videocassette recorder (Panasonic VHS NV-8950 or Sony AV-3600) located in the outer room. A Sony PVM-122 video monitor in the antechamber enabled the equipment operator to observe the session.

The experimenter pressed a foot pedal that switched the room light off and the infrared light on. The infrared light was the only source of light during the dark trials. The inner room was completely dark, with the exception of a dim red glow, which radiated from the infrared light. This red glow did not permit any visibility in the room and could only be detected by the infant if he/she put their head back and looked directly up at the infrared light source.

Procedure

The infants were tested in a double-walled sound-deadened chamber (background level 29 dBA), which was connected to an antechamber containing the video equipment and the equipment operator. Infants sat on their parent's lap, in front of the apparatus, which was knee level to the parent. The parents were asked to hold the infant by the trunk and refrain from talking and/or giving the infant any cues as to the location of the sound. The experimenter knelt on the floor at midline, directly behind the apparatus and facing the infant. The experimenter manually activated the rattles during the session. The equipment operator in the antechamber kept time by a video timer and signalled the experimenter at the end of each trial.

Each session began with five "warmup" trials in the light, one trial for each rattle position. All of the rattles were presented one at a time within the infant's reach. The warmup trials screened infants for their ability to reach and grasp an object. In addition, warmup provided an opportunity for the infant to become familiar with the sound, the toy and the experimenter. During warmup trials, the experimenter demonstrated that the Big

Bird toy could be removed from the rattle. Before each trial, the experimenter centered the infant's attention at midline by calling his/her name. The experimenter manually activated the rattle by lifting the weighted end of the rattle's handle, until the rattle was lowered to the infant's shoulder level. The experimenter shook the rattle three times, paused for approximately two seconds, and then shook the rattle again. This procedure continued for a maximum of 20 seconds or until the infant removed the Big Bird from the rattle. If the infant did not reach for the toy during this period, the experimenter assisted the infant or removed the toy and handed it to the infant in order to increase interest in the game. The experimenter only offered assistance during warmup. If the infant did not reach for the rattle during three of the five warmup trials, the infant was eliminated from the sample.

Following warmup trials, each rattle was presented 3 times, once in the light and twice in the dark. Test trials in the dark had two trial blocks, with all five positions presented in the dark once during each block. Five light trials (i.e., one for every rattle position) were interspersed throughout the test session to determine whether the infant was still interested in the game, to remind the infant of the toy and its sound and to encourage reaching (i.e., increase motivation). The dark(D)/light(L) sequence was as follows: D-L-D-L-D-L-D-D-L-D-D-L-D-D-D.

The procedure for light trials was identical to warmup trials. Dark trials were also conducted in the same manner except that the experimenter switched the room light off via the foot pedal immediately before the rattle was activated. The lights went on during the intertrial intervals in order to prevent distress of the infant and to allow the infant to see the toy. Two silent trials were interspersed, for a total of 17 trials in the test session. During silent trials, the lights were off for 20 seconds without any of the rattles being activated. These control trials provided a baseline measure of reaching activity in the dark in the absence of sound. The silent trials occurred randomly only in the second half of the test session. Piloting demonstrated that if the silent trials occurred during the first half of the session, the infants were likely to fuss and were often unwilling to continue with the session.

To prevent any possible trial position bias, rattle positions were counterbalanced for the trials on which they occurred. There were a total of 20 trial sequences. Each rattle position occurred equally often in every position of the order sequence. Rattles were also counterbalanced across the five positions, such that each rattle was assigned to each position four times. There were five rattle rotation sequences. Four infants were assigned to each of the five sequences.

An infant was considered a "complete" subject if all trials were completed except for 1 dark and 1 silent trial. If the infant became upset during the test session, a break was taken (which occurred for 4 of the subjects). When testing was resumed, an additional light trial was presented, regardless of where testing had ceased. This additional trial was used to get the infant back into the game.

Scoring System

The videotapes were scored by independent observers. Only trials which lasted 20 seconds were scored. Trial onset occurred when the rattle began to sound in the light or in the dark. In the light, the end of the trial was marked when the big bird was removed or the rattle was returned to its original position. In the dark, the end of the trial was marked when the big bird was removed or the room lights were turned on. A reach was defined as the extension of the forearm in a forward motion, away from the body and toward the apparatus.

The pretrial was examined in order to determine if the infant had extended one of the arms in one of the sectors that would flank the activated rattle for that particular trial or was facing those

sectors (i.e., head orientation). Pretrial was defined as the half a second which preceeded trial onset.

The latency of the first movement was scored for each arm. The first movement was defined as an extension or a lateral movement made by an extended arm. The end of this movement was defined as the arm or hand pausing for 40 ms or making a reversed movement which retraced the path that was just taken. The videotape was viewed in slow motion. The latency was measured with the use of a date-timer. The time at which the first movement ended was subtracted from trial onset to determine the latency of the first movement for each arm. The sector entered by this first movement and the head orientation during this movement were also scored.

A full extension by an infant may be made up of a number of movements. Therefore, the sector entered by the first movement may not be the sector that the hand is in after the infant has completed the first extension. In order to determine this, the location of the first extension of each arm and the sector it entered upon completion was scored. The latency to contact the object was also scored for each hand, if contact was made. Latencies were obtained by subtracting the point of contact from the trial onset time.

The first head movement after trial onset and the head orientation at point of contact were also scored. For noncontact trials, the cumulative duration that the head faced the correct sectors for that trial was measured with a stop watch.

Reliabilities

The data were scored from the videotapes on two separate occasions, by two independent scorers each time. Eight dark trials were eliminated because: the rattle came down on the infant's hand (5), the trial was cut short because of fussiness (2), and a mother caused interference during the trial (1). No light trials were eliminated.

Initially there were two independent observers on 55% of the trials. Disagreements were settled by a naive third observer. Each hand was scored separately, as well as head movements, necessitating multiple viewing of each trial.

There was 98.6% (289 out of 292 trials) agreement on whether a trial resulted in contact or noncontact with the object. With the use of the date-timer, latencies were determined by subtracting the point of contact from the trial start time. Between the first two observers, the Pearson correlation coefficients (r) were found

to be 0.88 for the left hand latency to contact and 0.97 for the right hand latency to contact. On noncontact trials, the cumulative duration that the head was oriented towards the correct sector on a particular trial was measured with a stop watch. The Pearson correlation coefficient was found to be 0.87.

For the remaining measures obtained in this initial scoring, observers reliability was computed as the number of agreements divided by the sum of the agreements and disagreements. The proportion of agreement between the first two observers on these measures were: 91% on the orientation of the first head movement, 91% on the presence of the first left extension, 88% on the sector entered upon completion of this extension, 89% on the presence of the first right extension and 89% on the sector entered upon the completion of this extension.

The data were scored a second time in order to obtain additional information. All subjects were scored by two new independent observers. Disagreements were settled by a third observer. Using the date-timer to determine trial onset and the completion of the first movement (as defined above), the Pearson correlation coefficient between the two observers was 0.993 for the latency of the first left movement and 0.996 for the latency of the first right movement. Observer's reliability, computed as the number of agreements divided by the sum of agreements and

disagreements was 95% for the sector entered with the first left movement, 95% for head orientation during that left movement, 88% for the sector entered with the first right movement, 95% for head orientation during that right movement and 94% for head orientation at the point of contact.

CHAPTER IV

RESULTS

Reaching was defined as a hand extension into any target sector of the apparatus. Reaching in the light represented a baseline measure of infants' ability to reach to all 5 locations when visual cues were available. Infants reached on every trial and their accuracy was almost perfect. At trial onset, infants typically oriented their heads to the correct sectors immediately and then, initiated the first hand movement of the trial within the first two seconds. The behavior displayed by 7-month-olds in the dark was similar, although the frequency of responding was lower and head orientation was often away from the sound during hand movements.

Behavior In The Light

A. Reaching. As expected, reaching occurred on every light trial. Reaching to the correct sector occurred on 95% (95/100), with reaches 30 degrees left or right of the activated rattle (i.e., adjacent) on 2% (2/100) and reaches beyond 30 degrees on 3% (3/100) of the light trials. When reaches were accurate, the very first hand movement was successful 94% (94/100) of the time.

Infants contacted the object 95% (95/100) of the time, removing the big bird on 64% (64/100) of these contact light trials. Thus, the success rate indicates that these infants had no difficulty in grasping and manipulating objects that were visible.

The arm used to execute the first movement was primarily ipsilateral to the activated rattle. Of the first movements to the activated rattle at the 30 and 60 degree left positions, 97.5% (39/40) occurred with the left hand. Of the first movements to the 30 and 60 degree right positions, 97.5% (39/40) occurred with the right hand. Infants displayed a left hand bias to only the midline position, when a rattle was activated. Of the first movements that occurred to midline, 62% (13/21) were executed by the left hand and 38% (8/21) by the right hand. On silent trials, when no rattle was activated, the left hand again dominated (i.e., 64% (9/14) of the movements with the left hand compared to 36% (5/14) of the movements with the right hand).

B. Head Orientation. Although the primary measure of the present study was reaching, head orientation was also scored. Infants, attracted by the movement of the rattle as well as the sound, tended to look toward the correct sector immediately after trial onset. Trials on which the midline position was activated were excluded from the first head movement analysis, because head orientation to this position was one of the criteria for initiating

the trial. On 84% (60/71) of the trials involving lateral positions, the first head movement was an orientation toward the correct sector after trial onset. As determined by the "pretrial" position, the head was oriented to the correct sector prior to trial onset on 22% (16/71) of the light trials. Correct head orientation prior to trial onset occurred because infants watched the descent of the rattle to its position for that trial. During the first hand movement, the head was correctly oriented towards the sounding object 100% of the time. On light trials which resulted in contact, the head was oriented towards the activated rattle at the point of contact 99% (96/97) of the time.

Behavior In The Dark

A. Reaching. In order to obtain a sounding object in the dark, infants first had to localize the sound, then execute an arm/hand movement in order to bring the hand in contact with the object on the basis of these sound cues. In addition, a motivational factor influenced the behavior in that infants sometimes chose not to respond during a particular trial. Reaching occurred on 77% (147/192) of the dark trials. On trials when a reach occurred, infants reached, contacted or grasped the object accurately 85% (125/147) of the time. The remaining 15% (22/147)

were reaches into sectors beyond 15 degrees left and right of the target. These reaches were specified as incorrect.

Infants entered the correct sector in the dark with their first movement 75% (110/147) of the time, with the remaining 10% involving a corrected movement (i.e., a lateral movement or a second reach). As in the light trials, the arm used to execute the first movement was primarily ipsilateral to the activated rattle. The first movements to the activated rattle at 30 and 60 degree left occurred with the left hand 76% (48/63) of the time. The first movements to the 30 and 60 degree right position occurred with the right hand 81% (52/64) of the time. A left hand bias to the midline position surfaced in the dark trials in an almost identical proportion to that on light trials. Of the first movement that occurred to midline, 60% (15/25) were executed by the left hand, as compared with 62% on the light trials.

On trials when a reach occurred, infants were successful in contacting the object 74% (109/147) of the time. Contacts consisted of touching, fingering, batting, swiping or grasping the object; complete removal of the toy from the rattle occurred on 26% (39/147) of these trials within twenty seconds.

B. Head Orientation. As compared to light trials, initial head movements were less likely to be toward the activated rattle

after trial onset in the dark. As in the light, trials in which the midline position was activated were excluded from the first head movement analysis because head orientation to this position was one of the criteria for initiating the trial. On 58% (84/146) of the trials involving lateral positions, the first head movement was an orientation toward the correct sector after trial onset. On 12% (17/146) of these trials, infants were oriented toward the correct sector during pretrial. Head orientation prior to trial onset can be attributed to air currents/vibrations or to the sound the hinge may have produced when the rattle descended.

No reaching occurred on 23% (45/192) of the dark trials. On 80% (36/45) of these trials the first head movement was toward the sounding object. The mean cumulative duration that the head was oriented toward the correct sector during these no reach trials was 10 seconds (SD=5.498; range from 0 to 20 seconds). On noncontact trials (i.e., misses, wrong reaches or no reaches), the mean cumulative duration that the head was oriented toward the correct sector was 9.62 seconds (SD=5.04; range from 0 to 20 seconds).

Although a large proportion of first head movements did not result in an orientation toward the correct sector, there was a greater tendency for the head to be oriented correctly when the first hand movement entered the correct sector. Of the dark trials on which correct reaching occurred with the first hand movement,

the head was oriented towards the sounding object 69% (76/110) of the time during that first movement. On the dark trials which resulted in contact, the head was oriented towards the activated rattle at the point of contact 79% (85/108) of the time. When the first movement was incorrect, the head was oriented towards the correct sector 63% (15/24) of the time.

Response Latencies In Light And Dark Trials

Although the number of reaches, the degree of accuracy in reaching behavior and head orienting is greater for light trials than dark trials, some characteristics of the behavior were similar. Figure 1 illustrates proportionately how rapidly infants execute the first movement into the correct sector after trial onset. The majority of first hand movements seem to occur within the first two seconds of trial onset for both dark and light trials.

Figure 2 illustrates proportionately the latency to contact the rattle, collapsing over the left and right hand. The majority of contacts are occurring within the first 3 seconds of trial onset for light trials and the first 5 seconds for dark trials. Thus, although the first movement is executed quite quickly in both light

and dark trials, a longer latency is required in order to make contact in the dark.

As was reported earlier, the first hand movements during light trials were 94% (94/100) accurate, in comparison to 75% (110/147) of the first hand movements in the dark. Eighty five percent (83/97) of these first movements in light trials resulted in contact, while only 53% (52/98) of the first correct movements for dark trials resulted in contact. In the light, infants directly reach and grasp the sounding rattle. Without visual cues, however, infants have a tendency to reach into the correct sector and then, make small lateral movements until the object is located. If the latency to execute this first movement that results in contact is compared proportionately between light and dark trials, an interesting difference surfaces. Figure 3 represents a subset of the data presented in Figure 1. Forty two percent (22/52) of the first hand movements that resulted in contact in the dark, occur within the first second, while only 29% (24/83) of these movements in the light occur within that time. Although fewer first hand movements result in contact on dark trials, when they do, they are executed within the first second.

The similarities in the latencies shown in the figures may indicate that infants were as confident or as comfortable reaching towards a sounding invisible object as they were for reaching for a

sounding visible object, although they were less accurate and a bit slower to make contact.

Two Handed Reaches

In order to obtain a more complete description of reaching behavior in the dark, the position of the first extension of each hand and the position of both hands during an incorrect first movement, were examined. Infants extended both hands at some point during the trial on 49% (49/100) of the light trials. On trials in which reaching occurred in the dark, 47% (69/147) involved an extension with both hands. For dark trials on which first hand movements were incorrect and two hands were involved, the first movement with the opposite hand entered the correct sector 76% (13/17) of the time. Although the position of both hands has been examined, a postural pattern (i.e., hands separated by a certain distance) does not emerge. These results suggest that the infant may extend both hands in order to provide some degree of balance; that is, very often the hand ipsilateral to the target reached for the target, while the other hand was simply extended slightly away from the body. However, because the magnitude of a reach was not scored, we cannot determine if there is a behavioral difference between these two types of arm extensions.

The criteria used to determine a bimanual reach was both hands had to contact the object within one second of each other. This strict criteria led to a small number of bimanual reaches (7% (21/292)) out of the total number of trials (i.e., light and dark). Although there were a limited number of bimanual extensions, if collapsed across light and dark trials, 52% (11/21) occurred at midline. It was hypothesized that fewer reaches would occur to the midline position because it would require the most effort. This hypothesis is possibly supported by the bimanual reaches in that two hands may be needed at midline in order to make a successful attempt.

Silent Trials

Silent control trials provided a baseline measure of arm activity in the dark. There were hand extensions into target sectors on 40% (14/35) of the silent trials. Of the first movements on these silent trials, 64% (9/14) occurred with the left hand. Of these first movements to the 30 degree and 60 degree left position, 50% (7/14) occurred with the left hand and 28% (4/14) of the first movement to the right positioned rattles occurred with the right hand. Of the reaches that occurred at midline, 14% (2/14) were with the left hand and 7% (1/14)with the right hand

(see Table 1). The head was oriented at midline during the first movement 64% (9/14) of the time.

The hand extensions on silent trials were also analyzed by designating the position in which the rattle was activated in the previous trial as the activated rattle for each silent trial. The correct or target sectors for a particular trial were the sectors that were correct for the last trial. The purpose of this analysis was to determine whether infants were reaching to the remembered position. Only 21% (3/14) of the extensions were "correct" and 21% (3/14) occurred to adjacent sectors, with the remaining 57% (8/14) being "incorrect". This is approximately what would be expected by chance. On 14% (2/14) of these trials the first head movement was "correct". This analysis was repeated designating the position of the last light trial as the activated rattle. "Correct" first movements occurred on 25% (3/12) of the trials, with adjacent and "incorrect" reaches equaling 8% (1/12), and 67% (8/12) respectively. On 23% (8/35) of the trials, the first head movement was "correct".

Rattle Position Effects

In order to determine position effects, the data were

analyzed using a 2-way repeated measures analysis of variance (i.e., Trial Type (Light vs Dark-2) x Rattle Position (5)). There were unequal N's in some of the cells because eight of the infants were missing 1 dark trial due to fussiness or the rattle descending on the infant's hand. In order to perserve the orthogonality of the sums of squares, the data were coded as the percentage of opportunities to respond which were correct at a particular rattle position. In addition, the assumption of homogenity of variance and covariance was violated. The correlation of the responses between the cells was unequal, which inflates the Type 1 error. The Huynh-Feldt adjustment lowers the degrees of freedom, providing a conservative judgement in terms of significance. This compensates for the inflated Type 1 error (Myers, DiCecco, White & Borden, 1982).

The frequency of correct responding with the first hand movement was significantly greater on light trials than on dark trials ($F=27.24$ $(1,19)$, $p< .01$) and varied with rattle position ($F=7.55$ $(4,76)$, $p< .0002$; see Table 2). More correct reaching occurred to off-midline positions than to midline. When contrasts for rattle position were compared, the ± 60 degree positions had more correct reaches than midline (see Table 2). One hypothesis which may account for the higher response rate at the extreme positions focuses on the increased chance of accidental contact due

to the natural position of the hands. However, Table 1, which presents the distribution of these first hand movements in the dark on sound trials and silent trials, demonstrates that there were actually fewer incorrect reaches to the extreme positions. Therefore, not only were there fewer correct reaches to midline, but a larger proportion of incorrect reaches occurred at this position, as compared to the extremes. In addition, a bias toward the left side surfaced when extensions were incorrect or occurred during silent trials (Table 1). This was not the case for correct reaches.

Table 3 presents the distribution of the latency of the first hand movement at each rattle position for light and dark trials. A number of infants did not reach to every rattle position in the dark. To statistically test the latencies, a subset of the data was analyzed. Fourteen out of the 20 subjects reached at least once to every position in the dark. The latency to respond for these first five dark trials and the test light trials were analyzed using a 2-way repeated measures analysis of variance (i.e., Trial Type (Light vs Dark-2) x Rattle Position (5)). The latency of the first hand movement of the trial was significantly faster on light trials ($F=5.40$ $(1,13)$, $p< .037$; Table 4). However, a rattle position effect was not found ($F=1.10$ $(4,52)$, $p< .3662$; Table 4).

Table 5 presents the distribution of the first head movement, at each rattle position for dark trials and silent trials, regardless of whether there was a reach or not. The frequency of a correct head movement after trial onset was significantly greater for light trials ($F=22.30$ $(1,19)$, $p< .01$; Table 6). Correct orientations with the first head movement are less likely to occur at the extreme positions ($F=6.53$ $(4,76)$, $p< .0003$; Table 6). A significant difference was also found between the 60 and 30 degree left rattle position ($F= -3.2904$ $(4,76)$, $\omega=.05$; Table 6). Incorrect head orientations in the dark are more likely to occur at the $\pm$ 60 positions (Table 5).

Trials were initiated when infants were oriented to the midline position. This would account for the majority of first head movements to midline on silent trials, as well as the small number of incorrect orientations at this position on test dark trials (Table 5). Position effects were re-analyzed excluding the midline position. The frequency of correct responding remained significantly different for light and dark trials ($F=17.09$ $(1,19)$, $p< .0006$; Table 7). A rattle positon effect was found ($F=4.05$ $(3,57)$, $p< .0124$; Table 7), with correct responding occurring significantly more often to the 30 degree left position than the 60 degree left position for combined light and dark trials. A position effect for correct responding on the measures of head

orientation at point of contact (Table 8) and head orientation during the first hand movement (Table 9) was not found. However, the frequency of correct responding was significantly greater for light trials ($F= 49.97$ (1,19), $p< .01$; Table 8: $F= 47.94$ (1,19), $p< .01$; Table 9, respectively).

The frequency at which no reaching occurred to each position was also examined. Of the dark trials on which no reaching occurred, 35% (15/43) were at midline. Twenty six percent (11/43) of these trials were at the 60 degree positions. Table 10 presents the distribution of the first head movement for trials on which no reaching occurred. Less correct head orienting occurred to the extreme positions, particularly to 60 degrees right.

Summary of Results

Infants were able to accurately reach for a sounding object in the dark at all 5 positions. Although the frequency of responding was lower than in the light, the accuracy of reaching behavior in the dark was quite good. Reaching behavior on light and dark trials shared a number of similarities. On the majority of trials, infants reached for the sounding object within two seconds of trial onset. The arm used to execute the first movement

was primarily ipsilateral to the activated rattle. The first hand movements to midline in the light, dark and during silent trials, were primarily executed by the left hand. This suggests a left hand bias. Although similarities were found, the form of a reach in the dark seemed to differ from the behavior that was observed in the light. Reaching in the light was more direct and more likely to result in contact with the object. In the dark, infants were more likely to make lateral movements before entering the correct sector and grasping the object. Head orientation was frequently away from as well as towards the activated rattle. As was anticipated, the midline position was the most difficult position for the infants to reach for. This was supported by the fewer number of reaches to this position.

CHAPTER V

DISCUSSION

The present study has demonstrated that infants do have the ability to accurately reach for a sounding object in the dark at 7 months of age. From the literature that had been reviewed earlier, other investigators would not have predicted this outcome. This ability to accurately localize a sounding object within the reaching space, in the dark, implies that: 1) the infant does not have to see the hand and/or the object in order to make a successful reach (i.e., reaching is not visually guided), 2) the infant "knows" or has an understanding that an object exists even when visual cues are absent and 3) auditory cues can be utilized in order to determine an object's position in space. Each of these points will be discussed below.

Type of Control in a Reach

Bushnell's (1985) hypothesis would not have predicted the present findings. Bushnell (1985) argued that between 4 and 6 months of age, the transition from visually elicited to visually guided reaching has just occurred and constant monitoring of the gap between the seen-hand and the seen-target is critical for a

successful reach. At 9 months of age, the reaching response is well practiced and possibly overlearned. Thus, little attention of the seen-hand and seen-target is necessary. A successful reach in the dark for a sounding object by a 7-month-old infant would not be predicted according to her hypothesis, because the infant is unable to monitor the seen-hand-seen-target gap. Although Bushnell (1985) supported her hypothesis, the studies she cited (Lasky, 1977; McDonnell, 1975; McDonnell & Abraham, 1977) involve distortions of the visual field. Infants may have been monitoring the gap because they were reacting to the strangeness of the visual information they were perceiving. Von Hofsten (1979; Von Hofsten & Lindhagen, 1979) reported that infants at 12 to 36 weeks of age fixated the moving object when reaching for it and did not look back and forth from the hand to the object. Even when corrective hand movements were made, infants remained fixated on the object. This would indicate that monitoring of the seen-hand-seen-target is not necessary for a successful reach in 7-month-olds.

If reaching behavior in the dark is organized in such a manner that it shares similarities with an earlier stage of development, Bushnell's (1985) hypothesis could possibly be supported. Bushnell argued that successful or aimed prereaching involves matching the seen-target and the felt-hand (i.e., kinesthetically driven), while reaching involves the seen-target

and the seen-hand (i.e., visually driven). In the absence of visual cues, the infant would seem to be dependent upon the kinesthetically moving hand in order to arrive at the location of a sounding object (Bullinger, personal communication, May, 1986). If the seen-target can be replaced with the "heard-target", accurate reaching in the dark could be predicted. This would account for the high rate of accurate reaching in the dark in the present study.

Reaching behavior does seem to be organized differently in the dark and light. Muir (Muir et al., 1985; Stack et al., 1986) described the reaching in the dark behavior he has observed in his lab as a response which is infrequent and "...might be characterized as groping, compared with the more accurate, visually elicited responses" (Muir et al., 1985, p. 304). The reaching in the dark behavior observed in the present study would not be characterized as groping. However, it would also not be described as identical to reaching in the light. Although the rate of responding and the degree of accuracy was greater for light trials, performance in the dark was quite good and would be considered exceptional in comparison to the other reaching in the dark studies which have been done.

The type of control in a reach differs. In the dark, the infant seems to be dependent on kinesthetic cues, while in the

light visual cues dominate. Bullinger (personal communication, May, 1986) states that "vision allows for a reach to be driven by an "address" in space, rather than the movement of the arm per se". In contrast, the infant must rely on the movement of the arm in the dark, until tactile cues are available (i.e., when and if contact with the object is made) (Bullinger, in press). The dependency on kinesthetic cues is more characteristic of global behaviors such as prereaching.

Prereaching behavior tends to be ballistic (Bruner, 1973; Bower, 1974; Von Hofsten, 1979; Bushnell, 1985). Bushnell (1985) describes a ballistic movement as an "arm movement which is preprogramed or fully aimed at the target object before or at the moment the movement is launched" (p. 140). This type of extension consists of only one movement element (Von Hofsten, 1979). Bruner (1973) and Bower (1974) have also described prereaching behavior as a unitary movement (i.e., a reach followed by anticipatory hand-closure). Although the present scoring system did not capture the anticipatory hand-closure element of a reach separately, a greater proportion of first movements in the dark compared to light trials resulted in contact within the first second of the trial. This may be an indication that reaches in the dark were more likely to be ballistic.

Von Hofsten (1979) has reported that the number of movement

elements per reach is greater in younger infants. There are also more zig-zag movements and the duration of approach to the object is greater. In the present study, although infants executed their first movements within the first two seconds of trial onset for both light and dark trials, corrective movements were needed on a larger number of dark trials, (in comparison to light trials), in order to enter the target sectors. There was also a longer latency to make contact in the dark.

A Form of Object Permanence

Reaching in the dark could possibly be interpreted as a form of object permanence. In Piaget's theory of cognitive development, object permanence has been defined as the child's realization that an object continues to exist even when it is out of sight or hidden. As infants enter stage III (i.e., 4-8 months of age), they are just begining to show this capability. At the end of stage III, infants will uncover partially hidden objects. Piaget (1952) found that the transition from stage III to stage IV was characterized by the infant's lack of intention to find the object (p. 217-226). Piaget (1954) identified this as a period of transitional search (occurring at approximately 6 months of age) in which infants uncover objects, but do not show intention to find

them. This period precedes intentional search which occurs at about 8 months of age. Thus, initially there is no attempt to search, then, infants enter a transitional period in which the infant uncovers a hidden object, but seems to be unaware of it. For example, when the cover is removed, the infant initially fails to look at the toy and then is surprised to find it (Piaget, 1954; Obs. 38). The last phase in the development of search is intentional search in which the infant is aware of the object and recovers it quickly.

Willatts (1984) also has demonstrated that infants between stage III and stage IV display different degrees of intentionality in their search behavior. Infants age 6, 7 and 8 months were presented with the task of recovering a toy that was hidden by a cup. The degree of intentionality was measured by noting the reactions to the cover, where the infant fixated, the behavior with the hidden toy and the speed with which it was retrieved (Willatts, 1984).

The session began with two familiarization trials. Infants were allowed to manipulate the toy and the cup prior to test trial onset. The majority of the infants displayed transitional search before intentional search. Intentional search and the infants' awareness of the toy gradually developed. Intentional search by older infants was characterized by the infant's direction of gaze

and speed with which the hidden object was uncovered.

Willatts (1984) stated that search studies with young infants may have misinterpreted their findings (Ginsburg & Wong, 1973; Rader, Spiro & Firestone, 1979), because young infants are more likely to be in the transitional phase of search development. Willatts (1984) defined transitional search as a form of object permanence, which as noted above, differs from stage IV in the degree of intentionality the infant displays in recovering the object.

Hood and Willatts (1986) have interpreted reaching in the dark as a form of object permanence. Recently, they have demonstrated that 5-month-old infants were able to represent objects that were no longer perceptually available, by reaching in the dark to an object's remembered position. They modified the Bower & Wishart (1972) procedure, correcting the methodological weaknesses of unspecified criteria used to determine accidental from intentional contacts and the failure to prevent the initiation of a reach before the lights were extinguished. The onset of a trial was marked by presenting the object at midline and allowing the infant to manipulate it. Infants' arms were then restrained by the mother and the object was removed from the infant's sight. The object reappeared within reach to the left or right. When the object was fixated by the infant, the room lights were switched off

and the object was removed. The mother released the infant's arms after a short delay. The duration of the trial was 25 seconds.

The number of reaches that occurred to the target region (i.e., area where the object was presented) and the non-target region in the dark were examined. Control trials consisted of a 10 second delay in the light in which no object was presented after the object was removed from the midline. Following this delay, the lights were extinguished for 25 seconds.

Hood and Willatts (1986) found that infants produced significantly more reaches to the target region than to the non-target region on the object trials. They concluded that 5-month-old infants demonstrate a form of object permanence by reaching in the dark to an object's remembered position. However, the number of reaches on control trials did not differ significantly from the number of reaches to the target or non-target regions of object trials. In addition, the direction (i.e., target or non-target region) of the first reach on object trials was random. This indicates that there was very little intentionality, which is characteristic of transitional search.

At 7 months of age, the arm transport has stabilized and the infant is completing the transitional phase or just entering the intentional phase of search behavior. At the very least, the

reaching in the dark behavior displayed by the infants in the present study can be seen as the form of object permanence described in Willatt's (1984) transitional period. However, the author would argue that reaching in the dark to a sounding object represents object permanence beyond the transitional period. Transitional search demonstrates minimal awareness of the hidden object. Infants uncover an object not fully appreciating that an object is hidden under the cover. In the present study, infants reached accurately to all 5 positions in the dark. Only a small percentage of the total number of accurate reaches involved corrective movements. Therefore, intentionality to retrieve or obtain the sounding object can be inferred by the high percentage of "on-target" first movements in the dark.

Intentional search characterizes Piaget's stage IV. However, from the literature that has been reviewed, the use of sound has been found to be unsuccessful in enhancing search behavior in a standard Piagetian task (Freedman et al., 1969; Bigelow, 1983; Uzgiris & Benson, 1980). Infants began to use sound to direct their search behavior only after they had entered stage IV (typically occurring between 8 and 12 months). If reaching in the dark is a demonstration of object permanence (i.e., intentional search), something must account for infants' use of sound in the present situation compared to the ineffective use of sound in a standard

Piagetian object permanence task. In addition, sound does not necessarily have to play a major role, in that, if the object is presented in a particular location infants will reach to that location when the lights are extinguished (Wishart et al., 1978; Hood & Willatts, 1986).

As proposed earlier, the nature of the transition seems to be the critical factor: the difference between an object that instantly disappears (i.e., annihilation) and an object that gradually is covered. The infant's perception of the occlusion may determine whether or not the infant will search for the occluded object (Gibson, 1969). Harris (1983) stated that the sudden loss of light may not be perceived as an object's annihilation, but rather a "new" situation in which to locate the object. Bower, Broughton and Moore (1971) found that infants who could not pass a standard Piagetian task, did reach for a hanging object at midline after the lights were extinguished.

The present study does not represent stage IV object permanence. Infant's did reach for an object that continued to exist when it was out of sight. However, the sound may have triggered this "understanding" of existence by acting as a retrieval cue in this "new" situation. A stage IV object permanence task places greater demands on the infant then reaching in the dark. Additional support for this is found in the analysis

of the silent trials. Infants did not reach to the position of the last activated rattle (performance was at chance level). Harris (1975) breaks down Piaget's transition from stage III to stage IV into 4 separate stages: 1) (4-5 months) move object placed in hand into visual field, 2) (6-7 months) withdraw an object that is already in hand from under a cover, 3) (8-11 months) search for an object that is removed from the hand and then covered and 4) (12 months) search for an object seen covered but has not been grasped. Reaching in the dark to a sounding object may represent an ability which falls between Harris' (1975) stage 2 and 3.

The Effects of Familiarization with the Sound

The reaching response rate in the dark was much higher in the present study than in the Stack et al. (1986) study. The latency to initiate a response was also much faster for both light and dark trials. The major difference between the two studies was the present study provided a "familiarization" phase during warmup. The infants not only saw the sounding object in the light, but they were also given the opportunity to manipulate a part of it (i.e., Big Bird). In the Stack et al. (1986) study, infants were unfamiliar with the sounding object. From the infant's perspective, the entire setting was dark and then an unfamiliar

sound was presented. Our familiarization or warmup stage possibly provided the infant with more information about the object and its sound so that the two could be associated. In addition, Harris (1971) found that infants searched more for an object if they had manipulated it. Thus, the infant's "motivation" to search or reach for an object may be increased by this familiarization process. Reaching in the dark does not represent a conditioned response because infants reached to all 5 positions accurately.

Similarities Between Sighted and Blind Infants

Fraiberg's (1977) work has demonstrated that blind infants can retrieve a sounding object at midline at approximately the same age that sighted infants enter Piaget's stage IV (i.e., 8 to 11 months). These findings have been interpreted as demonstrating that sighted and blind infants appear to be developing in parallel in terms of the effectiveness of sound cues in representing a physical object (i.e., object permanence). Varying performance levels at different presentation positions may provide additional evidence for this parallel development. At 7 months of age, sighted infants were reaching accurately in the dark for a sounding object to a number of positions on the azimuth, although performance at midline was poorer. Fraiberg (1977) has reported

that at 9 months of age blind infants are just begining to retrieve a sounding object from the midline (Stage 1= retrieve sounding object following contact, Stage 2= retrieve based on sound cue only). Fraiberg (1977) mentions the existence of a third stage in hand-ear coordination which involves directional reaches to a sounding object. Unfortunately, she did not determine when blind infants acquire this capability. Therefore, blind infants may be capable of retrieving sounding objects presented off-midline by 7 months of age, while at 9 months of age, sighted infants in the dark may be reaching to midline with the same frequency and accuracy that they display to the lateral positions.

Bullinger (in press) described an interesting behavior that blind infants display when they have acquired the ability to reach for sounding objects (i.e., 9 to 11 months: Fraiberg, 1977). When a sound is within reach, a head movement is produced which results in an orientation towards the object. Bullinger (in press) suggests that this allows for the auditory cues reaching the ear to be equal. The duration of head movements have been found to increase, when the sound is out of reach. The head oscillates, resulting in a position which maximizes the difference of interaural cues reaching the ears. This pattern of movement is analogous to the scanning and orientation behavior displayed by animals to facilitate the detection and location of predators (Dewsbury,

1978). Jenkins and Masterton (1979) discussed 3 levels in the hierarchy of the sound localization capacity: homing, scanning and localizing. Scanning involves the integration of sound intensity with a change in the direction of head movements. Mammals and birds have been found to display this behavior (Konishi, 1973; Payne, 1971).

In the present study, the first directional head movement in the dark after trial onset and the head orientation during the first hand movement was not necessarily toward the sound source. This might be surprising in lieu of the auditory localization literature that has been reviewed (see Muir & Clifton, 1985) and the accuracy of head orienting which occurred during the light trials of this study. However, head movements seem to serve a different purpose in the light and in the dark.

Hafter et al. (1973) suggested that head orienting usually serves the purpose of bringing the sounding object in line with the eyes or body, allowing the eyes to search the area. Thus, the center of the head does not have to be lined up squarely with the sound's position, as eye movements may complete the infant's orientation toward the sound. In the present study, head orientation was not 100% accurate in the light, but eye movements, had they been measured, may have shown fixation on the object. This hypothesis is supported with findings from the study of barn

owls. Knudsen and Knudsen (1985) have found that the visual system provides the spatial reference for fine-tuning auditory localization, even though visual acuity is relatively poor in comparison to the owl's highly developed auditiory localization.

As noted earlier, a number of studies have demonstrated visual-auditory coordination at birth. For example, newborns will flick their eyes towards a sound off midline (Crassini & Broerse, 1980; Turkewitz et al., 1966; Mendelson & Haith, 1976; cf Haith, 1980). Congentially blind infants at 2 weeks of age have also been found to produce abrupt eye movements to a sound that was within reach (Bullinger, in press). However, eye movements in the blind occur before the head rotates and the hand is extended. Thus, head orienting is not necessarily a precise indication of a sound's direction, because the response as displayed by adult humans and animals only requires general orientation towards the sound.

Bullinger (personal communication, May, 1986) hypothesized that the function of head movements change. Rather than the eyes scanning the surroundings, head movements are used to explore auditory space in the absence of visual cues, in order to locate a sounding object. There is no reason for the head to serve as a "pointing device" when movement ceases in the dark, because the gaze to the target location is not functional (Bullinger, personal communication, May, 1986).

Presently, there is no strong evidence to suggest that infants have a fine appreciation of auditory distance (Muir, Humphrey, Dodwell & Humphrey, 1985). In the light, the distance of an object is determined by utilizing the visual cues in the environment. In the dark, however, the sighted infant may have difficulty distinguishing between sounding objects within reach and beyond reach. The "poor" performance of head orienting (as defined in terms of the present study), may be attributed to head oscillations, which are similar to those displayed by blind infants. This type of head movement may serve to maximize the difference in interaural cues and possibly enhance the ability to locate the object in auditory space. Head movements in the dark would provide more sensory information than a stabilized head orientation. Thus, one would predict more head movements in the dark than in the light, including head turns away as well as toward the sound.

Visual-Motor vs Auditory-Motor Coordination

There were several minor aspects of the data which were interesting and should be addressed. Reaching in the light represented a baseline measure for infants' ability to reach to all 5 locations when visual cues were available. As expected, infants

reached on every trial and their accurracy was almost perfect. Von Hofsten's (1979, 1980) earlier reports were supported in that infants tended to reach directly to the object (i.e., zig-zag movements were absent). The power of the reach and the approach was concentrated in the first movement after trial onset, which was demonstrated by the shorter latency to contact and the extremely low number of corrective movements made in order to enter target sectors (i.e., only occurring on one trial). In terms of head movements, infants oriented to the sounding object immediately after the start of the trial and continued to face the object when the extension and/or contact was made. This confirms the behavior that has been reported in extensive studies of auditory localization, which have relied upon the head orienting response (Muir & Field, 1979; Clifton, Morrongiello, Kulig & Dowd, 1981b; Muir & Clifton, 1985).

Bower (1982) suggested that the same motor behavior is required in auditory-motor coordination and visual-motor coordination. The present study may offer partial support for this hypothesis. Certain aspects of reaching behavior in the light and dark were found to be similar. The majority of first hand movements occurred within the first two seconds of trial onset for both dark and light trials. The arm used to execute the first movement on all sound trials was primarily ipsilateral to the

activated rattle. Von Hofsten's (1980) work on 18-36 week old infants reaching towards a moving object would provide some indication that this would be expected. He reported that when an object was within reach and stayed within reach for several seconds, the ipsilateral hand was used most often. Another similarity which surfaced was the first hand movements to midline in the light, dark and during silent trials were primarily executed by the left hand. This seems to indicate a left hand bias in the present study. Seth (1973) reported a left hand bias in 20-36 week old infants on several measures of eye-hand coordination. However, a left hand dominance is usually found only in the prereaching period (Gesell & Ames, 1947; McDonnell, Anderson & Abraham, 1979). In conclusion, certain aspects of a reach are displayed in both auditory-motor coordination and visual-motor coordination.

It was anticipated that performance at the midline position would be poor in comparison to the laterally positioned rattles, because of the natural position of the arms at rest. This was supported by the fewer number of correct reaches to the midline position. However, a greater number of incorrect reaches occurred to this position rather than to the extreme positions. It was hypothesized that the midline position would be the most difficult because additional effort is needed in order to successfully grasp the sounding object. This hypothesis is possibly supported in that

the majority of bimanual reaches occurred to the midline position. Bower (1974) also reported that two-handed reaches were only observed when the object was at the midline position. However, a bimanual reach or few correct reaches to midline does not necessarily represent difficulty in retrieving an object, but rather may represent difficulty in deciding which hand to initiate the response. Therefore, conclusions can not be made as to why the midline position was difficult.

Reaching in the dark research has interesting implications for intervention with blind infants. The present study had revealed that when working with blind infants, sounding objects should be presented off-midline and within reach. Torso and head movements should also be emphasized so that kinthestic cues are maximized. We are now just begining to tap sighted infants' organization of auditory space. The present study has demonstrated that sighted infants can accurately localize a sounding object in the dark that is within reach. We must now determine how infants divide up their auditory space, in terms of depth and the horizontal vs vertical axes. The posture of the torso and the shape of the hand would seem to provide additional information about the sighted infant's expectations. By determining how auditory space is represented by the sighted infant, we will be able to make comparisons with the development of blind infants.

Through successful clinical application, we may be able to eliminate developmental differences by presenting the auditory world optimally to these infants.

APPENDIX A

SCORING SYSTEM FOR REACHING

Warmup and all Test Trials will be scored. Contact and Noncontact trials will be scored differently. REMEMBER Accuracy is Critical. Do Not rush or do a sloppy job. TAKE YOUR TIME.

Make sure you check to see what babies need to be scored and fill in the scoring log correctly.

On each data sheet fill in the required information from the subject log. Age will be in weeks. The video location will equal the location that you are on when you begin to use a particular scoring sheet. FOR EXAMPLE, the log says infant #99 is at the locations 256-650. If you are on trial 15 and the video deck reads 600, put that as your video location for the scoring sheet you are about to use.

FOR EVERY TRIAL

Make sure you fill in the trial number. Make sure you circle light or dark, depending on the trial. Write down the rattle you see being activated--->not what the protocal says.

CONTACT AND NONCONTACT TRIALS WILL BE SCORED DIFFERENTLY

Preview and Time the Trial

View the entire trial, watching for such features as obvious arm extensions and positions, bimanual arm movements, grasping or other hand movements and the removal of the object. If the object is removed enter "yes" in the appropriate space. Also, each scorer should time the trial. Enter the start of the trial and the end of the trial to the nearest .01 second in the appropriate spaces.

REACH= an extension of the forearm in a forward motion, away from the body. Keep in mind, when we speak of sector positions we are interested in the position of the hand, not the arm.

TRIAL START= when the rattle begins to sound, in the light or dark.

TRIAL END= DARK-->when the Big Bird is removed from the rattle, the rattle is returned to its original position or the lights go on. LIGHT-->Big Bird is removed from the rattle or the rattle is returned to its original position.

NOTE: in warmup--> the experimenter may assist the infant. Trial ends when the experimenter begins to help or touches the Big Bird.

SECTORS

The apparatus is divided into 8 sections. Each section equals approximately 15 degrees. Each rattle is associated with two of these sectors or sections. The sectors which flank the activated rattle are the correct sectors for that particular rattle. Therefore, the baby is localizing accurately if their hand is in one of the sectors on either side of the activated rattle. Sectors 0 and 9 are not marked on the apparatus. You must use your own judgment. Be conservative in your decisions.

CORRECT SECTOR

As defined above, the correct sectors are equal to the sector on each side of the activated rattle. Each rattle has two correct sectors, one on each side. Rattles 1 and 5 only have one of their sectors on the apparatus. Positions 0 and 9 must be estimated.

NOTE: if the infant or the experimenter moves the rattle out of the proper position (30 degrees left or right, 60 degrees left or right, or center). You must redefine what the correct sectors are equal to. Example, if rattle 3 is activated, the correct sectors equal 4 and 5. However, if the rattle is pushed or moved so that it is positioned between sectors 5 and 6, then 5 and 6 equal your correct sectors. HOWEVER, make sure on the scoring sheet, that if the baby was in the correct sector you indicate he was in sector 4 and 5. You have redefined the correct sectors (4 and 5) to equal the new sectors (5 and 6). Make sure you indicate what your new definition equals, but use the sector numbers that would be correct if the rattle was in the proper position. For later data analysis it is important for us to know that the baby was in the correct sector according to our present definitions.

PRE-TRIAL

Determine the position of both hands before the start of the trial. Indicate if each hand is extended in a particular sector or if it is by the infant's side. Identify the sector location for the Left and Right Hand, if it is extended.

Remember- Extended/Reach= forward extension of the forearm. Keep in mind, when we speak of sectors--> we are interested in the position of the hand, not the arm.

Head Orientation= the sector the infant is facing. Also, note if the head is facing up or down or is straight ahead.

Body Orientation= the sector the infants torso is facing--> use shoulder position as a guide. Determine if body is leaning forward, if it is reclining or if it is upright.

STATE:

Fussy = about to cry, whining, unhappy, doesn't want to play, turns toward mom. The key here is that the infant is making negative vocalizations.

Attentive= ready to play, interested in the game, not distracted.

Off Task= distracted, wiggling, interested in toes, turns toward mom.

TRIAL

CONTACT

For the Left and Right Hand, determine if the hand and arm are extended. Determine the sector position of the hand. Score every reach that occurs with each hand. Therefore, if the left hand makes two reaches, indicate that there were two reaches and note the sectors that they entered, as well as what they were doing (i.e., touch, grasp, flapping).

ADDITIONAL MEASURES

TIME

LATENCY TO CONTACT =the time it takes from the start of the trial (i.e., rattle begins to sound) until the infant contacts the rattle. Latency to contact is determined for all contact trials.

TYPE OF CONTACT=

T-->touch: obvious contact of the object by the hand, but without batting, fingering or grasping.

B-->Batting: repeated hitting of the object.

F-->Fingering: exploratory movements on the object, but not a grasp.

G-->Grasping: partial or full closure of part or all of the hand around the object.

S-->Swipe: arm movement which causes the infant to contact the rattle, but overshoots or by passes.

***NOTE: Type of Contact was not a reliable measure.

If a reach does not result in contact describe what the arm and hand are doing. Does a particular extension involve flapping or did the infant just reach out. Was there an extension or a lateral movement.

HEAD ORIENTATION---determine the sector that the first head movement is oriented towards. Record every head movement so that the proportion of time that the head was oriented toward the correct sector can be established. Again, the correct sector=one sector on either side of the activated rattle. Both of these sectors are correct.

Body orientation-the sector the infant's torso is facing. Use the position of the shoulders as a guide. Determine if the body is leaning forward, reclining or is in an upright position. Also, make NOTE of whether the body follows the head=--> or if they move together= +.

***NOTE: The proportion of time the head was
oriented correctly
and body orientation on contact trial were not reliable measures.

State= Fussy, Attentive or Offtask

<u>NONCONTACT</u>

Left and Right Hand-- Identify the sector that each hand of an extended arm is located at. Note if the hand itself is extended. Record the cumulative time each hand spends in the correct sector. ***If neither hand is in the correct sector, identify the sector position of the hands.

***NOTE: The cumulative duration of the hand in the
correct sector was not reliable.

Head Orientation--the sector the infant is facing. Record the cumulative amount of time the infant is facing the correct sector.

Body Orientation--the sector the infant's torso is facing--use the shoulder position as a guide. Determine if the body is leaning forward, reclining or is in an upright position. NOTE: if the body follows the head = --> or if they move Together = +.

***NOTE: Body orientation was not reliable.

State= Fussy, Attentive or Off Task

Silent Trials Note the sector position of each hand, if there was an extension, how many, where they occurred, the head and body orientation, and the state of the infant.

NEW MEASURES TO BE SCORED

The infants for the first reaching in the dark study have been scored. What you will be doing is going back to pick up a few additional measures. First, make sure you have a particular infant's scored data sheets. You will refer to these sheets so that you know what to expect during a particular trial. From the scored data, you can see when a trial started, if it resulted in contact and if the baby made an extension with each arm (in addition-->which hand, where it was located and what was the result).

Fill out the top of your scoring sheet completely. Trial start time can be taken from the old scored data sheets. If there are two scorers for a particular baby and they disagree by more than 10 ms, find your own start time. If the two scorers are within ±10 ms, take the average of the two.

You will score the latency to complete the first movement, AFTER THE TRAIL START TIME. This means the time it takes from the trial start time to complete the first extension or lateral arm movement.

EXTENSION=extending the arm away from the body in a forward motion towards the apparatus.

END OF FIRST EXTENSION OR MOVEMENT= when the arm/hand pauses for 40 ms or makes a significant reversal (i.e., not just a jerky movement).

If the first movement results in contact, find your own latency to contact. PLEASE NOTE ON YOUR SCORING SHEET THAT THE FIRST MOVEMENT RESULTED IN CONTACT.

The old scored data sheet should tell you where the first extension is going to occur. If you disagree with how the first person scored the first movement, PLEASE BRING IT TO MY ATTENTION.

You are scoring for the left and the right hand;

1). the time it took to complete the first movement, AFTER TRIAL ONSET.

2). what sector the extension or lateral movement occurred in

3). where the head was positioned during the extension

4). where the head was positioned during point of contact (NOTE THIS IS NOT ON THE SCORING SHEET, PLEASE MAKE SURE TO ADD IT, IF THE TRIAL RESULTED IN CONTACT)

GOOD LUCK....Remember Accuracy is important, don't rush. If you have a question, come get me.

A P P E N D I X B

Figure 1: Latency of the First Correct Hand Movement for Dark and Light Trials

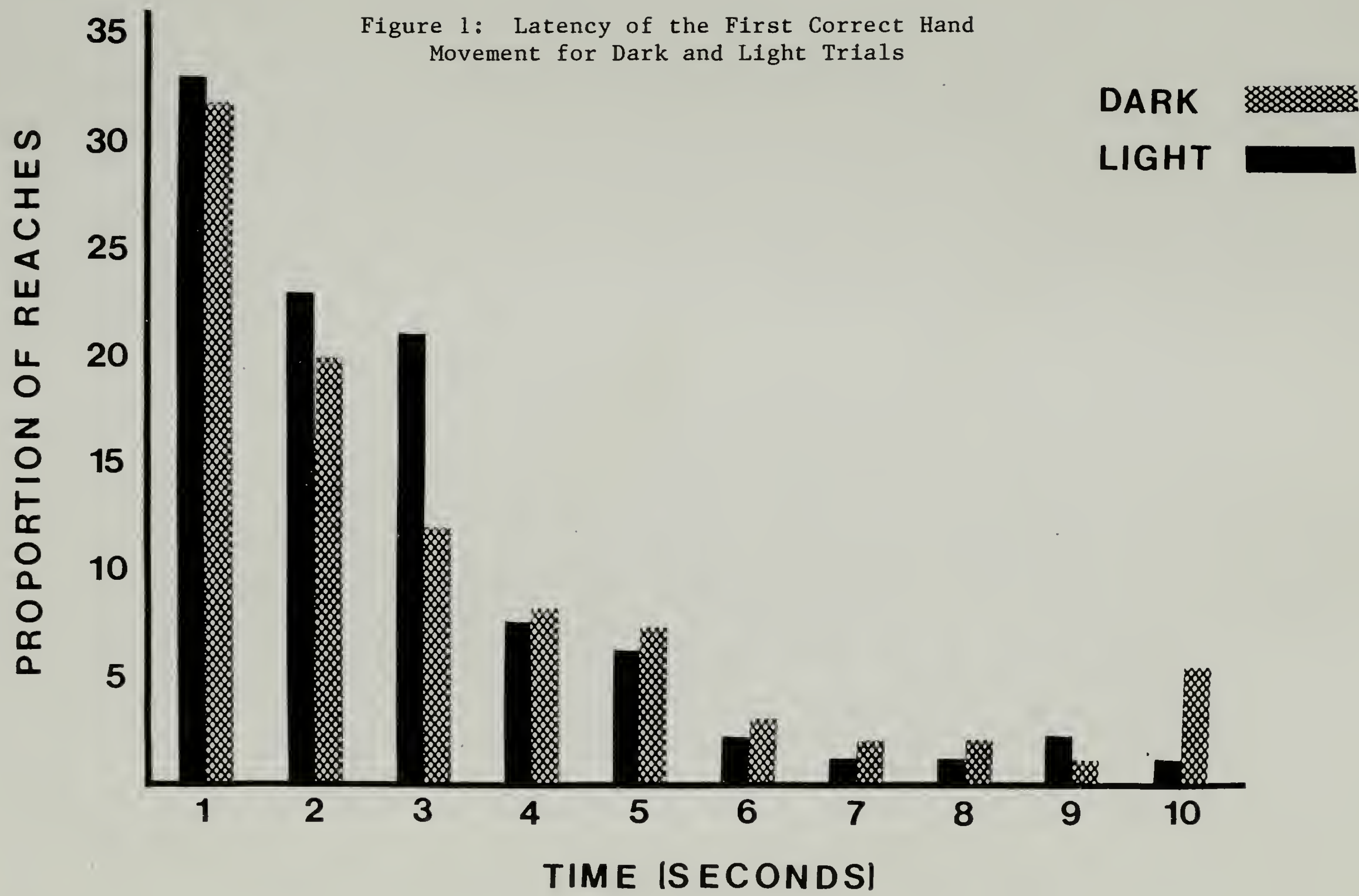


Figure 2: Latency to Contact Collapsed Over Left and Right Hand

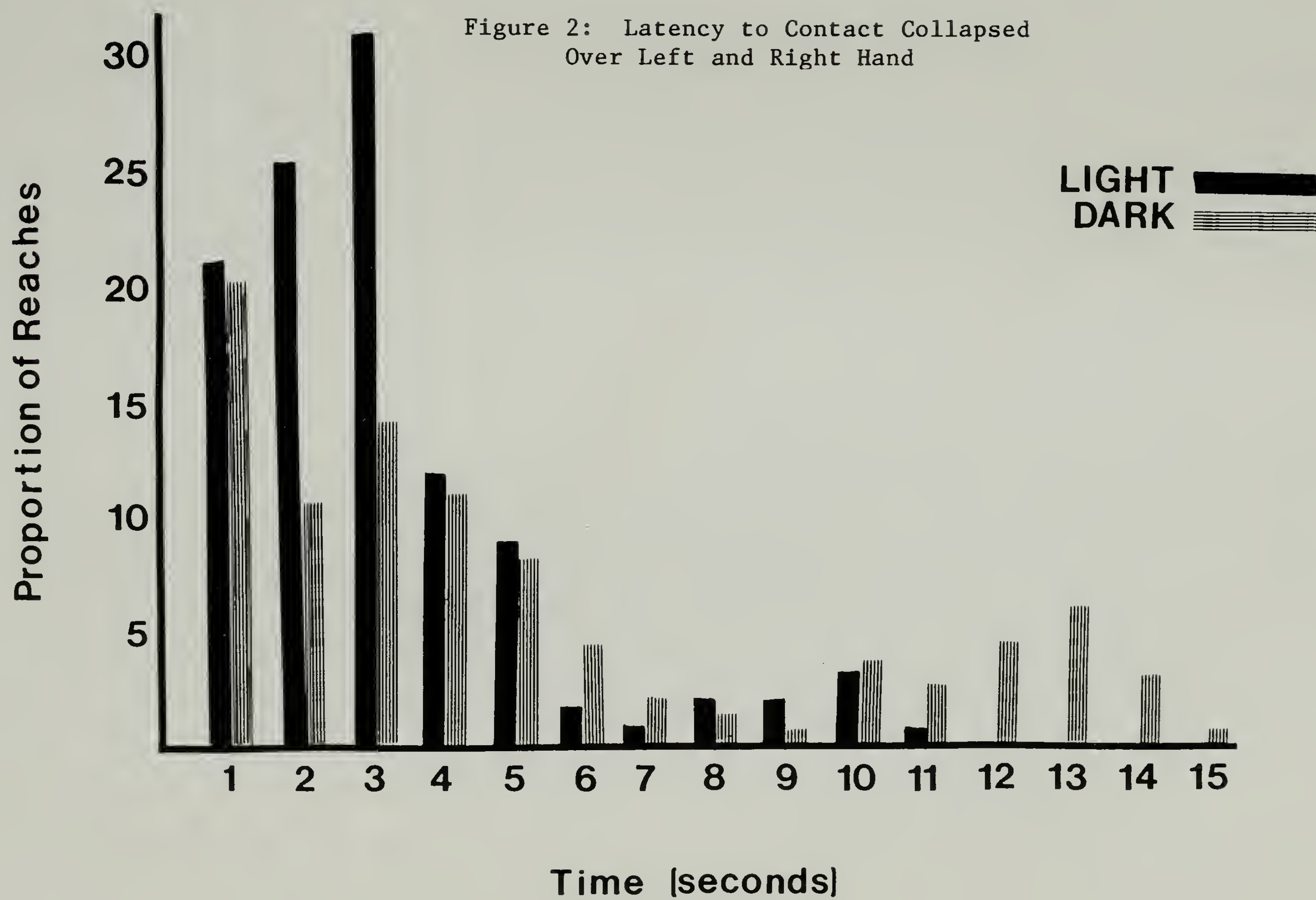
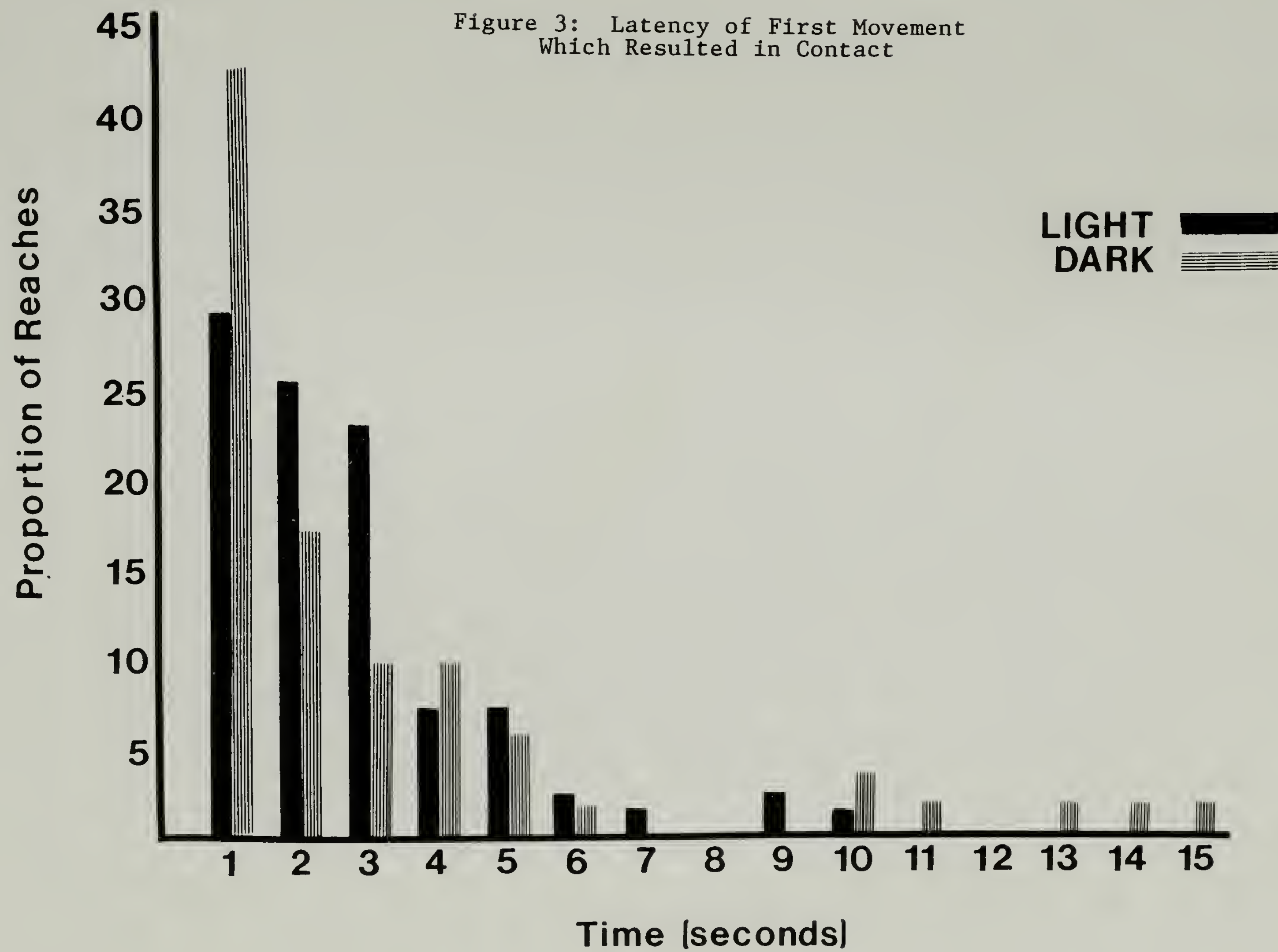


Figure 3: Latency of First Movement Which Resulted in Contact



A P P E N D I X C

Table 1. Distribution of First Hand Movements at Each Rattle Position in the Dark

Trial Type	Rattle Position					
	Left			Right		
	-60°	-30°	0°	+30°	+60°	
Correct (N=110)	21.8	17.3	14.5	19.1	27.3	100%
Incorrect (N=37)	18.9	29.7	21.6	21.6	8.1	100%
Silent (N=14)	35.7	28.6	14.3	7.1	14.3	100%

Table 2: First Hand Movement of the Trial Analysis For Correct Responding

SOURCE	MEAN (%)	F	PROBABILITY
Trial Type	Light .92	27.24	.01
	Dark .59		
*Rattle Position	1) .825		(Huynh-Feldt)
	2) .700		
	3) .612	7.55	.0002
	4) .737		
	5) .912		
Contrasts (Bonferroni)	1 vs 3	3.57	ω =.05= .05/10
	2 vs 3	1.47	N.S.
	4 vs 3	2.10	N.S.
	5 vs 3	5.04	ω =.05
Trial Type/ *Rattle Position	Light Dark		
	1) 1.00 .650	1.65	N.S.
	2) .92 .475		
	3) .80 .425		
	4) .90 .575		
	5) 1.00 .825		

*Rattle Position 1= 60° left, 2= 30° left, 3= 0° midline, 4= 30° right, 5= 60° right

Table 3: Distribution of the Latency of the First Movement at Each Rattle Position for Light and Dark Trials

Trial Type		Rattle Position				
		Left			Right	
		-60°	-30°	0°	+30°	+60°
	$\bar{x}$	2.75	3.4	2.7	2.8	2.45
Light Trials	SD	1.6	2.85	2.13	3.69	1.4
	Range	1-7	1-10	1-9	1-18	1-6
	$\bar{x}$	4.26	3.63	5.04	3.93	4.03
Dark Trials	SD	3.73	3.25	4.64	4.4	3.81
	Range	1-15	1-14	1-17	1-19	1-15

Table 4: Latency of the First Hand Movement of the Trial at Each Rattle Position

SOURCE	MEAN (%)			F	PROBABILITY
Trial Type	Light	2.061		5.40	.0370
	Dark	3.216			
*Rattle Position	1)	3.233			(Huynh-Feldt)
	2)	2.663			
	3)	2.925		1.10	.3662
	4)	1.876			
	5)	2.495			
Trial Type/ *Rattle Position		Light	Dark		(Huynh-Feldt)
	1)	2.366	4.101	.96	.4308
	2)	2.781	2.546		
	3)	1.819	4.031		
	4)	1.261	2.492		
	5)	2.080	2.910		

*Rattle Position 1= 60° left, 2= 30° left, 3= 0° midline, 4= 30° right, 5= 60° right

Table 5: Distribution of First Head Movement
At Each Rattle Position in the Dark

Trial Type	Rattle Position: Left -60°	Left -30°	0°	Right +30°	Right +60°	
Correct (N=138)	14	22	26	23	15	100%
Incorrect (N=54)	35	17	6	11	31	100%
Silent (N=35)	9	14	63	9	6	100%

Table 6: First Head Movement After Trial Onset
Analysis For Correct Responding

SOURCE	MEAN (%)	F	PROBABILITY
Trial Type	Light .90	22.30	.01
	Dark .72		
Rattle Position	1) .65		(Huynh-Feldt)
	2) .875		
	3) .962	6.53	.0003
	4) .837		
	5) .725		
Contrasts (Bonferroni)	1 vs 3	-4.57	ω =.05= .05/10
	2 vs 3	-1.28	N.S.
	4 vs 3	-1.83	N.S.
	5 vs 3	-3.47	ω =.05
	1 vs 2	-3.29	ω =.05
	4 vs 5	1.64	N.S.
Trial Type/ Rattle Position	Light Dark		(Huynh-Feldt)
	1) .775 .525		
	2) .975 .775		
	3) 1.000 .975	3.24	.0184
	4) .850 .825		
	5) .900 .550		

Table 7: First Head Movement After Trial Onset Excluding Midline Position Analysis For Correct Responding

SOURCE	MEAN(%)	F	PROBABILITY
Trial Type	Light .88	17.09	.01
	Dark .67		
*Rattle Position	1) .650		(Huynh-Feldt)
	2) .875		
	4) .838	4.05	.0124
	5) .725		
Contrasts (Bonferroni)	1 vs 2	-3.10	ω =.05
	4 vs 5	1.50	N.S.
	1&2 vs 4&5	-0.26	N.S.
	2&4 vs 1&5	2.32	N.S.
Trial Type/ *Rattle Position	Light Dark		
	1) .775 .525		(Huynh-Feldt)
	2) .975 .775		
	4) .850 .825	3.27	.0331
	5) .900 .550		

*Rattle Position 1=60° left, 2=30° left, 3=0° midline, 4=30° right, 5=60° right

Table 8: Head Orientation at Point of Contact Analysis For Correct Responding

SOURCE	MEAN(%)	F	PROBABILITY
Trial Type	Light .96	49.97	.01
	Dark .46		
*Rattle Position	1) .700	1.77	N.S.
	2) .662		
	3) .675		
	4) .725		
	5) .788		
Trial Type/ *Rattle Position	Light Dark		
	1) 1.000 .400		(Huynh-Feldt)
	2) .975 .350		
	3) .925 .425	2.44	.054
	4) .950 .500		
	5) .975 .600		

*Rattle Position 1=60° left, 2= 30° left, 3=0° midline, 4=30° right, 5=60° right

Table 9: Head Orientation During The First Hand Movement Analysis For Correct Responding

SOURCE	MEAN(%)		F	PROBABILITY
Trial Type	Light	.90	47.94	.01
	Dark	.68		
*Rattle Position	1)	.662	2.61	.054
	2)	.738		
	3)	.750		
	4)	.812		
	5)	.800		
Contrasts (Bonferroni)	1 vs 3		-1.68	N.S.
	2 vs 3		-0.24	N.S.
	4 vs 3		1.99	N.S.
	5 vs 3		.96	N.S.
Trial Type/ *Rattle Position	Light	Dark		
	1) .975	.350		(Huynh-Feldt)
	2) 1.000	.475		
	3) .975	.525	3.10	.0281
	4) .975	.650		
	5) .950	.650		

*Rattle Position 1=60° left, 2=30° left, 3=0° midline, 4=30° right, 5=60° right

Table 10: Distribution of First Head Movement at Each Rattle Position in the Dark When no Reaching Occurred

Trial Type	Rattle Position					
	Left			Right		
	-60°	-30°	0°	+30°	+60°	
Correct (N=35)	14	23	37	20	6	100%
Incorrect (N=5)	0	0	40	20	40	100%
Adjacent (N=3)	67	33	0	0	0	100%

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