Abstract

Nine infants were tested, at the age of onset of reaching, seated on their parent’s lap and reaching for a small plastic toy. Kinematic analysis revealed that infants largely used shoulder and torso rotation to move their hands to the toy. Many changes in hand direction were observed during reaching, with later direction changes correcting for earlier directional errors. Approximately half of the infants started many reaches by bringing their hands backward or upward to a starting location that was similar across reaches. Individual infants often achieved highly similar peak speeds across their reaches. These results support the hypothesis that infants reduce the complexity of movement by using a limited number of degrees-of-freedom, which could simplify and accelerate the learning process. The proximodistal direction of maturation of the neural and muscular systems appears to restrict arm and hand movement in a way that simplifies learning to reach.

Key words Human infant · Motor development · Reaching

Introduction

The ability of human infants to reach for and retrieve objects in their environment develops slowly over the first two years of life. Infants progress from a crude ability to direct hand movements toward targets at birth (von Hofsten 1982; Ennouri and Bloch 1996), to successful touching and grasping objects at around four months, and then to using pincer grasps on small objects at about 12–18 months of age (e.g., White et al. 1964; Touwen 1976).

Functionally, infants face two significant problems in learning to reach. First, they must transport the hand to the vicinity of the target object. Second, they must conform the hand to the object in order to perform a grasp. Both of these problems are formidable because of the dynamic complexity of the arm and because of the relative immaturity of the infant’s neuromuscular systems. Several investigators (von Hofsten 1993; Thelen et al. 1993; Berthier 1996) have suggested that infants find solutions to these problems through an interactive search or discovery process. While interactive learning has the advantage of not requiring solutions to be completely pre-specified by the genes, it has the disadvantage of requiring the learner to search through a very large space of possibilities to find correct solutions (the “degrees-of-freedom problem”, Bernstein 1967). If infants use interactive learning to discover effective ways of reaching, we have yet to determine how infants reduce search complexity to find good solutions in a reasonable time. The current paper suggests that the pattern of nervous-system development initially constrains reaching movements so as to substantially reduce the space in which possible solutions are searched for.

One important fact of neural development that might appropriately limit the kinematics of infant reaching is the proximodistal nature of development. Development of the neural systems controlling the trunk and the proximal arm occurs before that of the distal arm. The corticospinal tract is not functional at birth, but develops extensively over the first year, leading to a gradual development of the infant’s ability to control the distal musculature of the arm and hand (Kuypers 1981; Armand et al. 1997; Olivier et al. 1997; White et al. 1964). If young infants predominately use the musculature of the proximal arm and trunk in reaching, the learning problem would become much simpler with the reduction in the functional degrees-of-freedom of the arm.

The current study examined the kinematics of reaching in nine infants at the age at which they first successfully moved their hands to targets presented in their workspace. We reasoned that, at this age, where infants have poor hand control, any restrictions that neural maturation places on search or any strategies that an infant
uses to reduce the difficulty of the learning task would be especially observable.

Materials and methods

Subjects

Nine infants participated as subjects in the current experiment. All infants were the result of full-term pregnancies. The data reported here are from a larger longitudinal study that required parents and children to make repeated weekly visits to the laboratory. All infants were in good health on the day of testing and received a small gift for each experimental visit (usually a small toy or book). The experimental procedure was reviewed and approved by the institutional human-subjects committee and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Informed consent was obtained from the infants’ parents.

Equipment and procedure

Infants were seated on one of their parent’s laps at each session. The parent was asked to hold their infant firmly around the hips to support the infant and allow for free movement of the infant’s arms. The parent was further asked to refrain from attempting to influence the infant in any way.

The infants reached for a colorful plastic toy (Sesame Street’s Big Bird, 7 cm length). The toy was attached to a rattle and held by an experimenter, who sat facing the infant. At the beginning of each trial, the presenter attracted the attention of the infant to the toy and slowly brought it forward to a position 15–25 cm away from the infant while shaking the rattle to produce sound. To encourage use of the right hand, the toy was presented approximately 30° in the horizontal plane to the right.

Infants were videotaped throughout the session at 30 frames/s with an infrared camera (Panasonic WV1800) placed to the right of the infant for a side view of the reaches. In addition to the videotape, the reaches were monitored using an Optotrak motion analysis system (Northern Digital). This system consists of three infrared cameras that generate estimates of a marker’s position in three-dimensional coordinates. In the current experiments, four infrared-emitting diodes (IREDs) were used as markers. The Optotrak system estimated the positions of these markers at a rate of 100 Hz. Position data were acquired during 10–20 s trials. Two IREDs were taped on the back of the infant’s right hand, one just proximal to the joint of the index finger and one on the ulnar surface just proximal to the joint of the little finger. Two IREDs were used on the hand in order to keep at least one in camera view if the infant rotated his or her hand during the reach. Infants of this age are not bothered by the IREDs and tend to ignore them once they are in place. One IRED was also placed on the apex of the infant’s shoulder, and one on the lateral edge of infant’s elbow. The Optotrak cameras were placed above and to the right of the infants.

The video camera output was fed through a date-time (For-A) and into a videocassette recorder (Panasonic Model 1950) and a video monitor (Sony Model 1271). The Optotrak system and the date-timer were triggered simultaneously by a second experimenter in order to time-lock the IRED data with the video-recorded behavior for later scoring. The second experimenter was seated out of view and observed the infant on the video monitor.

The present study was part of a larger study investigating the use of vision in the service of reaching. Three levels of illumination, but with sound always available, were presented: (1) trials with full-illumination of the room; (2) trials with the room in complete darkness, but using a luminescent Big Bird; and (3) trials with the room in complete darkness using a Big Bird that was not visible, but was sounding through the use of a rattle. Infants made twice as many reaches in the fully-lighted and luminescent conditions than in the sounding condition. No condition effects on the kinematics of reaching at this age have been found in previous analyses of this data (McCall et al. 1994).

Kinematic data analysis and computational methods

Videotapes were first examined for any significant movement of the hand (defined as movements of more than 2–4 cm in length) that was made in the presence of the goal object. We defined a reach as a forward movement of the hand towards the goal object that was accompanied by the attention of the infant towards the goal object, usually visual attention, and by the viewer’s judgment that the infant was, in fact, attempting to reach for the toy, not simply batting at it or touching it incidentally in a movement towards the mouth, body, or contralateral hand. We found 78 movements that were defined as reaches, 15 movements that were primarily backward and or upward movements of the hand, 8 movements to the mouth, 4 “back and forth” movements, and 2 complex, undefined movements.

Reach onset was defined as the point in time when the hand started to move forward towards the goal object. Backward, upward, or other preparatory movements before forward movement were analyzed and are discussed below, but were not considered part of the reach itself. These preparatory movements were easy to score because they often involved large movements, such as an upward movement from the infant’s thigh to their shoulder. The end of the reach was defined by the time of contact. If the infant did not make contact with the toy, the end of the reach was defined by a speed minimum in the forward extent of the reach. Because of the detailed analysis of the data, and in contrast to our and others’ earlier work (Thelen et al. 1993), we required that Optotrak data for a reach to be complete and not have any missing values.

The data obtained from the Optotrak system are estimates of the true IRED position at the time of the sample. The dynamic programming method of Busby and Trujillo (1985) was used to estimate the position, speed, and acceleration of the hand. The algorithm assumes that the marker is a point moving through space and computes a smooth path based on a minimal input control. We used the criteria suggested by Busby and Trujillo for selecting the parameter B and used B=1x10⁻¹¹ (Milner and Ijaz 1990; Berthier 1996). While direct comparisons are difficult because of the algorithm, the data reported here are similarly smoothed to traditional low-pass filtering with a cutoff frequency of 30–50 Hz.

As we and others have found, young infants reach toward targets using multiple accelerations and decelerations of the hand. We analyzed the amplitudes of these individual peaks to determine if there were any dependencies in the peak amplitudes. To determine the time of a speed peak, we smoothed the speed data with a three-point moving average filter. We then defined peaks as times when the two previous samples of the smoothed speed function had positive slopes and the two succeeding samples of the smoothed speed function had negative slopes. The times and amplitudes of these speed peaks were then noted.

Principal component analysis was performed with custom software using the CLAPACK routines. Because of the distributions of the underlying measures in the current report, we used median, ranges, and other non-parametric statistics to describe the data.

Results

Data were obtained from nine infants at weekly intervals, starting when the infants were a median age of 11 weeks. We operationally defined the age of reach onset as the laboratory session where the infant attempted to reach for the goal object three or more times and where the infant showed continued reaching on subsequent testing sessions. Table 1 shows the age of first testing, age of reach onset, the number of reaches before onset, the