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The Impact of Objects' Visual Properties on Infant Reaching Strategies

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To the Graduate Council:

I am submitting herewith a thesis written by John Paul Connell entitled "The Impact of Objects' Visual Properties on Infant Reaching Strategies." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

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The Impact of Objects' Visual Properties on Infant Reaching Strategies

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ABSTRACT

The development of reaching in early infancy is a monumental milestone that signifies their independence and agency in their environment. Classically however, studies on infant reaching have been heavily limited to simple, single component objects that do not afford infants different areas from which to choose interest or reaching locations. Furthermore, the relationship between looking and reaching has been mainly derived from movement and kinematic analyses of the elements of the reach. To fully understand the impact of object properties on reaching, the visual patterns of the infants need to be accounted for during the reach towards and contact with the object.

The current study looks at the reaching and looking patterns of 21 infants aged 9 months when presented with rod, drumstick- or dumbbell-shaped objects. We observed where infants looked at on the object during their reaches. These looking patterns were then later compared to the area of the object that infants contacted first. Infants demonstrated three visual-manual coordination strategies: targeted, where infants maintained fixation on the object area to be contacted; catch-up, in which infants initially looked elsewhere before matching object contact and object fixation location, and untargeted where fixation and object contact location did not match.

The current findings indicate that infants employ different strategies when reaching for objects regardless of the shape of the object. First view reach latencies were shorter for subsequent contacts made to the rod locations and infants employed a catch-up strategy more often when opted to choose between locations with visually distinct sections of the same object (i.e. a rod or a ball of a drumstick). Further studies are needed to understand the degree to which visual fixations and saccades relate to kinematic changes present between employed strategies.

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CHAPTER ONE: INTRODUCTION

Utilization of Visual-Motor Strategies in Infant Reaching

Imagine that while working you find yourself thirsty and take a drink from a mug sitting on your desk. As an adult this task is second nature and you do not often think of the mechanisms or sequence of events that have just occurred in the act of you taking a drink. In this example there were several events that occurred for you to accomplish this task. Firstly, you located the mug. You identified the location of the handle of the cup. You reached for the cup and adjusted the speed of your reach when you were in proximity to the handle. You may have identified the rim of the cup and identified the amount of water in the cup and further adjusted your movements to prevent spillage. Every day our ability to reach for and interact with our environment is crucial in every act from opening drawers and doors in our morning routines to writing and typing at work. The act of locating and reaching for specific objects has become so second nature that we do not consciously pay much attention to our own actions when performing these goal-oriented movements. In mere moments we align the visual representation and spatial location of the desired object, the proprioceptive information of our own body and the motor sequences required to achieve the goal. The subconsciousness of these feats comes from a lifetime of experiences and actions that have been engrained into our action planning.

Infants in contrast do not have a cache of previous experiences informing their action planning and therefore must learn to align their visual and motor systems when reaching for an object. When presented with the same mug as adults, how do infants reach for it? How do infants visually map the mug's physical properties and do these patterns of looking relate to their contact made with the mug? How is it that infants develop the strategies of reaching and visually fixating that adults exhibit without consciously planning?

Infant reaching literature is rife with studies pertaining to the role of visual information during action planning. Specifically, some research principally focus on fixation patterns (Corbetta et al., 2012; Franchak et al., 2010; Oakes & Ellis, 2013). Other studies refer to the kinematics of the reach, speed, movements, and velocity, as they relate to the objects presented (Corbetta & Snapp-Childs, 2009; Lockman et al., 1984; von Hofsten & Fazel-Zandy, 1984). Few studies deal with reaching and vision and fewer still involve eye-tracking and reaching in tandem. The present study follows those few studies in recent years that focus on vision through eye-tracking and movements through kinematic analyses (Corbetta et al., 2014; Williams et al., 2010). However, this study investigates an area of vision and moment alignment that has been ignored, the fixations during the reach itself (the approach phase). While looking prior to the start of reach may be crucial for locational information or the processing of object properties (discussed in detail further), studies into the role of vision during the reach itself has been woefully lacking. This study then aims to explore the relationship between reaching the looking patterns during the reach as they relate to object properties. To answer this question, I will first discuss the history of reaching in the field of development. I will then give an overview of the field of infant reaching development regarding vision and kinematics.

CHAPTER TWO: LITERATURE REVIEW

Development of Reaching

The transition from non-reaching to reaching is a monumental step in development that allows infants between 3 to 5 months of age to begin expressing agency and direct influence on their environment. During this transition infants learn to align their visual fixations on a target with reaching movements towards the fixated object. The processes by which the visual and motor systems align during the reaching milestone has been contested over the last few decades. Originally the development of reaching was hypothesized to be a predominately visually-guided phenomenon. Recently however, an embodied origin approach has been presented that highlights the importance of proprioception, rather than vision, being the driving force for the development of reaching. This development then results in a cascade motor development, exploration, and new forms of environmental interactions.

Visually-Guided Reaching

In the 1930's Piaget began in-depth observations of his children as they progressed through maturity and differing milestones of development. One specific area of interest was the development of reaching in which he noted several instances of fixations to an attended object and the reaching hand as it was guided towards the object. Piaget (1952) proposed that infants' lack of control in reaching was due to an incongruency between the visual and the motor (reaching) systems. He postulated that the visual input of the hand's location in relation to the object was needed to guide the hand towards the desired object. It was this assessment of hand location and object or target location that was deemed "visually-guided". The role of the visual system in the emergence of reaching has since been debated to have varying degrees of importance from the utmost importance to the unnecessary.

The decades that followed the publication of Piaget's *The Origins of Intelligence in Children*, were filled with numerous studies touting evidence for the "visually-guided" hypothesis of reaching. von Hofsten (1982; 1984) demonstrated that infants in the first few weeks of life will adjust their movements in response to objects in their environments. Infants observed as young as 5 days old produced increased numbers of forward arm movements when a presented object was fixated on (von Hofsten, 1984). Von Hofsten argued that this was evidence of coordination between vision and movement shortly following birth.

The development of these forward arm movements were observed until the age of 7 weeks when visually-guided reaching begins (von Hofsten, 1984). At 2 months the number of forward movements increased from 4.5 to 21.7 per session. These forward movements occurred proportionately more often when the object was present, while the total number of all movements were also great when the object was not present. Furthermore, infants increasingly produced proportionally more fist closed arm movements until 7 weeks, at which time they began to decrease. This further illustrated the effect of visual engagement on directional movements as well as movements overall even in pre-reaching infants. Early attempts at reaching were further observed and defined as swiping towards an object at 2 months of age (White et al., 1964)**.** White et al., referred to these movements in their 1st stage as "visually-directed" as opposed to "visually-guided" as infants were not observed alternating fixations between their hands and the desired target. These observations, like von Hofsten (1984), showed that infants fixate on the presented objects and produce increased movement in response.

At 2 months of age infants were observed increasing their movements as well as their forward arm movements in response to stimuli across different spatial areas. Infants produced increased forward arm movements when an object was present and still, moving in view, and moving and stopping in view (von Hofsten, 1984).

To further understand the impact of visual information on reaching, the fixations or lack thereof were considered in relation to the opening the hand during forward arm movements. While these arm movements did not always result in contact with the object presented, von Hofsten (1984) found that infants, produced more forward movements accompanied with opening of the hand when they fixated upon the presented object.

The oscillation of fixations from hand to target were not observed until infants were 3 months old (White et al.'s 4th stage). During this stage infants were observed fixating on both their hands and the attended objects. However, these reaches were categorized as crude and White et al. did not label the movements as being in line with Piaget's observations until Stages 7 and 8 around 5 months of age, the age of reach onset. It is during these stages that infants slowed their reaches and guided their hands more succinctly to the desired target with frequent glances between their hands and the target.

Following the pre-reaching period infants quickly become adept at reaching. The role of vision during this time is however still debated. McDonnell (1975) controlled the visual feedback of the hand using prism glasses in order to determine the degree to which visual information affected reaching and successful retrieval of an object. While visual feedback was displaced, infants at 4 and 5 months old made successful contacts with targeted objects over 90% of the time. This accuracy was comparable with non-displaced vision reaches under normal conditions. Lasky (1977) identified that infants at 5 ½ and 6 ½ months, who were able and skilled reachers however, displayed disruption in their reaching when they were unable to see their hands due to the prisms' distorted view. These older infants more frequently contacted and retrieved the presented objects as opposed to younger infants in a similar paradigm but, this was true only when they could see their hands. When the hand was visually displaced the frequency of contacts made with the target object was the same between both experienced and novel reachers. Lasky argued that while infants at 5 ½ months and older were experienced in visually-guided reaching, the lack of visual information created a clear and distinct disruption in their reaching patterns and performances. Infants, therefore, used visual feedback to correct their reaches by incorporating the spatial displacement between hand and object in what White et al. (1964) referred to as a "Piaget-type reach", that is to say the alternation of looking from hand to target in order to correct reaching.

McDonnell & Abraham (1979, 1981) further confirmed these trends at both 6 and 9 months of age. In these studies infants were followed longitudinally and either repeatedly exposed to prism visual displacement or exposed once during a final trial. Those infants that were exposed to the prism displacement only once showed no significant difference in their reaching than those continuously exposed. Both sets of infants in these studies (those with continuous exposure and those without) corrected their reaching trajectories when they observed the reaching hand leading away from the targeted object. It was noted however that the infants exhibited fewer corrective movements at 7 months of age. This is arguably when infants begin to use visual guidance less and rely more on proprioceptive information (See (Bushnell, 1985)**.**

Rebuttals to Visually-Guided Reaching

The importance of visual input of the hand for reaching has been refuted in the last few decades. It has been argued that vision is not as foundational for reaching as previously believed. Infants have been observed reaching while attending to an object with no regard to their hands or even reaching for an object when unable to see their hands. This was illustrated by studies performed by Clifton et al. (1993, 1994; Robin et al., 1996) who observed infants reaching towards glowing objects in the dark, thereby having no view of their hand.

Infants have been observed reaching for objects with glow-in-the-dark properties where there was not vision of the hands. Clifton and colleagues (1993) sought to determine whether infants could reach in the absence of sight and if they would achieve reach onset without visual input of their hands. Infants reached for objects in the light and in the dark at comparable ages (12.3 and 11.9 weeks respectively) and continued to reach throughout the remainder of the observations. In a further study (Clifton et al., 1994), they explored 6 month old infants' ability to reach in the dark by removing all visual information of the hand and the toy presented by attaching a sounding rattle to the object. This study firstly confirmed the previous findings that infants reached similarly with and without visual information of the hand and surroundings. They further observed that infants could reach for objects with no visual information though the frequency of successful reaches was diminished. Infants did successfully reach for the presented object however at a lower rate. These results give doubt to the visually-guided hypothesis as infants do not heavily rely on visual information of the reaching hand but rather the object to which they are reaching. When presented with only the objects visual information they reached just as frequently, however even without this information they continued to reach though less successfully.

In a final study using this light and dark paradigm, Robin and colleagues (1996) presented objects to 5- and 7-month-old infants as before, however the objects where not stationary but rather moved in an oscillating trajectory within reach of the infants. This study again confirmed the previous results that infants reach at a similarly successful rate for objects in the light and the dark. However, infants reached for the objects in the dark less frequently than in the light though reaches were similarly successful. These studies in tandem counter claims of the necessity of vision in reaching and offer evidence for the visually-elicited reaching hypothesis.

The lack of visual input needed for reaching brought another sense, proprioception, into the forefront of infant reaching. To further illustrate the subdued role of vision in reaching, McCarty and Ashmead (1999) investigated infant at 5-, 7-, and 9-months old, reaching to both viewed and non-viewed objects by removing visual input of the object during the reach towards target objects. They found that not only did infants complete the reach when loosing visual information during the reach, but these reaches had a shorter duration and less movement units as compared to their lighted counterparts. McCarty and Ashmead however found no difference in the overall reaching speeds and therefore proposed that the difference in the duration of the reach was due to visual information processing. That is that infants reached for a longer time and made changes in their trajectories due to continuously processing the visual input. The increase to the processing load is argued to be beneficial as it increases the accuracy of the reaches in what McCarty and Ashmead referred to as “speed-accuracy-trade-off”.

Visually-Elicited Reaching

Arguably then, visual information during reaching is utilized beyond locational reference. Beyond visually-elicited reaching, vision is used in planning the contact of the reach. In this the visual properties play a more important role over the locational information of the object.

Infants have been found to reach towards locations of an object to which they looked the most, when the object had different features. When presented this same drumstick shaped object out of reaching space, Corbetta et al. (2014) found that infants with as little as 5 weeks of reaching experience, looked the most towards the ball-end of the drumstick and subsequentially contacted this location the most as well. This matching was seen in infants with only a few weeks of reaching experience. When presented with a plain rod or a dumbbell-shaped object, the infants match between look and first contact were not correlated. Nine-month-old infants attended to the larger areas of an object. Williams et al. (2010) found that infants looked more at the spheres of objects comprised of a rod and a sphere (a drumstick) or a rod and two spheres (a dumbbell), while looking towards a plain rod was more distributed.

Furthermore, Cobetta et al. (2014) found that infants younger than 9 months of age did not display either of these trends and instead progressed towards a more 9-month-old-like pattern of matching following as little as five weeks of reaching experience. Prior to this experience infants contacted the ball of the drumstick but looking did not shift to this location later. As infants gained experience, their match to most-looked-area, which remained the sphere, increased to be comparable to 9-month-olds after only a few weeks of reaching experience.

Other research has found that infants displayed a varied and unstable pattern of reaching and trajectories up until 30-36 weeks of age when their movements became more stabilized and remained so for the remainder of the first year of life (Thelen et al., 1996)**.** Therefore, while the alignment of “the look” on to “the reach” action begins at an early age, after only a few weeks of reaching, control and stability of the reach come later in the first year. It is during this time that infants shift from ballistic reaching to more controlled reaching as they gain experience.

In the first few months of reaching, infants’ movements are visually-elicited until around 4 months of age when vision appears to guide reaching toward targets. Around the age of 9-months the infants’ reaches become more visually-elicited though it is qualitatively distinct from the pre-reaching movements earlier in life. These reaches are reliant on visual information regarding the object’s physical shape rather than only location.

The stability of reach trajectory is the product of planning and incorporation of object properties towards which the reach is being aimed. These trajectories are characterized by speed of the reach, the number of movement units, and straightness of the reach (Thelen et al., 1996)**.** Even in the first year of life the reaching speed, movement units, and straightness of the reach vary as the infants gain experience and practice in reaching. Thelen and colleagues however, noted that the level of experience and practice was not the only factor underlying the transition from unstable to stable reaching trajectories. The individual preferred movement patterns of infants can constrain their ability to reach and develop stability in reaching. More active movers must learn to dampen their movements in order to reach for an object while the movements of more calm movers must increase in speed and strength to direct their arms towards and object (Thelen et al., 1993).

Other factors impacting reach

We should however note that reaching is affected by numerous other factors. The emergence of locomotion, for example, has been found to affect the reaching patterns and movements. While infants begin reaching in a more bimanual manner following reach onset, they increase unimanual reaches following crawling onset. Presumably as infants experience the alternating arm movements in crawling, they also decouple the arm movements during reaching (Corbetta & Bojczyk, 2002; Goldfield, 1993)**.** During the transition to walking however, infants with stable unimanual reaches revert to bimanual reaching. The hypothesis for this phenomenon is that infants become motorally fixated on the coupled arm motion utilized in balancing during haphazard inexperienced walking.

Furthermore, postural control itself can influence reaching patterns and the observable onset of reaching behaviors. While infants reach between 3-5 months, this is predicated on the head control and muscle coordination of the trunk and arms. The proposed explanation is that infants can reorganize muscle control after head control when they are able to reallocate attention from postural control of the head to another goal, reaching towards a toy for example (Thelen & Spencer, 1998).

The act of reaching requires the coordination of several new movements than infants learn to control while maintaining the intrinsic dynamics. On this matter Thelen et al. (1993) speculated that it may be that infants are recruiting past motor skills in order to attain a new function. In reaching, using previous movement skills to move the hand to the goal. This would then require the reevaluation of arm movements for the specific task of attaining the attended object. Due to fundamental variability in infants' intrinsic dynamics, infants pre-reaching spontaneous movements are drastically different from one another. Thelen (1998) further described this process as the degrees of freedom problem. Where the number joints each allow compounding degrees of freedom that must be controlled and regulated for infants to reach. The expression of control of the joints can be observed in infants when presented a toy at prereaching age where they exhibit more shoulder movement when compared to when no toy is present (A. N. Bhat & Galloway, 2007; Thelen & Spencer, 1998).

Bhat et al. (2005) found that infants displayed different arm movements when a toy was presented to them depending on their level of reaching experience between non-reaching (2 months), near reaching (3-4 months) and new reaching (4-5 months). Specifically, the 2-month-old infants increased the number of their arm movements when presented with a toy as opposed to a baseline. In contrast, those infants who were new to reaching displayed increased length in arm movements but no change in the number of arm movements. Furthermore, infants across the age groups displayed differences in their joint changes (shoulder and elbow) from baseline. While non reachers did not change in their overall joint movement speed of displacement, near reachers moved their shoulders more and elbows more while new reachers moved their elbows less. This aligns with the degrees-of-freedom problem discussed in that control of the joints centrally and extend to the more distal. This is further illustrated in the total movement of the shoulder, elbow and hand differences between the three groups. Non-reachers displayed the greatest change in their elbows but no extension of the shoulder. Near-reachers showed greater shoulder flexion but no other change. New reachers were the only infants to make a significant movement towards the presented toy and likewise displayed changes in the shoulder, elbow and orientation in the forearm.

Early phase infants (non-reachers) dampened down the movements of thier the hands when represented with a toy. They therefore displayed a quieting of the body when focusing on the presented toy though unable to reach for it (A. N. Bhat & Galloway, 2006). This same feature of scaling down movement in the *Early phase*, was seen in the shoulder movements and excursions in to the *Mid phase* as expressed in (Bhat et al., 2005; Bhat et al., 2007; Lee et al., 2008). Given the impact of the intrinsic dynamics of the infant and their level of motor movement experience, what other factors impact the manifestation of reaching as infants reach for novel objects?

Impacts on Reaching Kinematics

Reaching is affected in a variety of ways depending on overall availability of visual information, target size, competing stimuli, and orientation. These variations can be reflected in the kinematic profiles of the reaches, which may reveal modulations in movement speed, movement units or smoothness of the reach, in reach duration, and prehensile adjustments. The degree to which these aspects of the movement kinematics vary as a function of age and reach mastery must then be discussed (see Figure 1 for reach diagram, all figures and tables in appendicies).

Visual Input on Reaching Kinematics

Adults change the speed of their reach and aperture of their grasp based on the size of the object, levels of environmental and hand visual information (Berthier et al., 1996). When reaching for larger objects, adults were found to reach more quickly regardless of visual information. However, adults reduced the speed of their reaches as the size of a presented object was decreased and the light of the environment obscured visual information. Given the level of mastery adults have overreaching, how then do these conditions affect infant reachers?

Like adults, the level of visual information affected infant reaching. At 6 months, infants reached faster, had shorter durations, and less smooth trajectories, than their 12-month-old counterparts when visual information was removed (Berthier and Carrico, 2010) Visual information of stimuli was also incorporated in infants' reaches, however the degree to which this effect was manifested in their movement, depended upon age.

Object Size on Reaching Kinematics

The importance of object size has been found to play a role in infants prior to reach onset. Bruner and Koslowski (1972) found that size, as it relates to the graspabillity of an object, elicits different pre-reaching actions in infants as young as 8 weeks old. Infants were more likely to bring their hands to midline in response to small graspable objects. In contrast when presented with large balls they were more likely to swipe at the object. Although these infants were not able to reach and grasp properly yet, they exhibited different responses that illustrated the nature of their sensitivity to objects' visual properties.

The impact of object size continues into reaching infants. Rocha et al. (2006) found that infants between 4 and 6 months old displayed quantitatively distinct changes in reaching trajectory and smoothness that were dependent on object size. Infants made fewer movement units, fewer changes in reach trajectory, the older they were. However, the number of movement units, the number of trajectory changes within a reach, increased as object size decreased. That is to say that older infants made less correctional changes in their reaching paths than younger infants, but overall infants made more corrections for smaller objects over larger ones.

Competing stimuli of varying sizes further confound the kinematics of reaching. Infants younger than 1 year old that looked first at larger objects, when given the choice of two differently sized cylinders, however reached for and grasped the smaller of the two cylinders (Newman et al., 2001). Furthermore, when large, medium, and small objects where presented in pairs, the medium object was reached for by the infants when paired with the larger identical object and was looked at most when paired with a smaller object. This displays the significant difference in infants looking and reaching patterns to the same object when considering competing stimuli.

Rigidity on Reaching Kinematics

Rigidity along with the graspability (size) of an object further play a role following reaching onset, in the expression of more detailed reaching and grasping. Lee at al. (2006) illustrated that infants' ability to grasp and adjust their prehension to an object differentiate depending on the object presented. Infants as young as 5-months-old were able to perform one-handed-grasps for 5 cm soft ball but did not perform this same grasp on hard objects that were less graspable. At 9 months however the importance of rigidity decreases significantly. Rocha et al. (2006) found no differences in 9-month-olds reaching speed, trajectory movement units, or max velocity when reaching to soft easily grasped balls and rigid graspable ones. Furthermore, when prior reaching experience is incorporated, 9 month old infants adjusted their reaching and grasping to visually large yet graspable objects (pompons) following several contacts made to the object (Corbetta & Snapp-Childs, 2009). While these infants initially used visual information on the size of the object, large therefore reaching bimanually, they progressively transitioned to more single-handed reaches as a function of the graspability of the objects was discovered through object manipulation. This trend was not seen in younger 6-month-old infants who were unable to overcome the visually perceived size of the object and persevered reaching bimanually despite the objects one-handed graspability. These authors argued that this inability of younger infants to adjust their reaching in response to objects' visual and tactile information was due to their initially limited motor constraints that were present until at least 8 months old (Corbetta et al., 2000).

Object Orientation on Reaching Kinematics

The orientation of objects offers yet another layer of the information being processed in reaching that is being manifested at different ages and at different stages of the reach. A study on 5-month-old infants found that shortly after reach-onset infants did not incorporate orientation into the reach but rather made aperture adjustments after contact. After several months of reaching experience however, infants at 9 months old oriented their grasp in-reach prior to contact (Lockman et al., 1984). Furthermore, Lockman and colleagues found that 9-month-olds even performed these prehensile adjustments to orientation when they did not maintain looking fixations on the objects. These infants then could make distinct object-related adjustments in movements from visual information attained from brief looking fixations.

Goal planning on Reaching Kinematics

Beyond the impact that objects'' visual properties have on infant reaching; object use plays a role in reaching unfolds. Claxton et al. (2003) observed that 10.5 month old infants like adults, altered their reaching patterns depending on what they planned to do with the object afterwards. When planning to throw a ball, infants reached at a much faster speed than when they subsequently inserted the ball into a tube. Likewise, infants produced a significantly faster peak velocity for the “throwing” condition as opposed to the “fit in” condition.

Purpose and Hypotheses

The present study seeks to further understand the complex relationship between infants’ object-directed visual fixations during reach and the subsequent area of contact made to the object. Firstly, to test the role that object properties play on reaching planning and selection, we used three objects of varying shape (a plain rod, a drumstick, and a dumbbell). These objects were of a length that when presented allowed infants to reach for and grasp distinct areas on the object. The plain rod and dumbbell were symmetrical and provided concurrent information on both ends as both sides of the object matched. Given the lack of choices in symmetrical objects, if infants do not distinguish between the sides of the object, they should reach quicker for these objects and display straighter trajectories with later velocity peaks and less movement units. In the case of the ball-ended dumbbell, the ball area is a large area that does not require a great deal of precision to reach towards. The rod alternatively offers no specific area to visually fixate (Williams et al., 2010) and is more graspable. For the asymmetrical objects, this trend should be reversed if infants are processing the imposed choice between the distinct sides. If infants process this difference in the reach planning, the trajectories should be slower with an early reach velocity peak and more movement units during the reach as they adjust for a specific location of contact.

If infants plan their reaches with respect to physical features of the objects, the infants should display the most significant differences in looking pattern to the drumstick, followed by the dumbbell, while the rod, which has no distinguishable difference, should result in at chance looking patterns. An alternative hypothesis is that the size of the ball of the object will drive the looking patterns of the infants. if this is the case infants will reach more readily and smoothly to the drumstick, the dumbbell and then rod respectively.

The second aim of the study is to identify and determine how visual information is being used to perform the reach. This is defined as the visual-motor coordination strategy. Infants looking patterns will be categorized firstly by whether they match the area of the last fixation on the object with the area of first object contact. Secondly, for look-reach matched contacts, the fixation patterns prior to the contact will be identified and categorized into three visual-manual coordination strategies: targeted, catch-up and untargeted. Trials will consist of two time-frames of interest: pre-reach and during reach. If infants incorporate the objects' visual properties before reach start, we expect to see no difference in the kinematics during the reach itself. This is to say that if infants plan the location of reach before they begin to reach, they will reach at a similar manner with few changes in trajectory, and at similar speeds regardless of the object presented. If infants incorporate the objects' visual properties during the reach, kinematic changes will occur after reach start. In other words, infants will change their reaches in response to differences between the objects through trajectory changes (movement units), peak velocity speed, and reach durations.

CHAPTER THREE: METHOD

Participants

Twenty-one infants aged 9-months old (13 males, 8 females) were recruited in Knoxville, Tennessee, and surrounding cities, through mailings and follow-up phone calls. An additional 9 infants were recruited but were not included in the analyses due to fussiness (N=5), inability to calibrate the eye tracker (N=1) and technical issues with the equipment (N=3). All infants were healthy, full-term, and had no reported motor or visual abnormalities. Twenty-three infants were reported as white non-Hispanic and 7 were undisclosed. This study was approved by the University of Tennessee Institutional Review Board. Consent was given by the caregiver prior to the study and participants were thanked with a photo and a certificate of appreciation.

Stimuli and Apparatus

Infants were seated in a custom-made infant seat using a foam strap across the torso beneath the arms and secured behind the infant with industrial strength hook and latch strips. This allowed infants a full range of movements of the arms and legs, while maintaining postural support and controlling the degree to which infants could lean forward and to the side. The infant seat (Figure. 2A) was located at one end of the specially made table with a cut-out to maintain the required 60 cm distance from eye tracking. Atop the table was a transparent acrylic frame (Figure 2A-C). The open center window of the frame defined a calibrated area (30 cm tall x 30 cm wide) through which objects were presented to the infant within their reaching space. The frame was fabricated out of transparent acrylic to allow video recordings of the infants reaches from behind the presentation area. On top of the center window was a black occluder from which objects were placed before being lowered into the infants' view. This prevented the infants from seeing the objects prior to the presentation within the calibrated area. A blue foam padded the base of the acrylic frame to absorb the impact and reduce the loud sound of objects if dropped.

A clear acrylic plate with five calibration points, one in each corner and one in the center, was placed in the presentation window for eye-tracker calibration (Figure 2B). A remote eye-tracker (Tobii X120, Tobii Technology, Inc., Danderyd, Sweden) collecting at 120Hz, was on the opposite end of the table facing the baby (Figure 2C). The eye-tracker was adjusted to an angle that allowed the tracking of the infant's eyes. Tobii Pro Studio recorded the infant's eye movements using near infrared light during object presentation for each trial.

Arm movements were recorded with a motion tracker capturing the position and angle of 8mm wired markers at a rate of 120Hz (Flock of Birds, Ascension Technology Corp.). The markers were affixed centered on the dorsal side of the infant's wrists using Johnson & Johnson Hypoallergenic tape. The wires of the markers were then adhered to the rear of the seat to prevent infants from pulling on them. An electromagnetic emitter box was placed below and to the left of the infant seat. The box tracked the displacement of the markers in 3-Dimensioanl space across the X-, Y-, and Z, axis relative to the emitter box as well as the rotations on each axis with in a 70cm radius sphere. The full setup is depicted in Figure 2.

A webcam was placed atop the eye tracker with an angle that fully captured the infant's face, reach and subsequent manipulation of objects for offline coding. Two video cameras (Panasonic NV-GS27) on tripods were placed 45 degrees from the infant's center (Figure 2A). These cameras captured the infants, their reach and the object presented from each side. A Digital Video Mixer MX-4 DV (Focus Enhancements Inc., Sunnyvale, CA, United States) fed the two camera images into a recorded side-by-side split of the infant. A digital frame counter (TRG-50, Horita Co. Mission Viejo, CA, United States) was superimposed on the split screen video feed. A final camera was placed above and to the rear of the infant for the eye-tracking calibration and to record the scene of the presentations from the infant's view.

All presented objects were 18 cm and custom made (Figure 3). They were wooden and consisted of a combination of rods and spheres resulting in three configurations, a plain rod, a drumstick, and a dumbbell. The objects were sanded, then painted with non-toxic acrylic paint of varying solid colors, and finally sealed with several layers of waterproof, non-toxic sealant.

Demographic Questionnaire

During the session, questionnaires were given to the caregiver that included demographic information.

Procedure

Each participant was in the lab for the study for 30 to 45 minutes. Caregivers were informed of the study procedures and signed informed consent prior to starting the study. Infants were given with up to 32 objects presentations at midline within reach while looking patterns and movement kinematics were recorded. Objects were presented within the infants reaching space in order to understand the relationship between looking patterns and reaching movements.

The sessions began with the infant being seated in the infant chair at the presentation table. To alleviate any infant distress, caregivers assisted in placing the infant in the seat and attracting the infant's attention during calibration. Initially, the calibration plate was placed in the reaching window for eye-tracker calibration. Small animal toys were used to check the strength of the eye tracker signal and adjust the eye-tracker angle if needed. When signal strength was determined to be adequate, calibration was started. Calibration required infants to look at five points on the acrylic plate (one in each corner and one in the center). A small disc with a spiral pattern or a sounding colorful toy was used to attract the infant's attention to each of the five calibration points on the plate. When the experimenter saw the infant looking at the object, he signaled a second experimenter to continue to the next calibration point. After the 5 points were calibrated, the experimenter determined if the noise levels (the deviation of the fixation from the attended location) were acceptable. A minimum of 3 points (bottom 2 corners and center) had to have minimal deviation to proceed with the study. If this calibration accuracy could not be obtained the protocol was continued though the infant was not included in the analyses. If infants became irate and uncooperative, the study was ended.

Following calibration, infants were given a small toy to keep them entertained while the markers were placed on their wrists. The markers were adhered using Johnson & Johnson tape made of soft cloth that is not irritating to the infant's skin. The wires of the markers were secured to the infants' shoulders and to the rear of the infant seat using masking tape. Cotton knitted sleeves were placed on the infants' arms over the markers and wires to prevent infants from pulling them. With the markers in place, the calibration plate was removed and the black occluder was placed above the reaching window.

When the eye-tracker was running, a third experimenter operating the Flock-of-Bird started the video recording and triggered the motion capture. Objects were then presented one at a time from behind the occluder by lowering them directly into the calibrated area, in the infants' view, and within their reaching distance. All objects were presented horizontally and at eye-level. Due to the asymmetrical shape of the drumstick, with a sphere on one side, this object was presented in both left- and right-sided orientations. Each participant was presented with the objects in a quasi-random order to control for same object subsequent presentations. The kinematics and video of infants' arm movements and reaches towards the object were recorded from prior to reach to after the object had been taken from the experimenter by the infant. On trials where reaching did not occur, the object or another toy was presented to reengage the infant. Infants would complete trials until they became disinterested or up to a maximum of 32 trials. Following the study, the caregivers completed the demographic questionnaire.

Coding and Analyses

The primary experimenter coded all trials with an additional twenty percent completed by a secondary coder, who was naïve to the studies hypotheses, for interrater reliability. The following events were coded from the videos: Time of object appearance, reach start time, and contact time. These times were recorded in Microsoft Excel for further analyses of reach latencies and reach start and stop. The coded events were used to calculate the various velocity related dependent variables derived from the reaching kinematics using a custom MATLAB 2018b (MathWorks, Natick, Massachusetts, United States) program.

The latency between object viewing and reach start was coded for analyses relating to the length of visual exposure prior to reach start across three levels of object exposure: object first-in-view, object first-seen, object most-recently-seen. Object first-in-view was defined as the frame at which the rod, and if applicable half the sphere, was below the occluder. Object-first-seen was the frame during which the infant looked towards the object for the first time. Object most-recently-seen was the most recent look towards the object prior to reaching.

The visual manual coordination strategy was categorized into three different types of reach strategies (targeted, catch-up and untargeted) that were defined in relation to the area of visual focus on the scene during the reach and subsequent area of contact with the presented object. The targeted strategy was defined as a reach in which the infant fixated on the area of subsequent contact within the first two frames of the reach initiation and maintained this visual fixation until hand contact with the object was made. The catch-up strategy was identified when an infant fixated on an area of the object other than the subsequent area of contact but shifted its gaze to the area where it would contact the object during the reach. The final strategy, untargeted, occurred when the infant looked away from the object area that they subsequently contacted (see Figure 4).

The reaching kinematics were assessed from the start to the stop of the reach and were analyzed using a custom-made MATLAB program and filtered through a dual pass low path Butterworth filter with a cutoff of 6 Hz. Reach start was defined as the first frame of hand movement towards the presented object while the stop was the first frame of contact made with the object (Corbetta & Thelen, 1995). The duration of the reach was determined from the video frame counter at the start and the stop of the reach. Reach velocity was calculated using a 3-point calculation technique for each collection point divided by half the collection rate (120Hz). Mean velocity was calculated as the total hand trajectory during the reach divided by the reach duration. Maximum velocity is the highest velocity point exhibited. A movement unit is categorized by three data points a velocity apex and the minima prior to and just after the maxim. The number of these units characterizes changes in speed and trajectory during reach. The straight trajectory is the distance from the position of the hand at reach start to the position of the hand at reach stop. When divided by the trajectory length (the actual distance covered by the hand during the reach), it provides a rectilinearity index ranging from 0 to 1, where the closer the index is to 1, the straighter the reach.

All the above dependent variables were analyzed as a function of the type of object being presented, the area of contact, and the visual-manual coordination strategy used. The objects used in this study consisted of different levels of complexity and component sizes. The area of contact was limited to either the rod or the ball component.

Interrater reliability for the video coded variables were rated as follows: object first appeared was 98%, Object first seen 77%, Most recent view 85%, reach start 90%, reach stop 96 % and contact location 90%. All visual-manual coordination strategies were fully coded by two separate individuals with a reliability of 98%. Due to the variability of infants performing the different strategies and to account for the different number of trials each infant was able to complete, a GEE was performed to account for missing data.

CHAPTER FOUR: RESULTS

Visual Manual Coordination Strategy

To understand the representation of the strategies employed by infants, a GEE was used to analyze the visual manual coordination strategies across all objects. The GEE revealed a main effect of strategies, Wald $\chi 2(2) = 26.893$, $p < .001$. Pairwise comparisons revealed that infants employed the untargeted ($M = 59.61$, $SE = 5.13$) strategy proportionately more than the catch-up ($p = .041$) or targeted ones (ps < *.001* see Figure 5). There was no significant difference between the proportion of catch-up and targeted reaches ($p > .05$, see Table 5 for means).

Proportion of strategies by object type

To further understand the role of visual-manual coordination strategies employed by the objects presented, an additional GEE was used. The analyses revealed significant differences in the proportion of strategies used when reaching for a plain rod, Wald $\chi 2(2) = 12.772$, $p = .002$. Infants utilized the untargeted strategy for the rods more than the targeted and catch-up ones (*ps* = .003). Similarly, the same GEE revealed the same significant trend in the proportion of strategies used when reaching for a drumstick, Wald $\chi 2(2) = 20.936$, and the dumbbell Wald $\chi 2(2) = 19.695$ *ps* < .001. Infants utilized the untargeted strategy more than the targeted ($p < .001$) and catch-up for both objects ($p = .001$, see Figure 6, see table 6 for means).

Proportion of object types by strategy

Finally, to understand the proportion of each object that consists of the strategies a last GEE was used to analyze the proportion of each object present in strategies used. The GEE revealed no significant difference in the proportion of objects in the targeted, Wald $\chi 2(2) = 2.578$, $p = .276$; or un-targeted strategies, Wald $\chi 2(2) = 2.578$, $p = .276$ (see table 7 for means).

There was however a main effect of object in the proportion of objects represented in the catch-up strategy, Wald $\chi 2(2) = 6.925$, $p = .031$ (see figure 6). This strategy contained significantly more reaches to the drumsticks than the dumbbells (*p*=.041). The proportion of plain rods, however, was not significantly different from drumsticks or dumbbells (*ps* > .05). Infants were therefore more likely to utilize a catch-up strategy when reaching for a drumstick.

Infants generally used the untargeted strategy more often to reach regardless of the object being presented. Additionally, when an untargeted or targeted strategy was used by infants, it was equally likely to be a rod, drumstick, or a dumbbell. However, when infants employed a catch-up strategy, they we more likely to be reaching for a drumstick.

Latencies

To understand the role of latency to reach as it relates to object shape, areas of contact and the visual-manual coordination strategy used, we analyzed these three areas of interest using separate GEEs. We hypothesized that objects that presented a choice of looking preference (specifically a rod vs ball) would result in longer durations of latency to reaching. This was assessed across the three levels of latencies in reaching from object first being presented, first look at object, and most recent look prior to reaching.

By Object Type

Firstly, a GEE was used to analyze the latency durations between object types to determine the level that different objects' visual properties affected the start of reach. The latencies revealed no significant differences when the object first appeared (Wald $\chi 2(2) = 5.161$, $p = .076$). There was no significant difference in from the object appearing and infants beginning their reach towards the objects (see Table 1 for means).

A further GEE revealed a significant difference in object first seen latency (Wald $\chi 2(2) = 10.414$, $p = .005$) with a pairwise comparison indicating that latency of rods was significantly shorter than dumbbells ($p = .009$) but no difference between drumsticks and rods or dumbbells (see Figure 8 and table 1 for means, *ps* > .05). Similarly, an analysis of the latency related to the most recent view found a main effect of objects (Wald $\chi 2(2) = 9.789$, $p = .007$) however no significant pairwise differences (see Figure 8 and table 1 for means, *ps* > .05).Overall infants reached sooner for a rod than a they did a dumbbell after first viewing the object. Their delays in reaching following the first appearance of the objects was the same regardless of the object shown. Likewise, the latency between their most recent look at the object was the same for all three rods, drumsticks, and dumbbells.

By Area of Contact

To determine the role of the objects' visual properties on latency, the area of subsequent contact was analyzed in relation to the levels of latency. A GEE analysis revealed no significant difference between area of contact and object first appeared (Wald $\chi 2(1) = 3.064$, $p = .08$) or most recent view of object (Wald $\chi 2(1) = 2.334$, $p = .127$). There was no significant difference in the length of object first appeared latency or looking prior to reaching towards the objects and contacting rod or ball (see Table 2 for means). There was however a significant difference in object first seen latency (Wald $\chi 2(1) = 4.745$, $p = .029$ see Figure 9 and table 2 for means) where reach with a subsequent rod contact had a shorter latency than ball contacts. Additional analyses were conducted to better understand the relationship between area contacted and object.

A GEE analysis of first look at object for contacts made to the ball by object revealed no significant difference in the latency duration between drumsticks or dumbbells (Wald $\chi 2(1) = 0.435$, $p > .05$). Likewise, there was no significant difference between the latency of objects resulting in rod contacts (Wald $\chi 2(1) = 0.207$, $p > .05$ see table 2 for object means). Infants did not delay in their reaches from the object first appeared or looking prior to reaching regardless of the location they first contacted. Infants did however reach for the object sooner following their first look to the object when they contacted a rod rather than a ball.

By Visual manual coordination strategy

To determine whether the strategy employed by infants influenced the latency to reach, a GEE was used to analyze the relationship between visual-manual coordination strategy and latencies. Analyses revealed no significant difference between the visual-manual coordination strategy and when object appeared first (Wald $\chi2(2) = 2.337$, $p > .05$) or most recent view of the object (Wald $\chi2(2) = 2.534$, $p > .05$). There was no significant difference in object first appeared or the most recent view of object and visual-manual coordination strategy (see table 4 for means). There was however a significant difference in object first seen latency (Wald $\chi2(2) = 8.494$, $p = .014$ see Figure 10 table 4 for means). A pairwise comparison revealed that targeted reaches occurred significantly sooner than reaches using untargeted strategies ($p = .025$) but no difference between catch-up and targeted or untargeted (*ps* > .05). Infants therefore reached sooner after first seeing the object when they used a targeted strategy than when using another strategy (see Figure 10 and table 4 for means).

The analyses of latency revealed that infants reached sooner for the rods than for dumbbells. Infants reached with a similar delay for all objects following object first appearing and the most recent look. Similarly, infants reached sooner when making subsequent contact with a rod than with a ball. Again, there was no difference in the latency when the object first appeared or when the object was most recently seen. Finally, when infants used a targeted strategy, they reached sooner following their first view of an object than when they used an untargeted strategy. As with the other latency analyses there was no significant differences when the object first appeared or when they most recently viewed the object regardless of the strategy employed.

Kinematics

A final set of analyses were conducted to analyze the kinematics across objects presented and strategies employed by infants.

By Object Type

To determine the role of objects presented on reaching, a first set of GEE analyses was conducted on kinematic averages of the three objects. The GEE revealed no significant differences in reach duration, trajectory length, trajectory straightness, rectilinearity index, velocity at contact, mean velocity, maximum velocity, percent of reach duration or length at maximum velocity, or movement units across the three presented objects (see table 10 for means). Infants therefore did not significantly change their reaching patterns dependent on the object presented. They did not differentiate between rod, dumbbell or drumstick.

By Visual-Manual Coordination Strategy

To determine the role that the different visual-manual coordination strategies have on reaching, a set of GEE analyses was conducted on the kinematics of reaches averaged by the strategies.

Reach duration

The visual-manual coordination strategy GEE revealed a significant difference in the reach duration between strategies, Wald $\chi2(2) = 8.368$, $p = .015$, with a pairwise comparison indicating that reaches that used the catch-up strategy had significantly longer durations than the untargeted reaches ($p = .014$). Targeted reaches did not significantly differ from catch-up or untargeted ones (*ps* >.05, see Figure 11 and table 8 for means).

Trajectory length

The visual-manual coordination strategy GEE revealed no significant differences in the trajectory length across the three strategies (see table 9 for grand means)

Straight trajectory

The visual-manual coordination strategy GEE revealed no significant differences in the straightness of the trajectory across the three strategies (see table 9 for grand means)

Rectilinearity index

The visual-manual coordination strategy GEE revealed a significant difference in the rectilinearity index between strategies, Wald $\chi 2(2) = 7.903$, $p = .019$, with a pairwise comparison indicating that reaches using the catch-up strategy were significantly less straight than the untargeted reaches ($p = .014$) while targeted reaches did not significantly differ from the catch-up or untargeted reaches (*ps* >.05, see Figure 12 and table 8 for means). Infants who employed an untargeted strategy reached straighter than those using catch-up.

Velocity at contact

The visual-manual coordination strategy GEE revealed no significant differences in velocity of contact across the three strategies (see table 9 for grand means)

Mean velocity

The visual-manual coordination strategy GEE revealed no significant differences in the trajectory length across the three strategies (see table 9 for grand means)

Max velocity

The visual-manual coordination strategy GEE revealed a significant difference in the max velocities of the strategies, Wald $\chi 2(2) = 8.756$, $p = .013$, with a pairwise comparison indicating that reaches using the targeted strategy had significantly higher velocities than the untargeted reaches (p = .009) while catch-up reaches did not significantly differ from the targeted or untargeted reaches (*ps* >.05, see Figure 13 and table 8 for means).

Percent of reach duration at maximum velocity

The visual-manual coordination strategy GEE revealed a significant difference in the percent of the reach duration covered up to maximum velocity between strategies, Wald $\chi 2(2)$ = 6.592, p = .037, with a pairwise comparison indicating that the catch-up reaches had their velocity peaks sooner than the untargeted reaches (p = .037) while targeted reaches did not significantly differ from the catch-up or untargeted reaches (*ps* >.05, see Figure 14 and table 8 for means).

Percent of reach trajectory length

The visual-manual coordination strategy GEE revealed no significant differences in the percent of trajectory length traveled up to the peak velocity across the three strategies (see table 9 for grand means)

Movement units

The visual-manual coordination strategy GEE revealed a main significant difference in the number of movement units by strategies, Wald $\chi 2(2)$ = 11.091, p = .004, with a pairwise comparison indicating that reaches using the catch-up strategy had significantly more movement units than the untargeted reaches (p = .014) while the targeted reaches did not significantly differ from the catch-up or untargeted reaches (*ps* >.05, see Figure 15 and table 8 for means).

Overall infants reached the same for rods, drumsticks, and dumbbells. Regardless of the object presented, infant reach durations, movements, and speeds well not different. Alternatively, the infants displayed different reaching kinematics when accounting for the strategies they utilized. Infants using a targeted strategy achieving the highest speeds in reach. Those who employed a catch-up strategy had the longest duration of reaches, the most changes in their reach trajectory, and reached their apex velocities sooner n their reaches.

CHAPTER FIVE: DISCUSSION

The present study aimed to determine whether objects' visual properties are utilized in reach planning. Specifically, whether this information is evident during the reach through the visual manual coordination strategy employed. This study's findings suggest that objects' visual properties play a role in the latency between first viewing an object and making subsequent contact. Furthermore, the strategy utilized by infants seems to likewise be related to the object presented.

Latencies and reaching kinematics as a function of object types

The only significant difference found in latency was between plain rods and dumbbells, where upon viewing the object when it first appeared, infants reached for the rod sooner than for the dumbbell. Of interest was that there was no significant difference between the drumstick and the other objects. In previous studies (Corbetta et al., 2014) infants were observed to have looked for longer durations to the sphere of the drumstick and to have also subsequently reached to this location. Based on these findings, we would have expected for drumstick to have significantly different latencies from the rod and the dumbbell. However, the only difference found in latency was with the most recent look to reach start latency which revealed no significance in the GEE pairwise comparison between the objects presented. The lack of expected findings in the pairwise comparison may speak to a limitation of the latency measurement of reach delay which was based on looking towards the object rather than accounting actual looking on the object.

There was no significance found in the kinematic measures relating to stimulus type. This is most surprising again given previous work using drumstick stimuli where contact location was related to looking duration. When infants were allowed time to view the objects prior to reaching their contact location was more likely to occur there. However, this paradigm did not account for accumulated looking before the start of reach as in delayed reach paradigms which may explain the lack of differences between objects. Specifically, it could be that without the delayed out of reach exposure, infants are not forced to build spatial representation of specific object areas from prolonged fixations. By removing this delay, infants are uninhibited in their reaching and therefore may only act on obtaining the object rather than developing a spatial representation of the presented objects components followed by reaching in response to those locations.

Latency by area of contact

The first area of contact revealed an unexpected difference in the reach latency to first object fixation. Infants who contacted a rod location reached sooner than those who contacted a ball area. This may suggest that infants factored the area of reach into their reaching time response prior to the reach start. This was additionally related to the first look on object rather than the most recent look to the object. Infants, therefore, delayed their reaches to both rod and ball locations after a similar delay following their most recent look to the object. Oddly there was no difference between contacts made to the rod and the objects presented (rod drumstick or dumbbell). That is regardless of the components of the object, it was the location solely that drove the difference seen in latency. We had hypothesized that given the difference seen between ball and rod contact latency, objects consisting of a ball component would likewise have a longer latency from plain rods. Similarly, there was no difference in objects presented when reaching for a ball (drumstick or dumbbell). Given the physical components of these objects, rods and balls, we anticipated that differences would be related to the components of the objects. This is to say that those objects with balls would result in differences than the plain rods with the number of balls correlating to the level of difference. However, regardless of the objects component composition of rod and ball(s) the determining factor was which area the infants reached for and contacted.

Visual-manual strategy

The most interesting area of focus in this study was the visual manual coordination strategy, given the recent rebuttals to the visually-guided hypothesis between the alignment of the visual and manual system in infant reaching. The only difference found in reach latency occurred between the targeted and untargeted reaches where infants who employed a targeted strategy reached sooner after seeing the object than their untargeted counterparts. There was no difference however between the three strategies and the latency between most recent look and reach start.

Regarding the kinematic measures, infants achieved the fastest reaching speeds when they utilized the targeted strategy over the untargeted strategy. However, targeted and untargeted reaches did not differ in reach duration or the percent of duration at which they reached their respective peak velocities. That is to say that kinematically, targeted and untargeted reaches differed only by their peak speeds. They reached for the same amount of time and achieved their highest speeds at the same time within the reach. When using the catchup strategy, infants had longer reach durations produced more movement units and less straight trajectory than untargeted reaches. Additionally, catch-up reaches achieved their max velocity sooner than untargeted reaches. Infants that utilized a catch-up strategy had peak velocities sooner and made more corrections during their reaches than infants using the untargeted strategies but did not differ in reach duration or average speed of reach.

Limitations and future directions

This study has several limitations. Latency to reach was not initially part of the study and therefore the study was not designed with latency in mind. The addition of the latency measure was meant to encompass the potential looking exposure to the different objects presented. With eye tracking, we can look at active looking to the object or the scene and therefore account the looking time spent on each area of the object that could then be related to the visual-manual coordination strategy used.

The study did not offer infants only ball reaching (a comparable reach to the plain rod) which would strengthen the understanding of differences found in the area of contact. The present study used objects of varying combinations of rods and balls. However, we did not use a ball only object that would be comparable with the plain rod presented. The findings suggest that there was a significant difference in the latency of reach following the first view of objects and the area of first contact. Infants reached sooner when reaching towards a rod location. However, this may be due to the rod being the only object that does not afford a choice of difference across any of the areas with which they can contact. To fully understand the difference in the difference between locations of subsequent contact and latency to reach, a single ball object is needed to counterbalance the plain rod.

Regarding the strategies themselves, any contact that did not match the location of fixation in the end was considered untargeted. This has several issues as 60% of the trials were grouped into this broad category without looking further into the actual scanning done by infants. It may be that understanding the proportion of fixations on different areas will shed light on the strategy infants are using to align vision in reaching for these trials. Furthermore, we did not account for eye tracking following contact with the object. We therefore did not categorize those trials where infants shifted their fixations to the contacted location and those that did not. Corbetta and Snapp-Childs (2009) found that 9-month-olds incorporated previous tactile information in their subsequent reaches. It may therefore be prudent to analyze sequential trials in relation to the strategies utilized as they may relate to latter strategies in the future.

Finally, the objects were divided into three areas of interest. The choice of reaching location can be focused on by the objects-ends where infants reach. In this, infants have two different locations per object that are either the same (rod and dumbbell) or opposite (drumstick). Analyzing the contacts made to object-end would allow us to compare kinematic differences between reaches to the rod and the ball in the symmetrical objects. We can further look at the differences made when these contacts are made on the same object (the drumstick) where the choice is afforded for either rod or ball. A final analysis should investigate the role of peripheral information (the object-end areas) when reaching to the middle rod. All objects have the middle rod so if this peripheral information plays a role in reach planning; the increase of competing information should be evident from no ball to one to two progressively.

A last limitation of this study is the number of trials infants were presented and the number of infants in the study. Infants trials ranged from 8 trials to 32 trials. Given the three possible strategies identified, infants with 8 trials would not be able to demonstrate 3 of each strategy which may be responsible for the variance between infants (see Figure 7). Additionally, the infants in this study were 9 months old. At this age infants have had several months of reaching experience and it would be beneficial to following infants from reach onset onward to track their development and the developmental change of the visual manual coordination strategy as the infants developed the reach and visual systems.

Conclusion

The present study shows that infants to some extent incorporate the object properties in their reach planning following their first view of the object. Furthermore, infants used different strategies for obtaining a desired object with these strategies varying across infants and across reaches for each infant. It is noteworthy that infants used a catch-up strategy for drumsticks, an object that provides a choice in reaching area and fixation locations. This incongruity may be similar to the tendency for infants to look towards larger areas but reach for smaller areas (Newman et al., 2001). This is to say that infants may be drawn to looking towards the larger area but reach towards the smaller area. They then shift their vision to the area they are reaching towards. Better understanding of these strategies and the employment of them according to situations have implications in how infants interact with their environment. For example, in the creation of interactive toys intedned to direct infant learning. Areas that we as adults may find more interactive and interesting may not be the same that draw infant attention (i.e. objects that infants readily look at may not be what infants actively reach towards and interact with). This becomes further necessary in future studies where the alignment of reaching and vision are in question (i.e. the difference of reaches found may be due to strategies employed by infants). Specifically in motor development studies for reaching, the strategy used may play a role in the charateristics of the reach as infants interact with targeted objects. Furthermore infants may not reach to specific objects that researchers find more attractive due to untargeted reach strategies.

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APPENDICES

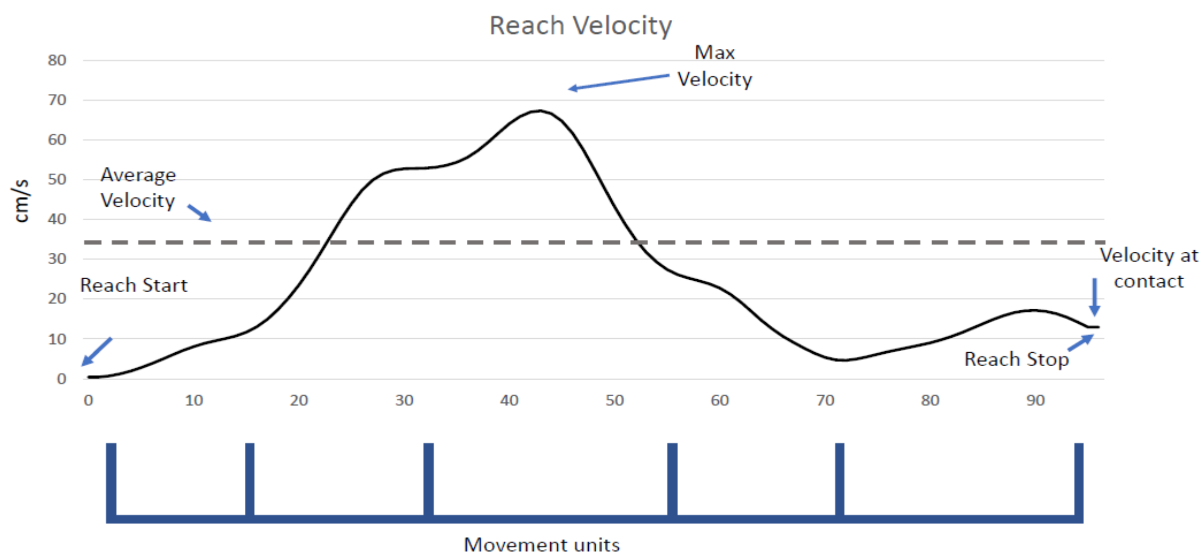

Figure 1. Diagram of velocity movement during reach. Reach start, reach stop, max velocity, and velocity at contact labeled on velocity curve. Average velocity indicated by dotted line. Movement units, identified by minima adjacent to a maximum, indicated below graph.

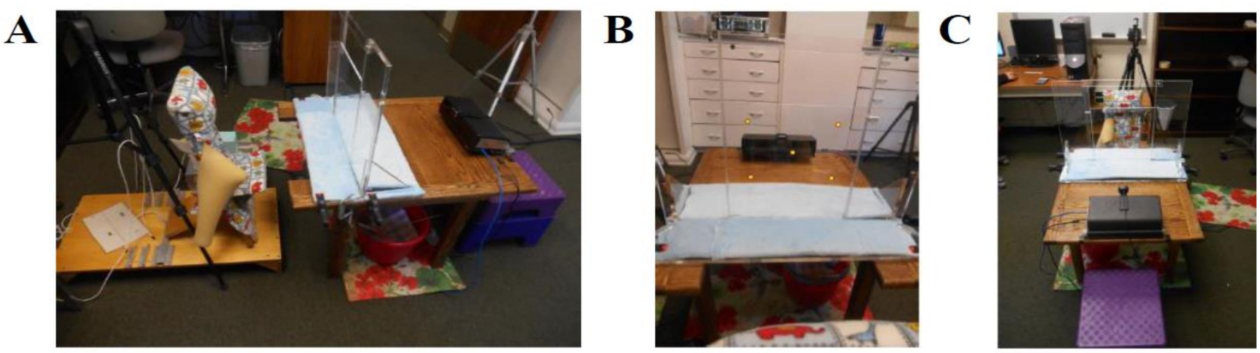

Figure 2. *(A) Side view of experimental setup, infant chair, eye-tracker, and side camera in view (B) The set-up for calibration with plexiglass calibration plate. Calibration points highlighted for print. (C) Experimental setup of eye tracker across from calibration area scene camera positioned behind infant.*

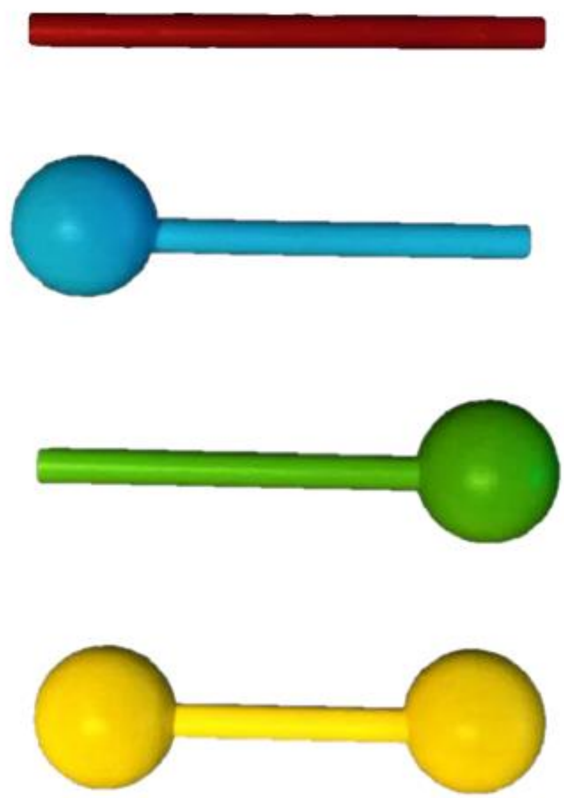

Figure 3. Objects presented (plain rod, drumstick ball left, drumstick ball right, dumbbell; top to bottom)

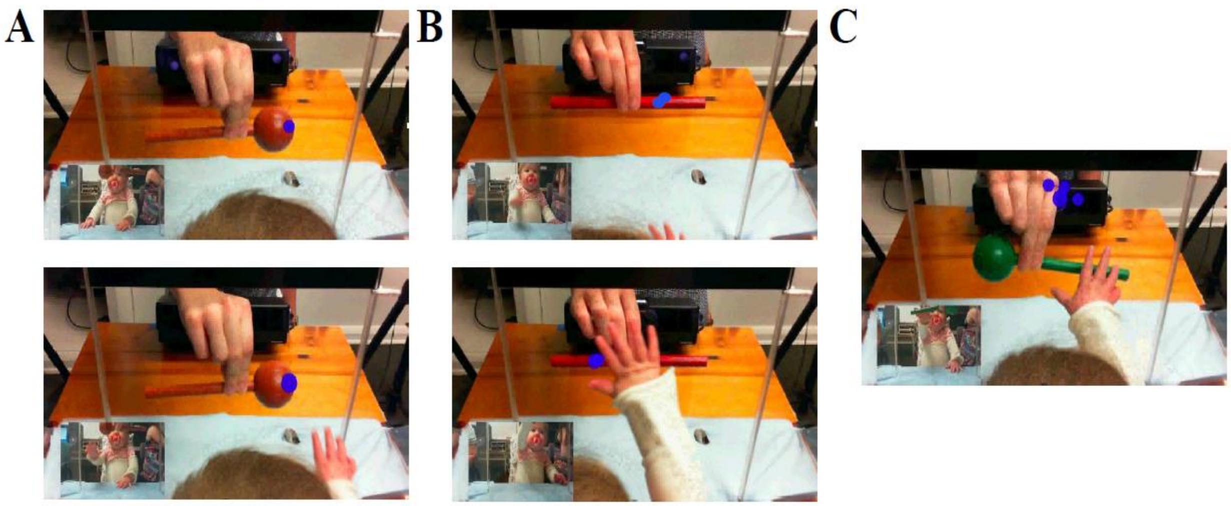

Figure 4. *(A) Targeted strategy with fixation on drumstick. Top: fixation on ball at reach start, bottom: fixation remains on ball. (B) Catch-up strategy on plain rod. Top: fixation on right rod-end at reach start, bottom: fixation shifts to right-rod end prior to contact. (C) Untargeted strategy with no fixations on the drumstick.*

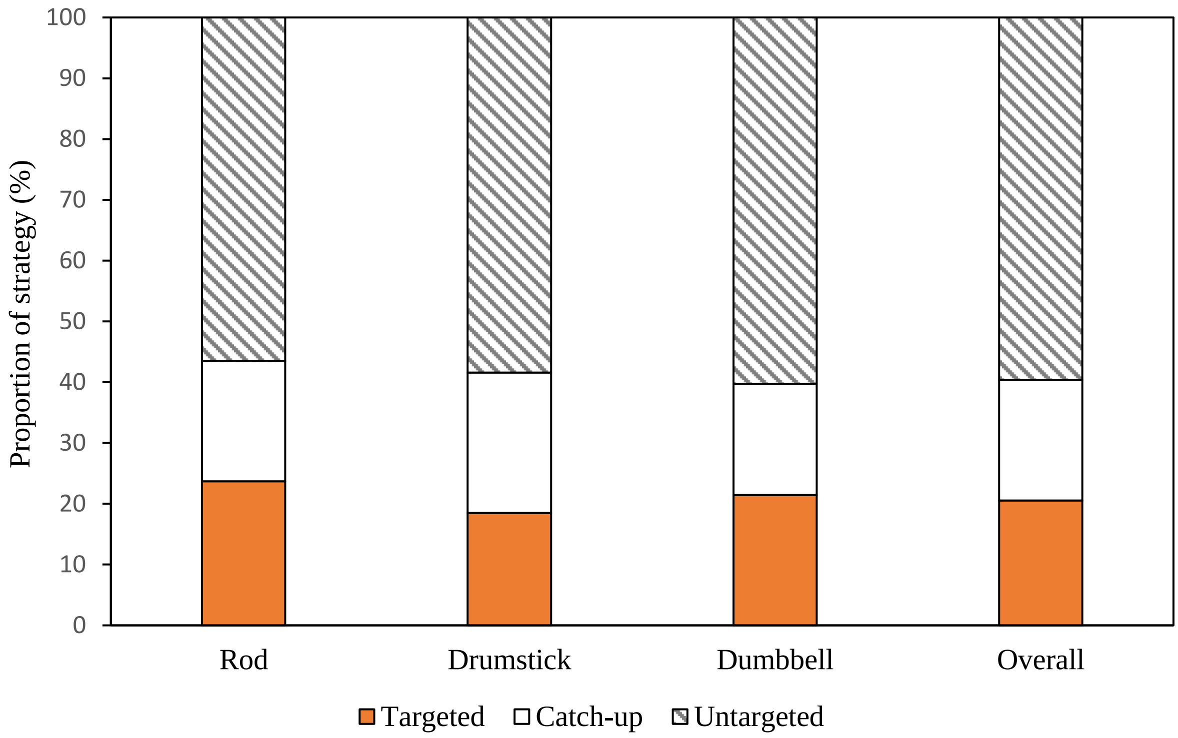

Figure 5. Proportion of strategies used by object and average across objects

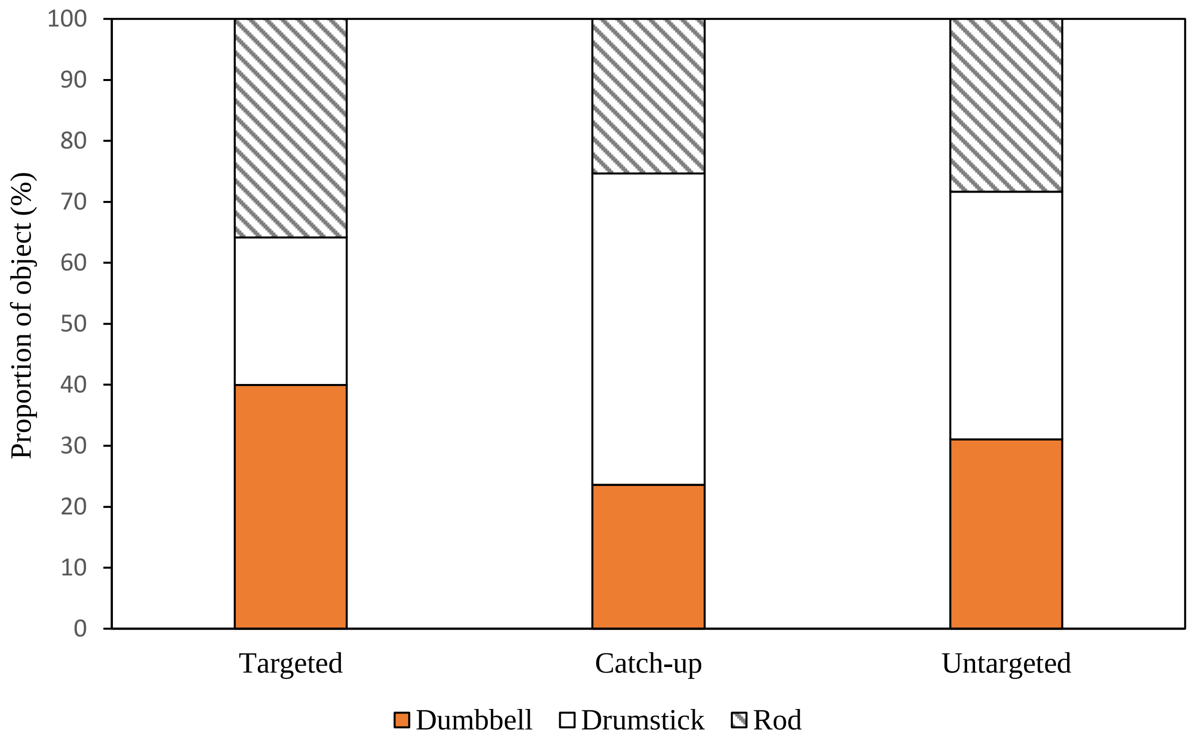

Figure 6. Proportion of objects by strategy

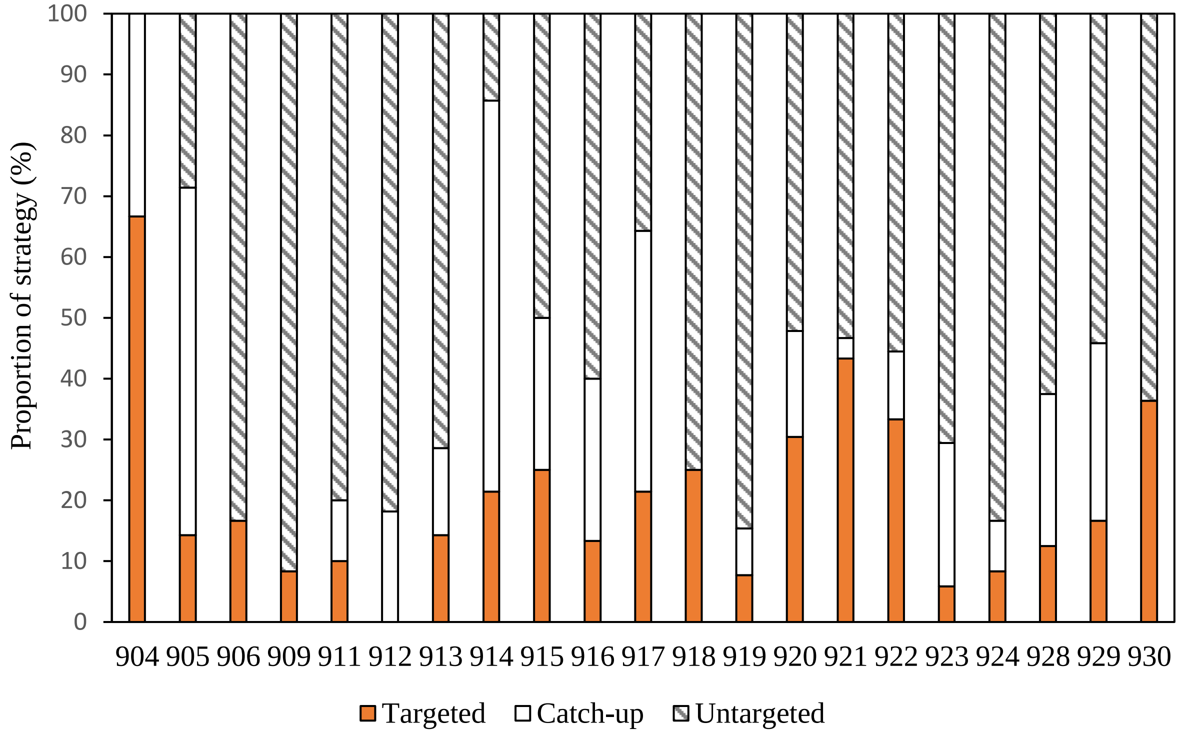

Figure 7. Proportion of strategies used by infant.

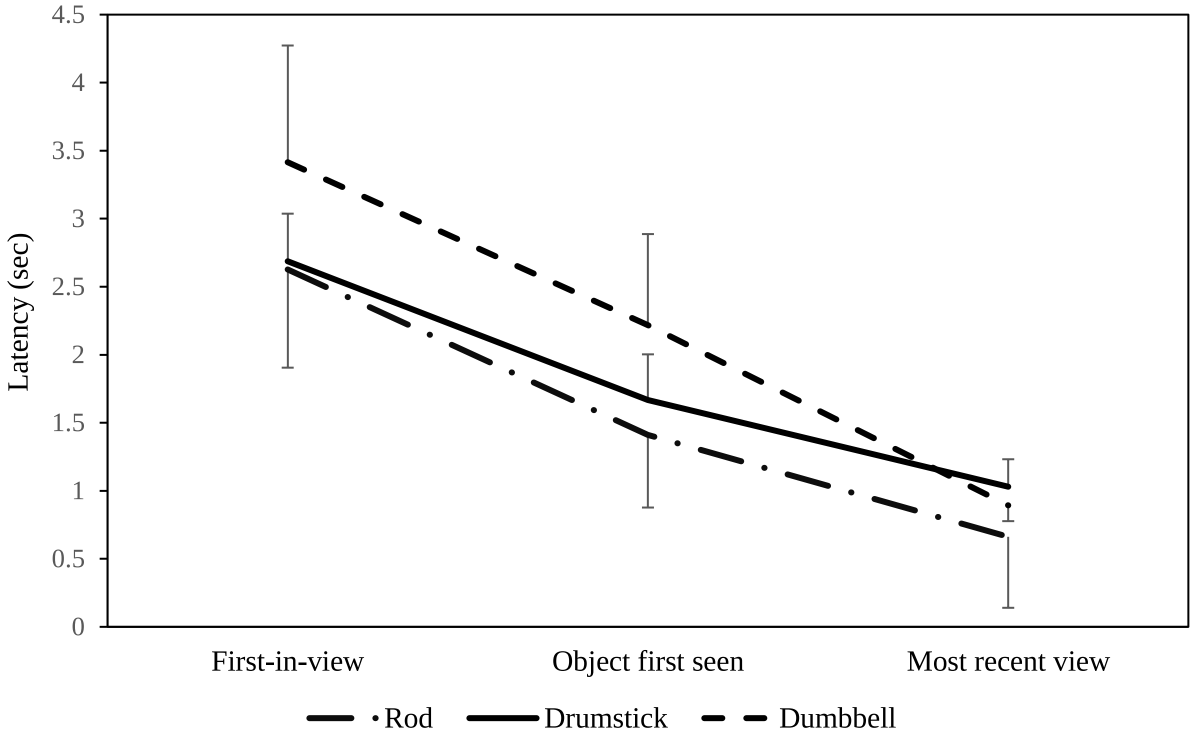

Figure 8. Average latency to reach by latency type and object type.

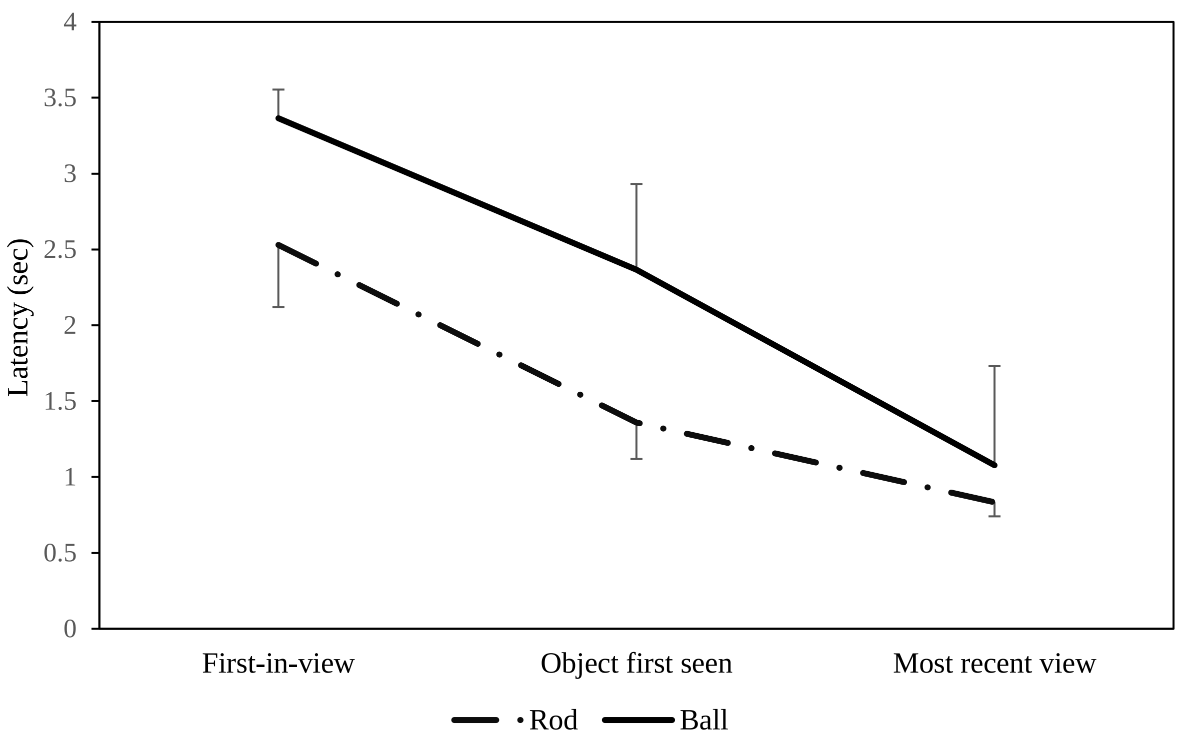

Figure 9. Average latency to reach by latency type and by area subsequently contacted.

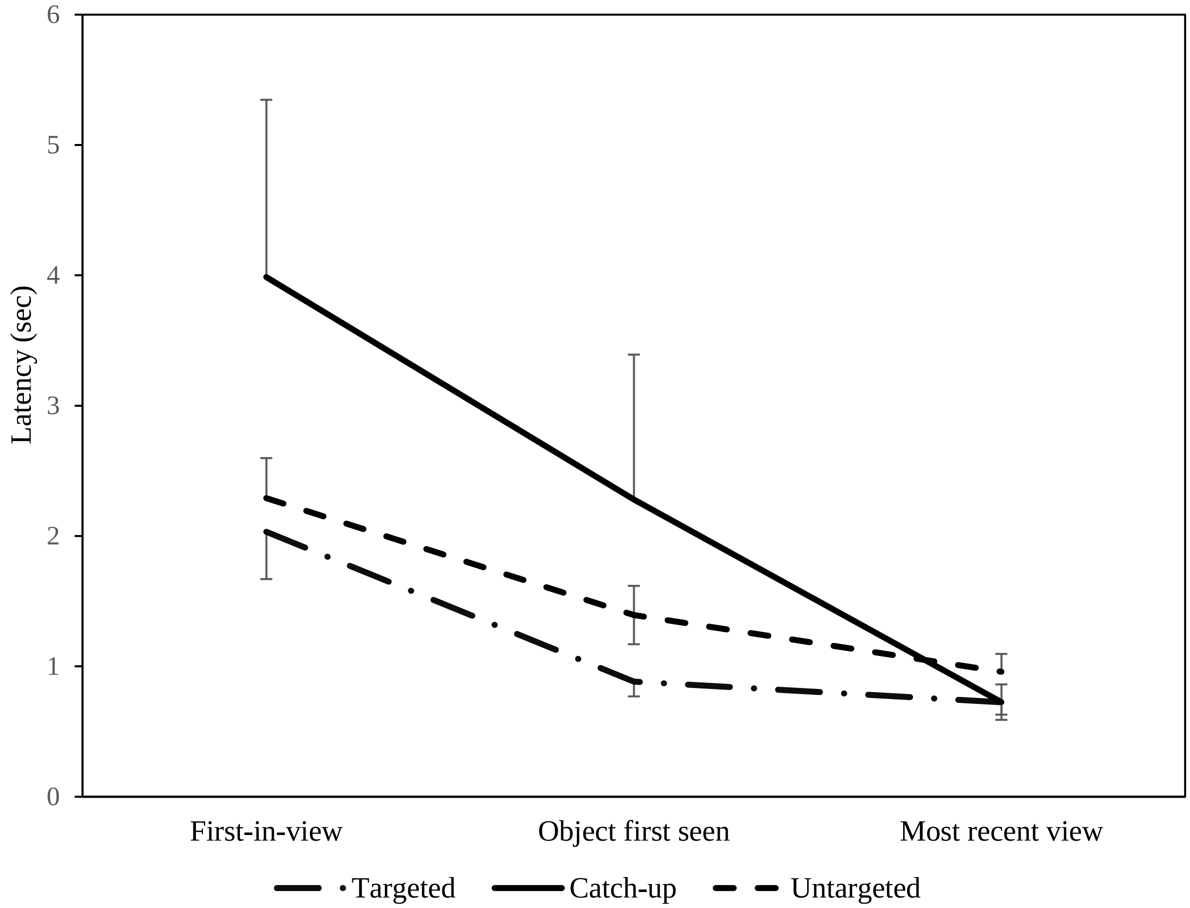

Figure 10. Average latency to reach by latency type and by strategy.

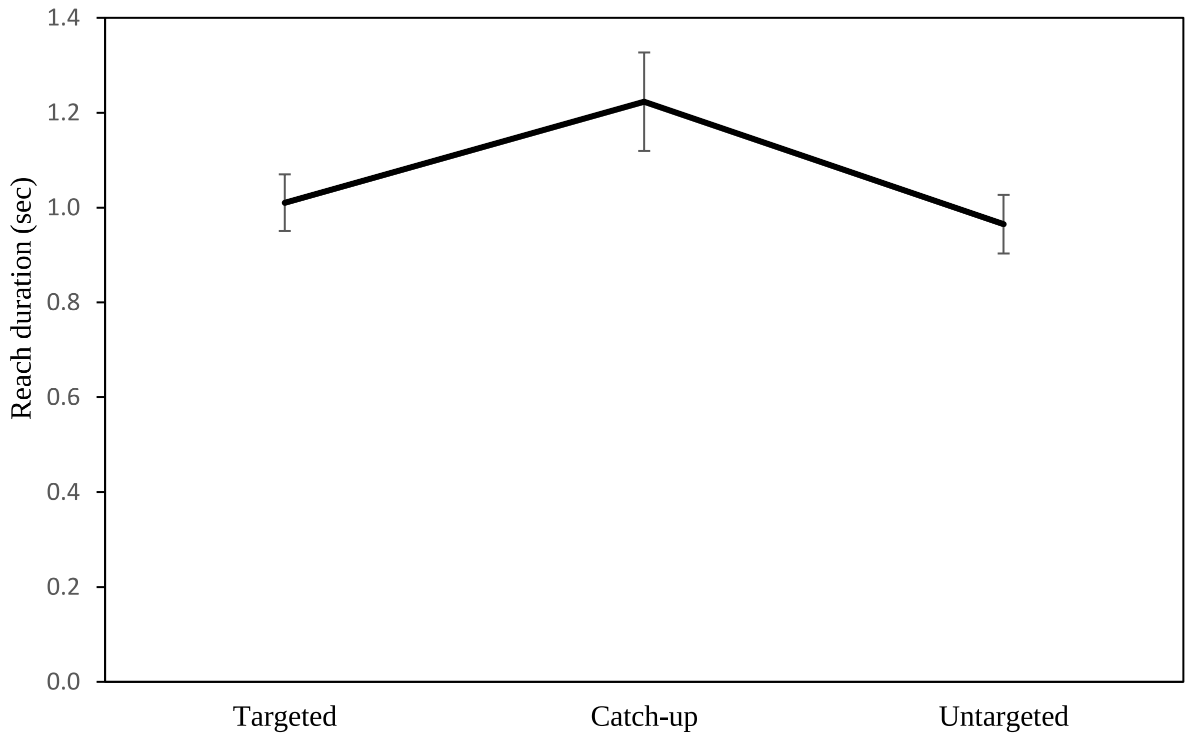

Figure 11. Average reach duration by strategy.

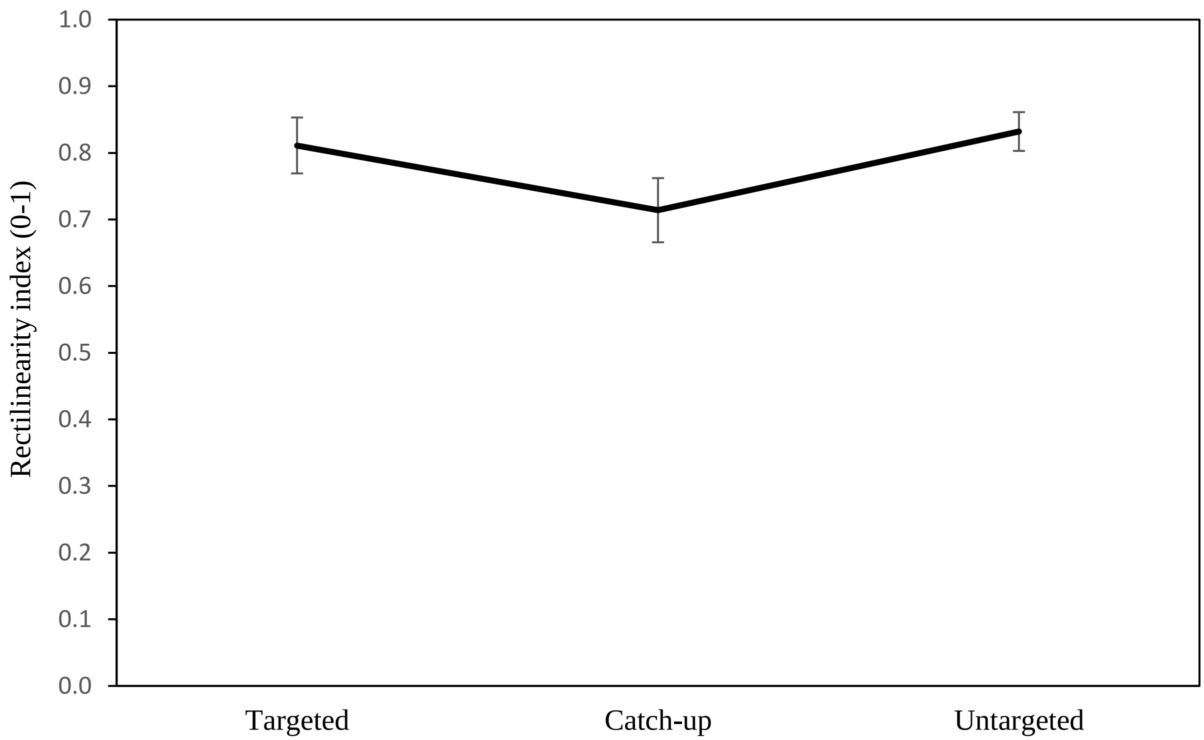

Figure 12. Average rectilinearity index by strategy.

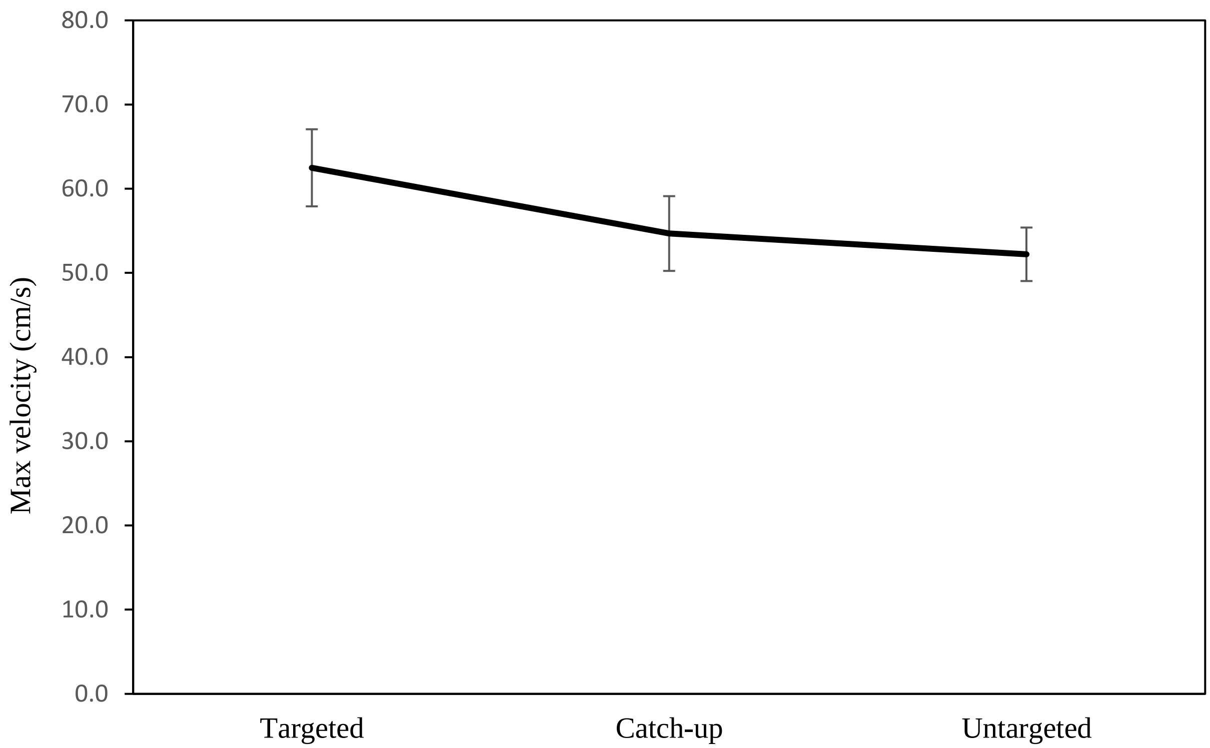

Figure 13. Average max velocity by strategy.

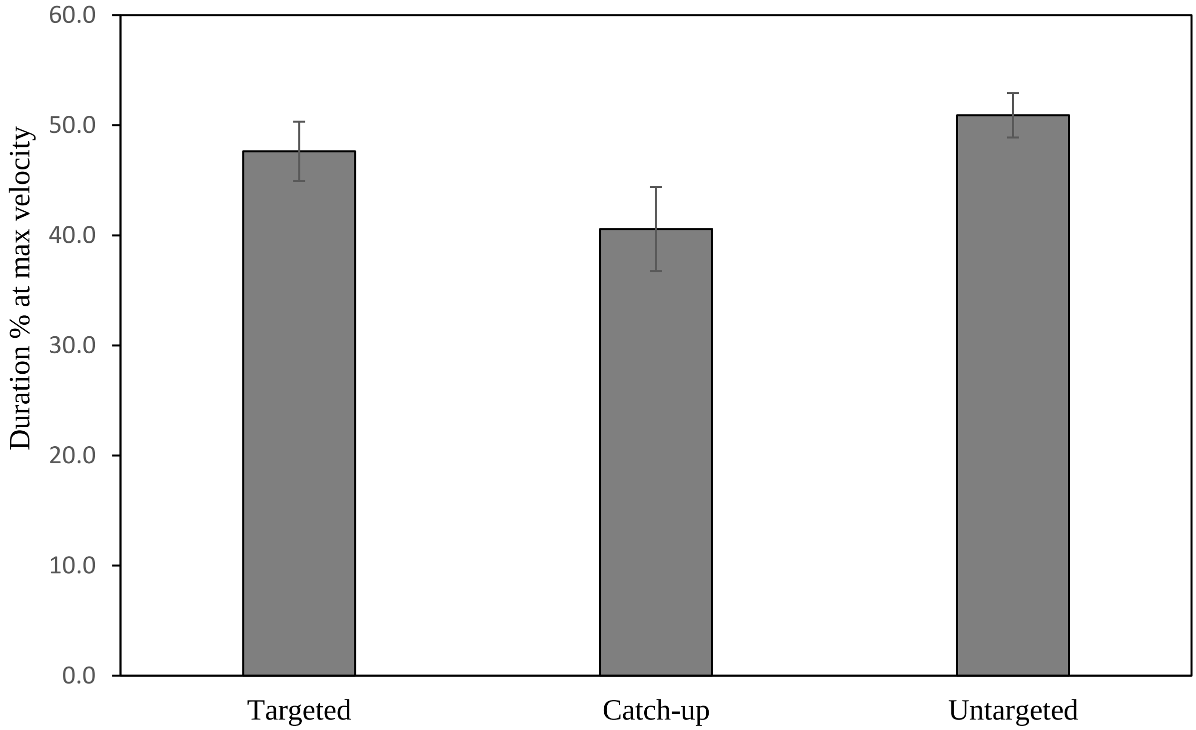

Figure 14. Percent of reach duration at max velocity by strategy.

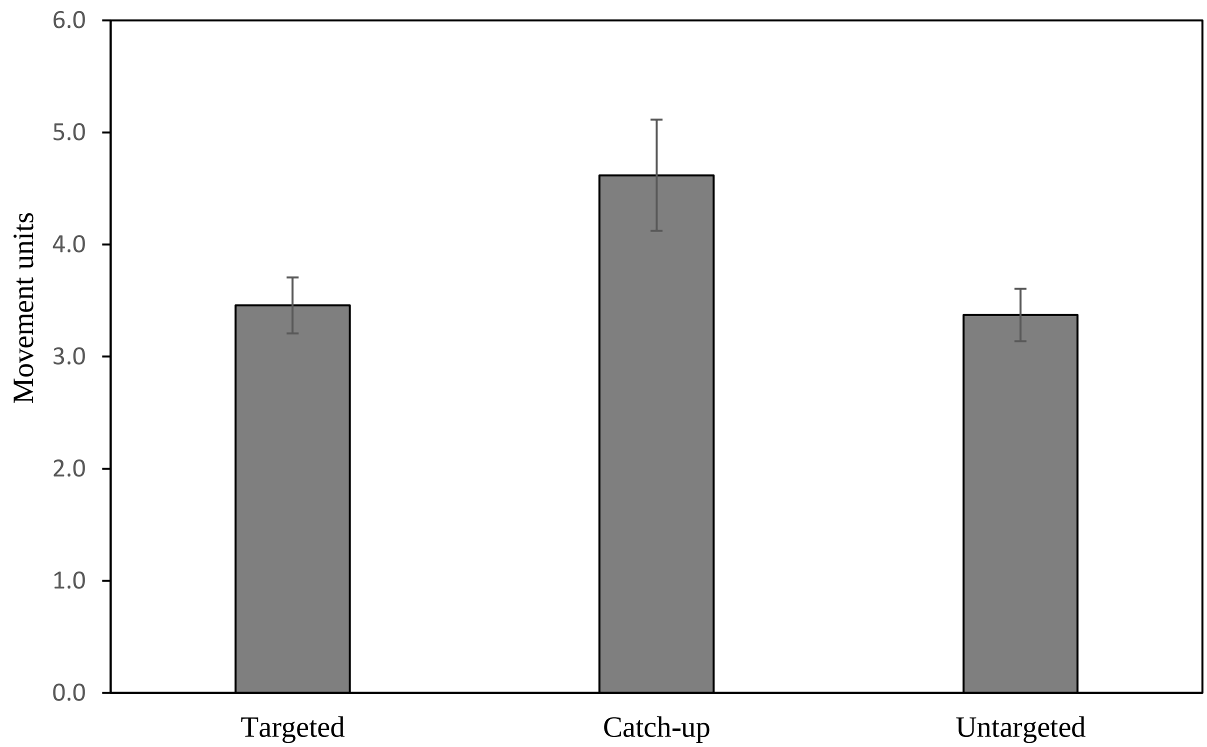

Figure 15. Average movement units by strategy.

Table 1
Mean estimate duration of latencies by object type

Latencies	Objects	Mean	Std. Error
First-in-view	Rod	2.627	0.722
	Drumstick	2.687	0.350
	Dumbbell	3.415	0.858
Object first seen	Rod	1.412	0.535
	Drumstick	1.667	0.336
	Dumbbell	2.217	0.670
Most recent view	Rod	0.662	0.522
	Drumstick	1.030	0.202
	Dumbbell	0.893	0.116

Table 2

Mean duration of latencies by area contacted

Latencies	Area Contacted	Mean	Std. Error
First-in-view	Rod	2.530	0.409
	Ball	3.365	0.653
Object first seen	Rod	1.359	0.240
	Ball	2.367	0.565
Most recent view	Rod	0.834	0.093
	Ball	1.078	0.189

Table 3
Mean duration of first look at object latency by area contacted by object

Area contacted	Object	Mean	Std. Error
Rod	Rod	1.222	0.339
	Non-rod	1.403	0.238
Ball	Drumstick	1.642	0.518
	Dumbbell	2.233	0.687

Table 4

Mean estimates for duration of latencies by each strategy

Latencies	Strategy	Mean	Std. Error
First-in-view	Targeted	2.033	0.363
	Catch-up	3.987	1.360
	Untargeted	2.291	0.307
Object first seen	Targeted	0.883	0.113
	Catch-up	2.280	1.112
	Untargeted	1.394	0.224
Most recent view	Targeted	0.725	0.095
	Catch-up	0.726	0.136
	Untargeted	0.959	0.137

Table 5

Mean proportion of strategies across infants

Strategy	Mean	Std. Deviation
Targeted	20.522	3.242
Catch-up	19.872	3.874
Un-targeted	59.606	5.125

Table 6

Mean estimates for proportion of strategies used per object

Object	Strategy	Mean	Std. Error
Rod	Targeted	23.718	4.797
	Catch-up	19.764	5.610
	Untargeted	56.518	6.489
Drumstick	Targeted	18.466	4.956
	Catch-up	23.133	4.081
	Untargeted	58.401	5.488
Dumbbell	Targeted	21.417	3.717
	Catch-up	18.333	5.733
	Untargeted	60.249	6.405

Table 7

Mean estimates for proportion of objects represented by each strategy

Strategy	Objects	Mean	Std. Error
Targeted	Rod	35.852	8.521
	Drumstick	24.155	5.721
	Dumbbell	39.993	4.086
Catch-up	Rod	25.350	1.591
	Drumstick	51.050	6.783
	Dumbbell	23.599	6.309
Untargeted	Rod	28.316	3.537
	Drumstick	40.646	3.627
	Dumbbell	31.038	3.240

Table 8

Mean estimates for kinematic measures by each strategy

Kinematic measure	Strategy	Mean	Std. Error
Reach duration (sec)	Targeted	1.010	0.060
	Catch-up	1.223	0.104
	Untargeted	0.965	0.062
Rectilinearity index (0-1)	Targeted	.811	.042
	Catch-up	.714	.048
	Untargeted	.832	.029
Max velocity (cm/s)	Targeted	62.484	4.579
	Catch-up	54.681	4.439
	Untargeted	52.214	3.176
Duration at max velocity (%)	Targeted	47.633	2.685
	Catch-up	40.580	3.820
	Untargeted	50.903	2.021
Movement units	Targeted	3.457	0.250
	Catch-up	4.618	0.496
	Untargeted	3.371	0.234

Table 9

Estimated grand means for kinematics by strategy

Kinematic measurement	Mean	Std. Error
Trajectory length (cm)	12.864	1.051
Straight trajectory (cm)	10.860	1.106
Velocity at contact (cm/s)	15.177	1.277
Mean velocity (cm/s)	25.445	1.515
Trajectory length at max velocity (%)	48.332	2.644

Table 10

Estimated grand means for kinematic by object

Kinematic measurement	Mean	Std. Error
Reach duration (sec)	0.995	0.049
Trajectory length (cm)	12.505	0.853
Straight trajectory (cm)	10.690	0.971
Rectilinearity index (0-1)	.812	.026
Velocity at contact (cm/s)	16.131	1.288
Mean velocity (cm/s)	25.790	1.404
Max velocity (cm/s)	54.357	2.861
Duration at max velocity (%)	49.376	1.586
Trajectory length at max velocity (%)	49.504	2.391
Movement units	3.609	0.206

VITA

John P. Connell was raised in Knoxville, Tennessee by Tessa Sterling Davis. He has Four brothers, Larry Connell, Dewey Connell, Joshua Connell, and Dante Mazzacone, and three sisters, Nicole Hembree, Nelisha Herscha, and Katlin Mazzacone. He attended the University of Tennessee, Knoxville and received a Bachelor of Arts degree in Psychology in 2015. John is currently enrolled at the University of Tennessee, Knoxville in the doctoral program in Experimental Psychology.