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The kinematics of intent : a new approach to measuring intention in infants.

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THE KINEMATICS OF INTENT: A NEW APPROACH TO MEASURING INTENTION IN INFANTS

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ABSTRACT

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Previous studies have shown that what an adult is going to do with an object after they pick it up affects the kinematics of the reach toward the object. This phenomenon has been referred to in terms of movement intent (e.g., Marteniuk, MacKenzie, Jeannerod, Athenes, and Dugas, 1987) and in terms of motor behavior context effects, (e.g., Johnson, McCarty, Clifton, submitted). The aim of this study was to examine whether future actions influence the kinematics of infants' approach toward an object. Twenty-one 10.5-month old infants were encouraged to reach for and grasp a ball in order to fit it down a tube, throw it, or hold it. Kinematic measures of the approach phase of the reach toward the ball were obtained using a motion analysis system (Northern Digitial OPTOTRAK). While we were unable to fully replicate the adult studies, we did find some kinematic differences in the reaches of infants depending on what they were going to do with the ball after they picked it up. We found that infants reached for the ball faster if they were going to subsequently throw the it as opposed to fit it down a tube. In addition, infants had a significantly shorter reach duration time for those reaches followed by a second action (fitting/throwing) than for those reaches followed by no planned second action (holding). In all conditions the perceptual aspects of the ball to be grasped were the same and cannot account for these kinematic differences. These results suggest that 10.5-month old infants are planning their actions in advance and that this intentional state can be quantified by examining the kinematics of the reach.

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CHAPTER 1

INTRODUCTION

A wide range of research has delved into the issue of whether or not infants perform intentional behaviors. In this research, there is controversy in what is meant by the term intentionality and in what is the best methodology to assess this intentionality in infants. While the primary focus of the current study was to find a unique methodology by which to measure intentionality in infants, the terminology surrounding intentionality must be addressed as well.

The controversy over what is meant by the phrase "intentional behavior in infants" is extensive and complex, in part, because of the differing levels of complexity used to define intention. We conceptualized intentionality as a continuum in which the complexity of cognitive processes involved to perform the intentional actions varied. At one end of the continuum is prospective control in which the infant must plan a single movement, the movement toward the object he/she wishes to reach (von Hofsten, 1993). In order to exhibit prospective control, the infant must provide evidence that he/she was planning in advance to reach for a particular object and not simply sticking out his/her hand randomly and encountering an object by chance. One example providing evidence of prospective control in infants is the observation that infants will start to reduce the grip size of their hand in anticipation of an encounter with an object (von Hofsten and Ronnqvist, 1988). This kind of evidence suggests that the infant was planning to reach for a particular object in that he/she was adjusting his/her reach in order to better grasp the intended object. Thus, in prospective control the infant is thought to show the ability to plan one movement, the reach for an object. Prospective control will be discussed in more depth in section A.

At the other end of this continuum of the complexity of cognitive processes is intentional means-end behavior, in which the infant must plan a sequence of two or more movements. This level of intentional behavior requires the infant to perform the complicated task of executing a movement not directed toward the desired object in order to eventually reach the desired object (Piaget, 1954, 1963). For example, in the classic hidden object task (Piaget, 1954, 1963), in order to retrieve an object hidden by a cloth barrier, the infant must first remove the cloth barrier that is concealing the object and then reach for the object itself. Thus, the infant must complete a sequence of movements to achieve the final goal of obtaining the toy. In successfully executing these movements by focussing on and retrieving the goal toy, infants are said to possess intentional means-end behavior. Section C will discuss intentional means-end behavior in further detail.

The current study takes a middle approach toward examining intention. Our approach toward intention requires more cognitive complexity than prospective control and a little less cognitive complexity than intentional means-end behavior. We are interested in examining the intentionality needed for when an infant reaches for an object and performs some action with it. While this type of intentionality, which we will be referring to as movement intent (Marteniuk, MacKenzie, Jeannerod, Athenes, and Dugas, 1987), has been studied in adult reaching behavior, (Johnson et al., submitted; Marteniuk et al., 1987) it has not been studied in infants. Movement intent, as defined by Marteniuk et al. (1987), involves two movements, a reach for an object and then an action performed with that object. For example, the infant might reach for a block and then drop it onto the floor. We, like Marteniuk et al. (1987), are defining movement intent to involve two movements such that what an infant plans on doing with an object (for example, dropping it onto the floor) affects how the infant reaches for the object. This definition assumes that during the infant's movement toward the object, he/she is planning ahead to what he/she is going to do with the object once he/she picks it up. However, this definition of intention does not specify whether planning occurs before the movement toward the object starts or during the movement toward the object. Instead, this definition claims that before the infant actually picks up the object, he/she has a plan or goal of what to do with that object after it is picked up. Thus, this type of intent requires more cognitive complexity than prospective control in which an infant anticipates an encounter with a desired object. Also, this intent requires less cognitive complexity than means-end behavior in which an infant must manipulate one object in order to reach another.

For the current study, we wanted to establish a unique methodology to study intentionality in general. Our unique methodology was to use the kinematics of the infants' reach to exemplify the infants' intent. Specifically, we hypothesized that what the infant plans on doing with an object after he/she picks it up (so, the type of action) will affect the kinematics of the reach towards the object. In using kinematics in order to measure intentionality in infants we hoped to avoid some of the past problems of using certain observational measures to measure intentionality. For example, intentionality is frequently measured using success/failure criteria (Frye, 1990) and causal relationships (Vedeler, 1987, 1991) in order to determine whether or not the infant is acting intentionally. However, these criteria have several problems which will be discussed further in sections B, D, and E.

Thus, in the current study we chose to focus on movement intent as this has not been previously examined in infants. We speculated that movement intent is reflected in infants' reaching behavior. Thus, we predicted that kinematics can be used as a unique way to assess infants' intentionality in reaching behavior, in the context of three behaviors that differed in speed precision, and apparent intent.

Following is a more detailed discussion of movement intent, prospective behavior and intentional means-ends behavior. After a more comprehensive discussion on how to define intent, different ways of measuring intentional behavior will be discussed in order to demonstrate the cons of using observational measures. Finally, the kinematics of reaching will be introduced as an alternative way to measure intentional behavior in infants.

A. Defining Intention in Terms of Von Hofsten's Prospective Control

One way to define intentional behavior is in terms of prospective control (von Hofsten, 1993). The prospective control view of intentional behavior explains how an infant anticipates an encounter with a desired object. Von Hofsten (1993) provided a good summary of prospective control as a necessary skill. Von Hofsten argued that an organism's encounters with the environment need to be prepared for and controlled for in advance. He referred to this property of human action control as prospective behavior. He argued that the development of action is a matter of acquiring this prospective control.

Von Hofsten argued that prospective action is a developmentally learned ability. Von Hofsten claimed that what Piaget (1963) referred to as circular reactions can be seen as the mapping of intent. When infants perform repetitive movements with slight alterations, they are exploring their own action systems. By this process of exploring their action space, infants learn to foresee and control actions with objects and events in the outside world. Von Hofsten referred to motor learning as getting to know the task space and to the development of coordinating perceptual information with actions.

There are numerous problems with coordinating action involving muscle contractions, such as maintaining balance and equilibrium of the body with a stable orientation relative to the environment, and the coordination of movements with the external world. We need to adjust the timing of our actions to our surroundings. An adult running across rough terrain exemplifies this need for adjustment. The runner's gaze must be focussed ahead of herself, unconsciously scoping out the upcoming terrain so that when she reaches that spot ahead of her where there is a hole in the ground, she will be prepared to jump over it. The runner's continuous movement forward is thus achieved by knowing about the terrain ahead before she actually reaches it. Accordingly, there is a lag time between the visual input (seeing the hole in the ground) and the adjustment that is made (changing her stride in order to jump over the hole when she reaches it). (see Warren, 1998 for a review of this research) However, in the above example, it is important to remember that the runner is not necessarily consciously aware of making these adjustments. The term "knowing" is meant to be used loosely. In this example, the runner seems to have an implicit knowledge of the upcoming surrounds from visual input.

Consider Anscombe's (1957) definition of intentional actions. In describing intentional actions, Anscombe claimed that "the description of what one is doing, which one completely understands, is at a distance from the details of one's own movements, which one does not consider at all"(p.54). In other words, the runner in the above example knows that she is jumping over the hole in order to avoid hurting herself, but she is not consciously aware of the kinematics of the movement which allowed her to jump over the hole at the correct time. She also may not have been explicitly aware of the hole ahead of time. Thus, this type of prospective behavior translates into an implicit knowledge of the environment and how to react in it. This view is similar to von Hoftsen's (1993) view. Prospective behavior coordinates perception with actions that anticipate an encounter with something in the environment.

Thus, von Hofsten (1993) described prospective behavior as a type of implicit behavior requiring the infant to be future-oriented when interacting with the world. Future-oriented refers to the need for the infant to prepare for and control encounters with the environment.

B. Measuring Prospective Control Using Early Reaching Behavior

One way to measure intention as it is defined by prospective control, is to use early reaching behavior. Von Hofsten (1993) suggested that one important aspect of sensorimotor development is the acquisition of prospective control over movements in order to make them more continuous and smooth. One such movement is reaching. Planned movements are smooth and continuous, whereas unplanned movements are choppy and discontinuous. Von Hofsten (1991) showed early reaching movements at 19-weeks to be discontinuous and composed of smaller movements called movement units. However, by 31-weeks these movement units started to become smoother and resemble those of adults' reaching trajectories. Thus, the movements by 31-weeks were two-phased movements. They consisted of a huge movement outwards towards the object followed by a more precise movement towards the object. Furthermore, the hand begins to decelerate before contact with the object (Clifton, Rochat, Robin, & Berthier, 1994).

In the last two decades, a few researchers (e.g., Lockman, Ashmead, & Bushnell, 1984; von Hofsten & Fazel-Zandy, 1984; von Hofsten & Ronnqvist, 1988; Thelen et. al., 1993) have turned toward examining the kinematics of early reaching in relation to prospective behaviors. For instance, Lockman, Ashmead, and Bushnell, (1984) and von Hofsten and Fazel-Zandy (1984) showed that young infants oriented their hand as a preparatory gesture early in the reach towards the object. When a rod was presented vertically or horizontally, the infant began to orient their hand in the appropriate direction before their hand reached the rod. These adaptations occur even when oriented rods are presented in the dark and infants cannot see their hands or the rod at the moment of contact (McCarty, Clifton, Ashmead, Lee, and Goubet, 2001). These results suggest that infants possess some anticipatory control over their reaches and thus are exhibiting prospective behavior.

Additional research has shown that grasping of the object is prepared before the object is touched. Von Hofsten and Ronnqvist (1988) examined how the size of an object affects the opening of the hand and the timing of the grasp in early reaching, in order to determine if grasping is initiated during the approach (prospective) as opposed to after the object is touched (reflexive). They claimed that a grasp must be adequately timed relative to the encounter with the object and that planning must occur in order for this to take place. They first established an adult criterion by using a motion analysis system to measure differences in apertures (distance between thumb and index finger) during reach movements for different sized spheres. The adults opened their hand more fully during the reach when reaching for a larger object, while the hand started to close at around 79% of the movement. The hand closed earlier for a small target than for a large target.

After establishing that these preparatory actions were observable in adults, the authors tested whether infants also show preparatory actions when for grasping differently sized objects. The question was whether infants start to close their hands in anticipation of the encounter or in response to contact, and if aperture would reflect size of object to be grasped. Using 6-, 9-, and 13-month olds, they measured the time of contact with the target (blocks graded in size) and the time when the distance between the thumb and index finger (aperture) decreased. These measures reflected different sorts of anticipation. The distance between the hand and the target at the time the hand began to close reflected anticipation of grasping an object. Size of aperture reflected anticipation of size of an object, a much more sophisticated skill. As seen in the adult subjects, the grasps of infants in all three age groups anticipated contact with the object before actual contact. For the more sophisticated aperture measure, the 13- and 9-month olds prepared their grasps sooner than the 6-month olds and were more able to anticipate the size of an object such that the aperture before the object was touched was significantly larger for the largest object than for the smallest. The 6-month olds do not adjust the opening of their hand to object size. Although 6-month olds do not make fine aperture adjustments to size of object, they do vary their grips by choosing to grasp larger objects with two hands and smaller objects with one hand (Clifton, Rochat, Litovsky, & Perris, 1991).

To summarize, prospective control is a type of intent where infants anticipate encounters with objects. Looking at the kinematics of early reaching behavior has allowed researchers to better quantify prospective behavior.

C. Defining Intention in Terms of Intentional Means-end Behavior

One of the other types of intention mentioned earlier in the introduction was intentional means-end behavior. Intentional means-end behavior differs from prospective control in that the infant must plan a sequence of two or more movements which involves the complicated task of directing a movement toward a different object in order to eventually reach the desired object. The now classic Piagetian example of measuring intent (the hidden object task) is to cover a toy with a cloth or barrier and observe whether the infant will remove the barrier in order to retrieve the toy. Piaget (1954; 1963) defined intentional behavior by how infants interacted with the objects involved in this task. If the infant manipulated the intermediary object (the barrier) without playing with it, maintained attention to the goal object (the toy), and quickly retrieved it, then the act was intentional. Thus, Piaget defined intention in terms of a future-oriented, goal-directed action that could be demonstrated through successful means-end behavior.

Similarly, Willatts (1999) defined intentional behavior as a behavior in which the movement in a sequence of movements is carried out so that a final goal can be accomplished. In his view, intentional behavior required the ability to complete a means-end task. Willatts stated that "means-ends behavior involves the deliberate and planful execution of a sequence of steps to achieve a goal and occurs in situations where an obstacle preventing achievement of the goal must initially be removed"(651). Thus, Willatts described intentional behavior as a deliberate and planful sequence of actions in order to achieve a goal. This view of intention assumes that the infant is able to plan a sequence of events or to represent a sequence of events before performing them.

Concurrent with the other definitions, Frye used terms relating to planning, goals, and future-oriented actions for a sequence of events. Frye (1990) also defined an act as being intentional if it is composed of a goal and a means or an attempt to achieve that goal. He also referred to the infant as having expectations. Thus, intentions can be seen in specific expectations for the outcome of certain actions.

D. Measuring Intentional Means-end Behavior Using Observational Measures

Studying intentionality through reaching behavior in general has proven to be a difficult endeavor. As Frye (1990) pointed out, whereas self-report can be a measure for assessing behavioral intention in adults, this method will not work with infants who are incapable of self-report. In an attempt to measure intent in infants, some early reaching tasks have used observational measures to determine whether or not infants are reaching intentionally toward an object (Bower, Broughton, Moore, 1970; Field, 1977; Rader & Stern, 1982). These studies provide contradictory results.

For instance, a classic study by Bower, Broughton, Moore (1970) argued that early reaching is a sign of intention in infants. They presented neonates with virtual objects (2-D) and with solid objects (3-D). They hypothesized that if an infant reaches toward a virtual object and nothing is there, they will become frustrated. This frustration would indicate that the reach toward the object was intentional. Frustration was measured by the length of crying time. They found that the neonates not only cried more when reaching toward the virtual objects as opposed to the solid objects, but also that they reached less frequently toward the virtual objects than toward the solid objects. Accordingly, they concluded that early reaching behavior is an intentional behavior.

Other research using early reaching (Field, 1977; Rader & Stern, 1982) failed to replicate Bower, Broughton, and Moore (1970). Field (1977) found that young infants did not show surprise or frustration in the virtual object condition, that the young infant's reaching behavior was no different in the virtual object condition than in the solid object condition. Likewise, Rader and Stern (1982) also found that reaching behavior was elicited as readily by the virtual objects as by the solid objects.

Another way to measure intention in infants using reaching tasks has made use of tasks with a definite end-state (traditional hidden object means-end tasks) (e.g., Piaget, 1954, 1963; Willatts, 1984, 1985; Frye, 1980). For example, Piaget (1954; 1963) assessed intentional behavior in means-end tasks using success and failure measures in addition to happiness/frustration measures. Piaget relied on observational data to decide whether or not the means-end act was intentional. If the infant manipulated the intermediary object without playing with it, maintained attention to the goal object and quickly retrieved it, then the act was intentional. Non-search means-ends tasks such as using supports to retrieve distant objects (Willatts, 1984; 1985) have also been used to measure intentional behavior. The traditional support task consists of a toy placed on a towel/cloth out of reach of the infant. If the infant pulls on the towel in order to achieve the toy, the act is said to be intentional. Willatts had a set of observable criteria to measure the level of intentional behavior in these tasks similar to those used by Piaget. If the infant manipulated the intermediary object without playing with it, maintained attention to the goal object and quickly retrieved it, then the act was intentional.

Another way of looking at means-end behavior is to have a condition in which the infant is presented a means-end task but the toy is not present (Willatts, 1999; McCall & Clifton, 1999). Willatts (1999) claimed that there is a transitional period between 6- to 8-months when the child is able to solve the non-search means-end task but may not be doing so intentionally. Thus, non-intentional behavior transforms into intentional behavior sometime between 6- to 8-months. He proposed that it is more important to look at the method that the infants used to solve the problem instead of looking at whether or not they could solve the problem. Willatts (1999) had two conditions, one in which a toy was present on the cloth and one in which the toy was not present. The 6-month olds behaved about the same whether or not a toy was present. He interpreted this behavior to be transitional instead of intentional, where transitional behavior was defined as having partial intention. Intentional behavior was scored in terms of cloth behavior, fixation on toy, and toy behavior. The 6-month olds appeared to be more directed toward retrieving the cloth rather than the toy. In contrast, the 7- and 8-month olds exhibited more intentional behavior when a toy was present as to compared to no toy. Thus, they removed the cloth without playing with it, they fixated on the toy, and quickly retrieved it.

Frye (1990) performed another variant of the means-ends task to try to better assess intentional behavior. Frye (1990) defined an act as being intentional if it is composed of a goal and a means or an attempt to achieve that goal. Thus, having intentions means having specific expectations for the outcome of certain actions. Frye suggested studying intentionality in infants without using success and failure measures. Instead, he proposed that we manipulate the outcomes and mismatch the means and goals in the classic means-ends tasks in order to measure intention. For instance, in Frye's version of the support task, the cloth was equipped with a hidden pulley system so that the experimenter changed the effect that pulling the cloth had on the toy. The infant was presented with a toy placed on a cloth and allowed to retrieve it three times in a row, as in the normal support task. Then, on the fourth trial, the unexpected event happened. When the infant pulled the cloth towards him/herself, the toy moved away from the infant instead of toward. In a similar condition, the infant was allowed three normal trials followed by an unexpected trial in when the infant pulled the cloth, the toy did not move. There was also a mismatch condition, in which the cloth was removed and the infant was presented a string attached to the toy. If the infant pushed the string toward the toy, then the toy came into reach. Thus, in this last condition, the means and goals were mismatched such that an action such as pushing the string resulted in an unexpected outcome.

Frye observed the infant's level of surprise when an unexpected goal was achieved or when an expected goal was not achieved for 8-, 16-, and 24-month olds. He argued that if an unexpected result occurred or something unexpected happened as the result of a particular action, then the intentional infant should show surprise. The infant's surprise was judged by facial expressions rated by blind observers using a 3-point scale. Mild puzzlement was defined as pausing, slight frowning or sober expression and surprise was defined as widening of the eyes, raised eyebrows, pointing, or exclaiming. Frye argued that surprise demonstrated that the infant knew that a certain means should not result in a certain outcome and thus had been acting intentionally.

Frye concluded that based on ratings of the infant's surprise that he could claim that the older infants (16- and 24-month) were exhibiting surprise in all of the conditions and thus were behaving intentionally. However, Frye could not conclusively conclude whether or not the 8-month olds were acting intentionally using this surprise measure. He claimed that there was partial evidence for intentional behavior in 8-month olds. The 8-month olds showed surprise in the unexpected outcomes conditions, but not were not surprised by the mismatch condition. However, Frye did not provide a clear explanation as to why this might have occurred, other than conjecturing that 8-month olds did not seem to have expectations for the outcome of actions.

E. Problems with Using Means-end Behavior as a Way of Measuring Intention

While the studies discussed above tried to measure intentional behavior by looking at reaching behavior (either reaching for an object or completing a means-end task), there are problems with their measures. The reaching for object studies provide contradictory results which could be due to using observational measures. Likewise, using means-ends behavior as a way to measure intention in infants has proved problematic for a number of reasons. One problem is the danger of assuming that a successfully completed task has been done so intentionally (Frye, 1990; Vedeler, 1987, 1991). In the hidden object task, it is unclear whether the infant was performing one action (removing the barrier) with the intention of performing another action (picking up the toy) or whether the infant picked up the barrier because it was interesting in its own right and then picked up the toy because it "appeared." Consequently, using a "success test" to measure intentionality is problematic because the completed act could have been accomplished by accident or by lucky chances.

Likewise, there is a danger in assuming that failure to complete a task is a mark of unintentionality (Frye, 1990). While an individual may intend for something to happen, he/she may fail to choose the correct means in which to make it happen. Even though the individual failed, it does not mean that they did not intend to complete the task. Therefore, using success or failure guidelines to measure intentionality such as used by Piaget (1954) and Willatts (1984;1985) can be problematic.

Another problem exists with using observational measures such as surprise to measure intention. For example, one possible problem with Frye's (1990) observational measure of surprise is his assumption that all ages are equally good at expressing these emotional levels. It could be that older infants are much better at expressing surprise than younger infants. Accordingly, the younger infants could have still been surprised, but were simply not as adept at displaying their surprise. Thus, this is another instance where relying solely on observational measures can lead to interpretation problems.

Another problem that exists with using observational measures is causal relationships. As we have seen it thus far, intentionality is referred to in terms of goal-directedness in which infants are tested using means-ends tasks. These tasks require an infant to have a goal in mind; a future-oriented, mental representation of a state of affairs which is yet to be realized. Vedeler (1987, 1991) argued that this common definition of intention in terms of goal-directedness is difficult to measure simply through observations. Although a certain end state has been achieved in these means-ends tasks, Vedeler pointed out that it is difficult to know simply from observation, whether or not the end state achieved was done so intentionally and whether the preceding behaviors were actual means to achieving that end state. Vedeler also suggested that the goal directedness definition of intentionality implicitly assumes prior intentions (doing one action in order to achieve some goal) and are thus difficult to validate. Vedeler referred to causal relationships in order to make his point. Causal relationships are those events which can be perceived to look intentional even when they are not. For example, you can observe causal relationships, like a foot hitting a ball. You see the foot move and see a ball roll, but you cannot attribute intentionality to this act with any certainty. The foot could have just stumbled onto the ball. Accordingly, Vedeler made the important point that a "description of causal relationships between behavior and environmental events thus would not suffice to account for the cues used when attributing an intention" (p. 7, 1987).

In order to alleviate this problem, Vedeler suggested that we focus on the infant's behavior as it is directed toward objects and assess this behavior using the infant's behavioral dynamics. Vedeler posited that there should be something in the way that the behavior is deployed, in the way the event is brought about that distinguishes an intentional action from unintentional behavior and that this something might be the kinematics of the behavior. Vedeler suggested that "if behavioral dynamics can be specified by kinematics, the behavioral feature we are looking for might very well be described in terms of kinematic patterns "(p.15, 1987). Whereas Vedeler suggested that kinematics should be used to measure intent, he remained vague about specifying the kinematic pattern and presented no data.

The idea remains that the kinematics of the behavior could be more revealing than describing or measuring the final outcome of the behavior. Accordingly, using the kinematic patterns would get around this problem of causal relationships and provide a more objective and quantifiable means to assess intentionality.

F. Defining Intention in Terms of Movement Intent

While both prospective control, e.g. anticipating encounters with the environment (von Hofsten, 1993) and means-end behavior, e.g. planning a sequence of steps in order to achieve a goal (Piaget, 1954, 1963; Willatts, 1999; Frye, 1990) are valid ways of defining intentional behavior, the current study approaches intentional behavior in a slightly different way. There are a couple of reasons for this different approach. First of all, while intentional behavior can have elements of prospective control, it is more difficult to claim that prospective behavior is intentional. In other words, on the basis of prospective behavior it is difficult to claim that the infant is consciously planning a behavior in advance, has a goal or some sort of representation of the future in mind. Prospective behavior anticipates an encounter with the environment by forming a link between perception and action. Prospective behavior is future-oriented behavior, but it is behavior that could occur without a definite plan in mind. The infant has the visual information in front of him/her, and could just be reacting to the visual stimulus. The aspect of intention that we wish to address relates to having some sort of representation of some future state of events that is not available from immediate visual perception of the object.

Secondly, as already discussed, the means-end tasks used to measure intention rely heavily on observational measures such as surprise, success/failure, and causal relationships by which to infer intentionality. These tasks require adult observers to infer the mental state of infants by relying solely on observational measures. We want to find an alternative way to measure intention that does not depend solely on subjective observational measures. We wish, instead, to be able to develop a better way of quantifying intentional behavior in infants. Therefore, Vedeler's (1987, 1991) findings combined with the success of using kinematic measures of prospective behavior (e.g., von Hofsten and Ronnqvist, 1988) and the adult studies that will be discussed in the next couple of pages, have lead us to believe that the kinematics of reaching would be an excellent measure of intent.

Our approach toward defining intention involves two movements such that what an infant intends to do with an object (for example dropping it onto the floor) affects how the infant picks the object up. In other words, during the infant's movement toward an object, he/she is planning ahead to what he/she is going to do with the object once they pick it up, thus exhibiting intentional behavior. Marteniuk, MacKenzie, Jeannerod, Athenes, and Dugas (1987) referred to this type of intention as movement intent. This definition of intention does not specify whether planning occurs before the movement toward the object starts or during the movement toward the object. Instead, this definition claims that before the infant actually picks up the object, he/she has a plan or an intention toward what to do with that object after it is picked up.

This definition of intention comes in part from the British philosopher, Anscombe (1957) who claimed that "in order to make sense of 'I do P with a view to do Q', we must see how the future state of affairs, Q, is supposed to be a possible later stage in proceedings of which the action, P, is an earlier stage"(p.36). Anscombe claimed that concern with a future state of affairs is an expression of intention. However, this definition must be qualified such that the agent must purposefully and directly bring about the future state of affairs. Therefore, an intentional act is a purposeful attempt to bring about a future state. Reaching for objects satisfies Anscombe's criteria of an intentional act. For example, in reaching for an object, the future state of affairs is grasping the object and then doing something with it (most often bringing it to the mouth in the case of early reaching infants). This future state of affairs is achieved by the infant actually reaching directly in space to the spatial location of the object before proceeding to the second action. This is similar to intentional means-ends behavior in that it requires two stages; however, the sequencing of events is more simple and only involves one object.

In addition, we are thinking of an intentional act in terms of a skilled, goal-directed action, such as reaching, grasping, or dropping. Take for example the intentional act of an infant dropping a toy onto the ground. In order to drop the toy onto the ground, the infant must first reach out for the toy, grasp the toy, and bring the toy to a location above the ground before releasing it. This definition of intention in part comes from Bruner (1970; 1973) who claimed that skilled behavior by its very nature is intentional. A skilled activity has an objective to be achieved. He defined skill as being a smoothly flowing action that results from anticipating what is coming next; the actor has a sense of the current, ongoing action and of what comes next. He defined skilled behaviors in the first year as those that allow the infant to manipulate the world, such as reaching and grasping. Bruner's philosophy was that the hands "both shape and express human instrumental intelligence" (p.247). Bruner proposed that early skilled motor behavior provides insight into human problem solving and thought.

The approach of the current study was to assess intent at a much more basic level than has been seen in the means-ends tasks and at a more complex level than the early reaching tasks discussed above. We are defining intentionality as a special category of goal-directed behavior involving elements of motor preparation to make something happen. That is, an action is undertaken with a subsequent goal in mind, rather than manipulating more than one object, as in the means-ends tasks. We expect to see that infants are acting with intent and that this is reflected into the kinematics of the reaching movements.

G. Using Kinematics to Measure Movement Intent in Adults

Using kinematics to measure movement intent has already been successfully used in adults. This approach has demonstrated that it is possible to use kinematic analyses of reaching speeds in order to measure intent, such that intent is reflected in the motor control of the reaching behavior. For example, Runeson and Frykholm (1981; 1983) demonstrated that visible, body movements can provide insight into the intent of the mover. Runeson and Frykholm (1981) had adult subjects observe videotaped adults lifting varying weights of boxes. Only the lifter's joints were visible as patches of light against a dark background. The observers were then asked to judge the weights of the boxes. Runeson and Frykholm found that by viewing the lifter's joints, the observers were able to judge the weight of the boxes with a good degree of accuracy. Similarly, Runeson and Frykholm (1983) found that even when only viewing the lead-in or approach movements of someone lifting a box, an observer can accurately determine whether the box will be heavy or light. They even found that when a lifter tried to fake whether or not they were reaching for a heavy or a light box that these deceptive movements did not obliterate the kinematic information about the true properties of a person's action. The authors hypothesized that the perceptible kinematics such as seen in postural preadjustments before the lifting act, cue observers into the intent of the lifter; i.e. whether they are preparing to lift up a heavy box or a light box.

These studies support the idea that kinematics (people's movements) provide useful insight into the hidden properties of behavior, such as intent. In many eases, kinematie changes in relation to intentionality are not easy to pereeive, and require the use of motion analysis systems. For instanee, Marteniuk et al. (1987) elaimed that thc intent of what one wishes to do with an object affeets the movement planning and control proeesscs of the initial reach for that object, and ean be measured in the kinematies of the reaehing behavior. Marteniuk et al. (1987) referred to this type of intention as movement intent. In other words, what one is eventually going to do with an object onee it is pieked up affeets the kinematies of the initial reaehing movement towards the objeet. In Marteniuk ct al., univcrsity students reached for a disk placed on a table in front of them, 30 cm away. Before trial onset, subjeets wcre instructed to reaeh for the disk quickly and either throw the disk into a box 15em away (throwing condition) or to fit the disk into a container with a diameter only slightly larger than the disk itself loeated 10-em away (fitting condition). The order of the two eonditions were counterbalanced and the conditions were blocked, so that for each condition, there were five practice trials and five experimental trials.

The kinematics of the reaches were recorded using WATSMART (a motion analysis system based on infrared emitting diodes), with four IREDS attaehed to the participant's right arm. Movement time for the initial reaeh (defined as starting with the first deteetable movement toward the disk and ending with eontaet with the disk), peak spced (thc highcst point on the speed curve), and time to peak speed (providing the aeeelerativc and deeelerative phases of the movement) were calculated. The peak speed was higher in the throwing condition than in the fitting condition. In addition, movement timc toward the object was longer in the fitting condition than in the throwing condition. This differcnce took plaee during the deceleration portion of the reach (amount of time from peak speed to contaet) such that thc deceleration phase was longer in the fitting condition than in thc throwing eondition.

Importantly, the first portion of the two tasks was identical (i.e., reaching out and picking up the disk). Therefore, there is nothing in the demands of the reach toward the object that should cause a difference in reaching speeds. Perceptually, the focus of the initial reach to pick up the disk was identical in both conditions. Thus, it was the goal of the task (either fitting or throwing) which affected the kinematics of the reach to the object. The authors suggested that one possible reason for the lengthening of the deceleration portion in the fitting condition was the task's requirement for precision. Hence, as the precision requirements of the task increased, the greater portion of the reach was spent in the deceleration phase. Thus, the precision demands of the task to be accomplished after the object was picked up affected the kinematics of the approach to the object.

While Marteniuk argued that it was the precision demands of the task that lead to the changes in movement time duration and time spent in deceleration, more recently, Johnson, McCarty, and Clifton (submitted) found instead that the anticipation of a second movement (M2) which required transporting an object to a new location affected the kinematics of the initial reach to the object (M1). Johnson et al. described this influence on the kinematics of the reach as occurring because of context effects. Similar to Marteniuk's movement intent, context effects refer to the idea that in a sequence of reaching movements the first movement is affected by the second movement, because the first movement is influenced by the context of the entire sequence. Thus, Johnson et al. argued that the individual movements that comprise a sequence of movements do not occur in isolation. In other words, they claimed that motor behaviors, in this case reaching specifically, are sensitive to the context in which they occur. In this case, the important context is whether or not an object will be transported to a new location and how this affects the initial reach differently.

Johnson et al. did a series of experiments looking at this phenomenon of how the goals of upcoming actions with an object, affect the kinematics of the initial reach toward the object. In experiment 1 there were two conditions; a grasp and lift condition and a grasp and place condition. In the grasp and lift condition, adult subjects reached for, grasped and lifted a cube vertically above its original location. In the grasp and place condition, adult subjects reach for, grasped and transported a cube to a new location before placing the cube through an opening in a tabletop. Johnson et al. found that the duration of M1 was longer in the grasp and lift condition than in the grasp and place condition. While the other kinematic measures, such as peak velocity and average velocity were not significantly different, the percentage of M1 where the peak velocity occurred was significantly different between the two conditions. Thus, less time was spent decelerating when participants intended to transport the cube to a new location (the grasp and place condition), than when the participants lifted and held the cube at the same location. If the kinematics of the reach were dependent on the physical attributes of the conditions (in both cases participants reached the identical distance for the identical cube) then the kinematics of the reaches should be identical. However, since the kinematics of M1 were not identical, these results suggest that the differences occurred because of what the adult was going to do with the cube once it was picked up; transport it to a new location or not.

In experiment 2, Johnson et al. examined the effects of task precision demands on the kinematics of the initial reach by having a grasp and place "easy" condition (in which the opening was $3.5cm^2$ larger than the cube) and a grasp and place "difficult" condition (in which the opening was $0.5cm^2$ larger than the cube). They found that task precision demands had no effect on M1's duration time or on the kinematic measures for the two conditions. Thus, unlike Marteniuk et al., who argued that the differing kinematics were due to the precision demands of the task, Johnson et al. argued that the differences they found were due to whether or not an object was transported to a new location.

Johnson et al. theorized that the duration and decelerative portion of M1 were shorter in the transportation condition because the goal of the task was highly specific (transport object to a specific new location) which led to less time spent in deceleration and consequently to a shorter duration. Conversely, in the non-transportation condition, the goal of the task was less specific and therefore the movements are more difficult to plan in advance. They suggested that this minimizing of goal specificity is what leads to more time spent decelerating and consequently to a longer duration. More broadly, they argued that context effects influence the kinematics of reaching.

CHAPTER 2

STUDY DESIGN

We propose to use the kinematic methodology to see if these context effects occur in the motor behavior of infants as well. That is, does what the infants intend to do with the object after they pick it up (movement intent) influence the kinematics of their initial reach for the object? Just as Marteniuk et al. (1987) and Johnson et al. (submitted) were able to show that movement intent/ context effects are reflected in the motor behavior of adults, we hope to show that the same is true in the motor behavior of infants. To accomplish this, we modeled our procedures after Marteniuk et al. (1987) and Johnson et al. (submitted), using 10.5 month olds as our subjects and a 4.5cm diameter ball as our object.

We had three conditions: a holding condition, a throwing condition, and a fitting condition. The hold condition allowed the infant to reach for the ball and explore it. This condition allowed us to measure the kinematics of the approach phase when there was no particular or consistent planned second movement that followed the first movement. The two conditions succeeding the hold condition (the throwing condition and the fitting condition) were counterbalanced across subjects. We were unable to counterbalance all three conditions, because once we demonstrated a specific planned second movement for the ball (i.e. throwing or fitting) we felt that infants might not be satisfied just picking up the ball. When infants did simply grasp and hold the ball in later trials, these were counted as "hold" trials.

In the throwing condition, the experimenter first demonstrated throwing or dropping the ball onto the floor or into a plastic tub several times. The ball was then presented to the infant and the experimenter encouraged the infant to reach for the ball and throw or drop it on the floor. Dropping and throwing behavior starts occurring around 9 to 10 months (Bayley, 1969). For example, the infant might be sitting in a highchair with a toy in hand and drop or throw it onto the floor. Once the toy has been retrieved by the parent and handed back, the infant will drop it again. This dropping behavior appears to be an intentional act because it is repeated over and over. Thus, we thought that this dropping behavior would be an activity that the infants had some familiarity with and would be eager and interested in participating.

In the fitting condition, the experimenter demonstrated fitting the ball into the opening of an opaque cylinder where it rolled through and came out the other end. The action was repeated by the experimenter several times, and then the infant was presented with the ball and encouraged to reach for the ball in order to repeat this fitting action. This task is based on a Gesell and Amatruda scales item (1974) in which the infant must pick up a cube and release it into a cup. In our version of the task, a cylinder was presented to the infant, and he/she was encouraged to place a ball in the mouth of the cylinder, so that it would fall through and come out the other end. We used a cylinder instead of a cup, so that unlike the cup, the infant would not be able to put his/her hand down the cylinder and reclaim the ball. In addition, the mouth of the cylinder was only wide enough for the ball to go through. To be successful, the infant had to release the ball at the cylinder's mouth.

In order to have an adult measure by which to base the kinematics of these reaching behaviors, we also ran 10 adult subjects in a modified version of the above procedures. The adults performed 3 different actions (fitting, throwing, and holding) with three differently sized objects (a disk, a small ball, and a large ball), resulting in a total of 9 conditions, whose order were counterbalanced across participants. There were a couple of reasons why we choose to use 3 different sized objects for the adults. First of all, we wanted to have an object condition which would replicate Marteniuk et al.(1987). Thus, one of our objects was a disk that was the same size as used in Marteniuk et al. Secondly, we wanted to have an object condition that would be the same as the object we would use in our infant study. Thus, the small ball was the same size as that used in the infant version of this study. Lastly, we wanted to see if hand to object size ratio would make a difference in the kinematics for these three actions. Since the small ball filled the hand of the infant, we used a large ball for our third object that filled the hand of the adult subjects.

The fitting and throwing procedures were similar to those of Marteniuk et al.(1987), in which the adult started at a designated position on a table, reached forward, grasped the object and then placed it through a hole in the table to the left of the original location of the object, or grasped the object and then threw it into a bucket placed on the floor to the left of the original location of the object. The holding condition procedures were similar to those of Johnson et al. (submitted), in which the adult started at a designated position on a table, reached forward, grasped the object and then picked it straight up into the air, holding it for a couple of seconds. In order to make our adult reaching more comparable to infant reaching, we asked participants to reach at a natural and comfortable reaching speed. This instruction was unlike those given by Marteniuk et al. and Johnson et al., who instructed their participants to reach at a rapid speed.

The three action conditions (fitting, throwing, and holding) allowed us to use both the Marteniuk et al.'s findings and Johnson et al.'s findings with adults and compare the kinematics of the movements across ages. As in Marteniuk et al. (1987), we had a throwing/ dropping condition and a fitting condition to allow us to look at whether precision demands affected reaching kinematics in infants. The releasing portion of the throwing task did not require much precision, whereas the releasing portion of the fitting task did. Based upon Martineuk's findings, we predicted that the intent of either throwing/dropping the ball onto the floor or fitting it precisely in the mouth of a cylinder would cause differences in the approach speed toward the ball as it had with adults. In addition, as in Marteniuk et al.(1987), we expected to find a longer deceleration phase in the approach toward the ball for the fitting condition than for the throwing condition for both the infant and adult subjects. A lengthening of the deceleration phase of the reach toward the object when a precision movement will follow grasping would indicate that intent is reflected into the motor control of reaching behavior in 10.5-month old infants. Thus, we would be able to conclude prior intentionality, such that at some point before the infant grasped the ball, they had already planned their next movement with it.

In addition, as in Johnson et al. (submitted), we had a no-second action condition (our hold condition) and a second action condition (our fitting or our throwing conditions), to see whether a second action, in which an object was transported to a new location affected reaching kinematics in infants. We expected to see a difference in speed between the single action condition and the other two conditions in both the infants and the adults. As was found in Johnson et. al.(submitted), we expected that when a second movement is not planned (i.e., the infant just picks up and holds the ball), that the approach speed would be slower than in the other conditions which involved a planned second movement (fitting or throwing).

Thus, these results would indicate not only that 10.5-month old infants possess behavioral intent in their interactions with external objects, but also that measuring kinematics of reaching can provide us with a new method of measuring intent in infants of various ages. We predicted that 10.5-month olds do possess intent in that they have the ability to plan a sequence of actions in advance and that this movement intent can be measured using kinematics. If, however, no kinematic differences among the three conditions occurred, we would be unable to conclude anything about intentionality. We would encounter the same problems presented by Frye (1990) and Vedeler (1987, 1991) regarding issues such as success at the endpoint does not indicate intent, as well as causal relationships do not indicate intent. We assume that kinematics are more revealing than the final outcomes of behavior. In addition to observing the infants perform the appropriate actions, we hoped to find something different in the kinematics of the approach that would allow us to claim that the act was intentional.

CHAPTER 3

METHODS

A. Participants

Thirty 10.5-month old infants participated in the study. Of these 30 infants, 5 were excluded because of fussiness and not wanting to complete the tasks, 1 was excluded because he/she would not wear the IREDs, and 3 were excluded because there was not enough kinematic data on their reaches, leaving 21 infants (15 males, 6 females, mean age = 10 months, 2 weeks; range = 9 months, 1 week to 11 months). The names of the infants were obtained through the Massachusetts state birth records. The parents were first contacted by an informational letter describing the study, followed by a phone call to see if they were interested in participating. The infant received a t-shirt with our lab's logo and a certificate at the end of the session as compensation for participation.

In addition, 10 right-handed University of Massachusetts at Amherst graduate students participated in an adult version of the study. One participant was excluded due to experimenter error leaving 9 total participants (2 males; 7 females). Participation was voluntary.

B. Materials

For the infant version of the tasks, the infant was securely seated in a booster seat or a highchair (without the table attached) opposite the experimenter. Stimuli consisted of 4.5cm diameter balls, a clear tube (5cm diameter) with openings on both ends, and a plastic tub (30cm by 13cm by 2.7cm). The clear tube was used for the fitting trials and the plastic tub was used for the throwing trials.

For the adult version of the tasks, adults were seated at a square card table. Stimuli consisted of three different sized objects; a 4cm diameter by 1cm disk, a 4.5cm diameter ball (small ball), and a 7cm diameter ball (large ball). For each trial, the object was placed 30cm medially from a designated starting point at the edge of the table. Appropriate sized holes (4.1cm wide hole for the disk trials, 4.6cm wide hole for the small ball trials, and 7.1cm wide hole for the large ball trials) were placed 30cm medially and 10cm left from a designated starting point at the edge of the table. A plastic tub (30cm by 13cm by 2.7cm) was placed 30cm medially and 15cm left from a designated starting point. This placed the tub on the floor next to the table. (see Figure 1)

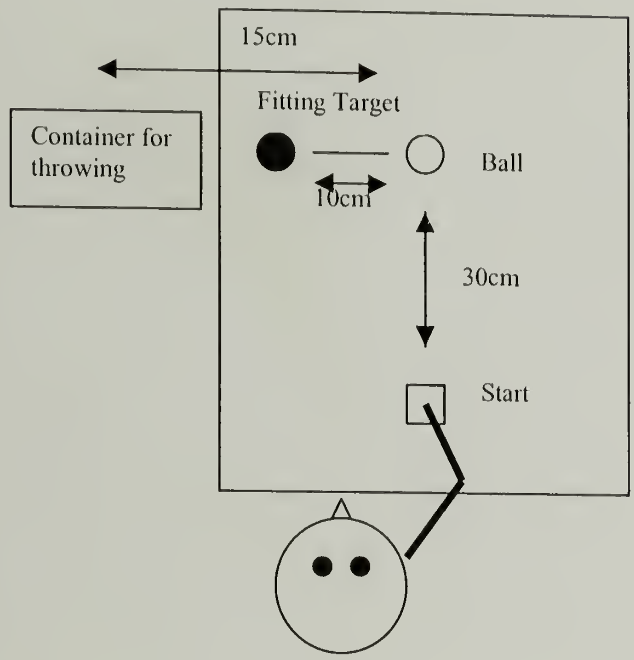

Figure 1. Schematic of adult study apparatus.

Kinematic measures were obtained from an Optotrak motion analysis system (Northern Digital). Two infrared emitting diodes (IREDs) were placed on the back of each of the infant's hands, one on the radial and one on the ulnar side. Two IREDs on each hand were used in case one went out of sight during hand rotation. For the adult subjects 2 IREDs were placed on only the right hand; one was positioned between the 2nd and 3rd knuckles and one was positioned slightly above the wrist. Three banks of three infrared cameras each, placed above, to the right, and to the left of the participants, estimated the location of the IREDs in

3D space throughout the trials. Data was collected at a rate of 100Hz for both the infants and the adults, for a duration of 15 seconds and 5 seconds for each trial, respectively.

A side view of reaching behavior for both the infants and the adults was recorded using a digital camera (Sony model#: DCR-TRV510). A red light, visible on the digital recording indicated when the motion analysis system was recording data. This red light allowed us to coordinate the two data sets (behavioral and kinematic).

C. Procedure

For the infant version of the task, the infant was placed in a booster seat or highchair with the parent sitting to the side and slightly behind the infant. Occasionally, the infant would be placed in the parent's lap if he/she did not want to sit in the highchair. One experimenter entertained the infant with toys while a second experimenter attached the four IREDs with micropore tape to the back of the infant's hands. During the testing session, the primary experimenter sat in a chair directly across from the infant.

A secondary experimenter and the equipment to run the session were positioned behind a curtain in a corner of the room. The role of this experimenter was to watch the video monitor and Optotrak monitor, and trigger the Optotrak to begin recording at the start of each trial. The start of the trial occurred when the primary experimenter positioned the ball within reach of the infant. The secondary experimenter was also responsible for making sure that 15 seconds elapsed before the next trial began.

There were three conditions: a hold condition, a throw condition, and a fit condition. Each infant was given the opportunity to participate in all three conditions, with each infant being giving the hold condition first, followed by either throwing-fitting or fitting-throwing, which were blocked and counterbalanced across participants. In the hold condition, the experimenter held the ball at midline in front of the infant within an easy reaching distance. The experimenter encouraged the infant to reach for the ball. The infant was allowed to reach for the ball and explore it haptically for the duration of the trial. The experimenter gently took it away, and then after a couple of seconds presented the ball to the infant again. This continued for 6 trials.

Next, the infant was assigned to either the throw first condition or the fit first condition. In the throwing condition, the experimenter first demonstrated the throwing action. In the demonstration, the experimenter held the ball, got the infant's attention, and then with much gusto threw the ball onto the floor or into a plastic tub. After a few demonstrations of the throwing action, the experimenter held the ball at midline in front of the infant and encouraged him/her to reach for the ball and to repeat the throwing action. Demonstrations were repeated as needed. The ball was presented at least 8 times or until the infant would no longer reach for the ball or perform the appropriate throwing action.

In the fitting condition, the experimenter first demonstrated the fitting action. In the demonstration, the experimenter held the ball, got the infant's attention, and with the clear tube in one hand, released the ball into it and caught it with much delight when it emerged from the other end. After a few demonstrations of the fitting action, the experimenter held the ball at midline (within easy reaching distance) and the tube (out of reaching distance) in front of the infant. After the infant grasped the ball, the tube was quickly moved into reach, so that the infant could fit the ball down it. Demonstrations were repeated as needed. The ball was presented at least 8 times or until the infant would no longer reach for the ball or perform the appropriate fitting action.

A modified version of this procedure was used with the adult participants. The same basic procedure was used as in Marteniuk et al. (1987), but with more actions and objects. Adults performed 3 different actions (holding, fitting, throwing) using 3 different sized/ shaped objects (a disk, a small ball, and a large ball), resulting in 9 different conditions. Each adult participated in all 9 conditions, which were counterbalanced to control for order effects. In addition, whereas Marteniuk et al. had the adults reach as quickly as they could for the object, we had our adult participants reach at a natural reaching speed which we thought would be more comparable to the infants' reaching behavior.

Each of the 9 conditions was blocked into groups of 10 trials each. Participants performed the 3 different actions on all 3 objects, using different grips depending on the object. For the disk trials, participants were instructed to use a pincer grip (thumb and index finger), the grip used in the Marteniuk et al. study. For the small ball trials, participants used a fingertip grip. For the large ball trials, participants used a palmer grasp as the infants did. For the holding trials, participants were instructed to reach for the object (30cm in front of them), pick it straight up into the air and hold it for a couple of seconds. For the fitting trials, participants were instructed to reach for the object, pick it up and fit it into a hole (10cm to the left of the object) and then return to the starting point. For the throwing trials, participants were instructed to reach for the object, pick it up, and throw it into a bucket placed on the floor (15cm to left of the object) and then to return to the starting point. The fitting and holding tasks were similar to Johnson et al. (submitted), and the fitting and throwing tasks were similar to Marteniuk et al. (1987).

D. Data Scoring

For the infants, behavioral scoring of all of the trials was done by viewing the digital tapes by a primary observer. In addition, half of the infants were also scored by a secondary observer in order to ensure reliability. Each trial was scored by viewing the digital tape to determine whether a reach had occurred and which hand was used to grasp the ball, the hand used to perform any subsequent action, and what that action was. The observers also had to determine whether the reach started before or after the Optotrak started recording. Those reaches that were not fully recorded by the Optotrak were excluded from the kinematic analyses. When a trial contained multiple reaches, all reaches were scored. Reach onset was defined as the first continuous forward movement toward the ball that did not reverse or stop and resulted in contact with the ball. Grasp time was defined as the time of contact, when the fingers started to curl around the ball. The start and end times were used with the Optotrak data to demarcate beginnings and endings of kinematic data for a reach. In order for the reach to result in a successfully completed action, the hand used to grasp the ball and the hand used to perform the action had to be the same. Thus, if the infant reached and grasped the ball with the left hand and then transferred it to the right hand for fitting/throwing, this trial was excluded.

The observers coded for 3 main infant behaviors: fitting, throwing, and holding. Fitting was defined as releasing the ball down the tube. In addition, a subcategory of fitting was used, because the infants did not always release the ball down the tube, but simply held the ball at the opening. This subcategory, called tube, was defined as the infant bringing the ball to the opening of the tube but not actually releasing the ball into the tube. Throwing was defined as releasing the ball by opening up the fingers and first moving the hand slightly upwards and then downwards before releasing. In addition, a subcategory of throwing was used, dropping, because the infants did not consistently vigorously throw the ball, but often simply released it. Thus, the term dropping was used to describe behavior in which the infant held the ball over the floor and simply released it by opening up the fingers around the ball. Holding was defined as holding the ball in hand for 3 to 4+ consecutive seconds. Any other action, such as placing ball in mouth, were described according to a list of coding guidelines. See Appendix A for complete coding guidelines and typical protocol sheet for scoring videotaped behavior.

A secondary observer scored one-half of the infants in order to calculate reliability for the reach onset time, grasp time, and action type. The two observers had 90% agreement within 0.1 sec in judging the moment of reach onset and 92% agreement within 0.1 sec in judging grasp time. The two observers had 97% agreement in judging action type.

For the adults subjects, reach onset and grasp times were determined by looking at the Optotrak data using the same procedure used in Johnson, McCarty, and Clifton (submitted).

Reach onset was defined as the point at which hand speed first exceeded and remained greater than 50mm/sec for a minimum of 350msec. Grasp time was determined by locating the point of minimal hand speed within a 700msec window. The validity of these 2 measures was checked manually and the extreme trials were eliminated. (1.0% of the trials were eliminated.) The reach distance also needed to be around 30cm for reaches to be included in data analyses.

E. Kinematic Data Analysis

For the infants, the reach onset and grasp times observed via the digital tapes were used in conjuction with the Optotrak data in order to obtain kinematic measures of the reach. Table 1 displays the number of trials and reaches in each condition, including a breakdown of reasons for excluded trials for the infants. Although an attempt was made to have the infants participate in 6 trials of holding and 8 trials each of fitting and throwing, we also needed to be flexible as to which tasks the infants were interested in and to the action that the infant chose to perform with the ball. In order to be included in any analysis, each infant had to contribute at least one Optotrak trial to 2 out of the 3 actions. As discussed in the data scoring section, for each trial, the observer recorded what action the infant actually performed as opposed to the action that the infant was "supposed" to perform, i.e., what the trial indicated. Thus, in trials in which the infants did something different such as choosing to hold the ball instead of fitting the ball down the tube for the fitting trial, then this trial would be considered a holding trial as opposed to a fitting trial for the kinematic analyses.

In Table 1 we can see the total number of trials that the infants held, fit, and threw the ball. In some instances, the infant would not reach for the ball at all. Those instances are listed under No Reach for Ball. In some instances, when the infant reached for the ball, he/she switched the hand that the ball was in before actually performing an action. Since our hypotheses are based on the idea that the reach for the object is affected by the next movement the child will make with that object, we can tell nothing relevant to our study when the infant switches the ball to the other hand before performing the action. Thus, we excluded those trials from analyses.

Table 1

Trials Analyzed and Excluded by Condition for Twenty-one Infants

Breakdown of trials and reaches	Holding	Fitting	Throwing
Total # of Trials	238	253	204
No Reach for Ball	7	40	38
Reached and Switched Hands	54	25	28
Ball to the Mouth	64	NA	NA
Reaches Missing IREDs	63	89	87
Reaches eliminated for criterion of 1 to 6 trials for each action	3	32	4
Total OPTOTRAK reaches analyzed for kinematic measures	**47**	**67**	**47**

Reaches that were missing more than 33 frames (=1/3 sec) of consecutive Optotrak data points were excluded from these analyses (denoted as reaches missing IREDs in Table 1). For reaches missing fewer than 33 frames of consecutive data points, a linear spline was used to fill in the missing data points. These reaches were then included in all subsequent measures. Missing data points in the reaches could have resulted from the IREDs being obscured by the highchair or the parent, or by the hand rotating the IREDs out of view of the cameras.

Some infants particularly enjoyed a certain activity and engaged in a large number of reaches in that condition. In order to prevent these participants from contributing an overwhelming amount of data to a category, we used a 1 to 6 trial criterion for each infant for each action. The use of this criterion meant that for each infant, he/she contributed 1 to 6 Optotrak trials to at least 2 out of the 3 conditions. For those infants who had more than 6 Optotrak trials that they could contribute to each condition, only the first 6 Optotrak trials for each condition for that infant were used in the analyses. Appendix B provides a breakdown of what each individual infant contributed in terms of actions performed and those trials that had usable Optotrak data.

For both the infants and the adults, several kinematic measures were computed. Reach onset times and grasp times were used to isolate the portions of the Optotrak data that were relevant for each reach. The velocity of the hand (mm/sec) was computed from the hand position files collected from the Optotrak starting with data at the onset of the reach and ending at contact with the ball. From these velocity profiles of the hand during the reach for the object, the average speed and the peak speed (the highest speed achieved during the reach) for each reach was calculated. In addition, percent peak was determined as the percentage of total duration of the reach where the peak speed occurred. Additional measures allowed us to look at the acceleration and deceleration portions of the reach. For instance, onset to peak was a duration measure for the amount of time spent from reach onset to the point at which peak speed was achieved. We considered this to be the overall acceleration portion of the reach. In addition, peak to grasp was a duration measure for the amount of time spent from the point in the reach where the peak speed was achieved to the grasping of the object. We considered this to be the overall deceleration portion of the reach. In all of these analyses we ignored the smaller peaks that occurred throughout the reaching profile.

We also used 3 different distance measures to calculate the distance which was traveled as well as the overall straightness of the reaching motion: distance traveled, straight line distance, and ratio distance. Overall distance traveled is a measure that combines both the forward distance traveled with the up-down distance traveled in order to determine the amount of distance traveled in 3D space. Straight-line distance was computed by subtracting the location in 2D space where the reach started from the 2D location where the object was grasped, and thus the distance between then object and the starting point of the hand. The ratio distance is a measure of how straight the reach was, with a 1.0 being a perfectly straight reach. This measure was calculated by dividing the distance traveled by the straight-line distance.

CHAPTER 4

RESULTS

The goal of this study was to determine whether intentional reaching behavior in infants can be measured using kinematics. Thus, we used two adult studies which measured intentional reaching behavior in adults as the basis for our study design and our hypothesized outcomes. We had two primary questions of interest. First, we wanted to compare the kinematics of the reach toward the object for those reaches which resulted in a fit and those reaches that resulted in a throw as was done with adults in Marteniuk et al. (1987). Secondly, we wanted to compare the kinematics of the reach toward the object for reaches which resulted in a hold (no second action) and those reaches that resulted in either a fit or a throw (second action) as was done with adults in Johnson et al. (submitted). Thus, we had two additional comparisons, a hold-fit comparison and a hold-throw comparison. The three primary dependent measures of interest for these questions of interest were reach duration time, (time from reach onset to contact with the object), peak-to-grasp time (the decelerative portion of the reach between peak speed and grasping the object) and speed of the reach. These were the three measures predicted to be statistically different for our fit-throw comparison and our hold-fit and hold-throw comparisons as was shown in Marteniuk et al. and Johnson et al respectively. Several additional kinematic parameters were analyzed for the reach to the ball, such as time from onset to peak, as well as 3 distance measures (straight-line distance, distance traveled, and ratio distance). These additional parameters provided us with a more complete picture of the reach kinematics for the three comparisons.

The data we used in our kinematic analyses fulfilled certain criteria discussed previously in the methods section, namely that only 1 to 6 trials for each infant for each condition were included in the preliminary analyses. Also, in order to be included in the analyses in general, each infant had to contribute at least 1 trial each to 2 out of the 3 conditions (fitting, throwing, or holding). Thus, out of the number of original participants (30 infants), 21 infants met these criteria.

The first analysis was essential to determining which specific actions to include in our analyses. As discussed previously in the methods section, actions which the infants performed with the ball fell into 3 main categories: fitting, throwing, and holding, as well as into two subcategories: tube (when the infant placed the ball at the opening of the tube but did not release it) and drop (when the infant simply released the ball by opening up the fingers enclosing the ball as opposed to a vigorous throwing motion). We wanted to determine whether or not these subcategories, tube and drop, were significantly different from fitting and throwing, respectively. We wanted to determine if we should analyze these actions of tube and drop separately, or if we could include them in the fitting and throwing conditions for the remainder of our analyses.

Using independent samples t-tests, we compared the kinematics of fitting and tube, and of throwing and drop. For these comparisons, all of the trials were included, such that each infant contributed all available trials to the analyses and all 21 infants were included. There were no significant differences between the fitting and tube conditions (see Table 2) or between the throwing and drop conditions (see Table 3). Thus, as there were no significant differences between the fit and tube trials, or the throw and drop trials, we decided to combine them, respectively. Accordingly, for the subsequent analyses, the fitting condition is a combination of fit and tube trials and the throwing condition is a combination of throw and drop trials.

Our preliminary analyses consisted of paired t-tests in which each infant contributed mean values for each appropriate condition, with the mean being calculated from up to 3 trials for that condition from each infant. Thus, for example, subject 4, contributed one mean for each kinematic measure to the hold condition, to the fit condition, and so forth. In our preliminary analyses we also only included those infants who contributed data to both

Table 2

Comparison of the Infant Fit and Tube Actions

	Fit (n=56)	Tube (n=11)	t	df	p
Duration (msec)	755.00 (274)	735.55 (140)	0.240	65	>0.05
Peak Speed (mm/s)	387.36 (141)	408.60 (112)	-0.471	65	>0.05
Percent Peak (%)	47.42 (28)	51.40 (29)	-0.427	65	>0.05
Average Speed (mm/s)	214.46 (78)	219.35 (74)	-0.191	65	>0.05
Onset to Peak (msec)	371.98 (267)	389.17 (265)	-0.195	65	>0.05
Peak to Grasp (msec)	383.02 (241)	345.38 (223)	0.480	65	>0.05
Ratio Dist. (mm)	1.41 (0.58)	1.66 (0.66)	-1.249	65	>0.05
Straight-line Distance (mm)	116.38 (49)	103.35 (37)	0.830	65	>0.05
Distance Traveled (mm)	155.20 (61)	158.86 (47)	-0.189	65	>0.05

Table 3

Comparison of the Infant Throw and Drop Actions

	Throw (n=22)	Drop (n=25)	t	df	p
Duration (msec)	854.55 (369)	1034.4 (528)	-1.335	45	>0.05
Peak Speed (mm/s)	551.24 (229)	504.35 (321)	0.569	45	>0.05
Percent Peak (%)	44.26 (27)	43.64 (26)	0.079	45	>0.05
Average Speed (mm/s)	282.49 (106)	243.96 (117)	1.178	45	>0.05
Onset to Peak (msec)	344.54 (195)	432.06 (363)	-1.009	45	>0.05
Peak to Grasp (msec)	510.01 (407)	602.34 (455)	-0.729	45	>0.05
Ratio Dist. (mm)	1.60 (0.42)	1.54 (0.60)	0.379	45	>0.05
Straight-line Distance (mm)	143.75 (44)	151.42 (68)	-0.452	45	>0.05
Distance Traveled (mm)	222.01 (72)	220.01 (99)	0.078	45	>0.05

conditions being compared, thus we had a n of 12 for the fit-throw comparison and the hold-throw comparison and a n of 15 for the hold-fit comparison, out of a total possible of 18 fits, 15 throws, and 18 holds.

We noticed in doing preliminary analyses on the three different comparisons of fit-throw, hold-throw, and hold-fit, that distance varied significantly with condition. Although we were not interested in distance as a variable, distance can affect speed, duration, and the peak-to-grasp measure, which was of primary interest. For the hold-fit comparison $t(14) = 2.971$, $p < 0.05$, such that the straight-line distance in the hold condition (M = 152mm, SD = 47) was significantly longer than in the fit condition (M = 112, SD = 41). While the hold-throw comparison, $t(11) = 0.627$, $p>0.05$, and the fit-throw comparison $t(11) = 1.842$, $p >0.05$, straight-line distances were not statistically different, both the small degrees of freedom in addition to the variableness of the data, led us to the decision that the straight-line distance needed to be statistically controlled for in all three comparisons (hold-throw means: hold M = 143, SD = 32, throw M = 136, SD = 38; fit-throw means: fit M = 111, SD = 46, throw M = 138, SD = 43). Thus, because of the confound in the data, we decided to statistically control for distance as a covariate in a repeated-measures ANCOVA design in all of the analyses below.

A. Comparing Fitting vs. Throwing for Infants

One of our primary questions of interest was to compare the kinematics for the fitting and throwing conditions to see if task precision demands affected kinematics as had been shown by the Marteniuk et al. adults. In order to analyze these data we used a repeated measures ANCOVA with straight-line distance as the covariate[1]. Whereas our preliminary

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[1] We used multiple regression analyses because of the unbalanced nature of the data as suggested by Neter and Wasserman (1974; Applied Linear Stochastic Models, Homewood, Illinois: Richard D. Irwin, Inc.) and Bogartz (1994; An introduction to the analysis of variance. Westport, Ct.: Praeger.). BMDP program 3V (BMDP Statistical Software, Inc) provided restricted maximum likelihood estimates of the regression parameters and F-tests were generated from the estimated parameters and their covariance

analyses used a paired t-test means procedure, we choose to use an unbalanced repeated measures ANCOVA design in order to have a more powerful statistical analysis which included more of our data. Thus, data from all 21 infants contributed to the analysis, with each infant contributing up to 3 trials. Each infant contributed data to either the fit condition, or the throw condition, or to both. Thus, 40 out of 67 fit trials and 34 out of 47 throw trials were included in the analyses. The means and standard deviations for fitting and throwing, as well as the statistics are provided in Table 4.

Unlike Marteniuk's adults, for duration time and the peak to grasp portion of the reach, we found no significant difference between fitting and throwing. However, for peak speed, our infants matched Marteniuk's adults such that there was a significant difference in peak speed for throwing and fitting; $F(1, 67) = 4.69$, $p<0.05$. The peak speed for throwing (M = 527mm/sec, SD = 315) was faster than the peak speed for fitting (M = 394mm/sec, SD = 135). In addition, we found a significant difference between the average speeds for the fitting and throwing reaches; $F(1, 67) = 4.89$, $p<0.05$. Thus, the average speed for throwing (M = 253mm/sec, SD = 113) was faster than the average speed for fitting (M = 201mm/sec, SD = 70). The distance traveled was also significant, $F(1, 67) = 5.32$, $p<0.05$. Thus, the path that the hand traveled through space was longer in the throw condition (M = 226mm, SD = 95) than in the fitting condition (M = 155, SD = 60). Thus, our infants reached significantly faster when they were going to reach for a ball and throw it than when they were going to reach for a ball and fit it down a tube (see Figure 2).

B. Comparing Second Action vs. No-second Action for Infants

In order to analyze these data we used a repeated measures ANCOVA with straight-line distance as the covariate. Data from all 21 infants contributed to the analysis, with each infant contributing up to 3 trials to the hold condition and/or to the fit/throw conditions. Thus,

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matrix. In this case, the error degrees of freedom are the difference between the total degrees of freedom and the number of parameters that are estimated.

40 out of 47 hold trials, 40 out of 67 fit trials, and 34 out of 47 throw trials were included in the analysis.

Figure 2. Speed comparisons for fit and throw.

Table 4

ANCOVA (Co-Varying Straight-Line Distance) for the Infant Fit-Throw Comparisons

	Fit (n=40)	Throw (n=34)	F	df	p
Duration (msec)	**788 (253)**	**1001 (473)**	**2.20**	**1, 67**	**n.s.**
Peak Speed (mm/s)	394 (135)	527 (315)	4.69	1, 67	0.034
% Peak	51 (29)	44 (28)	0.53	1, 67	n.s.
Ave. Speed (mm/s)	201 (70)	253 (113)	4.89	1, 67	0.030
Onset to Peak (msec)	410 (275)	421 (337)	0.01	1, 67	n.s.
Peak to Grasp (msec)	378 (257)	580 (426)	2.08	1, 67	n.s.
Distance Traveled (mm)	155 (60)	226 (95)	5.32	1, 67	0.024
Straight Line Distance (mm)	109 (47)	146 (60)			
Ratio Distance	1.5 (0.7)	1.6 (0.6)	1.75	1, 67	n.s.

We wanted to determine whether or not there were any differences in the kinematic measures for duration, deceleration time, and percent peak speed between the second action (a fit or a throw) and the no-second action conditions (a hold) as had been found for adults in Johnson et al. The means and standard deviations as well as the statistics for the various kinematic measures are provided in Table 5 for the hold-fit comparison and in Table 6 for the hold-throw comparison. For duration time, there was a marginal difference between hold-fit ($F(1, 75) = 3.81$, $p=0.054$) and a marginal difference between hold-throw ($F(1, 75) = 3.74$). Thus, as in Johnson et al., the reach duration that preceded holding the ball (M = 1107msec, SD =692) was longer than when it preceded a fit action (M = 788msec, SD = 253) or a throw action (M = 1001msec, SD = 473). However, there was no significant difference for the deceleration measure or the percent peak speed for either comparison. However, there was a significant difference not predicted by Johnson et al. The peak speed for the hold-throw comparison was significant, $F(1, 64) = 5.30$, $p<0.05$, such that the peak speed for the throw condition (M = 527mm/s, SD = 315) was faster than in the hold condition (M = 448mm/s, SD = 200). This difference was true for the hold-throw comparison, but not for the hold-fit comparison. Lastly, the distance traveled for the hold-fit comparison was significant, $F(1, 75) = 6.23$, such that the distance the hand traveled in space was farther in the hold condition (M = 218mm, SD = 72) than in the fit condition (M = 155, SD = 60).

Thus, the duration time of the initial reach was longer for when there was no second action (hold condition) than when there was a second action (fit or throw) as was found with adults in Johnson et al (see Figure 3). However, the difference in peak to grasp (while in the right direction) and in percent peak found in Johnson et al. adults were not found in our infants.

Table 5

ANCOVA (with Straight-Line Distance as Covariate) for the Hold-Fit Comparisons

	Hold (n=40)	Fit (n=40)	F	df	p
Duration (msec)	1107 (692)	788 (253)	3.81	1, 75	0.054
Peak Speed (mm/s)	448 (200)	394 (135)	0.12	1, 75	n.s.
% Peak	44 (26)	51 (29)	0.02	1, 75	n.s.
Ave. Speed (mm/s)	242 (127)	201 (70)	0.30	1, 75	n.s.
Onset to Peak (msec)	471 (416)	410 (275)	1.45	1, 75	n.s.
Peak to Grasp (msec)	636 (563)	378 (257)	1.63	1, 75	n.s.
Distance Traveled (mm)	218 (72)	155 (60)	6.23	1, 75	0.015
Straight Line Distance (mm)	150 (51)	109 (47)			
Ratio Distance	1.5 (0.3)	1.5 (0.7)	1.97	1, 75	n.s.

Table 6

ANCOVA (with Straight-Line Distance as Covariate) for the Hold-Throw Comparisons

	Hold (n=40)	Throw (n=34)	F	df	p
Duration (msec)	1107 (692)	1001 (473)	3.74	1, 64	0.057
Peak Speed (mm/s)	448 (200)	527 (315)	5.30	1, 64	0.025
% Peak	44 (26)	44 (28)	0.26	1, 64	n.s.
Ave. Speed (mm/s)	242 (127)	253 (113)	3.04	1, 64	n.s.
Onset to Peak (msec)	471 (416)	421 (337)	0.52	1, 64	n.s.
Peak to Grasp (msec)	636 (563)	580 (426)	2.98	1, 64	n.s.
Distance Traveled (mm)	218 (72)	226 (95)	1.38	1, 64	n.s.
Straight Line Distance (mm)	150 (51)	146 (60)			
Ratio Distance	1.5 (0.3)	1.6 (0.6)	1.40	1, 64	n.s.

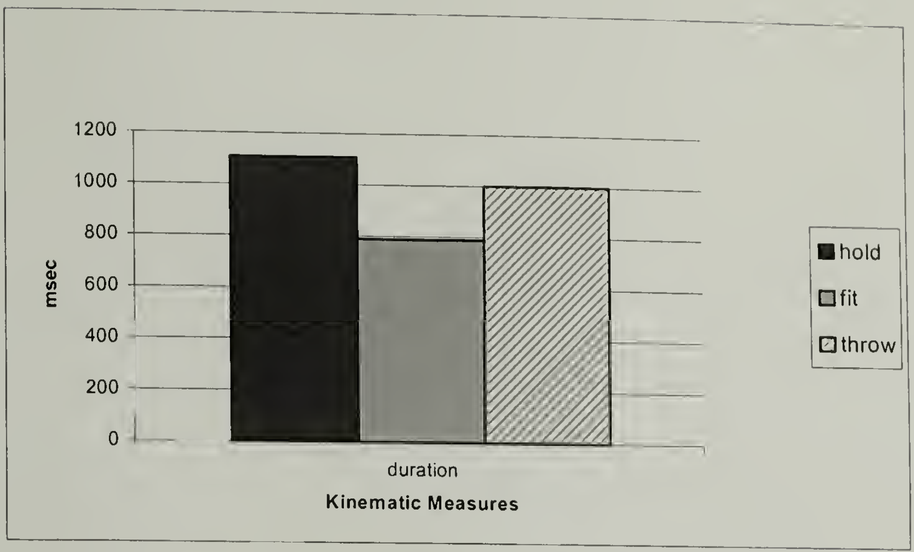


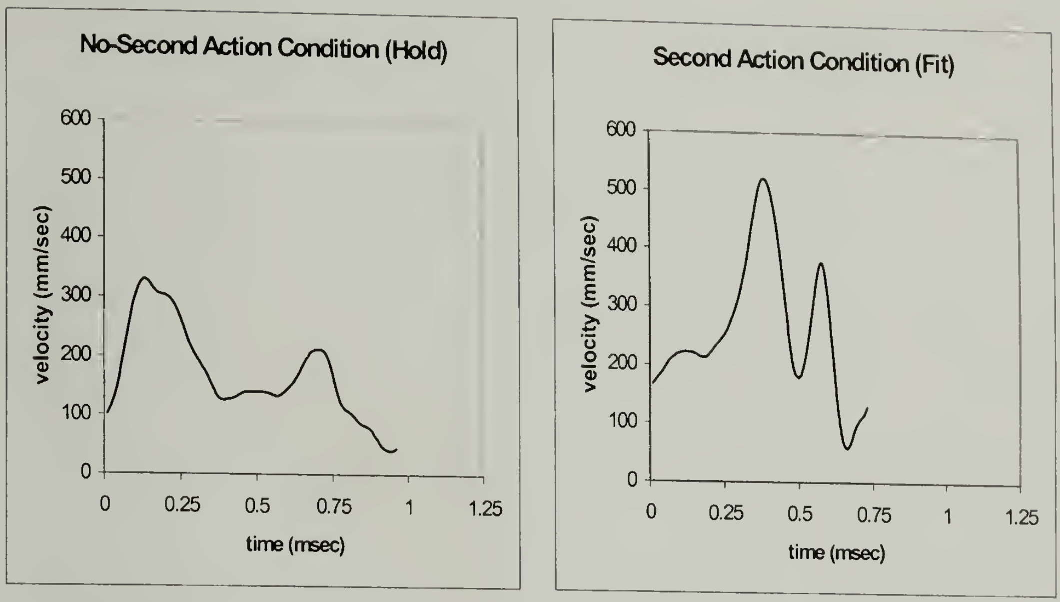
Figure 3. Duration comparisons for hold, fit, and throw.

Figure 4 illustrates sample speed profiles for second action and no-second action from two different infants.) These speed profiles exemplify how duration time is longer in the hold condition than for the fit or throw conditions. Also, infant 2 illustrates how the peak speed is higher in the throwing than in the holding condition.

C. Adult Reach Kinematics Comparisons on Action

Unless otherwise noted, the dependent measures for the adult analyses were done using a 3 (Action: holding, fitting, throwing) by 3 (Object: disk, small ball, large ball) repeated measures ANOVA design and the pairwise comparisons of the means were done using Bonferroni t-tests.

Table 7 presents a summary of the means and the statistical analyses for the 10 adult participants. For the effects of action on reach kinematics in the adults, there was a main effect of duration, $F(2,16) = 21.188$, $p<0.001$. Pairwise comparisons were significant for holding-fitting, holding-throwing, and throwing-fitting. Thus, the duration time for holding (M=756msec) was longer than fitting (M=701msec), and holding and fitting had longer movement time durations than throwing (M=631msec). In agreement with Marteniuk, Infant 1



Infant 2

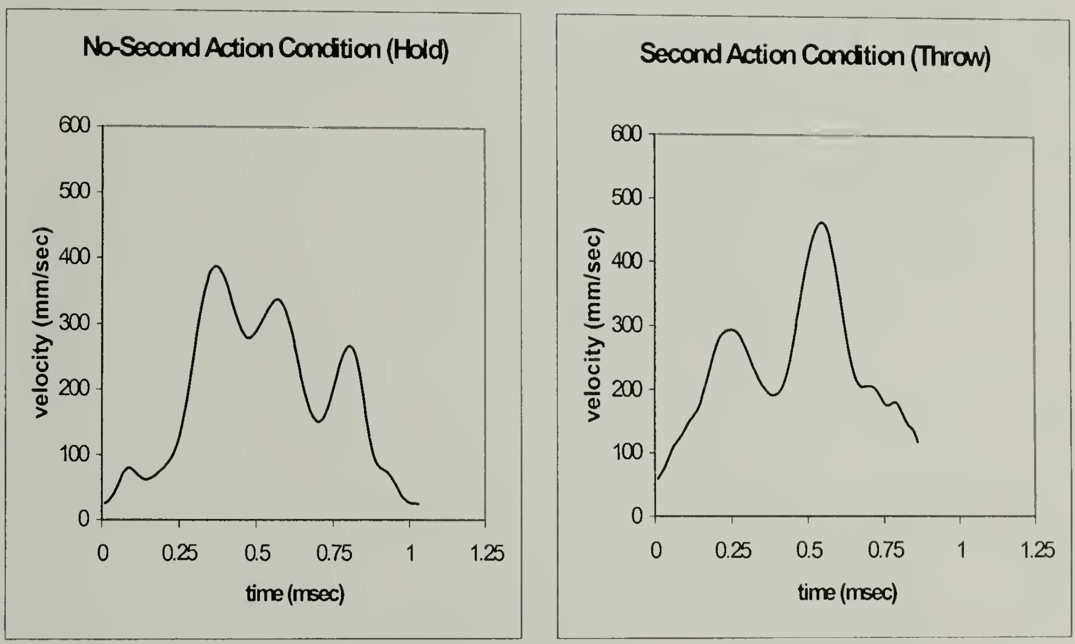


Figure 4. Speed profiles from two infants for second and no-second action conditions.

duration for fitting was longer than for throwing. There was also a main effect for % peak, $F(2,16)= 8.661$, $p<0.003$. A pairwise comparison showed that the % peak for fitting (M = 47%) was greater than the % peak for holding (M=41%). Thus, the peak speed for fitting occurred later in the reach than the peak speed for holding.

There was also a main effect for average speed, $F(2,16)= 12.4$, $p<0.001$. The pairwise comparisons were marginally significant, such that the average speed for holding (M= 508mm/s), for fitting (M =537mm/s), and for throwing (M = 589mm/s) were all significantly different from each other. Thus, adults were reaching fastest when their ultimate goal was to throw the ball, and slowest when their ultimate goal was to just hold the ball.

There was also a main effect for the peak to grasp measure, $F(2,16)= 22.204$, $p<0.001$. The pairwise comparisons were significant for holding (M = 446msec) and fitting (M = 376msec) and for holding (M = 446msec) and throwing (M = 332msec). Thus, as predicted by Johnson et al.'s findings with adults, when not performing a second action (the holding condition), the adults spent a longer portion of the reach in deceleration than when they did perform a second action (fitting or throwing). Interestingly though, this result does not replicate Marteniuk et al.'s adults, as there is no significant difference between the fitting and throwing decelerations. However, the means are in the correct direction with the fitting deceleration portion of the reach (M = 376 msec) longer than the throwing deceleration portion of the reach (M = 332 msec).

The three distance measures were non-significant. Thus, the distance between the ball and the adults' starting position was the same in all three conditions. In addition, the up/down distance traveled was similar in all 3 conditions.

Table 7

Mean Effect of Action on Reach Kinematics for Adults

Measures	Conditions Hold	Fit	Throw	Statistics F	df	p
Duration (msec)	756	701	631	21.188	2, 16	0.000
Holding-fitting **						
Holding-throwing **						
Throwing-fitting *						
Peak Speed (mm/s)	1187	1182	1240	0.435	2, 16	n.s.
% Peak	41	47	48	8.661	2, 16	0.003
Holding-throwing**						
Ave. Speed (mm/s)	508	537	589	12.4	2, 16	0.001
Holding-fitting $^{?}$						
Holding-throwing **						
Fitting-throwing $^{?}$						
Onset to Peak (msec)	310	325	298	2.36	2, 16	n.s.
Peak to Grasp (msec)	446	376	332	22.204	2, 16	0.001
Holding-fitting **						
Holding-throwing **						
Distance Traveled (mm)	380	375	373	0.304	2, 16	n.s.
Straight Line Dist. (mm)	309	314	305	1.815	2, 16	n.s.
Ratio Distance	1.23	1.19	1.22	1.471	2, 16	n.s.

$^{?}$ = marginally significant,* = $p<0.05$, ** = $p<0.01$

D. Adult Reach Kinematic Comparisons on Object-size

There were also some main effects of object-size which are summarized in Table 8. In general, object size did influence the kinematics of the initial reach for the object when the type of action was controlled for and there were no interactions between object size and action type. Our reasoning behind giving the adults 3 different ball sizes was to see if the hand to object-size ratio would have a significant effect, which it did not. Generally, the size results agree with Fitts Law (Fitts, 1954) in that one reaches more slowly for smaller objects.

Table 8

Mean Effect of Object Size on Reach Kinematics for Adults

Measures	Objects			Statistics		
	Disk	Small Ball	Large Ball	F	df	p
Duration (msec)	730	683	677	3.063	2, 16	n.s.
Peak Speed (mm/s)	914	1136	1544	4.229	2, 16	0.034
% Peak	40	46	49	7.238	2, 16	0.006
disk-small ball ?						
disk-large ball *						
Ave. Speed (mm/s)	469	547	618	19.5	2, 16	0.001
disk-small ball **						
disk-large ball **						
small ball-large ball ?						
Onset to Peak (msec)	292	311	330	2.98	2, 16	n.s.
Peak to Grasp (msec)	438	372	343	22.204	2, 16	0.008
disk-small ball *						
disk-large ball *						
Distance Traveled (mm)	336	371	421	8.429	2, 16	0.003
disk-large ball *						
small ball-large ball ?						
Straight Line Dist. (mm)	298	308	321	3.24	2, 16	n.s.
Ratio Distance	1.13	1.2	1.3	10.809	2, 16	0.001
disk-large ball *						
small ball-large ball *						

? = marginally significant, * = p<0.05, ** = p<0.01

CHAPTER 5

DISCUSSION

In the past, measuring intention in infants has proved to be a problematic endeavor. In part, this difficulty lies in the fact that one cannot use the end outcome of events in order to determine whether an action occurred intentionally. Accordingly, an act that looks intentional, might not have actually been intentional, but rather was part of a causal relationship (e.g., Frye, 1990; Vedeler, 1987, 1991). In addition, as infants cannot verbally explain what they had in mind before they performed or did not perform some action, it is up to the researcher to find ways in which to quantify their intentional behaviors. Research with adults suggests that this quantifying of intention can be accomplished using kinematic measures (e.g., Runeson & Frykholm, 1981, 1983; Marteniuk et al., 1987; Johnson et al., submitted), and we suggest that this procedure can be used with infants as well.

One way in which kinematics have been used to measure intention in adults is by measuring movement intent (Marteniuk et al., 1987). Marteniuk et al. described movement intent as being what one intends to do with an object after he/she picks it up, and how this intention affects the kinematics of the initial reach for the object. Marteniuk et al. has shown that when an adult plans or intends to do a precise action with an object, such as fitting an object down a small hole, the duration of that initial reach for the object will be longer than if the adult plans on doing a less precise action with the object, such as throwing an object into a large bucket. In addition, Marteniuk et al. found that for the fitting action, a larger portion of the approach toward the object was spent decelerating and peak hand speed was lower than when the approach preceded a throwing action.

Another approach to theorizing about how the goal of an action affects the reaching kinematics can be broached in terms of context effects. Similar to the idea of movement intent, context effects can also predict that what one intends to do with an object after it is picked up affects the kinematics of the initial reach toward the object (Johnson et al., submitted). While Johnson et al. were unable to support Marteniuk's precision argument, they found that whether one intends to transport an object to a new location, as opposed to keeping an object in the same location, affects the kinematics of the reach toward the object. Specifically, the duration of the reach is longer in the no transport condition than in the transport condition. In addition, the portion of the reach spent in deceleration is longer when the object will be held rather than subsequently transported. Johnson et al. claimed that these differences in duration time and deceleration times were caused by the goal specificity of the tasks. Specifically, they argued that because the goal of the no transport task is much less specific than the transport task, that more time for the reach is needed and that this is reflected in the deceleration portion of the reach.

The goal of the current study was to see if what the infant was going to do with the object after he/she picked it up affected how he/she reached for the object as has been demonstrated with adults. Thus, what the infant planned to do with the object, the infant's goal, should be evident in the kinematics of the reach for the object. We expected to replicate Marteniuk et al.'s findings using a task more similar to that used with his adults than Johnson et al. used. Consequently, we wanted to see if precision task demands did affect the kinematics of the reach toward the object. Specifically, we expected to see a lengthening of the duration time and the deceleration time in the reach for the object in our fitting condition as compared to our throwing condition. In addition, we expected to see a higher peak velocity in our throwing condition as compared to our fitting condition. We also expected to be able to replicate Johnson et al.'s findings that moving an object to a second location (which we labeled as a planned second action) would affect the kinematics of the reach toward the object differently than if the object was not moved to a different location after it was picked up (which we labeled as no-second action). Specifically, we expected to see a shortening of the duration time and the deceleration time in the reach for the object in our fitting and throwing conditions as compared to our holding condition.

The results of our adults and our infants for fitting vs. throwing are summarized in Table 9. We were able to replicate Marteniuk et al.'s precision task demands with peak velocity effects on the kinematics of reaching with our infants and for length of duration time with our adults. However we were unable to either replicate the duration time results with our infants or the peak to grasp time with either our infants or adults.

Table 9

Summary Table for Fitting vs. Throwing Actions

	Marteniuk et al.	Our Infants	Our Adults
Duration Time	FIT LONGER	NO DIFFERENCE	FIT LONGER
Velocity	THROW HIGHER	THROW HIGHER	THROW HIGHER
Onset to Peak	NO DIFFERENCE	NO DIFFERENCE	NO DIFFERENCE
Peak to Grasp	FIT LONGER	NO DIFFERENCE	NO DIFFERENCE
% Peak	THROW HIGHER	NO DIFFERENCE	THROW HIGHER

One explanation for our having different findings from Marteniuk et al. could pertain to reaching in general. The adults in the Marteniuk et al. study were instructed to reach as quickly as possible for the object. Infants, obviously, would not understand such an instruction, and reach at their own pace, which in turn would affect their reach kinematics. Marteniuk et al.'s instructions to reach quickly for a small object could have accentuated the differences in the reaching kinematics for the two conditions, thus finding differences that only occur when adults are reaching quickly.

The one finding that we did replicate of Marteniuk et al.'s for our infants was the velocity measure differences. Like Marteniuk et al, our infants were reaching for the ball faster in the throw condition than in the fit condition. Thus, at least on one critical dimension the kinematics of the approach to the object were affected by what the infant planned to do with the object after he/she picked it up.

The results of our adults and our infants for second planned action vs. no-second planned action are summarized in Table 10. Our infants and adults had a longer movement duration time for the reach to the object when they did not perform a planned second action (our holding condition), which matches Johnson et al.'s adult findings. However, the infants did not have a longer peak to grasp time for the initial reach when they simply grasped and held the ball. While the differences in percentages were not significant, they were in the right direction, with the percent peak occurring earlier in the unplanned condition compared to the planned condition. Thus, our infants only partially replicated the adult findings that whether or not the individual plans to perform a second action of transporting an object to a new location is reflected in the kinematics of the reach for that object.

Table 10

Summary Table for Second Planned vs. No-second Planned Actions

	Johnson et al.	**Our Infants**	**Our Adults**
Duration Time	NO-SECOND ACTION LONGER	NO-SECOND ACTION LONGER	NO-SECOND ACTION LONGER
Velocity	NO DIFFERENCE	THROW FASTER THAN HOLD	NO DIFFERENCE
Onset to Peak	NO DIFFERENCE	NO DIFFERENCE	NO DIFFERENCE
Peak to Grasp	NO-SECOND ACTION LONGER	NO DIFFERENCE	NO-SECOND ACTION LONGER
% Peak	NO-SECOND ACTION SMALLER	NO DIFFERENCE	NO-SECOND ACTION SMALLER

One criticism of our finding of kinematic differences between second and no-second action is that our holding condition always occurred first in the testing session and therefore was not counterbalanced with the fitting and throwing conditions. Our reasoning behind always giving the infants the hold trials first in session was because we were concerned that the infant might find holding "boring" in the later trials, and would be doing something else with the ball instead, such as throwing. However, always presenting the hold condition first could have potentially confounded our data. It could have been that reaches at the beginning of the testing session were slower on average than reaches at the ending of the testing session regardless of condition. Thus, our differences in duration should be interpreted with caution. Only a between-subjects design in which order was counterbalanced would this confound be solved.

Controlling the distance between the object and the infant was a problem for all three comparisons. It is difficult to control for the distance between the object and the infant partly because some of the infants would not reach for the ball unless it was placed fairly close to them. Also, unlike adults, whose reaching distance abilities are easy to judge, infants' reaching distance abilities are highly variable. In addition, unlike with adults, we could not control the starting point of the infants' hands. Thus, the starting position was not consistent over trials. The only solution to this problem is to continue to look for possible differences between conditions as we have done. Later, if differences in distance between the object and the infant occur, then one can try various ways to control for it such as statistically controlling for it in an ANCOVA.

In looking at both our fit-throw comparison findings and our second action- no-second action comparison findings, we note that movement intent is reflected in some aspects of the kinematics of infant reaching as it is in adults, but not in all. Specifically, velocity appears to be the most sensitive parameter of the reaching movement to the infant's upcoming action. Task precision affected speed of infants' movement in the same way as it does in adults – faster reaches when the upcoming movement is not precise. Likewise, velocity reflected the infant's intention to proceed with a second action once the object was in hand, even though this was not seen in our adults or in Johnson et al. (submitted). The longer decelerative phase, which is a hallmark of adult kinematics in this situation, did not appear in infants' reaching.

The immaturity of the infant's motor control is a likely explanation for this partial similarity to adult reaching. At 10-months of age, we see the beginning of how intentionality is reflected in the kinematics of reaching. It could be that at 10.5-months, infant reaching is too highly variable and that an older age group, such as 12-month olds who have had much more experience with fitting and throwing, might have less variable results with additional kinematic measures reflecting intentionality. In addition, while most infants had no trouble with the fitting task (perhaps because it had a more specific goal), not as many infants were willing to throw the ball. In fact, unexpectedly, many parents casually reported that their children dropped toys from their highchairs infrequently, or not at all. By 12-months, both fitting and throwing should be more highly practiced behaviors that infants will find easier to perform when encouraged.

While this study did not fully replicate the findings on intentionality of reaching in adults, the main goal was still accomplished, finding a new measure of intentionality in infants. We did find that infants reached for the ball faster if they were going to subsequently throw the ball as opposed to fitting the ball. Thus, the infants were exhibiting intentional behavior such that they had some sort of representation of the future state of events (fitting or throwing the ball) that was not available from immediate perception. This finding adds a deeper dimension to the early reaching behavior literature on prospective control by examining future-oriented behavior that has a definite plan in mind. Previous prospective control studies were able to show that infants adjust their speed (von Hofsten, 1991), orient their hand (e.g. Lockman, Ashmead, and Bushnell, 1984), and prepare grip size (von Hofsten and Ronnqvist, 1988) when reaching for a particularly oriented and shaped object. Our study goes one step further by demonstrating that when the object is perceptually the same, infants will adjust their speed reaching for that object depending on what they intend to do with the object after they pick it up. Therefore, instead of manipulating the object itself as was done in the prospective control studies, we left the object constant and instead manipulated what the child would do with that object after it was picked up. The prospective control studies demonstrated that infants are reliable in how they reach for objects depending on its perceptual features. Thus, since the reach for a perceptually identical object was different in our throw and fit condition, we can interpret this difference as due to what the infant intended to do with the object after it was picked up and not the visual stimulus.

In addition, this intentional behavior, while less complex than the traditional means-ends studies, achieves what the traditional studies have not. The traditional means-ends studies rely on success or failure of the task as a measure of intentionality (Fyre, 1990; Vedeler, 1987, 1991) which can be problematic. Just because a child succeeds on a traditional means-ends task, does not necessarily mean that he/she retrieved the object intentionally. The successful retrieval of the object could have been due to chance. Failure, too, is not necessarily indicative of unintentional behavior. For instance, the child could intend to retrieve the toy, but not have the skills to bring about the intended retrieval of the toy. Our study avoids this problem by using a new measure of intentionality: reaching kinematics.

Thus, we have found that as was suggested by Vedeler (1987, 1991), using the infant's behavior as it is directed toward objects and assessing this behavior using the infant's behavioral dynamics, such as the kinematics of the infant's reach toward the object can be an informative measure of reaching intent. Thus, the infant's intention of what he/she is going with an object after it is picked up affects the motor plan for the reach of that object differently, depending the infant's final goal. Thus, kinematic research provides us with an interesting way of quantifying intentional reaching behaviors in infants.

APPENDIX A

CODING GUIDELINES AND ISSUES FOR SCORING REACHES ON VIDEOTAPE

- Reach: Stands for reaches for the ball
- Condition: Reach, Throw, Fit
- OPTOTRAK:

1. OPTO # corresponds to the optotrak trial # on the protocol sheet. If the entire reach trial is not within an optotrak trial, then write unmarked trial and do not score times.
2. Y or N, whether the OPTOTRAK light is on throughout the entire reach trial. Code as Y, if the light remains on until the infant touches the ball; otherwise code as N. If N, indicate why in the comments; i.e. too early (to indicate that reach occurred before OPTO came on) or too late (to indicate that OPTO went off during the reach) and do not score times.

- Grasp Hand: Hand which grasps the ball
- Action Hand: Hand which does the action, i.e. the hand used for throwing or fitting.
- Actions (examples)

  Fit (releases ball down tube)
  Drop (the hand holding the ball releases the ball onto ground by opening the fingers around the ball)
  Throw (the hand raises upward and forces the ball to the ground)
  Switch (moves ball from grasp hand to other hand)
  Held (just holds in hands for 3 to 4+ sec)
  Mouth (brings ball to mouth)
  Clap (clapping with ball in hands)
  Tube (brings ball to opening of tube, but doesn't release it into the tube)
  Play (grabs tube with other hand and plays with it)
  Switch – drop (first switched hands and then dropped)
  Switch – fit (first switched hands and then fit)
  Mouth – fit (first brings ball to mouth and then fits)
  Held - fit (first holds ball and then fits)

- Trial Onset: First frame when red light appears
- Reach Onset: First continuous forward movement toward the ball that does not reverse or stop and results in contact with the ball.
- Grasp Time: Time at which infant's hands first wrap around the ball. When you first see the fingers getting in a curved position.
- Release Time: Time at which the ball leaves the infants hands such that the fingers holding the ball open. The frame in which the infant is no longer touching the ball with the hand that initially grabbed it. Only score release if the infant fit, threw, or held the ball (before a second action).

What if the infant first reaches for the tube, and then reaches for the ball?

If the infant does not retract the hand again into its body, then write down the time of the second reach, so the reach onset would be the time at which the hand leaves the tube and starts for the ball. Place note in comments (reach from tube)

9	8	7	6	5	4	3	2	1	Reach #
									Condition
									OPTO #; y/n
									Grasp Hd
									Action Hd
									Actions
									Trial Onset
									Reach Onset
									Grasp Time
									Release Time

APPENDIX B

TRIALS CONTRIBUTED BY EACH INFANT IN EACH CATEGORY OF BEHAVIOR

S#	# of holds	# OPTO Holds	# of fits	# OPTO fits	# of throws	# OPTO throws	Not included
1	4	3	2	1	4	2	
2	5	2	1	0	5	2	
3	8	1	13	0	6	6	
4	4	3	13	10	6	6	
5	____	____	____	____	____	____	Refused IREDS
6	____	____	____	____	____	____	fussy
7	11	1	8	3	4	6	
8	5	0	1	1	7	5	
9	7	2	4	1	0	0	
10	5	2	7	6	0	0	
11	____	____	____	____	____	____	Missing IREDS
12	3	1	6	2	9	1	
13	0	0	1	1	8	3	
14	0	0	8	7	1	1	
15	____	____	____	____	____	____	Missing IREDS
16	9	9	3	2	10	5	
17	____	____	____	____	____	____	Fussy
18	6	3	3	3	0	0	
19	____	____	____	____	____	____	Fussy
20	____	____	____	____	____	____	Missing IREDS
21	3	2	15	9	15	10	
22	____	____	____	____	____	____	Premature
23	6	1	9	1	9	5	
24	4	4	17	16	2	0	
25	5	2	16	0	4	1	
26	2	2	15	14	2	2	
27	8	4	15	12	8	4	
28	4	1	11	4	1	1	
29	____	____	____	____	____	____	Fussy
30	4	4	0	0	11	3	

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