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Development of infant reaching behaviors: Kinematic changes in touching and hitting

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ABSTRACT

This longitudinal study investigated the development of reaching in typical infants, from age 4 to 8 months, and described the pattern of hand kinematics underlying changes in the characteristics of infants' actions while reaching for a target. Thirteen infants were followed biweekly. Two reaching behaviors emerged during the infants' free interactions with the target, touching and hitting. Changes over time were documented for the number of movement units, straightness index, distance, peak velocity and time to peak velocity of the hand for touches and hits. We observed increases in the numbers of touches and hits and changes in hand kinematics over time; the distance traveled by the hand was greater for hitting compared to touching. These kinematic changes were specific to the movement patterns that infants adopted to reach to the target.

1. Introduction

There is a consensus in the literature that the ability to successfully reach toward objects starts at approximately 4 months of age (Fetters & Todd, 1987; Van der Fitts & Hadders-Algra, 1998; Von Hofsten & Lindhagen, 1979). The development of infant reaching has traditionally been investigated through the documentation of the spatial and temporal characteristics of the hand motions toward the target (Berthier & Keen, 2006; Von Hofsten, 1979). In a classic study, Von Hofsten (1991) affirmed that by 8 months post-term, infants have developed reaching skills. The reaching parameters achieve stability at this age, as illustrated by decreases in the movement units (MUs) (i.e., one or two MUs) and the straightness index (SI) of the hand movement (i.e., SI approaching one) (Thelen et al., 1993; Thelen, Corbetta, & Spencer, 1996; Berthier & Keen, 2006). However, these assumptions are controversial, as Fetters and Todd (1987) did not find reductions in either the number of MUs or in the approximation of the SI to one, between 5 and 9 months of age. In addition, measurements of hand velocity and the distance traveled during the development of reaching are conflicting. Halverson (1933) reported an increase in hand velocity, and Konczak, Borutta, Topka, and Dichgans (1995) reported an increase in the distance traveled by the hand, while Von Hofsten (1991) and Mathew and Cook (1990) did not find a developmental influence on these variables.

Despite this lack of consensus, kinematics continues to be an important tool for the documentation of reaching development. Berthier and Keen (2006) have identified 11 spatial–temporal variables commonly used to document the development of reaching; however, they acknowledged the possibility that many of these variables share redundant information. Using

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factor analysis, they concluded that MUs, SI, distance traveled, peak velocity and time to peak velocity of the hand during reaching provided independent information and were sufficient for a complete spatial–temporal description of reaching development.

In addition to the diversity of kinematic information used to describe infants' reaching behavior, the literature presents different objects to be reached, variations in contexts and specific investigation methods (i.e., cross-sectional or longitudinal studies) that may hamper comparison across studies. For example, Fetters and Todd (1987) used a plastic box filled with colored buttons that was fixed on a table in front of the participant while Thelen et al. (1993, 1996) did not specify the target's properties. In the Von Hofsten study (1991), the reaching had to be initiated with the hand initially at rest, i.e., the researcher would hold the infants' hands before the onset of reaching, controlling the starting spatial and time positions.

It is acknowledged that the development of infants' hand movements is influenced by a variety of factors, supporting different experimental manipulations. Some studies have manipulated the target, such as the object's size and rigidity, and have observed an influence on infants' movements (Rocha, Campos, Silva, & Tudella, 2012); others have tested the effects of visual occlusion on infants' reaching toward a target (Clifton et al., 1993; Lee & Newell, 2012; McCarty, Clifton, Ashmead, Lee, & Goubet, 2001). Furthermore, the effect of posture on reaching (Carvalho, Tudella, & Savelsbergh, 2007; Out, Van Soest, Savelsbergh, & Hopkins, 1998) and the influence of adding mass to infants' upper extremities and observing its resulting impact on their reaching movements (Out, Savelsbergh, Van Soest, & Hopkins, 1997) were also investigated to elucidate the development of reaching. These are examples of how researchers have experimentally manipulated the infant - object's interactions to observe its effects on infants' reaching kinematics.

The kinematics of hand movements during reaching development are also related to how upper extremity joint linkages are organized to meet a specific goal, behaving as a coordinative structure that is assembled to perform specific actions (e.g., touching, hitting) instantiated by the task (Tuller et al., 1982). Thus, properties of the object and the characteristics of the setting may support different behaviors when the infant directs his/her upper limb to reach toward the target. Differences in infants' actions while reaching for a target yield distinct kinematics; consequently, traditional kinematic parameters used as a reference to illustrate reaching development in infants may be restricted to the actions implemented by the infant that lead his/her upper extremity to the intended target. In addition, the reaching behavior, which results from interactions between the properties of the target and infants' action capabilities, may afford different movement patterns, such as touching or hitting. Descriptions of the kinematics underlying these movement patterns and their developmental trajectories over time are necessary to help improve our understanding of reaching development.

This study investigated the development of reaching in typically developing infants during spontaneous interactions with a target. We also described the pattern of longitudinal changes in the hand kinematics characteristic of infants' actions while reaching toward a target. We hypothesized that the hand kinematic parameters (SI, MUs, peak velocity, distance traveled and time to peak velocity of the hand) would differ according to the child's distinct actions used for reaching the target.

2. Materials and method

2.1. Participants

Fourteen 4-month-old infants were non-randomly recruited from private practice pediatrics offices to participate in the study. Inclusion criteria for study participation were as follows: (1) being born at term with birth weight greater than 2500 g and (2) no evidence of neurological impairment. One infant participated only in the first assessment and dropped out of the study because of family time constraints. This infant was excluded from the analyses, as the focus of this study is on longitudinal changes due to the development of reaching. Therefore, the final participant group included 13 infants (six boys and seven girls; mean gestational age of 39 weeks, SD = 0.8 week; mean birth weight = 3447 g, SD = 414 g). The ethics review committee of the Universidade Federal de Minas Gerais (UFMG) approved this study (ETIC 418/05). Written informed consent was obtained from the infants' parents before the beginning of data collection.

2.2. Procedures

Kinematic data were collected from 4 to 8 months of age in biweekly intervals. The age of the infants included in the study ranged from 7 days prior to and after the target ages. A Qualisys Pro Reflex® Motion Analysis System (Gothenburg, Sweden), with two cameras placed on each side of the infant, captured three-dimensional reaching movements of the two upper limbs at a frequency of 120 Hz. Reflective markers with a diameter of 1.5 cm were attached to the dorsal surface of the infants' wrists and to their acromions (Van der Meer, Van der Weel, Lee, Laing, & Lin, 1995) (Fig. 1). Two digital video cameras (8 mm) fixed on top of tripods were placed on the right and left diagonals to record infants' behaviors during reaching. The target consisted of a 5.8 cm diameter sphere made of rigid transparent plastic that could be reached (but not grasped) by infants. The sphere contained a yellow puppy and three free red balls, which attracted the infants' interest throughout the 4-month period of data collection. The target was fixed to the highest point of a rod placed on the floor, enabling its rotation around the rod's axis, in the frontal plane, with subsequent movement of the 3 balls and production of a sound.

The infant was placed in front of the target on the lap of his/her caregiver, who remained sitting on a chair. The caregiver was asked to hold the infant's hip to provide lower trunk and pelvis stability and not to interfere with the infant's upper