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I am submitting herewith a thesis written by Joshua L. Williams entitled “The effects of task exposure and simulated grasping experience upon the emergence of reaching.” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

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“THE EFFECTS OF TASK EXPOSURE AND SIMULATED GRASPING EXPERIENCE
UPON THE EMERGENCE OF REACHING”

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Dedication

This thesis is dedicated to my grandfather, John L. Scheidel, Jr., my wife, and parents for the support and encouragement they provided in the pursuit of my goals.

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Abstract

Based on previous research, three-month-old infants who received simulated grasping experience via “sticky mittens” showed increased object-directed activity relative to infants who did not receive experience (Needham et al., 2002). The current study wanted to examine the importance of the “stickiness” aspect of the “sticky mittens” experience. Thirty pre-reaching infants were followed for 16 consecutive days. Each infant was randomly assigned to one of three groups: Velcro (grasping simulation), non-Velcro (no grasping simulation), or Control (no experience). On the first day of the study all infants visited our laboratory for a baseline assessment without mittens to ensure they were unable to reach. The Velcro and non-Velcro groups were seen in their homes from days two through 15 by an experimenter to receive their training. All infants returned to our laboratory on day 16 of the study to reassess their reaching skills without mittens. All testing conditions were held constant over the 16 days. Infants sat in a custom-designed infant chair behind a small table. The experimenter faced the infant and placed toys one-at-a-time onto the table within infants’ reaching space. Trials lasted one minute and infants received 10 trials each day. Results showed that both the Velcro and non-Velcro groups significantly increased their amount of intentional reaching between the first and final days. When intentional reaching was examined day-by-day, only the non-Velcro babies showed a sustained increase from week one to week two, while the Velcro babies’ rate tended to decline. Analysis of the duration of visual attention to the toy indicated that the non-Velcro group tended to pay more attention to the toy as compared to the Velcro group. Analysis of the kinematic measures showed that the Velcro and non-Velcro groups spent a significantly greater percentage of time closer to the toy after they were exposed to the training. These results suggest that

simulated grasping experience did not provide an advantage to the Velcro group in learning to reach. Rather, it is argued here that repeated, task-specific experience, not simulated grasping, may be more important for the development of reaching.

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Introduction

Theoretical standpoints

The ability to reach out, touch, and subsequently manipulate an object is a crucial skill for human infants to possess in order to interact within and upon their environment. In detail, the emergence of this skill allows for further development in perceptual, motor, cognitive, and emotional-social domains. For instance, with the ability to direct reaches to an object, an infant will be able to gather haptic information as they explore an object's surface as well as proprioceptive information as they move their arms through space. Also, the emergence of reaching seems to induce shifts in attention from faces to objects and also provide more opportunities for parent-child interactions (Thelen & Smith, 1994; Fogel, Dedo, & McEwen, 1992; Eppler, 2005; Ruff & Rothbart, 1996). Although this skill is extremely important for development in multiple domains, infants typically do not perform their first successful reaches until about three to five months of age (White, Castle, & Held, 1964; Clifton, Muir, Ashmead, & Clarkson, 1993; Thelen, Corbetta, & Spencer, 1996).

Many decades of research concerned with infant reaching provided contemporary developmental scientists with a large bank of descriptive information about reaching behavior and when it typically emerged. This has been an invaluable tool as it provided a foundation of knowledge about this behavior. Unfortunately, it has deterred developmental scientists from seeking the answer to the more important question of “how” infants begin to reach for objects. More specifically, what are the processes and mechanisms by which an infant begins to figure out how to coordinate their bodies, actions, and intentions to successfully reach for an object? Two pioneers in the field of developmental psychology, Arnold Gesell and Myrtle McGraw,

provided theories that were very attractive and very popular at the time they were proposed. Both McGraw and Gesell were proponents of a maturationist perspective of development, which purported the notion that motor behaviors emerged as a primary result of neuromuscular maturation. Simply stated, infants had to wait for the neuromuscular connections, which had originally been subcortically-controlled, to mature and come under cortical control in order to perform particular behaviors such as reaching (McGraw, 1945; Thelen, 1995). These hypotheses were deduced from methodologies that were fairly rudimentary; however, aside from the methodological issues, this type of thinking along with the intense descriptive manner of behavior led to development being thought of as a linear progression through developmental steps, which was driven by pre-determined, inborn rules (Thelen & Smith, 1994). With the adoption of such a framework, interest in the processes by which behaviors emerged waned for a substantial amount of time.

Another proposal on how infants began to reach and grasp objects was provided by Piaget (1952), who utilized a constructivist perspective. Primarily, Piaget believed that the reflexes infants possessed at birth were the foundation for later motor behavior. For instance, reaching and grasping behaviors were built upon reflexive grasping and looking. Secondly, sensory modalities (e.g. vision, touch, proprioception) were considered to be separate and unconnected. Thus, the problem that infants had to solve was to coordinate the sensory modalities, and more specifically, coordinate perception and action. In contrast to McGraw and Gesell, Piaget stated that the infant was an active participant in driving his/her own development, thus coordination between perception and action was the result of active exploration. Through the active exploration, infants progressively matched the multiple modalities such as movements

of the hand and arm (proprioceptive information) with vision of the hand. This perspective was heralded by White, Castle, & Held (1964) when they observed that infants near the onset of reaching performed many alternating glances between their hand and the desired toy as if they were actively analyzing and coordinating their vision and arm movements. In sum, the Piagetian view was that infants must integrate the initially separate sensory and perceptual streams of information by interacting within the environment in order to successfully construct the knowledge of how to reach for objects (Piaget, 1952; White, Castle, & Held, 1964; Thelen & Smith, 1994).

More recently, with the help of novel technologies, researchers have begun to understand the emergence of behavior. Theories of development have begun moving away from the single driving force views (i.e. McGraw and Gesell) to support more multi-causal ones where the properties of nervous system, body, and environment interact to drive the emergence of behavior (Chiel & Beer, 1997; Corbetta, in press; Thelen, 2000). Dynamic systems theory has become one of the more popular of these theoretical perspectives. Primarily, this theory has focused upon the processes of transition and change that lead to the emergence of novel behaviors. According to dynamic systems theory, new behaviors are assembled through the multiple and continuous interactions among the many interconnected components of an organism's system. The components of the organism's system include all components within and surrounding that particular organism. Through these interactions, not pre-determined rules, new behaviors become self-organized (Thelen, 1989, 1992, 1995). In the case of infant reaching, some things have been considered necessary for the infant to extend their arm and touch an object. Primarily, the infant must be able to see the target object and be motivated to touch it. In addition, the

infant must control the muscles of the arms to lift them against the force of gravity, be able to make visual and proprioceptive corrections of their arm movements online, and control their posture, just to mention a few (Clearfield & Thelen, 2001). How then does an infant just all of a sudden put all of these variables together to produce successful reaches? It has been assumed that this doesn't just happen all of a sudden, but the infant has been learning to reach since the day he or she was born through multiple experiences stemming from parent-infant interactions and early sensorimotor behaviors. Here the term learning refers not simply to a change in behavior as a result of past experiences but more specifically to infants' active exploration of the capabilities of their bodies and subsequent selection of successful reaching movements within the particular reaching context. According to dynamic systems theory, novel behaviors have a history. It has been inferred that newly assembled behaviors emerge from previously assembled behaviors and thus, the new assemblies will provide the basis for future ones (Thelen & Smith, 1998; Corbetta & Verijken, 1999; Corbetta & Thelen, 2002; Goldfield, Kay, & Warren, 1993; Berthouze & Goldfield, 2008). In the context of the emergence of reaching for objects, current reaching behavior was assembled, or selected, from prior reaching or non-reaching behaviors and the current reaches will provide the substrate for subsequent reaching development.

The dynamic systems approach was used by Thelen, Corbetta, Kamm, Spencer, Schneider, & Zernicke (1993) to examine the emergence of reaching in four infants. This study highlighted many of the factors involved in the process of beginning to reach and especially the process of selection of novel behaviors from ongoing behaviors. The four infants in the study were followed weekly from three weeks of age until 30 weeks of age and then biweekly after 30 weeks. Following infants longitudinally in this fashion aided in the capture of the transition from

non-reaching to reaching, which was important for upholding the dynamic systems approach. Also, due to the view that development was considered to be multi-causal, Thelen et al. (1993) measured many different aspects of the infants' reaching behavior. The measures included successful contact with toys, hand trajectories, muscle contraction patterns (EMG), joint movement and torques, and many naturalistic observations. Thelen and her colleagues noticed that each of the four infants in the study possessed their own developmental histories and thus their own intrinsic dynamics. More specifically, each infant had their own preferred patterns of spontaneous arm movements. For instance, some infants moved their arms quickly and with a lot of force, while others showed slower movements with very little force. Two of the infants in the study, Gabriel and Hannah, exhibited non-reaching behaviors that were in high contrast to one another. Gabriel was a very active infant. He performed very quick arm movements, which typically began at the shoulder joint, and were performed in a repetitive fashion. Torque measurements at his joints were very high and his agonist and antagonist arm muscles were usually co-contracted, which made for a very rigid arm. Hannah, on the other hand, was quite a bit calmer in her movements. Her movements were very slow with much less joint torque and less co-contraction of arm muscles than Gabriel exhibited. These different intrinsic dynamics among the infants required each infant to explore and select their own individual solutions to the task of reaching. When the first reaches for each infant were examined, it was clear that the first reaches emerged from the ongoing movements. Gabriel's first reaches were very fast, rigid, and proximally-generated. The examination of the multiple measurements (trajectories, EMG patterns, etc.) indicated that Gabriel voluntarily adjusted his intrinsic dynamics to produce a more efficient and successful reach. His adjustments required him to use less co-contraction of

the arm muscles and slow down his movements. Hannah's first reaches were very slow and it seemed like she had to work hard to lift her hand against the gravitational force. Thus, in contrast to Gabriel, Hannah made her adjustments by increasing her arm movement forces in order to move her arm against gravity. These two infants provided great examples of how novel reaches emerged from previous non-reaching behaviors. It was also evident that although the goal of the reaching task was the same, each infant had to approach the problem in different ways due to their intrinsic dynamics and developmental histories (Thelen et al., 1993; Thelen & Smith, 1994; Konczak, Borutta, Topka, & Dichgans, 1995).

The biomechanical aspect of reaching has been an essential part in the attempt to understand the development of infant reaching. However, the contributions of the nervous system have not been ignored nor should they be. The dynamic systems theoretical perspective on reaching has been complemented quite well by the neuronal group selection theory proposed by Gerald Edelman (Edelman, 1987; Sporns, & Edelman, 1993). Early in development, redundancy in the nervous system has been exhibited by the intrinsic overproduction of unspecified synaptic connections in anticipation of typically-occurring experiences (Greenough, Black, & Wallace, 1987; Bertenthal & Campos, 1987; Bourgeois, 2001). Due to that redundancy, many networks of neurons have been implicated in similar patterns of behavior (Huttenlocher, 2002). The process of neuronal selection has been proposed to work to stabilize certain synaptic connections when those connections that were activated coincided with a successful adaptive, goal-directed behavior. This stabilization of active synapses has been termed experience-dependent plasticity by Greenough et al. (1987). The generation of successful goal-directed movements has previously been proposed to occur via computational strategies by

which the nervous system computed the proper trajectory a priori to the movement and then activated the behavior (Hollerbach, 1982). Edelman and his colleagues did not agree with that interpretation. Rather, they proposed that organisms, infants in this case, produced many different exploratory arm movements, through which they discovered a solution to the task. As can be deduced, this explanation fits well with Thelen et al. (1993). The solution infants discovered satisfied two tenets, according to Edelman and his colleagues. First, the infant discovered a solution that was appropriate to the task at hand. Secondly, the infant discovered a solution that possessed adaptive value. The adaptive value of a behavior, it has been proposed, was determined via neuronal activation of innate value systems. The innate value systems had been selected over evolutionary history. According to a selectionist theoretical perspective, infants may have entered the world with a set of neural constraints, which allow the infant to produce a set of movement patterns that have been evolutionarily selected because of adaptive value (Berthier, Clifton, McCall, & Robin, 1999). These neural constraints have been proposed to decrease the space within which an infant has to motorically explore in order to discover a successful action (Schlesinger, Parisi, & Langer, 2000). Through the activation of such movement networks, the value of particular behavior will be determined. As an example, if an infant reached out and contacted a toy, the value system would increase its firing rate to indicate that the behavior just performed possessed some adaptive value. Thus, the more positive activation of these synapses will strengthen the synaptic connections that were involved in that behavior. Through this strengthening process, those particular synaptic linkages will be more likely to be activated in similar future situations (Edelman, 1987; Sporns & Edelman, 1993).

Overall, the history of research into infant reaching development has been a very active area for attempting to understand behavioral change and the emergence of new forms. During contemporary developmental science, researchers have been adopting a more dynamic perspective on how infants learn to coordinate their bodies, actions, and intentions in order to successfully reach and touch an object. Due to the impossibility to separate brain and behavior from one another, it has become necessary to delineate a theoretical perspective that can combine both in a coherent fashion. Dynamic systems theory in tandem with Edelman's neuronal selectionism has provided a strong foundation to investigate the emergence of behavior, especially infant reaching.

From pre-reaching to reaching

Infants do not begin to voluntarily reach for objects until approximately three to five months of age, as previously mentioned. During the span of time prior to the emergence of this novel behavior, infants move through various phases of arm movements, which will affect the initial reaching behaviors produced. During the time prior to the emergence of voluntary reaching, infants perform what have been termed spontaneous movements which are defined as arm movements, sometimes repetitive, that are prevalent in the apparent absence of any known stimuli (Thelen, 1996). Also, just after birth infants perform what have been termed pre-reaching behaviors, which appear to be a precursor to the more mature voluntary reaching. Pre-reaching movements, which involve an extension-flexion synergy between the arm and hand, have been shown to occur in neonates when a toy is placed within reaching space (von Hofsten, 1982; 1984). Thus, within the first three months of postnatal life there are multiple opportunities

for infants to explore the properties of their arms and the possible effects that may be produced through their own activity.

The importance of developmental history in the process of beginning to reach has indicated that the onset of reaching does not simply emerge from nothing. Immediately following birth, the spontaneous arm movements and pre-reaching behaviors produced will set the stage for the onset of voluntary reaching. Due to the importance of these prior movements for the formation of initial voluntary reaches, it is plausible to review what types of upper limb behavior infants are typically engaged in prior to the emergence of reaching. The changes in upper limb movements, both qualitative and quantitative, have been described in great detail in the previous literature and tend to follow a similar sequence across different studies, despite many individual differences. Primarily, spontaneous arm movements have been described by pioneers in such ways as random, unintentional, writhing, and non-functional (Gesell & Armatruda, 1947; Piaget, 1952; White et al., 1964; Hadders-Algra & Prechtl, 1992). All of these terms insinuated that these early arm movements were randomly generated through space, possessed no organization at all and served no function. However, according to many researchers this may not be the case. Many studies have examined the spontaneous arm movements of neonates and young infants and have discovered these movements to be structured and organized in specific ways. For instance, these movements possess properties present in all movements such as accelerations and decelerations, which have been termed movement units. In one study, von Hofsten & Ronnqvist (1993) found that these early arm movements possessed a temporal and spatial patterning. Within these units arm movements tended to be straight, while the timing and location of changes in arm movement direction was closely coupled with

transitions between movement units. A different study conducted by van der Meer, van der Weel, & Lee (1995) contradicted the view that neonatal spontaneous arm movements were purposeless and unintentional. By attaching neonates' hands to a pulley system, the researchers were able to show that neonates voluntarily counteracted a pulling force in order to keep their hand within their visual field. These studies indicated that the arm movements generated by neonates may be constrained by specific organizing principles and not be completely random as many previously thought. As von Hofsten & Ronnqvist (1993) stated, "the involuntary character of neonatal movements has been grossly overestimated in the past."

Many studies have found changes in upper limb behavior with the introduction of a toy into infants' reaching space. For instance, von Hofsten (1989) found that neonatal pre-reaching behaviors tended to display a synergistic relationship between arm and hand extension and flexion when a toy was present. More specifically, he found that neonates tended to extend their fingers during arm extension and flex their fingers while they flexed their arms. One of the main ideas to be put forth by many of the early pre-reaching and reaching studies was the notion that early reaches were visually-guided or visually-directed to the toy (Piaget, 1952; White et al., 1964; Bower, Broughton, & Moore, 1970; von Hofsten, 1982, 1984, 1986; Bushnell, 1985). Visually-guided reaching referred to the idea that infants relied upon vision of their hand and the toy in order to reach, touch, and grasp the toy. Specifically, the infant's hand and toy needed to be visible throughout the entire movement to the toy. There has been a plethora of studies that seemed to provide evidence that this notion was accurate. In the 1970s, Bower and his colleagues concluded from a series of reaching studies that if specific conditions such as infant alertness and full postural support were met, that the neonates possessed the ability to visually-

direct their movements to reach out and grasp objects. In Bower et al. (1970), for instance, newborns were presented with toys in five different locations. The researchers found that 40% of all forward arm extensions culminated in direct contact with the toy (Bower et al., 1970; Bower, 1974). Due to the general agreement that this type of behavior was too sophisticated for neonates, many studies attempted to replicate these results, but they were unsuccessful (Dodwell, Muir, & DiFranco, 1976; Ruff & Halton, 1978). Von Hofsten (1982) utilized a more sophisticated methodology in order to examine eye-hand coordination in the newborn and concluded that there seemed to be a rudimentary coordinative relationship between eye and hand. He discovered that when infants visually fixated an object they performed more forward arm extensions relative to when they did not visually fixate the object. Although, von Hofsten (1982) discovered few successful toy contacts, he found the forward extensions during visual fixation of the toy to be better aimed and ended closer to the toy relative to non-fixated forward movements. Also, when the toy was fixated, the speed of the hand slowed down as it neared to the toy. It was evident from this work that even in neonates there was some sort of link between vision and arm movements in the newborn; however, it was not fully developed as successful contacts were extremely infrequent (von Hofsten, 1982). Around two months of age, infants have been found to exhibit a low amount of forward arm extensions, however, during this time researchers have discovered some of infants' first object-directed swipes toward toys within their reaching space. The forward extensions performed tended to be unilateral with no attempt to grasp the object because the majority of movements were performed with a fistful hand (White et al., 1964; von Hofsten, 1984). After two months, von Hofsten (1984) found a significant increase in the number of forward arm extensions with a decrease in the amount of extensions while the hand

was fistled. Just prior to three months of age, von Hofsten (1984) also noted increased hand opening during reaches to the toy. This increase in hand opening only occurred when infants were fixating the toy. Around three to four months of age researchers have documented an increase in bilateral arm movements toward objects presented at midline. These bilateral arm movements were accompanied by alternating glances between the hands and target objects as the hand-object distance decreased. These alternating glances between hands and object indicated that the infants may have utilized vision to guide their hand to the object for contact (White et al., 1964). Unilateral arm movements tended to re-emerge around four months and were still accompanied by alternating glances between hand and object. Just prior to their first week of consistent success at reaching and touching, infants increased their overall activity. This increase in activity corresponded to an increased number of arm movements and movement speed (von Hofsten, 1984; Bhat, Heathcock, & Galloway, 2005). Prior to the onset of successful reaching and touching, the distance from hand to toy changed relatively little; however, at the emergence of reaching this distance tended to decrease and infants brought their hands to the midline more often (Bhat et al., 2005; Spencer & Thelen, 2000). On average, around five months of age, infants began to exhibit reaches to the toy characterized by one quick movement of the arm while the hand did not need to be seen (White et al., 1964). Studies such as these suggested that early in the learning to reach process infants were dependent upon vision to get their hand to the object for contact.

It was proposed by Bushnell (1985) that early in life, infants went through a period of visually-guided reaching, which allowed them to successfully learn to reach and touch objects. However, as infants became better at the task, vision was no longer needed to guide their hand to

the object. The term provided to describe reaches that did not utilize visual guidance of the hand during reaching was visually-elicited reaching. In other words, infants saw an object within reaching space, which elicited a reach to that object without the use of vision to get the hand to its final destination. Thus, with proficiency, infants moved from a visually-guided approach to a visually-elicited one (Bushnell, 1985). Although this was an attractive explanation based upon the reaching literature at the time, Clifton and her colleagues conducted experiments that countered this hypothesis. Clifton et al. (1993) designed a study to test the idea that vision of the hand was important early in the learning to reach process. They tested infants longitudinally from six weeks to 25 weeks of age in order to compare their reaching onset times in the light (vision of the hand) versus in the dark (vision of toy, but no vision of the hand). According to Clifton et al. (1993), if vision of the hand was important to the emergence of reaching then reaching should occur in the light before it occurs in the dark. If vision of the hand was not crucial for the onset of reaching then the onset times for the light and dark conditions should have been equal. The findings supported the idea that young infants did not need to see their hand to guide their movements to the toy. All infants began reaching in the light around the same time they began reaching in the dark. Clifton et al. (1993) suggested that the proprioceptive modality had been underestimated as infants in their studies were just as successful at the reaching task without vision of the hand as they were with it. They did not conclude that the visual modality was unimportant in the learning to reach process; however, they proposed a different developmental progression than many previous researchers. Clifton et al. (1993) suggested that early in the development of reaching, infants' reaching was visually-elicited, while visually-guided reaching developed later when more sophisticated movements of

the hand were necessary for grasping. Overall, Clifton and her colleagues pointed out that learning to reach was not driven by utilization of a single modality, but required the coordination of multiple modalities.

From prior research dealing with infants' behaviors during the time prior to the onset of voluntary reaching, it has been evident that learning to reach is a very complicated process. This complicated process has recently been determined to be a multimodal process rather than one reliant upon a single modality (Clifton et al., 1993, Clifton, Rochat, Robin, & Berthier, 1994). The literature showed that infants exhibited many different upper limb behaviors, both in the absence and presence of an object. While the behavioral progression mentioned above was a "typical" progression, it is important to note that individual differences have been abundant. The individual differences in spontaneous and pre-reaching behaviors have been shown to influence future reaching behavior, thus stressing the importance of individual infants' developmental histories (Thelen et al., 1993). Unique experiences in early development tend to shape developmental histories of individuals. Many researchers have manipulated infants' early experiences in order to understand the processes of learning and development of motor behavior. This particular idea has important implications for the topic of this thesis.

Experience and motor behavior

Locomotor patterns and reaching behavior

Previous research has shown that motor experience and training affects existing behavior. For instance, with the emergence of new locomotor behaviors such as crawling and walking, infants have been shown to use their arms in different ways. When researchers analyzed the arm movement patterns exhibited during locomotion they found that these patterns tended to be

transferred to reaching tasks. For instance, Corbetta, Williams, & Snapp-Childs (2006) analyzed the reaching patterns of two infants who displayed unique locomotor behaviors. One of the infants displayed a unilateral army-crawl strategy during which he utilized only one arm to pull himself along in a forward motion. When this infant's reaches were analyzed he showed more unilateral reaches with the arm he actively used during locomotion. Another infant utilized a scooting strategy to move about his environment, during which his arm movements were coupled. During the reaching task, the researchers found that the infant used more bilateral reaching movements. When this particular infant switched his locomotor strategy to hands-and-knees crawling, thereby decoupling his arm movements, he performed more unilateral reaching (Corbetta et al., 2006). Corbetta & Bojczyk (2002) examined why infants returned to two-handed reaching for all sizes of objects, despite extensive reaching experience, when they began to walk independently. Once again, there seemed to be a connection between how infants' arms were used during locomotion and how they reached for objects. When infants began to take their first independent steps, arms were coupled in the high-guard position. During this time of coupled arm behavior infants exhibited more bilateral reaches. However, as infants became better walkers, their arms decoupled and moved down to their sides. Coincident with this decoupling was an increase in unilateral reaching, which was tailored to object size again as it was during the months preceding independent walking (Corbetta & Bojczyk, 2002). These studies exhibited that the way infants utilized their arms in some tasks was reflected in the way they used their arms during different tasks and thus provided evidence that motor experience influenced other ongoing behaviors.

Motor training of the lower limbs and trunk

Many studies have provided specific training to existing motor behaviors and have found that even young infants took advantage of novel experiences and modulated those behaviors. Some of the behaviors that have been used to demonstrate this idea were stepping, kicking, and sitting. Zelazo, Zelazo, & Kolb (1972) & Zelazo, Zelazo, Cohen, & Zelazo (1993) provided training to the newborn stepping reflex. The newborn stepping reflex has been documented to become less prevalent around eight weeks of age. However, if newborn infants were trained to actively use the stepping reflex, the newborns increased the amount of stepping as well as exhibited the stepping reflex for a longer period of time (Zelazo et al., 1972, 1993). Vereijken & Thelen (1997) also trained infant stepping behavior, but the training was provided to three- and seven-month-old infants. Both groups received treadmill training of their stepping behavior which resulted in increased amounts of stepping in both age groups. Another study that dealt with lower limb behavior provided an experimental situation to examine three-month-old infants' ability to modulate preferred kicking patterns, which was previously shown to be performed in an alternating fashion (Thelen, 1985). Thelen (1994) created a situation in which infants were in a supine position underneath an attractive mobile. Infants' legs were attached to the mobile in different ways, which in turn required different kicking movements to fully activate the mobile. Some infants had only one leg attached to the mobile, which required them to kick that one leg more in order to activate the mobile. Other infants had both legs attached to the mobile, which called for simultaneous kicking of both legs in order to fully activate the mobile. Despite entering the situation with different preferred kicking patterns, both groups of infants modulated those preferred patterns and activated the mobile in concordance with their leg

attachment condition. For instance, infants who had only one leg attached to the mobile showed increased kicking with that leg while infants with both legs attached showed increased simultaneous kicking (Thelen, 1994). Training has also been shown to influence infant sitting behavior. Zelazo et al. (1993) provided training specific to sitting behavior and found that infants who received this type of training sat independently for longer periods of time than infants who did not receive experience. Thus, it has been shown on quite a number of occasions that existing lower limb and trunk behaviors can be affected by experience and the application of specific types of training.

Motor training of the upper limbs

As previous research has shown, behaviors that were already present in infants' behavioral repertoires were susceptible to experience and training. What has been less examined are the effects experience and training may have upon the emergence of upper limb behaviors. Lobo, Galloway, & Savelsbergh (2004) conducted a study that attempted to understand how particular types of experiences affected the emergence of reaching behavior in infants. Non-reaching infants were provided with two different types of upper limb experience: general movement experience and task-related experience. In the general movement experience condition, infants' arms were attached to a toy or mobile that hung above them in their crib. A wide range of arm movements activated the toy or mobile in rewarding ways. Infants in the task-related experience condition were provided opportunities to actively try to reach for objects placed within their reaching space. Thus, in the task-related condition, only certain types of arm movements produced a rewarding outcome. Both groups received their additional experience for 20 minutes per day for 11 to 17 days. Following the training, their changes in hand-toy contacts

were assessed in a reaching context. Infants in the general movement experience condition exhibited significantly more hand-toy contacts than infants who did not receive additional experience, while the task-related experience group produced the greatest increase in hand-toy contacts. Lobo and her colleagues deduced that the infants who received the general movement experience were able to explore a wide range of arm movement possibilities and properties of their arms through which they gained better control over their movements. This better control allowed them to perform more generalized arm activity in the reaching context thus increasing the likelihood of success. The infants who received the task-related experience were able to practice in the reaching situation and actively utilized arm movements that were necessary for success in the reaching situation. Thus, through this specific practice in the reaching context the infants gained better control over arm movements specific to the reaching situation (Lobo et al., 2004).

Along a similar line of thought, some researchers have proposed that repeated exposure within a task context could be enough to induce improvement in behaviors related to that specific task. Bojczyk & Corbetta (2004) provided exposure to an object retrieval task each week to infants from six and a half months of age until they were successful at retrieving the toys from inside the box. When the task was presented to the infants, no specific guidance or training was provided to aid the infants in arriving at a solution to the task. The researchers found that infants who were exposed to the task outperformed infants who were only presented with the task once. They argued that repeated exposure, and thus increased familiarization with the task, enhanced infants' performance on the task. It was also noted that no specific guidance or training seemed necessary to enhance infants' learning to succeed at the object retrieval task (Bojczyk &

Corbetta, 2004). This explanation fits well with the Lobo et al. (2004) findings in that repeated exposure in the task of reaching for objects enhanced the number of hand-toy contacts.

Another study was conducted by Needham, Barrett, & Peterman (2002) in which they created an ingenious method to examine the effects of simulated grasping experience upon three-month-olds' upper limb behavior. The simulated grasping experience was provided to pre-grasping infants by "sticky mittens", which were constructed with the 'soft' side of Velcro on the palm while the objects used possessed the corresponding 'hard' side of the Velcro. If the infants happened to hit a toy, the toy adhered to the mitten as if they had reached out and 'grasped' the object. Infants' parents provided this experience for ten minutes per day for 12 to 14 consecutive days. The researchers found significant increases in object-directed action and attention following the "sticky mittens" experience. Specifically, they discovered that infants who received the experience looked at the objects more, orally explored objects more, and showed more intentional attempts to reach for the objects. The increased object-directed behaviors were found when the mittens were on as well as when the mittens were off. According to Needham and her colleagues the experience with the "sticky mittens" had a significant impact upon three-month-olds' ongoing object-directed behavior.

Scope and focus of the current study

The purpose of the current study was to utilize the "sticky mittens" paradigm designed by Needham and her colleagues (2002) in order to examine its effects upon the emergence of reaching. Specifically, we asked, was it the "stickiness" experience, which provided a successful "grasping" outcome, that induced the increase in object-directed activity found by Needham and her colleagues or simply the task-specific experience and repeated exposure as found by Lobo et

al. (2004) and Bojczyk & Corbetta (2004)? For instance, did the provision of this experience affect ongoing arm movements of the infants? In particular, Thelen et al. (1993), Edelman (1987), and Sporns & Edelman (1993), among others, have argued that infants perform a wide variety of upper limb movements prior to the emergence of voluntary reaching, which will allow the infant to explore the properties of their arms as well as the effects they may have upon their surrounding environment. Through this active exploration infants gradually select those arm movements that proved to be more successful for reaching an object. Does the “stickiness” property of the “sticky mittens,” which seemingly highlighted the successful grasp outcome, promote the efficient selection of the arm movements resulting in hand-toy contact or could it be the repeated task-specific experience and exposure? These questions were not addressed by Needham et al. (2002), but are important to the study of infant reaching development because they may reveal something about the processes involved in the onset of voluntary reaching.

The current study departed from the Needham et al. (2002) study in many different ways. Primarily, there were many methodological concerns that were prevalent in the Needham study. The first main concern was that it was unknown whether the three-month-old infants used in their study were already able to voluntarily reach prior to receiving the “sticky mittens” training. The current study insured that all of the infants, prior to receiving their respective upper limb training, were unable to reach out and touch a toy. Many infants were unable to participate in the current study due to their ability to voluntarily reach and touch toys. This was an important criterion to follow in order to examine the effects of the “sticky mittens” experience upon the emergence of reaching. A second concern dealt with the provision of the upper limb training. Needham et al. (2002) allowed the parents to provide the training to their own infants, which

could potentially have introduced some parental biases during the training. In order to eliminate parental biases we traveled to the infants homes each day to provide the training. Thus, we were able to insure that all infants in the study were provided the upper limb training in the same manner. Also, due to the fact that an experimenter provided the training each day we were able to examine the behaviors during the training period whereas the Needham group relied on the information provided by the parents. Another aspect of the training provided by the Needham group was that parents were instructed that toys could be placed in the infant's hand(s) if the infant seemed uninterested in the task. The training provided in the current study was an active exploratory task for the infant, therefore no additional encouragement was provided to the infant nor were toys ever placed in the infants' hands. The Needham group also presented multiple toys at once to the infants rather than one at a time. This could have been a possible confound in their study in that the presence of multiple toys may have increased their chance of hitting the toys without imposing accuracy. Also, due to the fact that more toys were present infants may have shown more interest simply based upon the greater salience of the display. Thus, the current study presented toys one-at-a-time for a duration of one minute in order to control for this possible problem.

Secondly, the Needham et al. (2002) simply concluded that the "stickiness" experience was important to the increase in object-directed activity rather than address the possibility that it may not have been the "stickiness" of the mittens at all. Thus, the type of sensorimotor training was manipulated in an attempt to address the importance of the "stickiness" experience to the emergence of reaching. Three groups of infants received different degrees of sensorimotor training while changes in upper limb behavior and arm kinematics were assessed. One group

received simulated grasping experience provided by “sticky mittens” (Velcro mittens) within a reaching context. If infants in the Velcro mittens group happened to contact a toy it would adhere to the mitten, thus providing the sensation of a successful grasp. A second group of infants received “non-sticky mittens” (non-Velcro mittens) experience, which lacked grasp simulation but was also conducted within a reaching context. If infants in the non-Velcro mittens group contacted a toy it did not adhere to the mitten, thus providing the opportunity for further object interaction. Finally, a control group was seen that never wore mittens and received no additional experience within a reaching situation other than what would occur in everyday life experience. Thus, we manipulated the training in such a way as to examine the effects of the different action consequences provided by the different mittens groups upon the emergence of reaching. If the simulated grasp outcome is important for highlighting success during reaching, then the Velcro group should select successful reaching movements from their overall movement repertoire more than the other groups. If repeated, task-specific experience is important to the emergence of reaching, the non-Velcro group should exhibit more success at reaching due to the non-stickiness of the mittens at contact. On the other hand, if repeated task exposure is all that is necessary to promote improvement in reaching, then both the Velcro and non-Velcro group should not be different from one another but both should outperform the control group.

Based upon the findings of Needham et al. (2002), the following hypotheses were tested:

1. The sensation provided by the Velcro mittens will allow those infants to better select successful movements, thus they will produce the greatest amount of successful, voluntary reaches. Due to the additional experience within the reaching context, the non-Velcro mittens group will produce an increased number of intentional reaches, however, they will not produce

an equivalent amount to the Velcro mitten group due to lack of successful grasping simulation. Both the Velcro and non-Velcro groups will outperform the control infants in amount of voluntary reaches; 2. The Velcro mittens group will lend more visual attention to the toys than the non-Velcro and control groups due to their increased success at voluntary reaching and “grasping” of the toys. As the non-Velcro group will improve in voluntary reaching and contacting objects via experience within the reaching context, they too will show an increase in visual attention to the toys. The control group will allocate less attention to the toys due to their lack of simulated grasping experience as well as experience within the reaching context; 3. Kinematic measures of the arm movements post-training will indicate that the infants who received additional experience will exhibit greater decreases in movement velocity, which has been associated with greater control of arm movements. The Velcro group will exhibit greater amount of arm control than the non-Velcro group. The Velcro group will spend more time near the toy than the non-Velcro mittens group and control group due to the simulated grasping experience, which allowed them to select the more successful reaching movements from their overall movement repertoire.

Method

Participants

Thirty infants (mean age = two months, 21 days) were recruited from the greater Knoxville, Tennessee area via formal letter and follow-up phone calls. The names and addresses for the formal recruitment letters were obtained through a government-supplied database of births in the Knoxville area. Each infant was randomly assigned to one of three groups: Velcro mittens group (simulated grasping experience), the non-Velcro mittens group (no simulated grasping experience), or the control group (no mittens and no additional experience). There were two key criteria for participation in the study. Primarily, infant participants possessed no known neurological or physical disorders. Secondly, the infants were unable to voluntarily reach for objects at the start of the study. All infants meeting these requirements were followed longitudinally for 16 consecutive days. Overall, a total of 63 infants were contacted to participate in the study. Of this total 16 infants were unable to participate in the study due to fussiness upon their first visit to our laboratory. Another 14 infants who came to our laboratory had to be excluded from the study due to their ability to voluntarily reach. Three additional infants were excluded from the analysis because they completed less than half of the experience trials per day. All participants were given \$10 to cover driving expenses, a picture scrapbook of their infant, and a certificate of participation.

Material

All infants during all visits were seated in a specially-designed, slightly-reclined (15 degrees from vertical) infant chair for testing. The chair provided the young infants with full trunk support while permitting a full range of motion of the arms and legs. The provision of full

trunk support was essential for the age group being studied due to the lack of postural control necessary for reaching to occur. A small, wooden table (15" wide X 25" long X 15" high) was placed directly in front of the infants. The height of the table was approximately waist-high for all infants.

Laboratory sessions

Three Sony Hi8 video cameras were used to record the reaching and looking behaviors of all infants. Two cameras were placed 45 degrees front-right and front-left of the infants to capture reaching activity. The third camera was situated directly across the table from the infants at eye level in order to capture looking behavior. The two cameras that recorded reaching activity were sent through a Digital Video Switcher (Datavideo Corp., Whittier, CA) to create a split-screen arrangement of the two camera views. This split-screen view was then fed into a Panasonic AG-1980 VCR where it was recorded onto a VHS tape. A Horita TRG-50 (Horita., Mission Viejo, CA) generated a timer, which was also sent to the VCR and recorded onto the same VHS tape. The Flock of Birds motion analysis system (Ascension Technology Corp., Burlington, VT) was used to capture reaching kinematics for each infant. Movement was sampled at 120 Hz and required the use of two eight millimeter markers. One marker was placed on the dorsal side of each wrist with Johnson & Johnson soft-cloth tape, which was both hypoallergenic and non-irritating. The wires for each marker were taped along the arm and behind the infant chair with the same tape to prevent hindrance of the infants' arm motion.

Toys utilized during laboratory sessions were a mixture of small, colorful Peek-a-Blocks (Fisher-Price., East Aurora, NY) and plastic squirt toys (Target Corp., Minneapolis, MN). All toys were made of non-toxic materials.

Home sessions

One Sony Hi8 camera was used to capture the reaching and looking behavior of the infants during all home visits. The camera was placed directly across the table at the infants' eye level. All behavior was recorded onto VHS-C video tapes.

Mittens were constructed from white infant bobby-socks. Each sock was altered by removing the toe portion and cutting a thumb-hole in order to permit free movements of the fingers. All mittens were fastened around the infants' wrists with a strip of Velcro. The Velcro mittens group wore mittens that were covered on all sides by the "soft" portion of Velcro. The non-Velcro mittens group wore mittens that did not have any Velcro applied to any area.

Toys used during all home sessions were the same type of Peek-a-Blocks (Fisher-Price., East Aurora, NY) and plastic squirt toys (Target Corp., Minneapolis, MN) used during the laboratory sessions. No infant saw the exact same set of toys on consecutive visits. The toys for the Velcro mittens group were altered by applying the corresponding, "hard" portion of Velcro to several areas of the toys. The toys used for the non-Velcro mittens group did not have any Velcro applied to any area.

Design and procedure

Reaching assessment (day one)

Figure A1 illustrates the design and procedure of the study. All infants participated in this session, which was conducted in the laboratory on the first day. The main goals were to confirm that the infant was unable to voluntarily reach for toys and to establish baseline measurements of reaching and looking behavior. Infants did not wear mittens during this session. Following an explanation of the study and completion of the consent form, the infant

was securely placed into the infant chair just behind the small wooden table. Prior to applying the Flock of Bird markers to the infants' wrists, one of the markers was placed on the table-top to denote the position in space where the toys were to be placed for each trial. One experimenter was situated across the table from the infant with the toys out of sight. A second experimenter was in charge of triggering the Flock of Birds and keeping track of trial duration, which was one minute. The experimenter revealed one toy, captured the infants' attention, and then placed the toy on the table-top at midline and within reaching space. The one minute trial duration began when the toy first contacted the table-top. After the toy had been placed on the table-top, the experimenter did not interfere with the infants' behavior. On average, nine, one minute, trials were collected. All infants who were included in this study performed zero intentional toy contacts (e.g. look at the toy prior to, during hand transport, and at toy contact) on the first day. This was a criterion that was strictly followed in order to examine the full effect of the sensorimotor experience upon the learning to reach process. If an infant performed one intentional contact they were not permitted continue with the experiment.

Sensorimotor experience (days two through 15)

Only the infants randomly assigned to the Velcro and non-Velcro mittens groups participated in this portion of the study. An experimenter traveled to the infants' homes to administer the sensorimotor experience for 14 consecutive days. The same experimenter conducted all of the sessions in order to ensure that all infants received the experience in the same manner. Particular care was taken to run the sessions in a quiet area of the infants' homes (e.g. no siblings, no television, no pets, etc.). Parents did not conduct the sessions to avoid possible parental biases. After placing the mittens on the infants' hands, they were placed into

the infant chair behind the wooden table with one video camera situated directly across the table at eye level. No reaching kinematics were recorded during the sensorimotor experience sessions. On average, nine, one minute trials were collected each day and began when the toy first contacted the table-top. All toys were presented in the same manner as during the reaching assessment session. It is important to note again that once the toy had been placed on the table, the experimenter did not interfere with the infants' interactions with the toy. Also, no toys were ever placed in the infants' hands. The goal of each trial was to allow the infant to freely interact with the toys. If infants in the Velcro mittens group contacted the toy in such a way that it adhered to the mitten, they were permitted to "hold" the toy for 10 to 15 seconds. This was slightly different for the non-Velcro group in that if they contacted the object, it did not adhere to the mitten, thus, they could repeatedly contact the toys. Due to individual differences in infant reaching development, some infants began voluntarily reaching during the 14 days of sensorimotor experience. An infant was considered to be voluntarily reaching if he/she intentionally contacted toys at least once on 80% of the trials for two consecutive days. If the infant attained this criterion, the sensorimotor experience sessions were ended and the infant was not seen again until day 16.

Learning assessment (day 16)

All infants participated in this portion of the study, which was conducted in the laboratory on the sixteenth day of the experiment. The purpose of this session was to reassess the infants reaching and looking behavior following the 14 day training period. After the infant was securely placed in the infant chair and fitted with the Flock of Birds motion analysis markers, the experimenter conducted the session in exactly the same manner as during the first

laboratory session on day one. Infants did not wear mittens during this session and the toys used were the same type of toys as those presented on the first day of the study.

Analyses

From video analyses, the dependent variables of interest were the percentage of trials with an intentional toy contact and duration of looks. Look durations were calculated for five separate categories: toy, experimenter, right hand, left hand, and elsewhere. Kinematic data was used to calculate the average resultant difference in hand-toy distance, displacement, velocity, peak velocity, and number of movement units. Also, the percentage of time the infants' had their preferred hand within 10 cm of the toy was calculated.

Video analyses

Percentage of trials with an intentional contact

We classified a toy contact as intentional if the infant looked at the toy prior to and during the reaching movement as well as at hand-toy contact. If the infant looked away during any of these time periods the reach was classified as unintentional. This variable was calculated by dividing the number of trials during which the infant performed at least one intentional toy contact, by the total number of trials collected. Average percentage of trials with an intentional contact was calculated for all groups by day. This included the sensorimotor experience days for the Velcro and non-Velcro groups. The average percentage of trials with an intentional contact was also computed by week (week one = days one through eight; week two = days nine through 16) for the Velcro and non-Velcro groups. Mean ranks for each group were calculated on the percentage of trials with an intentional contact for day one and day 16. Two independent coders analyzed the videos of 20% of the sample and reached 95% agreement.

Look Duration measures

All videos were imported into a Noldus Observer XT (Noldus Information Technology b.v., Wageningen, The Netherlands) in order to compute the percentage of time spent looking to each of the following five categories: toy, experimenter, right hand, left hand, and elsewhere. Elsewhere was used when the infant was not looking at one of the other four categories. For instance, if the infant looked at the table-top, the infant was considered to be looking elsewhere. This code was also used if the coder was unsure as to what the infant was looking at. These behaviors were mutually exclusive and thus were defined as state events in the Observer XT. When the infant was looking to one of the aforementioned locations, a button was pressed to start the behavior. Upon a gaze shift, the previous behavior was ended and a new behavior began. Infants were considered to be looking elsewhere if the coder was unable to determine where the infant was directing his/her gaze. Two independent coders observed these behaviors on 20% of the infants in the study. Percent agreement between coders was 90%. Calculations were only performed on times when the toy was present (e.g. during trials). The percentage of total time spent looking was computed by dividing the individual duration value by the total duration for each infant. The total duration excluded between trial times. Average percent of total duration spent looking each of the five categories was computed for all groups by day. This calculation included the sensorimotor experience days for the Velcro and non-Velcro groups.

Also of interest was the Velcro group's average percent duration spent looking to each category while the toy was stuck to the mitten. This analysis was performed on the training days for the Velcro group (days two through 15). Time intervals were defined in the Noldus Observer XT to denote when the toy stuck to the mitten and when it was removed. The duration of time

spent looking to each category was divided by the total duration that the toy was on the mitten to obtain the percentage value.

Kinematic analyses

All kinematic data collected during the first and final days of the study was entered into a customized Matlab (The Mathworks, Inc., Natick, MA) program, which first filtered the data with a zero-phase, second-order Butterworth filter with a 6 Hz cut-off. Then the program allowed the user to select the toy position trial. After this trial was imported the average resultant position was calculated and saved as the toy position for all subsequent trials. Time codes from the video recordings were entered into the program to define the portion of the entire kinematic stream corresponding to the trial start and the trial stop. We classified the start of the trial as the point in time when the toy first contacted the table within reaching space. Statistical analyses were performed on the preferred hand of each infant. The preferred hand was determined based upon two criteria. First, if the infant had contacted toys during the study, the hand that was utilized the most was considered to be the preferred hand. Secondly, if no toy contacts were made during the study the hand with the lowest average velocity on the final day was used. This criterion was utilized based upon previous research indicating that just before the emergence of reaching, arm activity tends to decrease as hands move closer to midline (Bhat et al., 2005).

Average resultant difference in hand-toy distance

The resultant difference in hand-toy distance was calculated for the preferred hand by determining the difference between the x, y, and z coordinates of the original toy position and the x, y, and z coordinates of the hand position. The square root of the summed squared differences

was then computed to obtain the resultant difference. This value was then divided by the length of the data in order to obtain an average value.

Resultant displacement and average velocity

The average resultant displacement was calculated for the preferred hand by taking the square root of the summed squared x, y, and z coordinates. In order to compute the average velocity of the resultant displacement, the program calculated the absolute difference in resultant displacement in a point-by-point fashion then multiplied by the sampling rate (120 Hz). Following this computation the value was divided by the length of the data to obtain an average value.

Average peak velocity

The average peak velocity was calculated by dividing the values of the velocity peaks by the total number of velocity peaks in the time series for the preferred hand.

Average number of movement units

The average number of movement units was computed for the preferred hand from the velocity time series in a point-by-point fashion. The program counted a movement unit when it reached a change in direction (i.e. acceleration and deceleration) in the velocity time series. Movement units were only counted for velocities greater than 5 cm/second. Averages were then computed for each group by day.

Average percentage of time within 10 cm of toy

The percentage of time the infant spent with the preferred hand within 10 cm of the toy was calculated. The program analyzed the resultant hand-toy difference in a point-by-point fashion to calculate the proportion of time spent within 10 cm of the toy. This proportion was

then multiplied by 100 to obtain a percentage value. These values were then averaged by group and day.

Results

Prior to data analysis it was necessary to insure that both the Velcro and non-Velcro groups received equivalent durations of task exposure over the training period. Total durations were calculated in minutes of exposure. An independent samples t-test indicated that there was no difference in the amount of task exposure between the Velcro mittens and non-Velcro mittens groups, $t(18) = -1.085$, $p = 0.292$.

Intentional reaching & contacting

Infants in each group began the study on day one with zero intentional contacts. However, each group exhibited variability in intentional reaching and contacting behavior on day 16 of the study. Figures A2, A3, and A4 depict the average percent of trials on days one and 16 with at least one intentional contact for each infant in the Velcro, non-Velcro, and control groups, respectively. Only one infant in the Velcro group met the 80% reaching criterion on day 16, while four of these infants did not exhibit an increase in their amount of intentional contacts. Three infants in the non-Velcro group met and/or exceeded the 80% criterion on day 16 and three others did not change their amount of intentional reaching and contacting. One of the control infants performed intentional contacts on 100% the trials, while six of the infants did not increase their amount of intentional reaching (see figures A2, A3, and A4). All groups appeared to show an average increase when comparing day one to day 16. Figure A5 depicts the mean ranks on the average percent of trials with at least one intentional contact for each group. A Wilcoxon Signed-ranks test indicated that the Velcro group showed a significant increase in the average percent from day one ($M = 0$, $SD = 0$) to day 16 ($M = 24.43$, $SD = 32.21$), $Z = -2.207$, $p = .027$. The non-Velcro group also exhibited a significant increase from day one ($M = 0$, $SD = 0$)

to day 16 ($M = 37.47$, $SD = 38.31$), $Z = -2.371$, $p = .018$. The control group did not show a significant increase from day one ($M = 0$, $SD = 0$) to day 16 ($M = 20.33$, $SD = 34.44$), $Z = -1.826$, $p = 0.068$. All groups began the study with zero intentional contacts on day one. A Kruskal-Wallis test was performed to examine the difference between groups on day 16 of the study. The three groups were not significantly different from one another on the average percent on day 16 ($\chi^2(2, N=30) = 1.982$, $p = 0.371$). The average percent of trials with contact was examined over the training period and distinct developmental curves were evident for the Velcro and non-Velcro groups (see figure A6). The developmental curves indicated that over the first eight days of the study (week one) both the Velcro and non-Velcro groups performed in a similar manner. However, during the second eight days of the study (week two), the Velcro and non-Velcro groups diverged from one another. The Velcro group exhibited a slight decline in the average percent during the second week, but the non-Velcro showed a continued increase (see figure A6). Due to this divergence between groups during the second week, the average percent was split by week for the Velcro and non-Velcro groups (see figure A7). The Velcro group did not significantly increase their average percent from week one ($M = 16.79$, $SD = 9.64$) to week two ($M = 22.69$, $SD = 7.02$), $Z = -1.260$, $p = 0.208$. However, the non-Velcro group did significantly increase their average percent from week one ($M = 13.37$, $SD = 8.6$) to week two ($M = 32.21$, $SD = 5.69$), $Z = -2.521$, $p = 0.012$. Despite the non-Velcro group's significant increase from week one to week two, a Mann-Whitney test indicated that they did not produce significantly more intentional contacts during week two when compared to the Velcro group ($U = 41$, $p = 0.529$).

Looking

Figures A8 through A12 depict the average percent of trial duration that infants in all groups spent looking to one of five categories: toy, experimenter, right hand, left hand, and elsewhere by day, respectively. All groups allocated equivalent amounts of visual attention to each category of looking on days one and 16. Also, no group indicated any significant change in attention allocation to any category of looking from day one to day 16 of the study. The longitudinal looking data of the Velcro and non-Velcro groups were entered into a repeated measures ANOVA to examine differences in the amount of attention allocation to each of the five looking categories over the 16-day study. The two groups did not significantly differ in the amount of visual attention allocated to each looking category. The non-Velcro group tended to spend more time looking at the toy compared to the Velcro group (see figure A8), however this finding did not quite reach significance ($F(1, 15) = 4.280, p = 0.058$).

In order to examine visual attention allocation within groups for the Velcro and non-Velcro groups, a grand average was computed from the average percent duration spent looking to each of the five looking categories over the 16 days of the study (see figures A13 and A14). Due to the normality of the data for the Velcro and non-Velcro groups paired t-tests were utilized to compare average percent duration spent looking to each category. Figure A15 depicts the Velcro group's grand average of the percent duration spent looking at the toy ($M = 31.91, SD = 7.79$), experimenter ($M = 19.99, SD = 5.4$), right hand ($M = 2.34, SD = 0.93$), left hand ($M = 5.65, SD = 3.23$) and elsewhere ($M = 40.11, SD = 4.08$). The Velcro group spent significantly more time looking at the toy than the experimenter ($t(15) = 3.959, p = 0.001$), right hand ($t(15) = 15.292, p < 0.001$), and left hand ($t(15) = 10.67, p < 0.001$). They also spent more time attending

the experimenter than the right hand ($t(15) = 12.882$, $p < 0.001$) and left hand ($t(15) = 8.601$, $p < 0.001$). The average amount of time spent looking at the left hand was significantly greater than that of the right hand ($t(15) = -3.850$, $p = 0.002$). The Velcro group also spent significantly more time looking elsewhere than to the toy ($t(15) = -2.998$, $p = 0.009$), experimenter ($t(15) = -12.135$, $p < 0.001$), right hand ($t(15) = -33.352$, $p < 0.001$), and left hand ($t(15) = -33.723$, $p < 0.001$). Figure A16 depicts the non-Velcro group's grand average percent duration spent looking at the toy ($M = 45.36$, $SD = 6.67$), experimenter ($M = 13.17$, $SD = 3.63$), right hand ($M = 2.87$, $SD = 1.83$), left hand ($M = 2.61$, $SD = 0.99$), and elsewhere ($M = 35.95$, $SD = 5.11$). The attention allocation pattern of the non-Velcro group was similar to that of the Velcro group. The non-Velcro group spent significantly more time looking at the toy than the experimenter ($t(15) = 13.548$, $p < 0.001$), right hand ($t(15) = 23.106$, $p < 0.001$), left hand ($t(15) = 28.081$, $p < 0.001$), and elsewhere ($t(15) = 3.304$, $p = 0.005$). They allocated more visual attention to the experimenter than the right hand ($t(15) = 10.230$, $p < 0.001$) and left hand ($t(15) = 9.657$, $p < 0.001$). They also spent significantly more time looking elsewhere than to the experimenter ($t(15) = -17.172$, $p < 0.001$), right hand ($t(15) = -24.694$, $p < 0.001$), and left hand ($t(15) = -23.837$, $p < 0.001$). In general, both the Velcro and non-Velcro groups allocated more attention to the toy when compared to the experimenter, right hand, and left hand. However, the non-Velcro group spent more time attending the toy rather than looking elsewhere while the Velcro group spent less time attending the toy than looking elsewhere.

When the toy did adhere to the mitten(s) the Velcro group spent the majority of time looking elsewhere (see figure A17). The grand average of the percent duration spent looking at the toy ($M = 32$, $SD = 10.61$), experimenter ($M = 21.28$, $SD = 7.38$), right hand ($M = 1.96$, $SD =$

1.91), left hand ($M = 2.48$, $SD = 2.69$), and elsewhere ($M = 42.24$, $SD = 6.43$) was calculated for the Velcro group during the time period when the toy was stuck to their mitten(s). Figure A18 depicts these grand averages. During the time that the toy was on the mitten, the Velcro infants paid significantly more attention to the toy than the experimenter ($t(13) = 2.415$, $p = 0.031$), right hand ($Z = -3.296$, $p = 0.001$), and left hand ($Z = -3.296$, $p = 0.001$). More attention was allocated to the experimenter than to the right hand ($Z = -3.296$, $p = 0.001$) and left hand ($Z = -3.296$, $p = 0.001$). Overall, more time was spent looking elsewhere when compared to the toy ($t(13) = -2.598$, $p = 0.022$), experimenter ($t(13) = -7.149$, $p < 0.001$), right hand ($Z = -3.296$, $p = 0.001$), and left hand ($Z = -3.296$, $p = 0.001$). When compared to the experimenter, right hand, and left hand, the majority of visual attention was allocated to the toy while the toy was stuck to the mitten. However, the Velcro infants spent more time looking elsewhere rather than the toy, experimenter, right hand, and left hand when the toy was stuck to the mitten.

Kinematics

Figure A19 depicts the means and standard deviations for the average resultant difference in hand-toy distance of the preferred hand for the three groups by day. The data were then entered into a one-way ANOVA to examine differences by day between the three groups. There were no significant differences on day one in the average resultant difference in hand-toy distance between groups ($F(2, 29) = 0.858$, $p = 0.435$) nor on day 16 between groups ($F(2, 29) = 0.410$, $p = 0.668$).

Figure A20 depicts the means and standard deviations for the average velocities of the preferred hand for the three groups by day. The data on the average velocity of day one and day 16 were entered into a one-way ANOVA to examine differences between groups by day.

According to the one-way ANOVAs, there were no significant differences between groups for the average velocity of the preferred hand on day one ($F(2, 29) = 0.392, p = 0.679$) nor on day 16 ($F(2, 29) = 0.964, p = 0.394$).

Figure A21 depicts the means and standard deviations for the average peak velocities of the preferred hand for the three groups by day. The data for the average peak velocity of the preferred hand on day one were non-normal and entered into a Kruskal-Wallis test while the normal data from day 16 were entered into a one-way ANOVA to examine differences between the groups. The Kruskal-Wallis test indicated that there was no significant difference between the three groups in the average peak velocity on day one ($\chi^2(2, N = 30) = 3.601, p = 0.165$). The one-way ANOVA indicated that there were no significant differences between groups on the average peak velocity on day 16 ($F(2,29) = 3.291, p = 0.053$); however this result was nearing significance.

Figure A22 depicts the means and standard deviations for the average number of movement units of the preferred hand for the three groups by day. The data were entered into a one-way ANOVA in order to examine differences between the groups. The one-way ANOVA indicated that there were no significant differences between the three groups on the average number of movement units on day one ($F(2,29) = 0.323, p = 0.727$) and day 16 ($F(2,29) = 0.847, p = 0.440$).

Figure A23 depicts the means and standard deviations for the average percent of time that the preferred hand spent within 10 cm of the toy for the three groups by day. All groups appeared to increase the average percent of time. Separate Wilcoxon Signed-ranks tests were utilized to examine changes in the average percent of time that the preferred hand spent within

10 cm of the toy for each group. The Velcro and non-Velcro groups were the only groups to show a significant increase in the average percent of time from day one ($M = 5.05$, $SD = 9.94$; $M = 11.59$, $SD = 17.21$, respectively) to day 16 ($M = 28.86$, $SD = 29.36$; $M = 34.45$, $SD = 36.15$, respectively), $Z = -2.803$, $p = 0.005$ and $Z = -2.090$, $p = 0.037$, respectively. The control group did not exhibit such an increase but was approaching significance ($Z = -1.886$, $p = 0.059$). There were no significant differences between the groups on day one ($\chi^2(2, N = 30) = 0.968$, $p = 0.616$) nor on day 16 ($\chi^2(2, N = 30) = 0.389$, $p = 0.823$).

Discussion

The overarching goal of this study was to examine the effect of the “stickiness” of the “sticky mittens” experience upon the onset of reaching. In order to truly assess the effect of the training upon the emergence of reaching we insured that all infants included in the study were unable to reach prior to being trained, which was something not addressed in the Needham et al. (2002) study. This proved to be a fruitful criterion as 14 infants were excluded from participation due to their ability to reach for toys on the first day. Due to having a large number of infants who were already reaching it highlights the fact that it is unknown whether the infants in the Needham et al. (2002) study were already reaching prior to receiving the “sticky mittens” training, which could be one possible explanation as to why that group significantly outperformed the control.

In the current study, all training provided to the infants was experimenter-led rather than parent-led in order to eliminate parental biases, which was not controlled in the Needham et al. (2002) study. One group of infants was exposed to 14 days of sensorimotor training, with Velcro mittens, which provided active, task-specific experience in conjunction with simulated grasping while another group received training with non-Velcro mittens, which provided active, task-specific experience without simulated grasping. Thus, the difference between the two groups was the consequence of successful actions. On the one hand, if the Velcro mittens group hit the toy it adhered to the mitten as if they successfully “grasped” the toy. On the other hand, if the non-Velcro mittens group hit the toy, it did not stick, and thus allowed for more active interaction with the toy. Referring to previous work, the provision of simulated grasping makes a lot of sense. The “stickiness” of the Velcro mittens should have allowed for more efficient

selection of successful reaching movements from the infants' overall arm movement repertoire. More specifically, according to a selectionistic perspective, the “stickiness” should have highlighted the value of the successful reaching movements for the infants and in turn, the infants should have selected the more valuable movements from their overall repertoire (Edelman, 1987; Sporns & Edelman, 1993). However, another possibility may be that the “stickiness” of the Velcro mittens may not have been as important for the emergence of reaching as the active, task-specific experience and repeated task exposure as was found by Lobo et al. (2004) and Corbetta & Bojczyk (2004), respectively. Based upon the results of Needham et al. (2002), the Velcro mittens group was predicted to outperform the non-Velcro and control groups on measures of intentional reaching, visual attention toward toys, and reaching kinematics due to the simulated grasping experience. However, the results of this study indicate that the provision of simulated grasping may not be the important factor of the mittens experience that influences the emergence of reaching.

On measures of intentional reaching both the Velcro and non-Velcro infants significantly increased their amount of intentional reaching following their respective training while the control group did not. Thus, the provision of simulated grasping experience did not appear to offer an advantage to the Velcro group on this measure. Examination of the developmental curves over the training period indicated that over the first week of training both groups performed similarly in the amount of intentional reaching; however, during the second week of training the non-Velcro group continued to improve while the Velcro group exhibited a slight decline. When the amount of intentional reaching was examined from week one to week two of the training period, the non-Velcro group was the only group to exhibit a sustained increase in

the amount of intentional reaching. From a selectionist perspective, the “stickiness” of the Velcro mittens did not allow for the more efficient selection of the more successful, or valuable, reaching movements as both the Velcro and non-Velcro groups significantly increased from day one to day 16. Due to both of the mittens groups significantly increasing their amount of reaching from day one to day 16 while the control group did not, it is possible that the infants only needed the repeated task exposure to improve their reaching performance. After examination of the training days the results indicated a divergence during the second week of training where the non-Velcro group significantly increased their amount of reaching while the Velcro group exhibited a temporary decline. This result suggests that the action outcome provided by the non-Velcro mittens, which promoted further active, task-specific experience, may have been the more important aspect of the mittens experience rather than the simulated grasping, which may have temporarily hindered reaching behavior.

When the amount of visual attention allocated toward the toy was examined no group spent significantly more time than the others engaged in looking at the toy. The non-Velcro mitten group tended to allocate more attention to the toy than the Velcro group over the study although this can only be loosely concluded due to the difference only approaching significance. It is possible that the repeated, task-specific experience promoted by the non-Velcro mittens motivated the infants to continue reaching and thus enhanced interest in the task, which was indexed by visual attention to the toy. The consequence of successful contact for the Velcro mittens group meant that no repeated contacts could be made, which could be a reason why they spent less time looking at the toy. Over the entire study both the Velcro and non-Velcro groups did spend significantly more time looking at the toy rather than at the experimenter or their

hands. However, the non-Velcro group attended the toy significantly more than looking elsewhere whereas the Velcro group allocated attention elsewhere significantly more than to the toy. Thus, when examining within groups, the non-Velcro group spent more time “on-task” than the Velcro group relative to the other four looking categories.

The reaching kinematics indicated that there were no significant changes on measures of average hand-toy distance, average velocity, and average number of movement units of the preferred reaching hand from day one to day 16 for all groups. Both the Velcro and non-Velcro groups significantly increased the amount of time they spent with their preferred reaching hand within 10 cm of the toy from day one to day 16 while the control group did not. Once again, this result indicates that the “stickiness” of the mittens experience did not offer an advantage to the Velcro group. Another result of interest was that the difference between groups in average peak velocity on day 16 was approaching significance. Figure A21 exhibits that the Velcro and control groups tended to increase the average peak speed of their preferred reaching hand while the non-Velcro infants tended to decrease their peak speed. A decrease in peak velocity of the reaching hand has been shown to occur at the emergence of reaching while increases in peak speed tend to occur about one week before onset (Bhat et al., 2005). This result, although only approaching significance, may suggest that the non-Velcro group was beginning to exhibit more control over their reaching movements due to the repeated, task-specific experience, which allowed for more exploratory arm movements specifically related to the task of reaching, while the Velcro and control groups were still in the process of exploring their overall movement repertoire. Once again, these results support the notion that the active, task-specific experience

along with repeated task exposure may be the aspect of the mittens experience that promotes better control of the arm movements to be utilized at the emergence of reaching.

Concluding remarks

Primarily, these results suggest that the simulation of grasping provided by the “stickiness” property of the Velcro mittens was not the important aspect of the mittens experience in driving the onset of reaching. The action outcomes for the Velcro and non-Velcro groups were different and it is suggested here that the mechanisms of learning present in the non-Velcro group may have been more beneficial to the emergence of reaching than those of the Velcro group. This supports prior work such as that of Thelen et al. (1993), who argued that infants perform a large number of arm movements that not only allows for the exploration of the arm dynamics, but also affords the exploration of the consequences of different movements. This is also consistent with the work of Lobo et al. (2004) who showed that infants who received active reach training, which allowed for exploratory arm movements within the specific reaching context, outperformed infants who received general arm movement training or no training. Both mittens groups in this study received active, task-specific experience; however the outcomes of success differed. For instance, if the Velcro group happened to contact a toy it adhered to the mitten, thus eliminating the possibility for further attempts to reach for the toy. On the other hand, the non-Velcro group was able to engage in more active interaction with the toys because at contact the toy remained within reaching space thus promoting repeated reaching attempts. Thus the learning process set-up by the non-Velcro mittens training promoted more active, task-specific experience. This may be an explanation as to why the non-Velcro group was the only group to exhibit sustained increases in the amount of intentional reaching.

An alternate explanation for these results, but certainly one that fits well with the Lobo et al. (2004) explanation could be that no specific training needed to be implemented at all in order

to see improvement in reaching behavior. Previous work from Bojczyk & Corbetta (2004) argued that improvement in an object retrieval task could be due simply to repeated task exposure. They showed that infants who were presented with the object retrieval task repeatedly over time exhibited more improvement in solving the task than infants who were only exposed to the task once. Bojczyk & Corbetta (2004) made it clear that no additional encouragement was provided to the infants during the object-retrieval session as their goal was to have the infants actively explore the task on their own in order to reach a solution. Similarly, one could make this argument here. Primarily, we did not provide any additional encouragement to the infants during the reaching task in order to foster the infants' own active exploration. The Velcro and non-Velcro groups both significantly increased their amount of intentional reaching and percentage of time spent within 10 cm of the toy from day one to day 16 of the study. Also, despite the non-Velcro's continued increase in reaching during the second week of training, there was no difference between the Velcro and non-Velcro infants in the amount of intentional reaching or percentage of time spent within 10 cm of the toy on the final day of the study. Thus, it is possible that simply being exposed to the task repeatedly over time allowed for the infants to become more familiar with the task and in turn more successful at solving it.

The results of this study are sufficiently explained by the union of the two aforementioned explanations. However, there is an important overarching message to be gleaned from this particular study. The message is that studies in developmental psychology, especially those that provide particular types of training, should shift their focus from the resulting behavior to the processes involved in learning that resulting behavior. This is not a novel idea as researchers who adopt a dynamic systems perspective on the development of infant reaching

have argued for a process-oriented approach for many years. By examining the processes involved in the emergence of behavior we can better understand the properties and characteristics of the resulting behavior. This was evident in the present study. We showed that simply providing the “end result” of successful reaching behavior did not seem to aid infants in beginning to reach for objects. Rather, the action outcome that promoted further exploration of the arm movement properties and capabilities seemed not only to increase the amount of intentional reaching but also influenced the continued interest and persistence in the task at hand. Based upon this take-home message, future work in this area will be directed at the creation of training paradigms designed to promote infants’ motivation to be persistent in learning to reach. For instance, one way could be to highlight the contingency between action and outcome within an active exploratory task thereby making it possible to increase the value of the training and in turn maintain interest in the task. The sustained interest in the task will in turn promote more active, task-specific reaching behaviors and thus greatly impact the emergence of reaching.

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Appendix

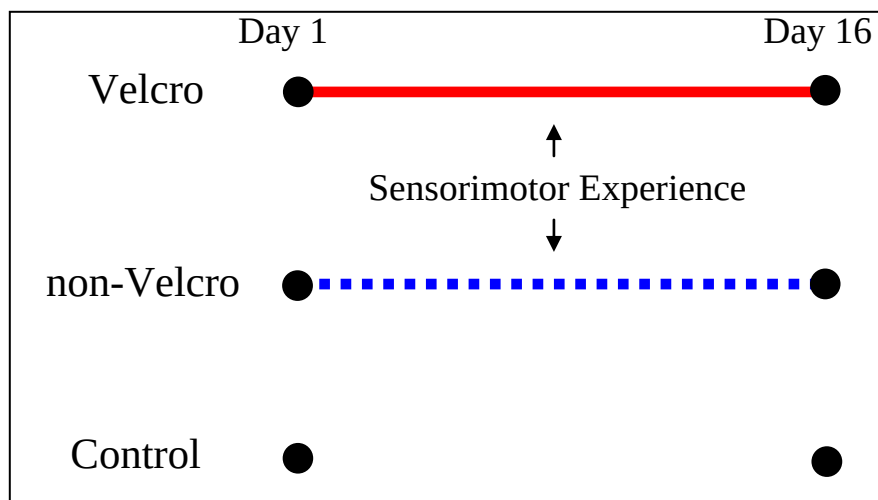


Figure A 1: Procedure diagram

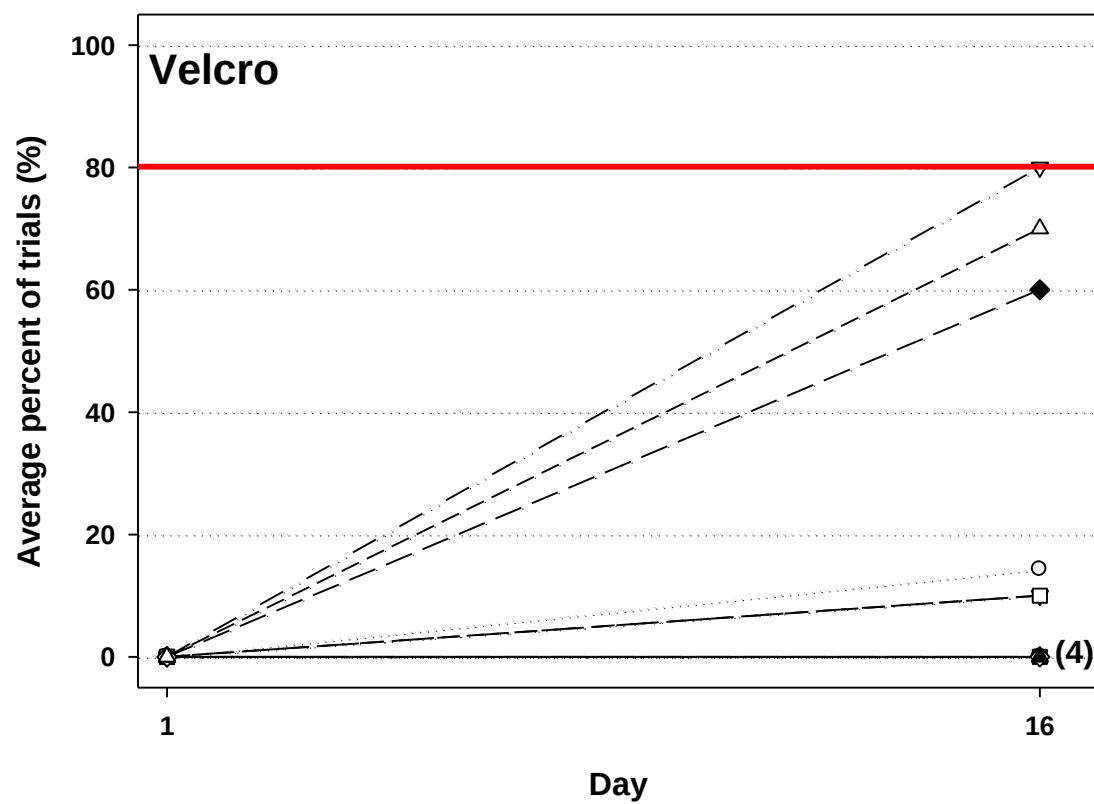


Figure A 2: Velcro group average percent of trials with intentional contact

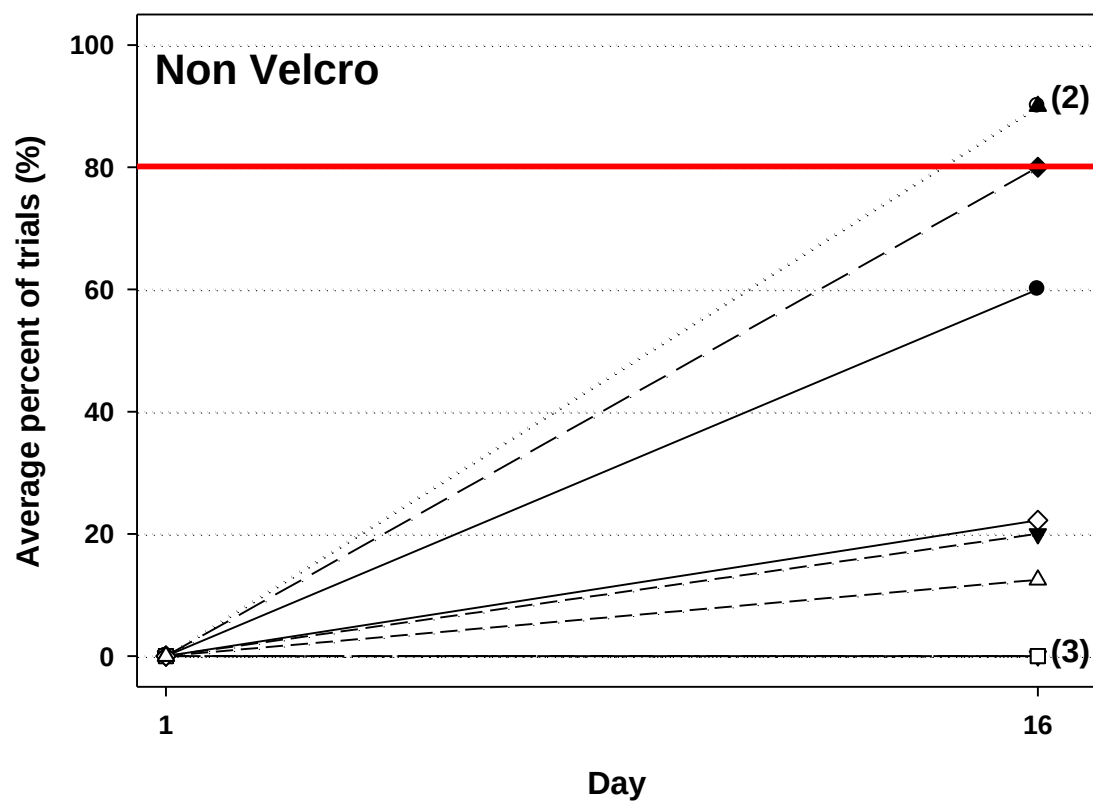


Figure A 3: Non-Velcro group average percent of trials with intentional contact

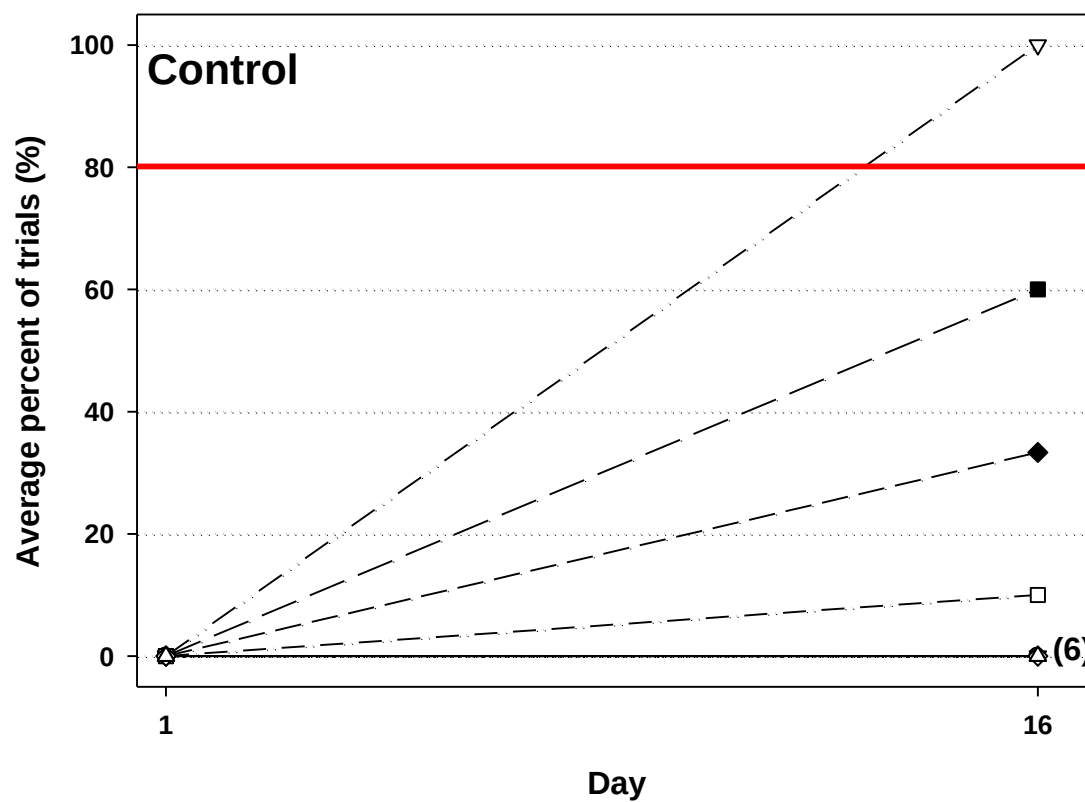


Figure A 4: Control group average percent of trials with intentional contact

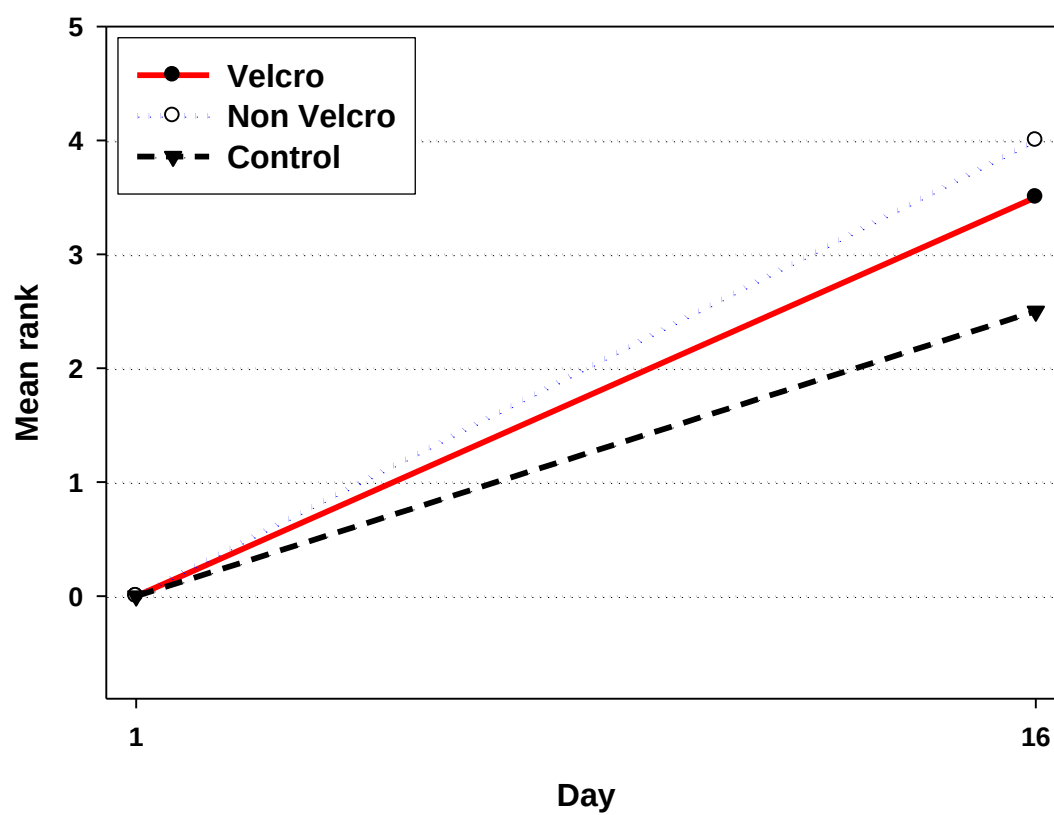


Figure A 5: Mean ranks on average percent of trials with intentional contact

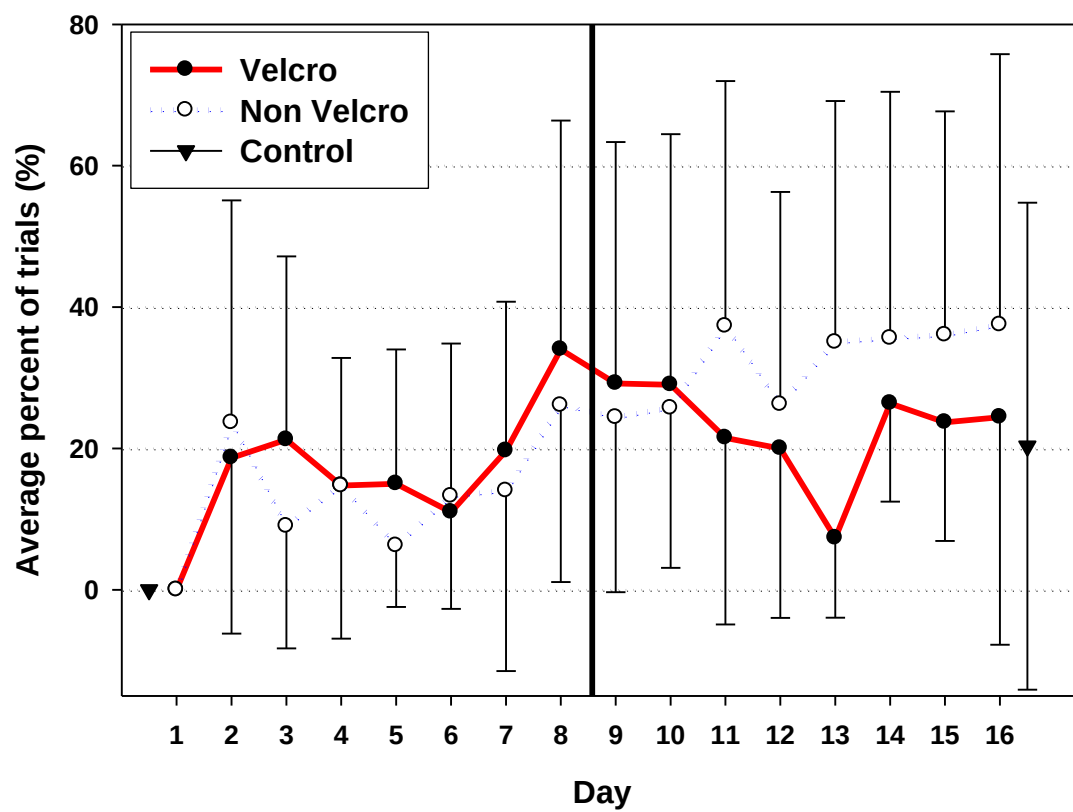


Figure A 6: Average percent of trials with intentional contact

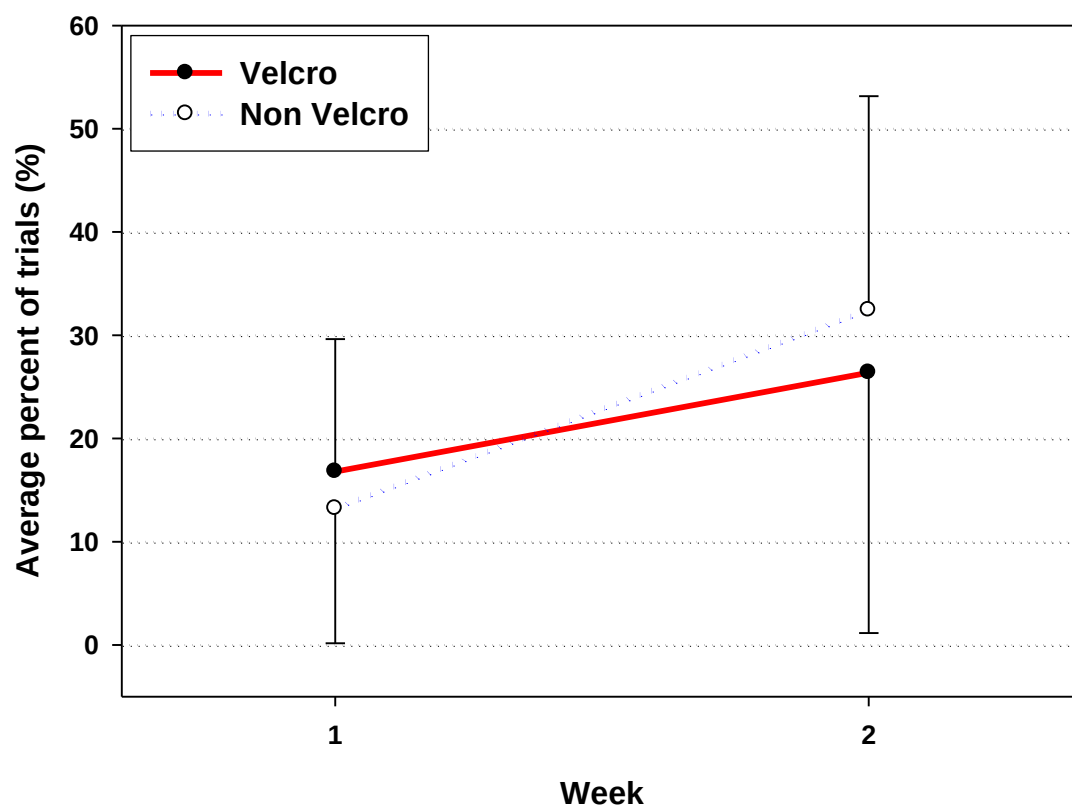


Figure A 7: Average percent of trials with intentional contact by week

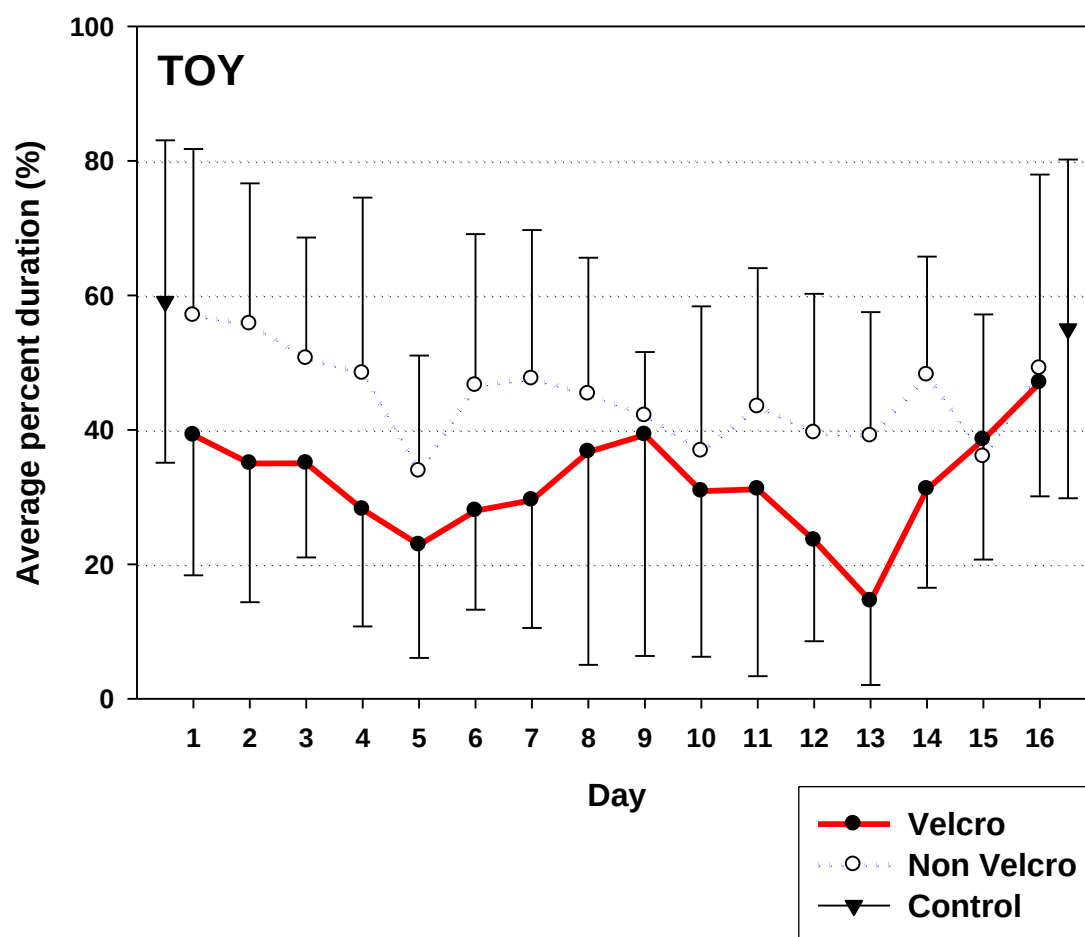


Figure A 8: Average percent duration spent looking at toy

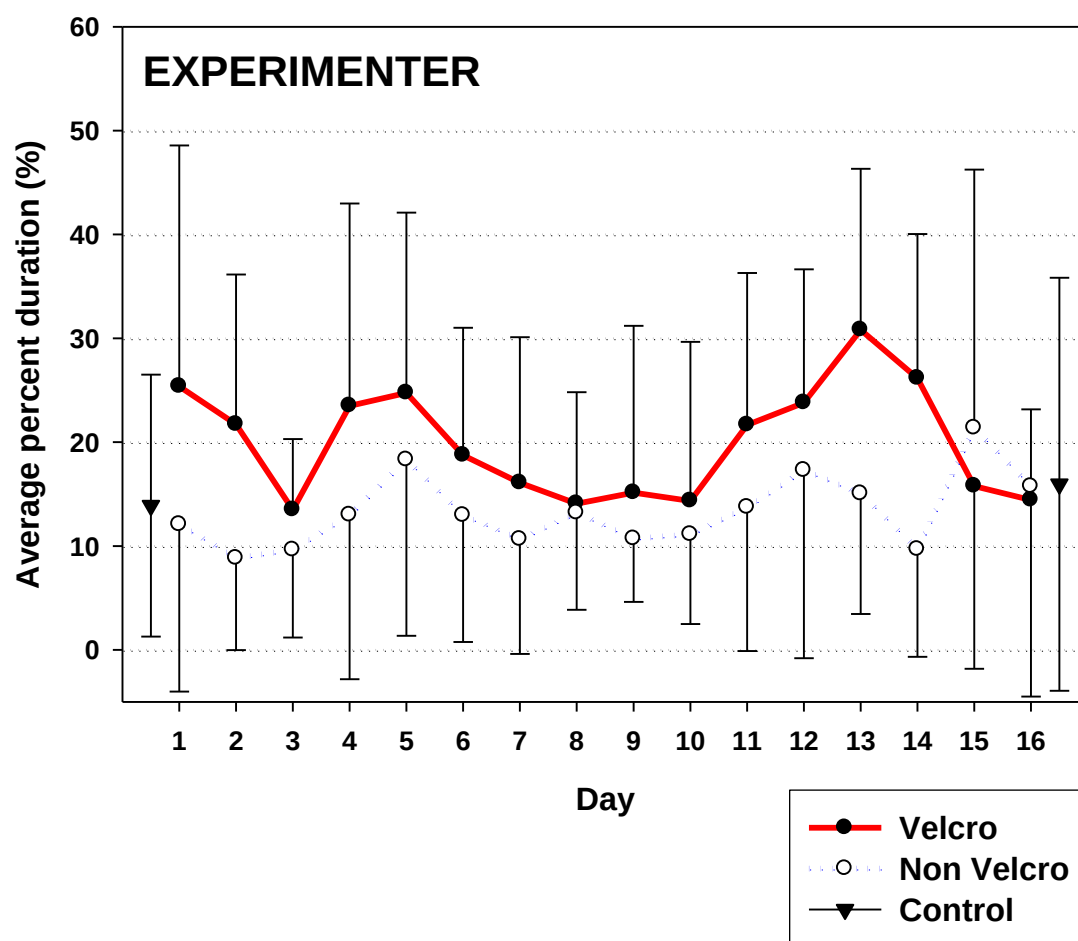


Figure A 9: Average percent duration spent looking at experimenter

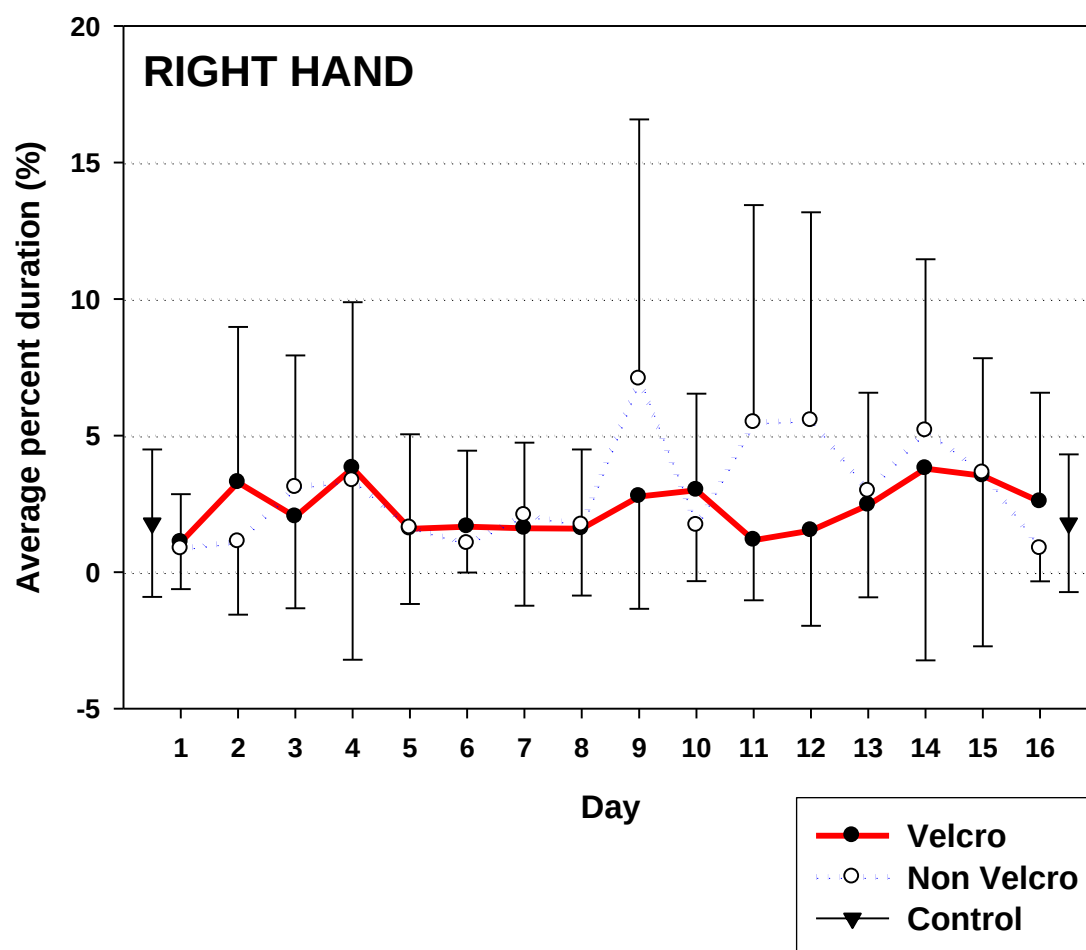


Figure A 10: Average percent duration spent looking at right hand

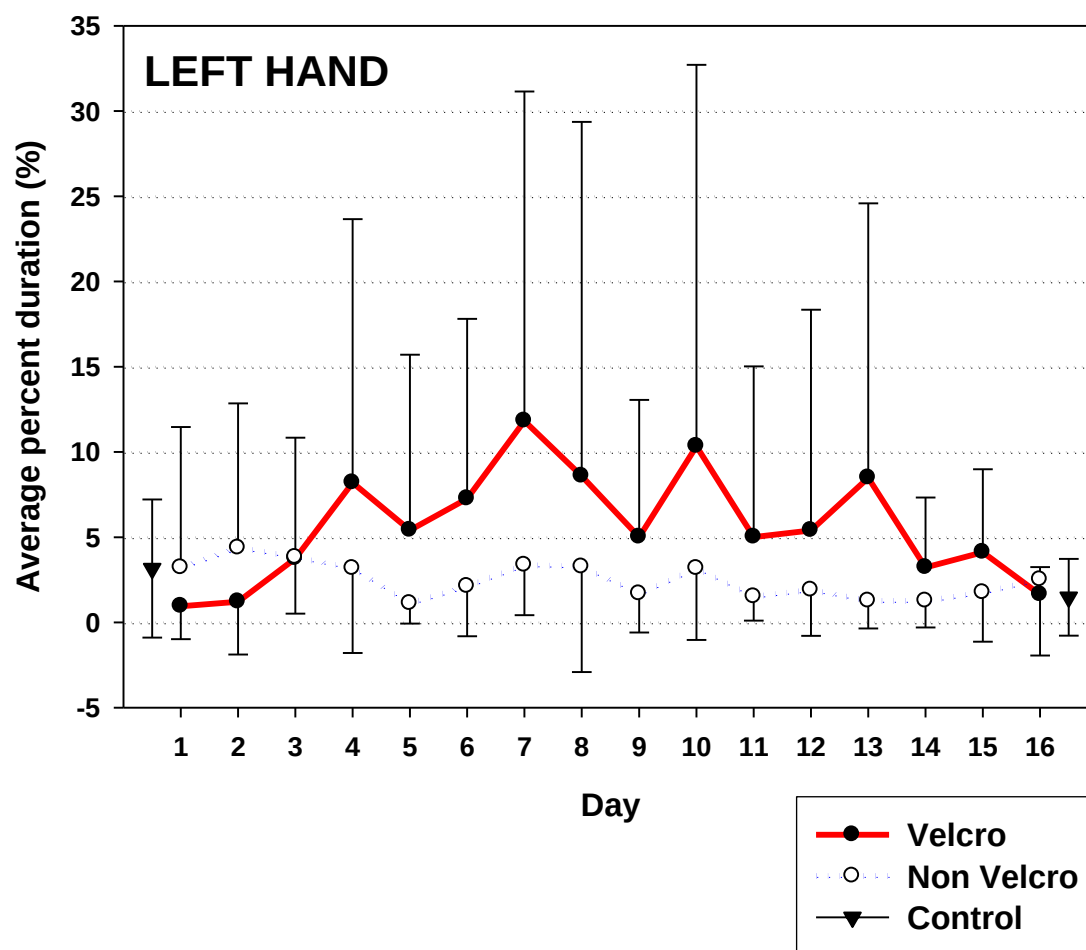


Figure A 11: Average percent duration spent looking at left hand

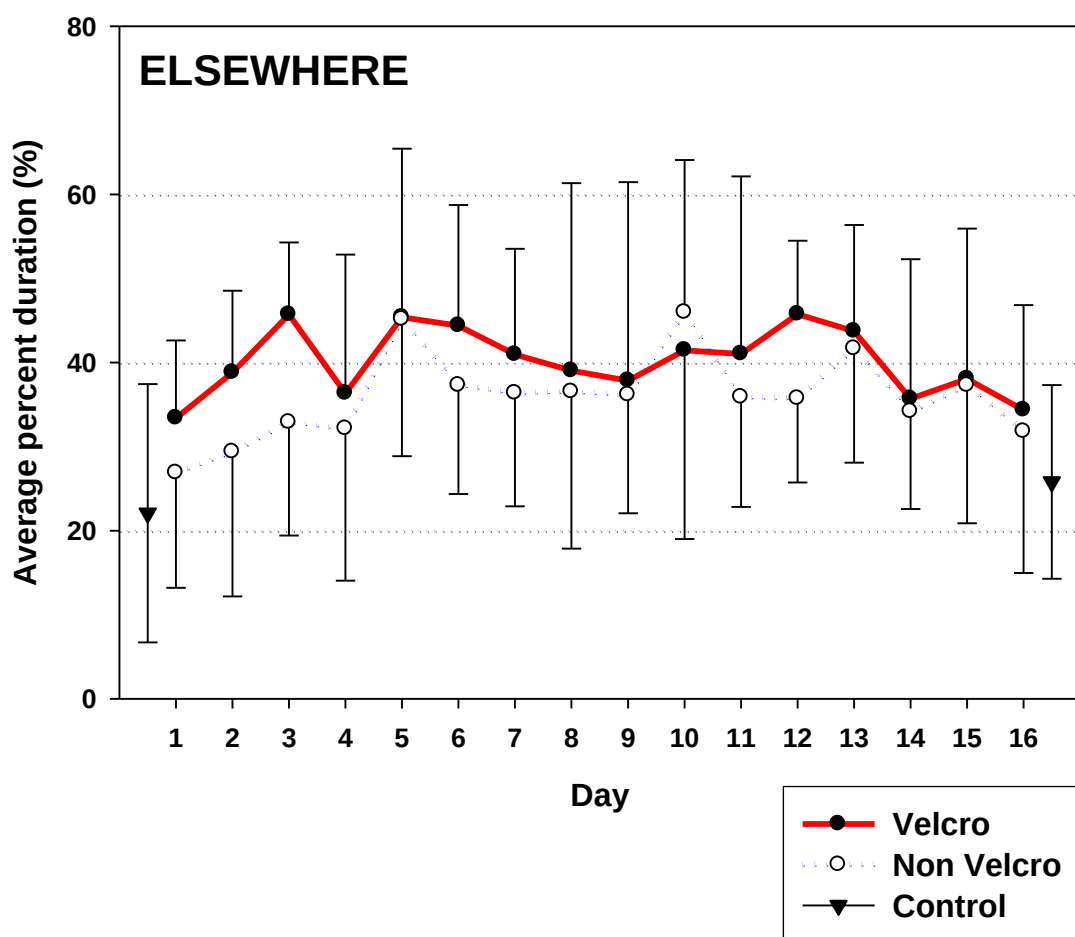


Figure A 12: Average percent duration spent looking elsewhere

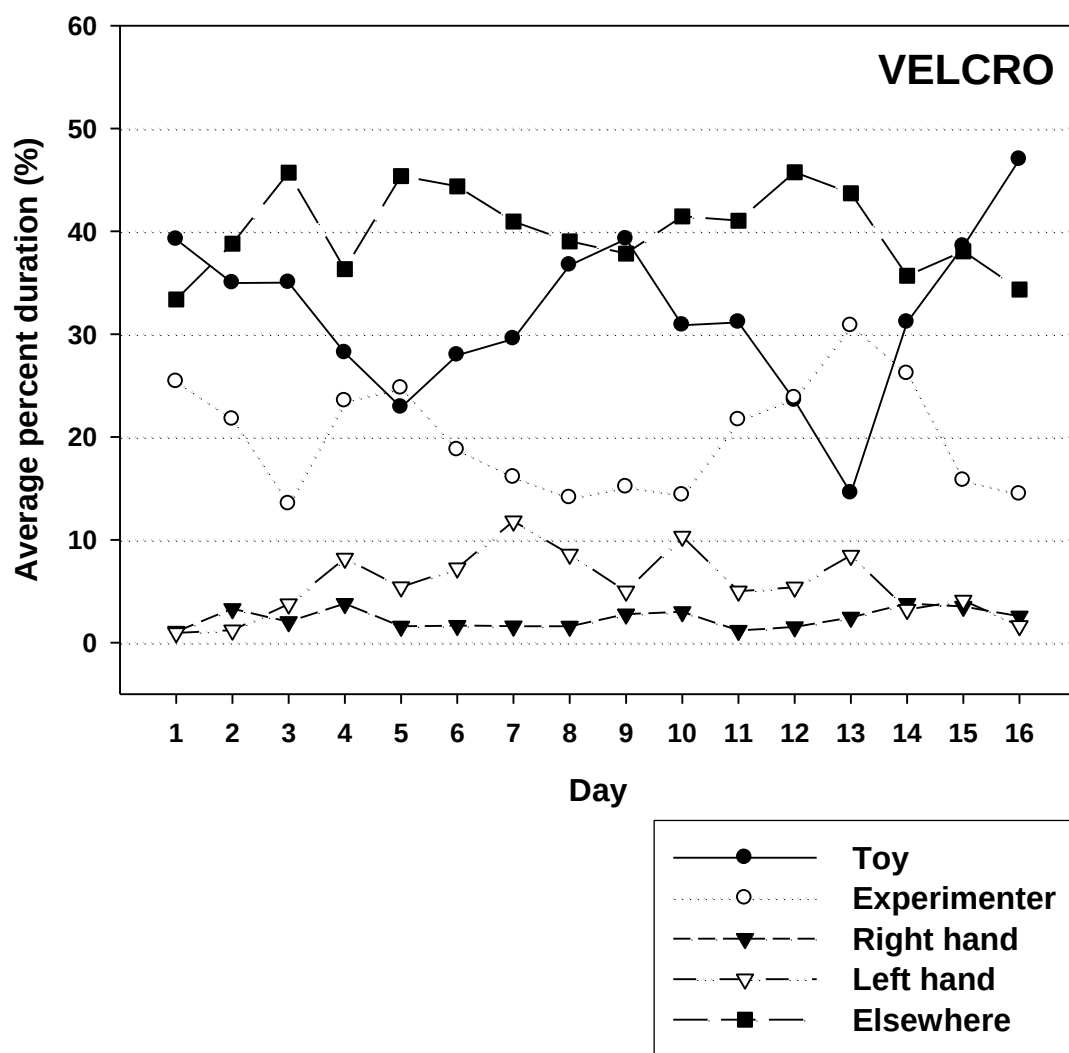


Figure A 13: Velcro average percent duration spent looking to the five categories

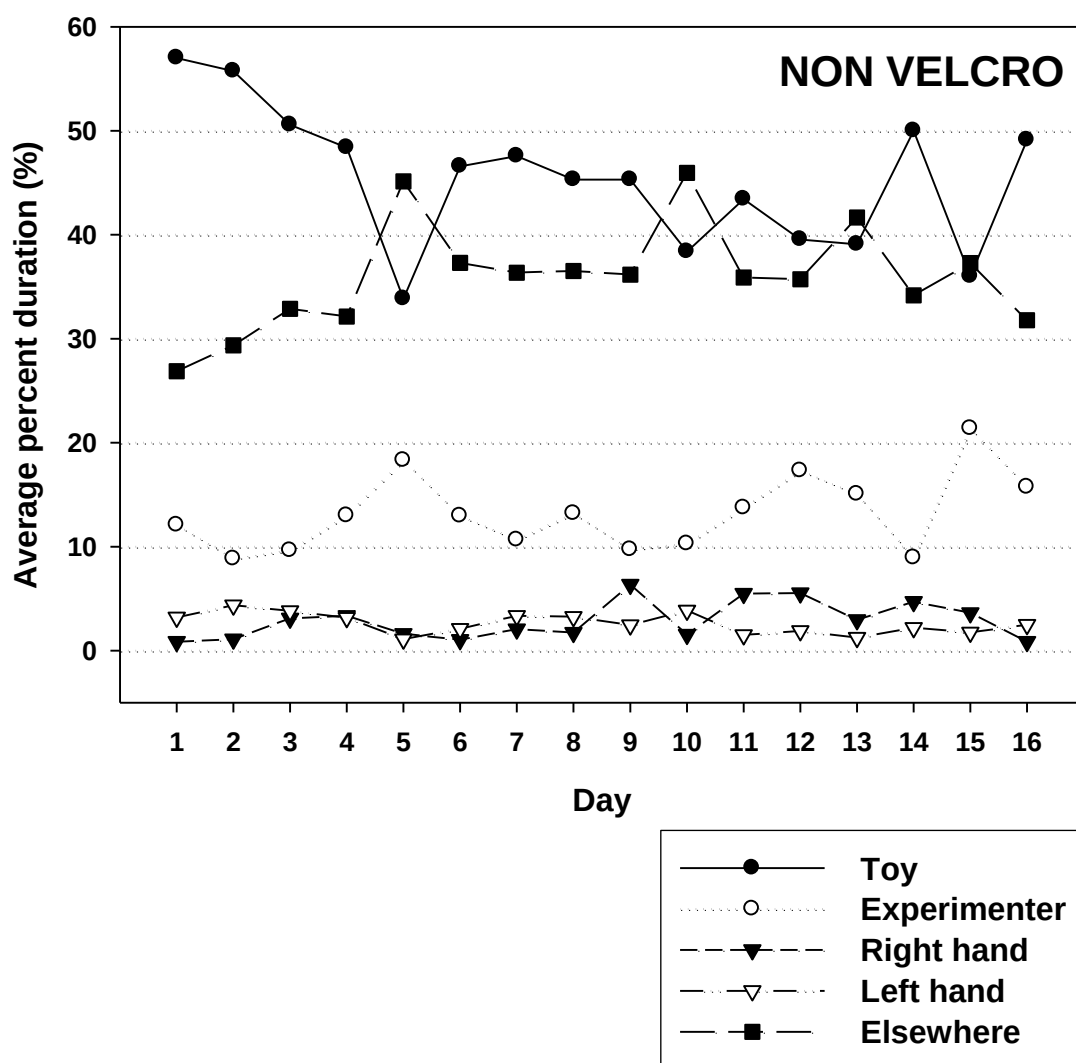


Figure A 14: Non-Velcro average percent duration spent looking to the five categories

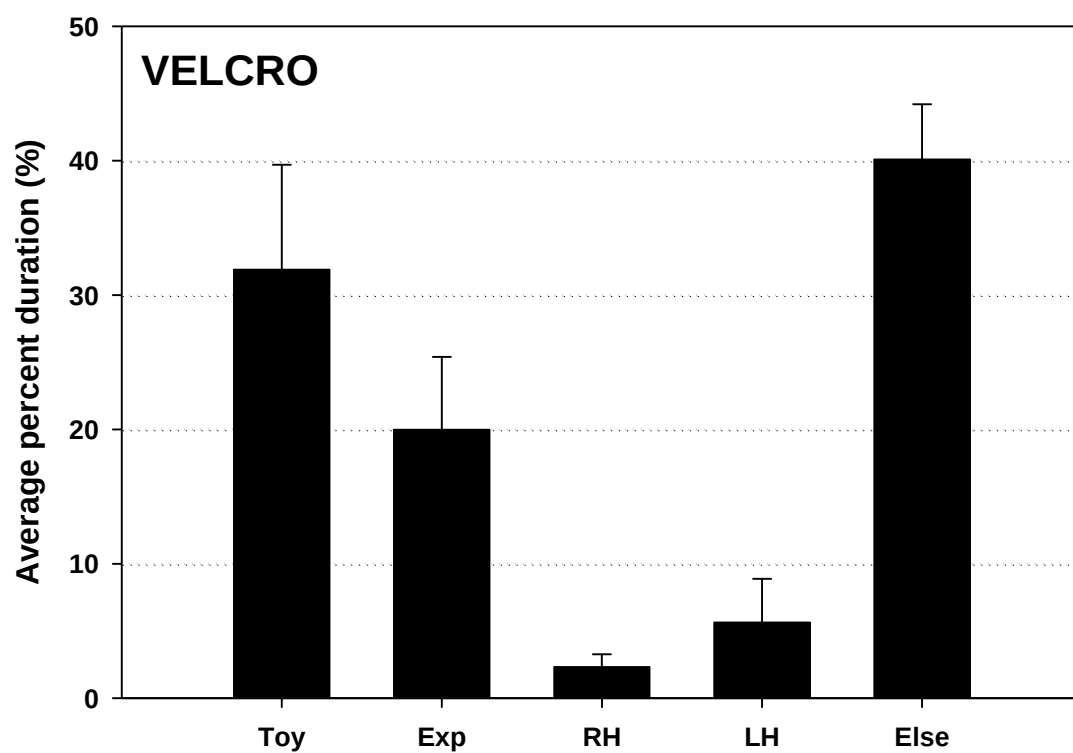


Figure A 15: Velcro grand average percent duration spent looking to the five categories

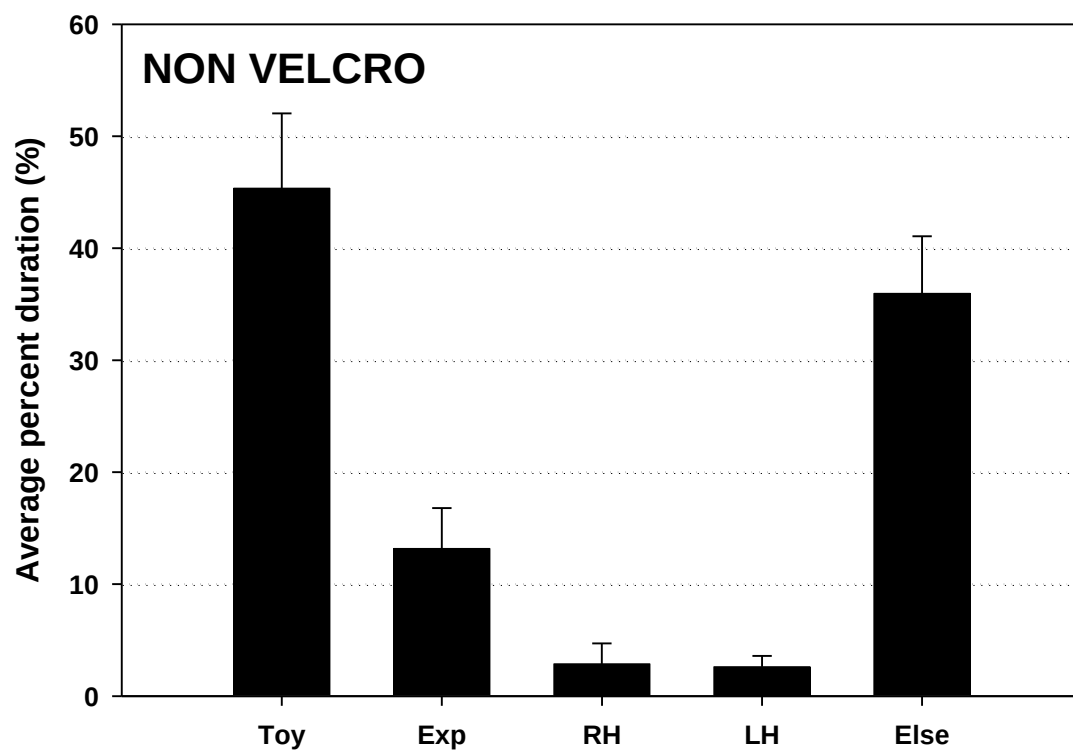


Figure A 16: Non-Velcro grand average percent duration spent looking to the five categories

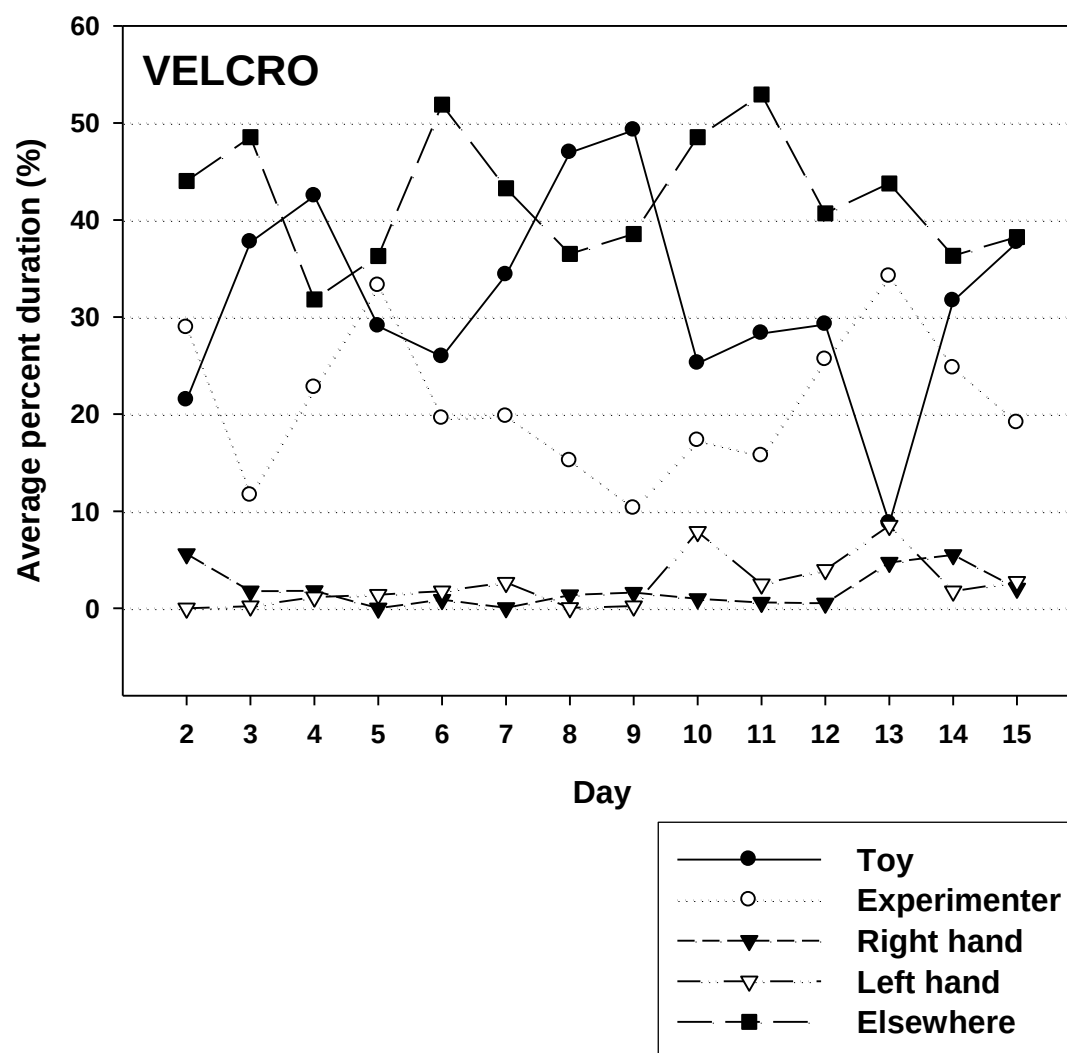


Figure A 17: Average percent duration spent looking to the five categories with toy stuck to Velcro mitten(s)

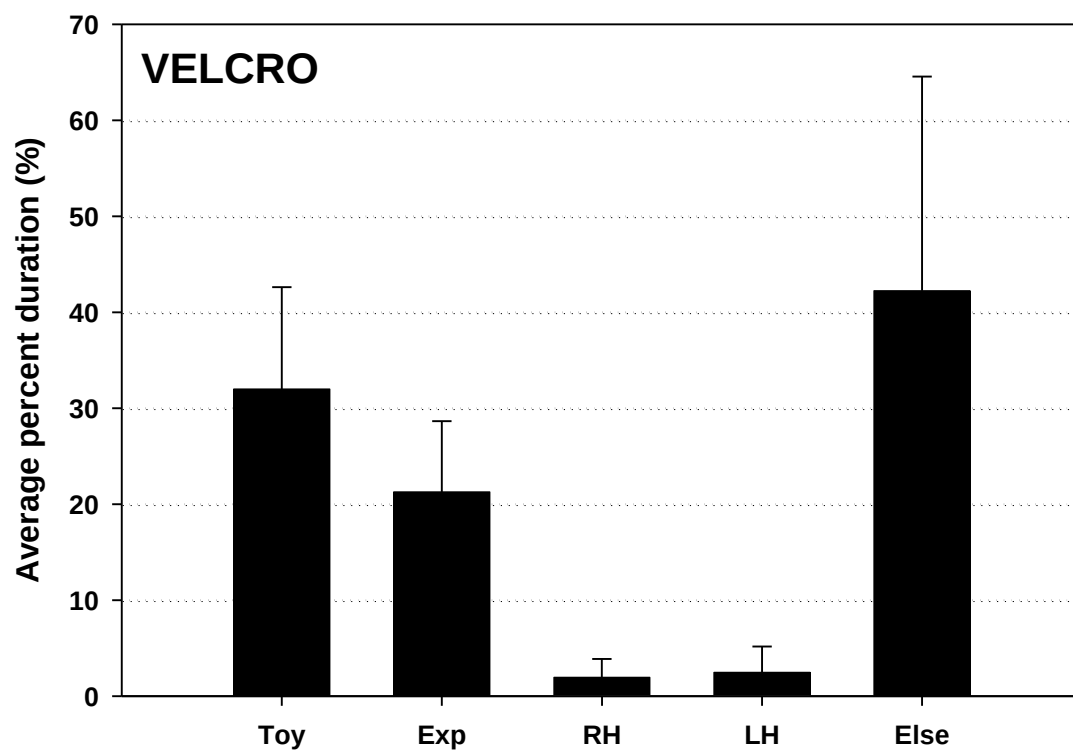


Figure A 18: Grand average for the percent duration spent looking to the five categories with toy stuck to Velcro mitten(s)

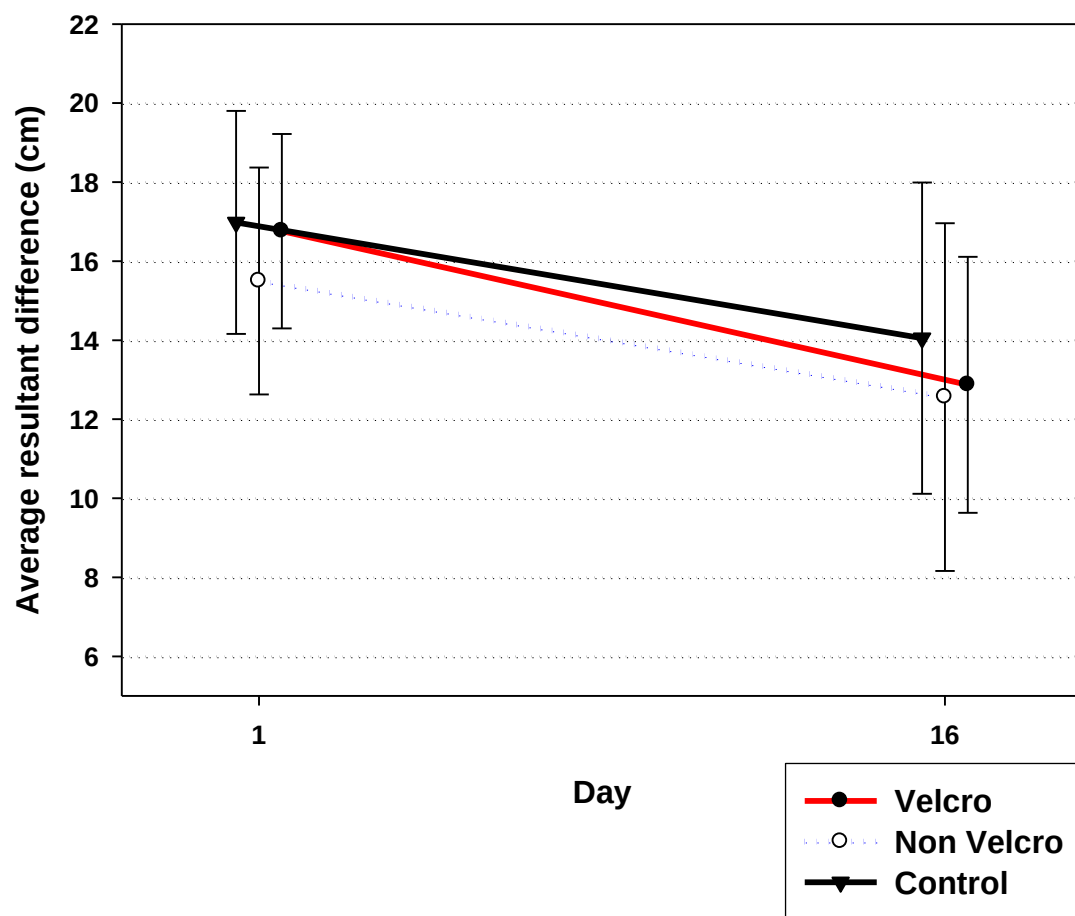


Figure A 19: Average resultant difference in hand-toy distance for the preferred hand by group for days one and 16

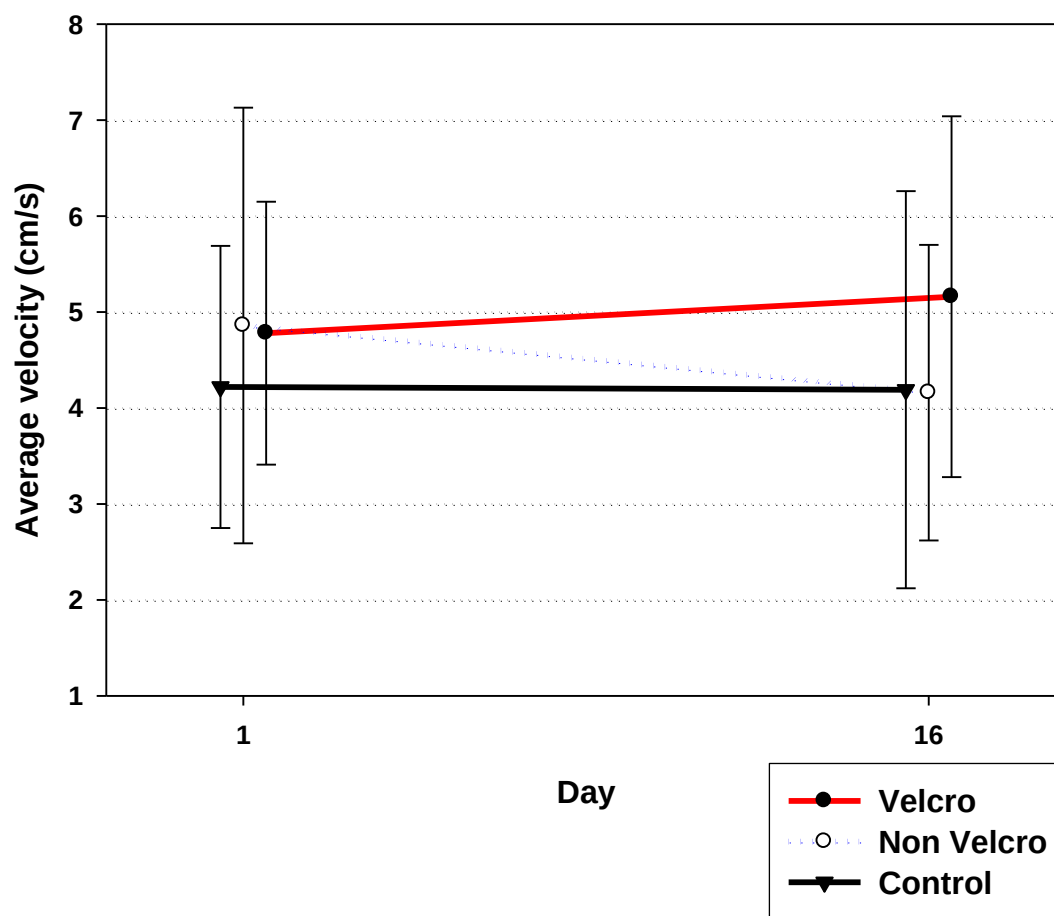


Figure A 20: Average velocity of the preferred hand by group for days one and 16

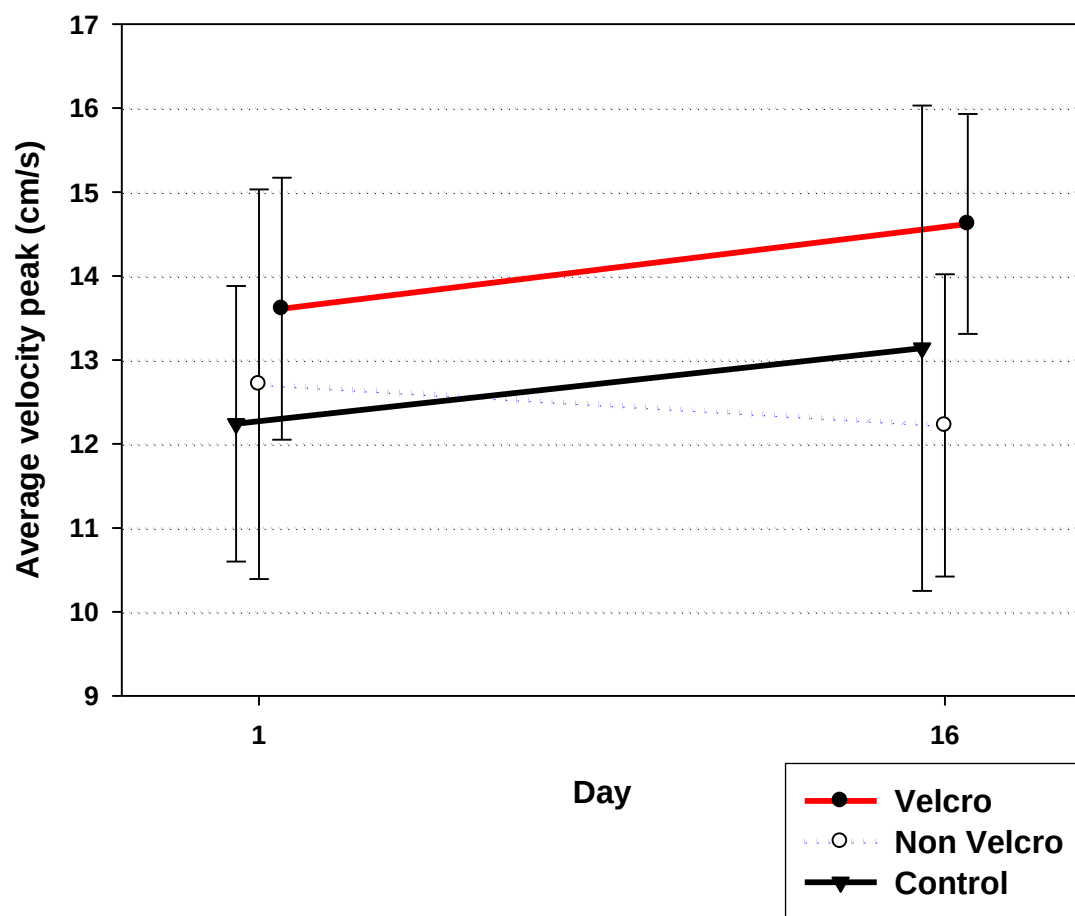


Figure A 21: Average velocity peak of the preferred hand by group for days one and 16

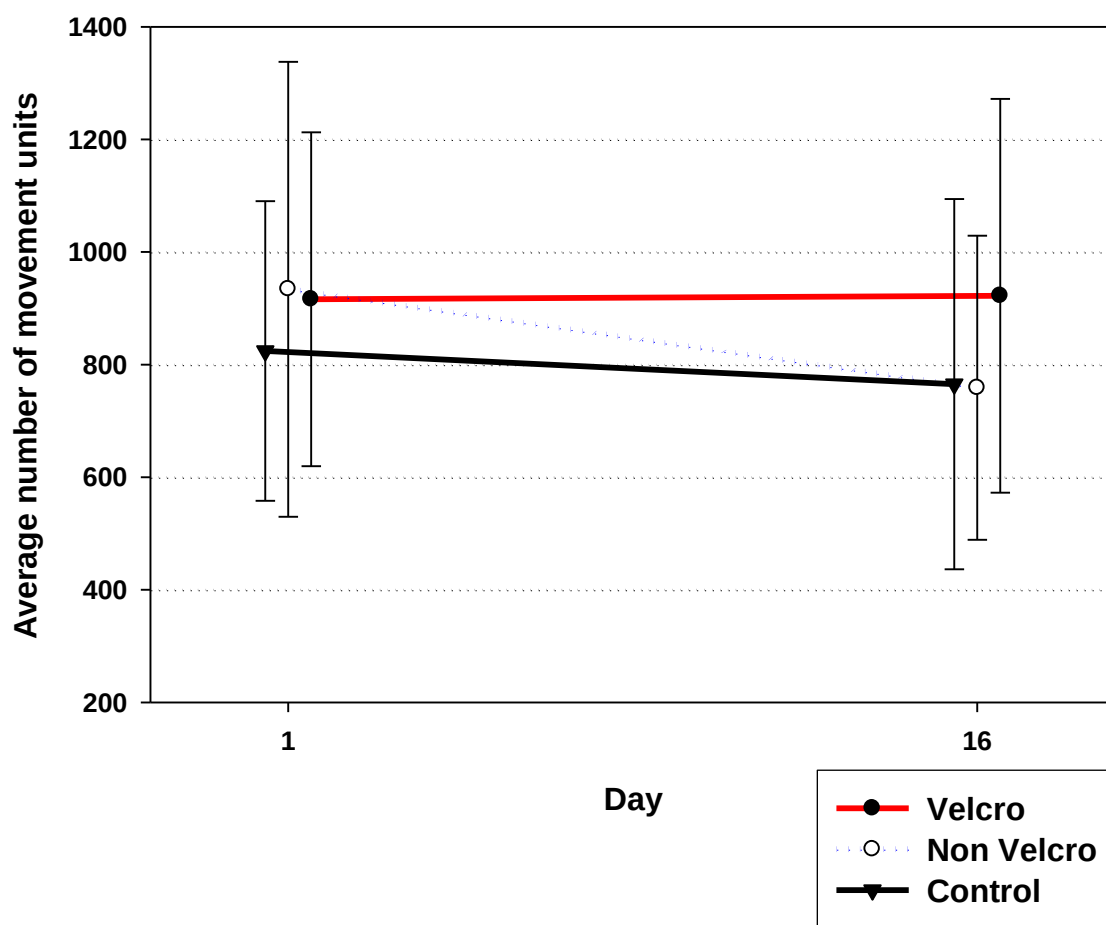


Figure A 22: Average number of movement units of the preferred hand by group for days one and 16

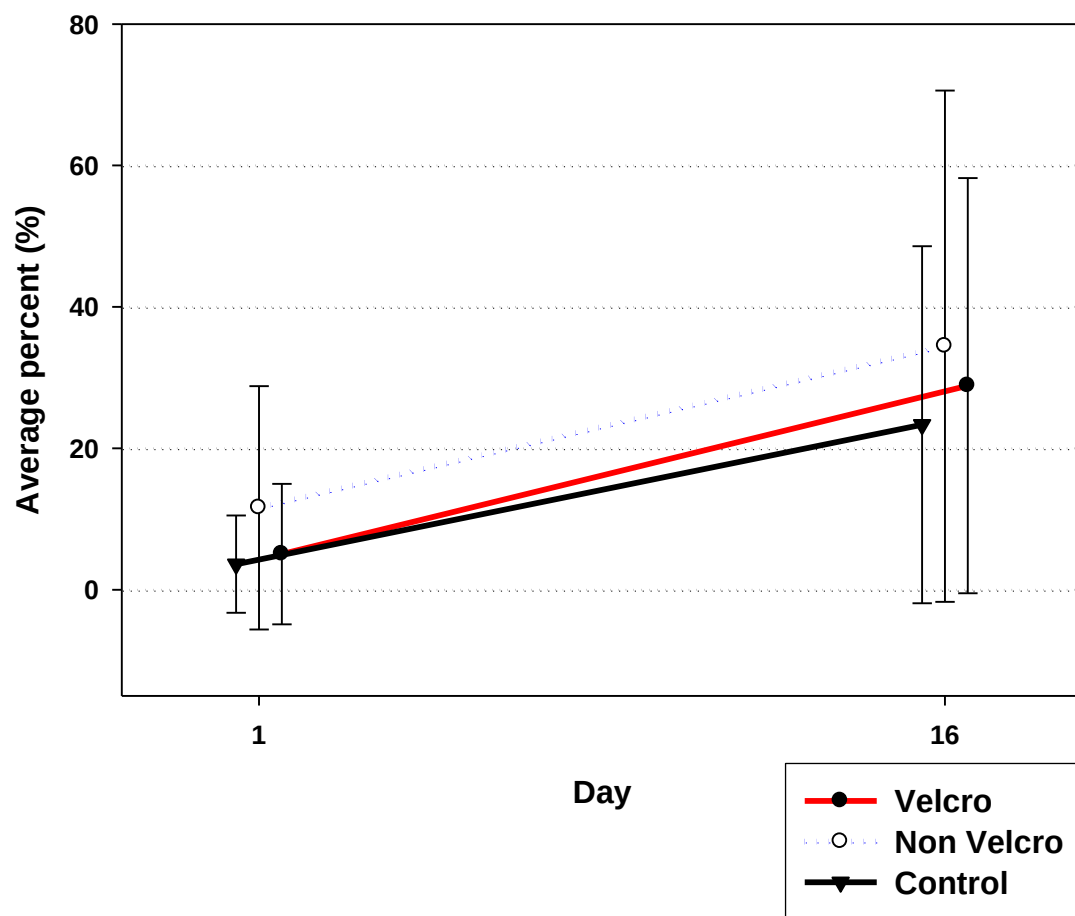


Figure A 23: Average percent of time preferred hand spent within 10 cm of toy by group for days one and 16

Vita

Joshua L. Williams was born in Indianapolis, Indiana on September 15, 1982. He was raised in Evansville, Indiana. He received a B. A. in movement and sport science from Purdue University in May 2004. He is currently pursuing his doctorate in experimental psychology with an emphasis in developmental psychology at The University of Tennessee, Knoxville.