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Going the Distance: Locomotor Choices in Crawling and Walking Infants

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LOCOMOTOR CHOICES IN CRAWLING AND WALKING INFANTS

by

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Little is known about infants' ability to make choices that vary along multiple dimensions. This research sought to describe strategies used by infants to direct their own locomotion in a multi-target environment. Infants repeatedly chose between pairs of objects that differed in distance and value. The choices made by crawling and walking infants were compared under two conditions: an experience-controlled, age-varied comparison and an experience-varied, age-controlled comparison. When experience was held constant, walking infants' choices did not vary with object distance while crawling infants preferentially selected close-by objects. When age was held constant, all infants' choices were distance-sensitive. The findings suggest that infants do selectively allocate their locomotion according to properties of the environment, but the relevance of the property of distance changes over development. The way that infants approach their environment has a shaping role in the choices they make and, consequently, the information and feedback available to them.

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Introduction

> For those researchers who view psychology as the study of behavior, motor development is the stuff of the science. (Adolph, Tamis-LeMonda, & Karasik, 2010, p. 269)

> Developmental studies ... describ[e] the initial state of the perception-action system, identify change and the emergence of new forms, and ... determin[e] the processes which engender these changes. (Thelen, et al 1991, p. 43)

The study of motor development is microcosm characterized by many fundamental principles shared across all developmental domains. Events are perceived, goals are defined, and actions are planned and executed under the guidance of perceptual information (von Hofsten, 2004). While the infancy period features rapid change in many areas, motor acquisitions are among the most striking. Over the course of the first year or so, infants undergo a metamorphosis. They develop from neonates unable to support their own heads or smoothly coordinate their eye movements, to infants able to use their trunk muscles to sit unsupported with arms free to reach towards intriguing objects. They eventually become walking toddlers, able to carry interesting items to others in order to initiate social interactions. As one might guess, this rich cascade of skill acquisition is accompanied by changes to all types of psychological domains, and these changes interact in interesting and sometimes surprisingly sophisticated ways. By studying the nature of particular events during this time of rapid motor learning, we may be able to garner insights about the nature of development and even about the way that psychological domains are coupled as children gain experience and proficiency in navigating and exploiting their environments.

Motor transitions are an especially rich target for analysis, as they allow us to examine how systems may interact. For example, Adolph and colleagues have shown an interaction between posture and the problem-solving that must be done to successfully navigate the edge of a slope. Experienced crawlers who can skillfully find their way down a steep slope lose this ability as they become novice walkers and must relearn handle the terrain in their new locomotor modality (Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008). Piaget (1954) proposed a theory of development characterized by the acquisition of skills in a stage-like, all-or-none manner. Adolph's work suggests that, instead, infants acquire skills in a context-dependent, softly assembled way. The presence and nature of a behaviour are subject to a variety of body-centric factors.

Another example of this context sensitivity in the world of motor research comes to us from the legendary Esther Thelen. Thelen and colleagues were interested in the mechanism behind the disappearance of the stepping reflex. Holding an infant upright so that his or her feet touch a surface will elicit alternating steps in infants up until approximately two months of age. After this age, the reflex disappears, and upright alternating leg movements are not seen again for many months. This "skill loss" was thought to be somehow developmentally programmed, perhaps through brain maturation. However, these researchers demonstrated that the stepping movement could be shown even by babies who had "lost" it by placing them in waist-deep tanks of water or on moving treadmills (Thelen, Fisher, & Ridley-Johnson, 1984; Thelen, 1986). This suggested that the stepping movement was in fact dependent on the possession of a strength to leg weight ratio that exceeded some set threshold. This finding was further buoyed by the result that small ankle weights eliminated the stepping reflex from infants who still possessed it (Thelen et al., 1984). The stepping reflex was described as grounded in properties of the infants' body, rather than being somehow neurally programmed to appear and disappear according to a progression through firm, all-encompassing developmental stages.

Research of this type reminds the reader that complex skills are sensitive to the coupling of the body and the environment at all points and this motoric "context" must be part of our understanding of their behaviours and abilities. Motor behaviours (like the stepping reflex or negotiating a steep slope) do not proceed in a linear, invariant way but rather are multiply determined and sensitive to context.

Motor development is "at the heart of development" (von Hofsten, 2004). The study of movement, especially motor transitions, reflects larger aspects of developmental change, including perception, planning, and motivation. The third member of that list, motivation, is perhaps the most understudied of the three and will form a large part of the basis of this work.

Motivation: Studies and Theories

> The role of motivation is an important but neglected field of study in motor development. Do motives precede or do they simply accompany important transitions in motor development? To what degree can motivational factors in perception and action be accounted for in terms of an instinct to explore the opportunities provided by the environment and the acting self? (von Hofsten, 2004, p. 271)

The role of motivation in guiding infant behaviour is difficult to study empirically. One of the difficulties in working with infants and young children is that they are unable to verbally report on their internal states. Measuring internal states is a methodological issue across all of psychology, of course, as the validity of self-report measures is difficult to ascertain. Developmental researchers have devised alternatives to self-report in a number of inventive ways, including (but not limited to) employing visual habituation measures to determine the types of categories that infants can recognize (Fantz, 1964) and violation-of-expectation paradigms to understand the rules infants expect events to follow (Kellman & Spelke, 1983;

Hamlin, Wynn, & Bloom, 2007). However, a procedure for quantifying infants' motivation to pursue a course of action is still absent from the science. This omission makes it difficult to review the literature relevant to our knowledge of the role of motivation in infants' experiences. However, there are still a number of studies that can clarify our thinking about motivation in infants engaged in motor tasks. These readings originate from a number of sources including animal, infant, and adult literatures, but all will follow the common theme of informing our thinking about how motivated infants might organize their behaviour. Several studies that examine the role of infant motivation in shaping their action will be described, and two bodies of theory from outside developmental psychology will be discussed with regard to their applications to this research question.

Motivation and infant action.

> Internally generated motives are crucial for the formation of new behaviour and the maintenance of established behaviour patterns. (von Hofsten, 2004, p. 267)

One study that experimentally manipulated infants' motivation to locomote was performed by Adolph et al. (2010). These authors instructed mothers to either encourage or discourage their infants from travelling over a sloped surface while wearing slippery Teflon-soled shoes or non-slippery crepe-soled shoes. They found that 18-month-old infants selectively used the information from their mothers’ instructions about whether to proceed only under conditions of uncertainty. Therefore, social information from the mothers was salient to infants' motivation to walk only under conditions of where infants did not know whether they could successfully navigate a surface. When infants were certain that they were able to cross a surface successfully, social information was irrelevant to their motivation to do so.

In contrast to this example of a study that externally manipulated infant motivation, studies of internal motivation (or "preferences") are relatively rare. This is understandable because spontaneous preferences are difficult to interpret and are a relatively abstract concept. We can define a preference for one item over another as a difference in the degree to which infants are motivated to seek out or interact with one item versus the other. Thus, we can think of preference as a (presumably) stable expression of an internal motivational state, directed towards objects.

A few factors thought to shape infants' spontaneous object preferences have been investigated. One such factor is object novelty or familiarity. Willatts (1983) familiarized 6- and 12-month-old infants to trays of objects, then presented some familiar and some novel objects for exploration. He found that 6-month-olds fixated more on novel objects but manipulated both types equally, while 12-month-olds both fixated and manipulated the new objects more frequently. In this study, then, infants seem to show a novelty preference in their looking behaviour at both ages and in their manual exploration at 12 months. Similarly, Schaffer and Parry (1970) found that at both 6 and 12 months, fixation on an object decreased as the object was presented repeatedly. These studies taken together suggest that preference for an object tends to decrease with the increasing familiarity with that object. The preference for novelty also leads infants to selectively enter rooms with larger numbers of novel objects (Ross, Rheingold, & Eckerman, 1972; Ross, 1974).

However, novelty is not the only feature possessed by the real-life objects that infants encounter. Complexity is another potential factor that could play a role in infants' preferences. Eleanor Schneider (Schneider, 2009) videotaped infants at 10, 12, and 14 months while engaging with novel objects. She found that even at 10 months, when all objects are novel infants show a preference for toys that are interesting, engaging, and challenging.

Adam Sheya and Linda Smith (Sheya & Smith, 2010) performed a preference measurement task closely mirrored by the current research. They asked: how do infants select among multiple targets when directing their reaches across a complex array of objects? They refer to research suggesting that individuals direct their hands using "priority maps" that in adults can be modulated by factors like the context of the task, remembered past events, similarity of objects within the set, the possibility of reward, goals in the task, and the physical distinctiveness of the objects. They reported that 12-month-old infants directed their reaches primarily according to objects' location rather than their properties. Children in the middle age group (15-months-old) were particularly likely to reach to majority rather than minority objects. The older children (18-months-old) were the most sophisticated, and sequentially reached to objects that were alike (employing "classification"-type acts).

In summary, then, previous research concerned with infants' spontaneous, internal preferences has found that infants prefer objects that are novel, engaging and challenging. The way their motivation guides their reaching behaviour is age-dependent, and moves from being location-driven at 12 months to object property driven at 18 months.

Bodies of theory. There are no bodies of theory within developmental psychology that explicitly make predictions regarding the role of motivation in guiding infant actions. However, the issue has been considered by other fields, and developmentalists can benefit from their insights. Two major bodies of work, one from adult decision-making and one from ecology, will be outlined and their implications for development discussed.

The first body of work that examines how adults organize their behaviour with respect to the goal of maximizing gain is delay discounting. This literature describes how adults make choices when their options differ on two or more dimensions (for a review see Green & Myerson, 2004). While it makes both evolutionary and economic sense that individuals prefer high- rather than low-value objects and immediate rather than delayed rewards, these two dimensions interact in interesting ways when both vary within the same choice set. Research demonstrates that a reward may be viewed as less preferable or "discounted" as the delay in receiving it increases (Ainslie & Herrnstein, 1981). This discounting can lead to preference reversals - changes in which choice is preferred as the delay of one or both choices changes. The typical example of this is the presentation of a choice between two rewards: one larger and one smaller. If the small reward is available much sooner than the large reward, it may be preferred (e.g. $100 now vs. $120 in one month). However, if the difference in delay between small and large rewards remains constant, but an equal amount of time is added to both (e.g. $100 12 months from today vs. $120 13 months from today), the preference may be reversed. Such preference reversals have been demonstrated in pigeons (Ainslie & Herrnstein, 1981), rats (Green & Estle, 2003), rhesus monkeys (Hwang, Kim, & Lee, 2009), among human adults (Madden, Begotka, Raiff, & Kastern, 2003), and among special populations such as smokers (Bickel, Odum, & Madden, 1999). Tolerance to a delay in gratification (i.e. an individual's discounting rate) is related to impulsivity and emotional self-regulation (Stolarski, Bitner, & Zimbardo, 2011). Studies on discounting and role of delay have been performed in children as young as two and three years-old (Green, Myerson, & Ostaszewski, 1999; Mischel, Shoda, & Rodriguez, 1989; Olson et al., 2009; Steelandt, Thierry, Broihanne, & Dufour, 2012), but the author is aware of none that examined infants under two years of age. The open question is as follows: are infant preferences also sensitive to multiple dimensions of object features?

The procedure used in the current studies may be thought of as a series of choices that vary in two dimensions: value (as determined by "raw" preference when objects are presented at equivalent distances) and distance. Since it takes time to cover a set amount of distance (especially if one is inexperienced at locomotion), this difference in distance also represents a delay in time. Therefore, conditions in which a higher-value object is also further from the infant are candidates for discounting. This principle allows for the generation of certain predictions about infant behaviour during this procedure. In the current studies, a differential preference between pairs of objects was used as an index of motivation. Based on the previous delay discounting research, we might expect to see evidence of preference reversals.

The second body of work that deals with individuals organizing their behaviour around a motivating goal is foraging theory, originating in ecology. Identifying a set of behaviours that will maximize some kind of reward or gain with a limited amount of time or energy is a problem that has been tackled by foraging theory models (MacArthur & Pianka, 1966). In these models it is assumed that natural selection should push foraging organisms to behave in a way that approaches this optimal set. There are numerous models that seek to describe this set with respect to the inclusion of a certain number of resource "patches" (MacArthur & Pianka, 1966), residence time per patch (Charnov, 1976), or a central place (Brown & Orians, 1970). Such strategies are demonstrated by foraging animals (Andersson, 1981) and in adults searching for information (Pirolli & Card, 1999).

Specific foraging models rely on a number of assumptions (e.g. encounters with patches happening in sequence) that are not met by the procedure that was ultimately used in this research. This means that the elaborate equations derived in these models cannot be directly applied to the current results. However, the underlying concept of maximizing gain relative to expenditure may still carry over. If it is still assumed that infants will employ strategies that maximize gain (i.e. interaction with an interesting toy) relative to energy expenditure in order to determine where to travel, then relevant predictions can be made about behaviour in the proposed study.

Delay discounting and foraging theory are alike in that they both describe ways in which individuals might make choices in order to maximize their gain relative to a cost. In delay discounting, that cost is calculated in terms of delay, while in foraging theory this cost is typically represented as a distance an animal must travel between patches or risk that predation will be unsuccessful. The current studies are informed by these ways of thinking because they too ask infants to make choices that have both gains (engagement with an interesting toy) and costs (distance, bringing with it both effort and delay) associated with them. The specific predictions that can be drawn from reflection on these bodies of theory will be discussed in the Research Questions (p. 27).

In summary, the role of infants' internal motivational states in shaping their motor behaviour is a relatively under-described topic. The current studies hope to begin to address this gap. They will examine the role of internal motivation in determining the allocation of motor behaviour in a sample of infants who are either crawling or walking. Predictions gathered from consideration of the delay discounting and foraging theory literatures will be evaluated.

Thus far, the literature we have considered has all centered on the way infants' motivations may relate to objects of interest. The role of infants' motivation directed towards objects, however, may not be the only factor that shapes the way they direct their locomotion in the current studies. The role of the space itself in infants' exploration should also be considered before predictions can be made. Next, literature concerning infants' organized, exploratory behaviours in space will be considered.

Directed Exploration

Learning about affordances entails exploratory activity. (E. J. Gibson, 1988, p. 5)

The idea of identifying the affordances of an environment originates with J.J. Gibson (1977). Affordances are what the environment allows an actor to do, the "action possibilities" that exist for a given object or space. As infants gain new skills, new action possibilities become available to them, and they come to perceive them through exploration (E. J. Gibson, 1988). As infants' environments gain affordances across the progression of development, the movement choices available to the infant increase.

A movement can be thought of as a choice if it is performed non-randomly with respect to some goal state. This way of thinking about choice does not necessitate movement of the whole body. The coupling of motor control and choice can be observed at fine levels such as control of individual body parts. Even if the location of the whole body is not within an individual's control, the position of the head, torso, or limbs may be. Evidence suggests that on this smaller scale, this pairing of motor control and intentional choice is present for humans even at birth. For example, van der Meer found that newborn infants would resist a pull on their arm that would remove that arm from view (van der Meer, van der Weel, & Lee, 1995), and spontaneously produce arm movements that keep their hands visible in a beam of light (van der Meer, 1997). These movements, then, are non-random with respect to the goal state of illumination, and we can therefore think of them in "choice" language. The fact that newborn infants have multiple arm positions available to them, have sufficient motor control to select arm positions, and do so according to certain desirable properties of those positions (i.e. positions in which the hands are visible and illuminated) supports the characterization of these movements as choices. These very young infants are exploiting the fact that their environment affords them the possibility of illuminating their hands.

Exploration in infants looks very different as children develop. At a young age, exploration is based on watching and listening. Older infants can reach for, grasp, and manipulate objects, while self-locomoting infants have even more methods at their disposal to investigate objects or people of their choosing (Ross, 1974). Literature dealing with infant exploration of their environment through their motor choices across early development will be described.

Eyes. The earliest emerging motor choice frequently measured by developmental researchers is movements of the eyes. Infants will look towards the remembered location of a non-visible item or in anticipation of an event. Work has examined infants' competency in guiding these looks across a variety of conditions including those with single landmarks (Lew, Bremner, & Lefkovitch, 2000), delays (Schwartz & Reznick, 1999), and changes in the baby's location (see Acredolo, 1990 for a review of her lab's work in this area). Infant look responses in these types of studies are generally characterized as predominantly egocentric from 6-11 months, shifting to reliance on single landmarks from 11-18 months and finally using a more adult, map-like representation at approximately 18 months (Acredolo, 1990).

The assumption that infants make choices about where to direct their gaze is also foundational to the group of looking time paradigms. Gaze is assumed to be directed by the infant based on features of a target, such as its novelty or familiarity (Fantz, 1964), or the infant's (inferred) expectations about the target's properties or behaviours (Kellman & Spelke, 1983;

Hamlin et al., 2007). The infant’s volitional control over their own eye movements was assumed in this field from early on; Horowitz, Paden, Bhana, and Self (1972) even designed a procedure that presented stimuli in a presentation schedule controlled by the infant’s looks.

Infants' looks while exploring may also be social in nature. A study by Mayes, Carter, and Stubbe (1993) let 15-month-old infants explore a dresser with 15 clear drawers in an unstructured way. These authors examined infants' looks to mother while performing their exploration. They found that infants tried to involve their mothers in their exploration frequently and in many ways ("bidding" by holding up objects or bringing them to the mother, looking to mother).

Arms and hands. Other studies have used infants' volitional arm and hand movements as a behaviour of study. Manual search strategies used to search for partially or fully occluded objects have been used as a staple index of infant knowledge about non-visible objects in developmental psychology since the foundational work of Jean Piaget (Piaget, 1954). In Piaget's initial formulation of the classic "A not B" paradigm, the child repeatedly witnesses an object being hidden in one location ("location A") and retrieves it. Then, the object is hidden, still in view of the child, at a second location ("location B"). Children between the age of seven and twelve months then typically make an error: they search for the hidden object at location A even though they witnessed its movement to location B. Manual search in object permanence tasks has been the subject of a staggering amount of investigation (see Smith, Thelen, Titzer, & McLin, 1999 for a review), that I will not review here but I will simply emphasize that the infant's desire and ability to direct their own hand towards the location of his choosing is the foundational assumption of this type of work. Of course, directed hand movements are employed by infancy researchers outside of this paradigm frequently and in varied situations. A few instances of such examinations are: directed hand movements in the presence of barriers (Moore & Meltzoff, 2008), in the absence of light (Bower and Wishart, 1972), in reference to future goal movements (Claxton, Keen, & McCarty, 2003) and towards moving targets (von Hofsten, 1980) as well many other examples.

Whole body. The body of research most directly related to the work performed for the current studies, however, focuses on the use of full body travel as the unit of study. Such work can be done both with animals (Nadel, 1991; Sutherland, Whishaw, & Kolb, 1983) and of course with infants. Since whole body exploration is typically done by crawling and walking, these studies will be reviewed exhaustively in the upcoming section. Two short examples will be listed here.

First, Ross (1974) performed a simple experiment that used a controlled set of object locations. She placed 12-month-old infants on the floor of a room with two rooms adjacent to it: one containing novel toys and one containing familiar toys. She found that three factors influenced infants' exploratory behaviour: familiarity of the toys, their complexity (i.e. their number), and the familiarity of the rooms. All three factors had an effect on infants' exploration. Infants spent the most time with novel, complex objects in a novel room.

Second, Adolph et al. (2012) examined periods of unstructured exploration in complex environments for the purpose of quantifying early walking experience. This group found that locomotor experience from 12- to 19-months is vast, and averages over 2000 steps and 17 falls per hour. This particular study did not examine the targets of infant exploration.

The topic of the current research could be characterized as being interested in infants' self-directed exploration of a complex, object-populated space. Describing how children guide their own exploration in the presence of complex environments is crucial for understanding how children perceive and acquire new actions and thus develop their behavioural repertoire. Exploration provides a rich bank of opportunities for infants to develop strategies by making choices based on their preferences, which may themselves be context-sensitive depending on multiple factors.

Research examining infants' directed exploration using a variety of motor movements has been described. Infants make motor choices that allow them to explore their environment from birth, including eye, hand, and whole body movements. Interestingly, the type of movements that infants are performing plays a huge role in the information they can gather from their environment, the way they are perceived by others, and their developmental progression. The role of motor skill acquisitions as these type of "setting events" will be discussed next.

Motor Changes Act as Setting Events

> Locomotion is a setting event, a control parameter, and a mobilizer that changes the intrapsychic states of the infant, the social and nonsocial world around the infant, and the integration of the infant with that world. (Campos et al., 2000, p. 151)

Developmental transitions disrupt established couplings of skills across psychological domains and allow for rich analysis and theoretical insight. Focused studies on key transition periods allow researchers to examine larger principles guiding development as well as some of the causal relationships that are experimentally opaque once solidified. Major skill acquisitions have effects that reach far outside their own domain of development. Reaching and manual exploration, independent sitting, crawling, and walking are some of these key "mobilizers" that change the relationship of the infant with its world.

Reaching and manual exploration. Use of the hand and arm to obtain and explore objects are crucial movements to the young infant as he or she builds an understanding of his or her world and the actions it affords. As infants become able to perform more and more elaborate movements to explore objects, they are able to perceive new object properties (Bushnell & Boudreau, 1993). For instance, infants are able to perceive the temperature of objects through static contact before they are able to perceive the weight of objects, which requires unsupported holding and is later to emerge.

Progression in reaching and manual exploration skills is associated with skill acquisitions and changes across a variety of psychological domains. Some of what we know about what infants learn from manually manipulating objects comes from the "sticky mittens" paradigm developed by Amy Needham. In this set-up, infants wear mittens with Velcro palms, and are able to pick up Velcro-covered toys by batting or swiping at them. The special mittens therefore allow infants to receive visual feedback that is contingent on their manual movements of objects even at an age where they would not be able to successfully grasp and hold the objects unaided. Sticky mitten experience has been shown to enhance performance of 3-month-old infants in forming expectations about actors' goals (Sommerville, Woodward, & Needham, 2005), in engaging with and exploring objects in sophisticated ways (Needham, Barrett, & Peterman, 2002), in spontaneous orienting towards faces (Libertus & Needham, 2011), and in developing more advanced reaching behaviour and visual exploration of agents and objects presented live but not while televised (Libertus & Needham, 2010). Reachers look at their mother's face more than non-reachers do, and this effect interacts with their postural position (sitting, reclining, or supine) (Fogel, Dedo, & McEwen, 1992).

While manual exploration and reaching are rich research areas in their own right that could be explored much more thoroughly (see von Hofsten, 1980, 1982, 1991; Sacrey & Whishaw, 2010; Sacrey, Karl, & Whishaw, 2012 for additional examples of the breadth of reaching as a research area), we will continue on our brief tour of motor milestones and examine independent sitting.

Independent sitting. As mentioned in the previous section, infants' postural position (sitting, reclined, or supine) interacts with reaching ability to shape the frequency of their looks to their mother's face (Fogel et al., 1992). The ability to sit independently has ramifications for the way that infants execute their emerging reaching abilities. Infants who can sit on their own are also able to coordinate a reach with forward leaning of their trunk, while non-sitters cannot link these movements. However, if non-sitters are given extra hip support, they begin to be able to perform this trunk-reach pairing. The ability to coordinate the trunk with the reaching arm has real-life benefits to infants, as it allows them to expand the space into which they can successfully reach (Rochat & Goubet, 1995).

Independent sitting is associated with the fine-tuning of several other skills. Bertenthal, Rose, and Bai (1997) found that as infants learn to sit, they are able to more precisely coordinate their visuomotor system in order to scale their posture according to peripheral visual information. To demonstrate this, they used a "moving room," that gradually swayed back and forth around the infant. If infants are able to make appropriate postural adjustments based on visual information, they are tricked by the moving room and make postural changes. The extent to which they can make these adjustments can then be used as an index of their ability to coordinate visual information with postural control.

So to infants, the milestone of independent sitting is able to literally expand their reach and, by extension, the area around themselves in which they have control. The next few motor milestones they attain will exponentially increase this "sphere of influence" as they become able to self-locomote and will have equally large effects on all domains of the infant's experience of objects, people, and the larger world.

Crawling.

> What happens to a child's intellectual growth when his physical growth enables him to enlarge his scope of observation on his own? (E. J. Gibson, 1988, p. 3)

The important role of self-produced locomotion in shaping mature behaviours has been documented ever since the foundational experiments of Held and Hein (1963) using the "kitty carousel" paradigm. In this work, Richard Held and Alan Hein used a yoked-control study design to examine whether sensory feedback's contingency on self-produced movement was required for kittens to learn to extend their paws as they were carried down to the edge of a table (visually-guided paw placement), to avoid an apparently deep cliff (height discrimination), and to blink in response to an approaching object. The researchers placed pairs of darkness-reared kittens in a situation where the active kitten pulled the passive kitten in a "gondola" around a lighted circular enclosure for three hours daily. This controlled set of visual experiences provided the active kitten with movement-contingent visual experience, while the passive kitten received the same visual experience without the movement contingency. The authors found that active, but not passive, kittens succeeded on all three tests of visual guided behaviour. This work demonstrated that self-produced movement with concurrent visual feedback is crucial for the development of mature vision-based behaviours.

Once established, the question of how independently mobile individuals differ from stationary individuals in terms of cognitive development has persisted in inspiring new research. The onset of crawling brings with it large-scale changes to the infant's experience. A large review by Campos et al. (2000) describes many of these changes. These authors argue that self-produced locomotion acts broadly as an "agent of transition" across social, emotional, spatial, and perceptual domains. The effects of the onset of self-produced locomotion are significant and widely penetrating across psychological domains.

As infants begin crawling, they learn about the mobility of their own body (Adolph & Robinson, 2008). By extension, infants also gain experience seeing the same scene from multiple viewpoints. This experience reduces the usefulness of previously successful egocentric coding strategies in which infants remember the location of an object based on its relationship to their own body (Acredolo, 1990). Encoding an object's location as "to the left" is more useful when stationary than when moving around the environment. Visual tracking of objects therefore increases in prominence across this period. Acredolo, Adams, and Goodwyn (1984) demonstrated that 12-month-olds (relatively new to self-locomotion) tended to visually track a target as they moved, while 18-month-olds (who were relatively experienced at self-locomotion) visually tracked an object significantly less while moving, presumably because by this point mental representation has become adequately sophisticated.

Horobin and Acredolo (1986) also showed that crawling experience was related to success on three different variations of the A-not-B search task. Kermoian and Campos (1988) similarly demonstrated that 8.5-month-old infants with self-locomoting experience outperform their stationary peers on a battery of object permanence tasks. Bertenthal, Campos, and Barrett (1984) further demonstrated that this is true even if the self-locomotion is imposed by the researcher.

Wariness of heights, as indexed by heart rate, when lowered onto the deep side of a visual cliff, is present in crawling infants and those with walker experience but not in prelocomotor infants (Campos, Bertenthal, & Kermoian, 1992). When the dependent variable is latency to cross over an apparent visual cliff, the results are the same and persist regardless of the infant's age at crawling onset.

Similarly, socioemotional development is shaped by crawling onset. Crawling brings with it more opportunities for adults to provide facial and vocal signals to the infant especially about objects or other referents that are distal to the infant. The child also becomes able to control his or her distance from other individuals - either seeking proximity or departing to explore alone (Campos et al., 2000). The child's new autonomy understandably also changes how mothers perceive their infants.

Campos, Kermoian, and Zumbahlen (1992) found that mothers of crawling infants were more likely to report that their infants showed more anger, more affection for the primary caregiver, a higher level of sensitivity to their mother's location and to mother leaving, and more social looking to "check in." Crawling infants also initiated more interactive games and displayed more positive affect during these games. When it came to mothers' reports on themselves, they reported having higher expectations that their child would and should comply with instruction, a higher level of anger towards their infant, a higher likelihood of using their voice as a means of prohibiting their child from performing an action, and a higher level of use of verbally prohibitions in total. Fortunately, mothers also reported more frequent and intense displays of affection towards their infants. Many of these findings were replicated by a longitudinal study (Zumbahlen, 1997).

Crawling infants were found to follow pointing gestures more successfully than noncrawlers at 8.5-months-old (Campos, Kermoian, Witherington, Chen, & Dong, 1997). Interestingly, in this study pre-locomotor infants with walking experience showed the same pattern as the crawling infants. Campos et al. (2002) refer to unpublished work by Tao & Dong that similarly found that the onset of crawling was associated with more successful gaze following. This was true despite the fact that crawling onset is delayed in the Chinese population they studied relative to the Western infants used by Campos and colleagues.

As we can see, the transition from the prelocomotor to locomotor state reorganizes infants' ways of acting in their environment as well as the way they are perceived and treated by their caregivers. These principles also hold true as they change the mechanism by which they travel and become walkers.

Walking.

> [W]hat infants learn about the world is related, at least in part, to how they move in it. Thus, the onset of walking results in a reorganization of infants' cognition. (Clearfield, Osborne, & Mullen, 2008, p. 299)

The transition from crawling to walking, like the transition into crawling, serves as a "setting event," that transforms how the child experiences the world, the affordances the environment provides to him or her, and the way that the child is perceived and treated by social partners. Each of these changes interacts with the others, producing a transformation so drastic that we typically recognize it by bestowing a new name: the infant becomes a toddler. Walkers sometimes display returns to earlier forms, they perceive and are perceived in novel ways, and they act in space differently than do crawlers.

Perceiving and being perceived.

> Thus, organism-environment interactions are likely to be altered by developmental events that dramatically change the infant's "presence" - both as an individual and as a relationship partner. (Biringen, Emde, Campos, & Appelbaum, 1995, p. 499)

Recent research placing mobile eye-trackers on travelling infants reveals that crawlers and walkers see different things in their environment, even when performing ostensibly the same task – crossing a flat stretch of floor towards a parent (Kretch, Franchak, Brothers, & Adolph, 2012). Crawlers have a better view of the floor, while walkers have a better view of the whole room and are more likely to see people and objects. Unsurprisingly, crawlers are more likely to sit up when travelling, and the frequency that they sit up increases with the number of interesting toys in their vicinity. The walking posture does not necessitate these stops to "take stock" of the surroundings.

Upright locomotion allows toddlers to interact with their setting differently; they can see their destination while en route, and can hold up toys in view while on the move (Clearfield et al., 2008). The onset of walking is associated with a cascade of changes to infants' role as a social partner. Researchers have shown that walkers show more "testing of the wills" than prewalkers of the same age, and mothers of walking infants are less praising than mothers of prewalkers (Biringen et al., 1995). These same authors found that, while still prewalking, infants who will go on to walk early have fewer praise interactions than those who go on to walk late. Early walkers also show a more clear-cut change in emotional communication (in both infant and maternal affective style, as well as "testing of the wills") across their transition to walking. In comparison, for late walkers only maternal affective style showed a change across the transition to walking. These interesting findings suggest that early and late walker groups differ even before the onset of walking takes place. Another study examining walking infants as social partners was conducted by Clearfield et al. (2008). They followed children longitudinally across the transition to walking and found that the transition to independent walking was associated with changes to the frequency that infants watched others communicate and that they made bids for interaction.

Return to earlier forms. Intriguingly, the "reorganization" that takes place with the onset of walking can require walkers to relearn skills that they possessed as crawlers. Kretch and Adolph (2013) showed that learning how to negotiate a drop-off is posture-specific. Crawling experience teaches infants to perceive action possibilities from the crawling position, but these old action possibilities are no use when approaching a drop-off in an upright posture. Walking experience is the only way to acquire the new set of skills.

Sarah Berger (Berger, 2004) documented another instance where crawlers outperformed walkers. She presented infants with a locomotor version of the A-not-B task in which infants received experience travelling along an "A" path towards a parent, then were required to update their plan and locomote down a novel "B" path towards the (visible) parent's new location. She found that as infants transitioned from expert crawlers to novice walkers, their rate of perseverating or choosing the now-incorrect "A" path increased. She suggests that their errors are due to the exhaustion of limited attentional resources - the relatively new act of upright locomotion taxes the attentional system and so infants have fewer remaining resources to inhibit the memory of travelling down the "A" path.

Another study showing the reemergence of more primitive forms in association with walking was conducted by Daniela Corbetta and Kathryn Bojczyk (Corbetta & Bojczyk, 2002). These researchers demonstrated that as infants begin to walk independently, they "lose" their ability to perform targeted single-handed reaches and return to two-handed reaching, even for small familiar objects, until they achieve adequate balance control as walkers. Early walkers spend hours each day practicing their new skills, often assuming a "high hand guard" position with both arms raised. These authors suggest that this return to two-handed reaching may be due to this extensive practice moving the two arms in a coordinated fashion. Only as the new walkers become more skillful and do not rely on raised arms for stability does single-handed reaching reemerge.

Acting in space. Infants' understanding of space is a topic that has interested developmental psychologists for a long time. It is difficult to directly measure memory for space in infants for two reasons: firstly, because an infant cannot verbally report what they remember or know, and so indirect measures must be used; and secondly, because space is, in and of itself, not very motivating. These two facts shape the types of studies that tend to be performed: a variety of motor behaviours are used as measures of knowledge, and experimental space is often populated with interesting objects or people in order to induce infants to produce behaviours indicating that they have expectations about the contents of locations (and by extension, an understanding/memory of location at all). Looking, reaching, and locomotor studies all roughly agree that the order of spatial memory development progresses from egocentric coding to the use of single and eventually multiple landmarks, but there are discrepancies on the exact ages that these skills emerge. This is likely due to the fact that while motor behaviours (e.g. looking, reaching, locomoting) can be used as measures of memory for locations in space, they also have a role in shaping the ability to process spatial information. For instance, on a task requiring infants to travel down one of two tunnels to reach a parent, Berger (2004) found a dissociation between looking and crawling/walking behaviour, with 35% of infants who successfully travelled down the correct path still showing perseveration by looking to the (previously reinforced) incorrect path prior to travelling in the correct direction.

As noted earlier, there is a rough consensus within the literature on the order that memory for space develops. Initially, coding of object location appears to be "egocentric" or based on the position of the self. Looking studies suggest that infants expect hidden objects to remain in the same place relative to their bodies at 6 months (Acredolo, 1990). Next, infants gain the ability to use single landmarks. Another set of looking studies showed a reliance on distinctive landmarks to navigate correctly to a hidden location at 8.5 months-old (Lew et al., 2003). Finally, infants progress to the use of map-like representations that they can update following their own movement. This is shown by infants' ability at 16 months to revise their head-turning according to intervening movements between training and anticipation of an event at a location (Acredolo, 1978). This progression from egocentric to map-like reference systems appears to also be true of other mammals, including rats (Nadel, 1990).

Looking measures tend to indicate the presence of sophisticated forms of memory earlier than reaching measures, which in turn appear earlier than self-locomoting measurements. These discrepancies suggest that spatial memory does not exist as a single concept or skill that is either present or absent but rather that it is dependent upon the body and experience of the infant.

There are a number of studies (including the current research) that use directed locomotion as a measure of cognitive skills. One group of examples are studies by Bushnell, McKenzie, Lawrence, and Connell (1995) who probed 11.5-month-old infants’ memory for the location of a hidden object by allowing the infants to search for an object hidden in a pool filled with pillows. Most of the pillows were the same blue colour, and landmarks in the form of distinctively coloured pillows were introduced in various configurations. These authors found that 11.5-month-old infants could code the location of a hidden object with reference to a direct landmark (i.e. a brightly coloured pillow directly on top of the object). The infants also performed fairly well in the absence of any landmarks but had difficulties using what the authors called "indirect landmarks:" brightly coloured pillows directly to one side of the hidden object. The researchers did not report on any differences between the performances of crawling and walking infants in their study; however, they do mention that they had participants using both modes. According to this system of measurement, the use of distal cues develops around 12 months, and place learning (that incorporates both distal cues and the distances between them) is not solidified until 16 months.

Clearfield (2004) also studied crawling and walking infants exploring a large space. She built on previous findings by providing a detailed breakdown of crawler versus walker differences on her task. She used a version of the Morris water task (Morris, 1981) that was originally designed to measure the ability of rats to locate hidden objects based on distal cues. Clearfield found overall that success in locating a hidden goal (a hidden mother in this case) was positively related to locomotor experience, but the nature of that locomotor experience mattered. Experience in the crawling modality was only helpful as long as infants remained crawlers; this experience did not result in higher success rates once infants began walking. Eight-month-old early crawlers and 14-month-old early walkers both performed fairly poorly, but 11-month-old experienced crawlers were more successful. Gibson et al. (1987) similarly showed that patterns of exploration differ between crawling and walking infants on various supporting surfaces. She required crawling and walking infants to navigate both rigid and flexible (waterbed) surfaces. She found that crawlers did not differentiate between the two types of surfaces, but walkers had a longer latency to initiate locomotion, more exploration, and more displacement when traversing the deformable surface, suggesting that the two surfaces had different affordances for walkers but not for crawlers.

Karasik, Tamis-LeMonda and Adolph (2011) performed one particularly relevant naturalistic observation study. These authors videotaped infants for an hour of unstructured time in their home environments, once at 11-months and once again at 13-months. For infants who made the transition from crawling to walking during this period, interactions with distal objects doubled and interactions with proximal objects decreased. This was not the case for infants who remained crawlers. Thirteen-month-old walkers were three times more likely to travel to objects than 13-month-old crawlers. The authors conclude that "[w]alkers explore their environment differently than crawlers."

Study 1

Introduction and Research Questions

The current research will explore several questions clustered around the larger topic, "How do infants make choices about traveling to objects?"

While a number of studies have dealt with how infants choose the location of a reach when given multiple targets (e.g. Bremner & Bryant, 1977; Diamond, 1985; McDonough, 1999; Piaget, 1954; Sheya & Smith, 2010; Smith & Thelen, 2003), and a number of studies have examined infants' attempts to remember and travel to a single target location (e.g. Bushnell et al., 1995; Clearfield, 2004), there are no studies to our knowledge that have investigated how infants direct their navigation when presented with multiple targets in a “target rich” environment. Given this lack of previous research, the current research was intentionally designed to be somewhat exploratory.

The goal of the research in Study 1 was to provide a baseline description of the range of choices made by crawling and walking infants. The description was made more comprehensive by systematically varying an aspect of the choices presented to infants: the travel distance required to obtain each object.

In an exploratory spirit, several predictions were made:

(1) Overall, infants' choices when required to travel will be consistent with their choices when required only to reach (i.e. infants will choose preferred objects more frequently than non-preferred objects).

(2) Overall, infants will contact close objects more frequently than objects that are more distant.

(3) Overall, infants will make trade-off choices rationally such that the rate at which they choose preferred objects will differ across distances.

(4) Trade-off choices will differ based on infants' mode of locomotion.

The predictions were based on the delay discounting and foraging theory literatures as well as previous research (Karasik et al., 2011). Both theoretical literatures agree that infants should prefer previously preferred ("high value") to previously non-preferred ("low value") objects (Prediction 1) and close ("low cost") over far ("high cost") objects (Prediction 2). This is because both theories state that individuals should employ a cost-minimizing, gain-maximizing approach.

Foraging theory also supports the prediction that infants should selectively allocate the extra energy required to travel to a more distant object only if that object is high- rather than low-value since a higher gain may justify a higher energy expenditure (Prediction 3). If we add an assumption that walking is less effortful than crawling, foraging theory then also predicts that as locomotion becomes less effortful as infants go from crawling to walking (i.e. "cost" of travel decreases), infants will be more willing to pass up a nearby, low-value object in favour of a more distant but more valuable object (Prediction 4).

Delay discounting, like foraging theory, supports Prediction 3. However, it does so not because of the "cost" associated with distant objects, but instead because of their delay. If delay discounting is observed, it will manifest as the choice between close and near distal objects being treated differently than the choice between near distal and far distal objects. Likewise, if we add the assumption that walking infants can cover distance more quickly than can crawlers (as shown by Adolph et al., 2012), delay discounting falls in line with Prediction 4, since walkers will experience distal objects with a shorter delay than will crawlers.

Predictions 2 and 4 are also based on findings made by Karasik et al. (2011). This paper found that infants chose to interact with proximal objects more frequently than distal objects. It also found that infants who began walking between 11 and 13 months accessed more distal objects than did their still-crawling peers. This suggests that the process of aging alone may not drive changes in object interactions, but rather experiences accumulated over time may play a role.

Method

Recruitment. Participants were recruited through contact information provided by parents to the EDGE (Early Developmental Group Exchange) database. The EDGE database is a confidential and protected resource shared between the three developmental laboratories at Ryerson University. It houses a diverse sample of families from the Greater Toronto Area (GTA), ranging from pregnant mothers to families of children up to the age of six or seven years. To populate it, EDGE group members (including professors, graduate students, and undergraduate research assistants) regularly gave brief presentations at family-centered events such as infant/toddler sessions at local libraries and parenting conventions, and provided the opportunity for interested parents to provide contact information. Parents of infants eligible for participation were contacted by phone or email to schedule appointments for participation.

Participants. Eleven and 14-month-old infants were chosen as the groups of interest in order to align this study with previous work involving infants searching in an open space (Acredolo, 1978; Clearfield, 2004). It was anticipated based on these earlier publications that, on the whole, 11-month-olds would be experienced crawlers and 14-month-olds would be new walkers. However, the participants were less homogenous in their modes of locomotion than we anticipated (see Figure 1 for a detailed breakdown of the mode of locomotion used by the participants).

The possibility of moving the lower age group even younger (to ensure that none had progressed from crawling to walking) was considered, but pilot testing revealed that 10-month-old infants were less well suited to the study and refused to select a toy at an unacceptably high rate. There were also several 10-month-old infants whose parents reported that they could not participate because they were not yet engaging in self-produced locomotion.

An upward adjustment of the age of the older group upwards beyond 14 months was also discounted in order to keep the inter-group age gap relatively narrow. Of course, even a three-month gap (as was used) is likely to contain developmental changes in a variety of domains in an infant's life - a topic that will be further addressed in the discussion. It was also deemed unacceptable to reduce the age of the older age group, as it was anticipated that too few walking infants would be sampled. Karasik et al. (2011) reported that at 13-months-old, half of their sample was crawling and half had progressed to walking. The composition of their sample was likely to be demographically similar to the one used in the current study, as New York City is similar to Toronto in being a large, diverse North American urban centre. Since the older age group was intended to be predominantly walking, 14 months was deemed to be the youngest (and therefore closest in age to the younger group) that the boundary could be set to meet this goal.

11-month-old group. Twenty-six 11-month-old infants participated in testing for Study 1. Seven infants were tested but excluded for selecting an object on fewer than three trials. Therefore, data from nineteen 11-month-olds (11 female, 8 male) were included in the final analysis of Study 1. Their ages ranged from 10.7 - 11.4 months-old (11.1±0.20, *M*±SD). None were reported by their parents to be overdue or premature (defined having a birth date within 21 days before and 14 days after their due date), and all made object selections on a minimum of four trials and produced a minimum of eight trials that could be coded. The ethnic background of the final sample contained Caucasian (n=13), Mixed Ethnicity (n=2), South Asian (n=1), Jewish (n=1), and Filipino (n=1) infants. The parent/guardian of one infant did not complete the self-report question on ethnicity. Eighteen of the infants completed the task crawling (with 3.1±1.5 [*M*±SD] months experience crawling and no experience walking) while one completed it walking (with 1.4 months walking experience in addition to 2.8 months crawling experience), see Figure 1. One of the crawling infants provided only data on object choice for each trial (that was coded live during testing) but no data from the video record (e.g. latency to touch, play duration) due to a mechanical failure during testing. Including this infant, the average 11-month-old infant selected an object on 7.5 trials and completed 11.1 out of a possible 12 trials total including refusals.

14-month-old group. Twenty-nine 14-month-old infants participated in testing for Study 1. Nine of these infants were excluded from the final analysis for failing to select an object on at least four trials (n=8) or for preterm birth (n=1). Therefore, data from twenty (12 female, 8 male)

14-month-olds were included in the final analysis of Study 1. Their ages ranged from 13.6 - 14.4 months old (14.0±0.30, *M*±SD). None were reported by their parents to be overdue or premature (as defined for 11-month-olds), and all made object selections on a minimum of four trials and produced a minimum of six trials that could be coded. The parent-reported ethnicities for the final sample were Caucasian (n=7), Mixed Ethnicity (n=6), Black (n=1), Japanese (n=1), and Chinese (n=1). Ethnicity data were not reported by the parent/guardians of three infants. Eight infants completed the task by crawling (with 5.6±1.4 [*M*±SD] months experience crawling and no experience walking). Twelve infants completed the task by walking (with 2.8±1.5 [*M*±SD] months experience walking in addition to 6.4±1.3 [*M*±SD] months since crawling onset), see Figure 1. Crawling onset data were missing for one walking infant. The average 14-month-old infant analyzed chose an object on 8.3 trials and completed 10.8 out of a possible 12 trials total including refusals.

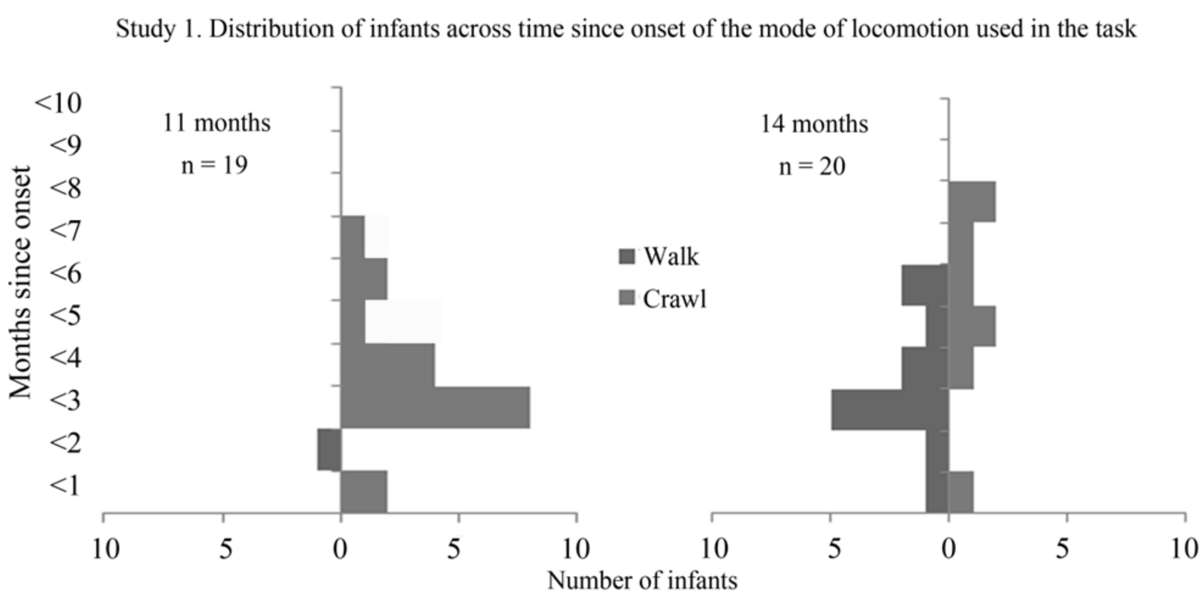


Figure 1. Distribution of infants in Study 1 across time since onset of the mode of locomotion used in the task.

Intergroup comparisons. The comparison of all crawlers (n=26) with all walkers (n=13) revealed no differences in time since onset of the movement used ($t[36]=1.37$, $p>.05$; M=3.6, 2.7 months respectively). The groups did show a significant difference in age ($t[37]=-4.4$, $p<.01$; M=12.0, 13.8 months respectively) and in total experience with self-produced locomotion ($t[35]=-3.6$, $p=.001$; M=3.8, 6.1 months respectively). Restricting group comparisons to only 11-month-old crawlers (n=18) and 14-month-old walkers (n=12) does not change the significance of any findings (time since onset of selected movement does not differ, $p>.05$, while age and total self-produced locomotion do differ between groups, both $p<.05$).

Study Design. In order to examine infant choice-making strategies, a novel experimental situation was designed in the hopes of eliciting naturalistic self-directed object pursuit and exploration. Under video-recording, infants were encouraged to choose between pairs of objects, firstly by reaching and secondly by traveling, in a format similar to exploratory play in the home environment. Infants' willingness to travel to various appealing objects was used as a measure of their task strategy. Observational coding of the video record was used to describe the strategies used by crawling and walking infants to guide their own locomotion.

All infants (both 11- and 14-month-olds) received the same procedure upon arrival at the lab. This procedure involved a short warm-up play period during which parents were briefed and signed consent forms, the controlled introduction of approximately ten toys to each infant, a set of proximal, reach-based choices presented to the infant to determine toy preferences, and finally the presentation of a set of travel-based choices. No manipulations were performed between subjects. However, the two choice phases of the study (the reaching and travelling phases) contained carefully counterbalanced trials.

The twelve trial layouts used in the Travel Phase of the study were generated through manipulation of three variables: distance (close, medium, or far), object preference as gauged in the Reach Phase (preferred or non-preferred), and laterality (left or right). See Figures 2-5 for visualization of the trial layouts. The twelve trials were presented according to a predetermined random order that was unique to each participant.

Camera placement. Two video cameras recorded infant behaviour throughout the study. They were positioned in such a way that the entire floor of the testing room was visible at all times from at least one perspective. One camera was approximately four feet from the ground and filmed through a gap in a curtain that made up the back wall of the testing room. It was trained on the door that formed the infants' start position. The other camera was placed approximately seven feet from the ground in the left-hand corner of the testing room (from the perspective of someone looking at the start position door). It filmed the majority of the floor space.

Procedure

Visit. Each infant visit followed the same format: warm-up, introduction phase, reaching phase, travel phase, and cool-down phase.

Warm up. As described above, infants and their parents were welcomed into the lab environment and were seated on the floor, along with the experimenter and a research assistant (RA), in the testing room. The experimenter and RA engaged the infant with some toys in order to acclimatize the infant to the new people and the lab environment. The study procedure was explained to the parent, who was given consent forms to sign and a motor milestone questionnaire about their infant's development (the CPOQ, see Appendix 3) to complete. Any questions raised by the parent were answered. The warm-up period continued until all parties felt that the infant was comfortable and ready to continue. Two video-cameras recording the testing room were turned on at the end of the warm up phase once written parental permission had been obtained.

Phase 1. Introduction phase. The experimenter introduced the toys to the infant one-by-one. A toy was removed from the toy bag by the experimenter, who would demonstrate the toy by describing and demonstrating its features for ten seconds. A sample introduction is:

> "Hi (baby's name), look what I have! It's a yellow shaker! I can bang it (bangs toy on carpet) and shake it (shakes toy) and hold it like this (demonstrates grabbing the toy with one hand)!"

After the ten second introduction period, the experimenter would place the toy on the floor directly in front of the infant, saying, "Would you like to try?" Infants were then given twenty seconds to interact with the object in any manner they chose (most manually explored the objects). After twenty seconds, the object was removed by the RA and placed into a second bag, introduced as the "all-gone bag," that infants were not allowed to explore. Infants were not restrained during the introduction phase, so some remained seated while others moved about the room during this period.

Phase 2. Reaching Phase. Two toys were presented simultaneously (roughly matched in size). Both were placed on the ground within the infants' reach, one to the left and one to the right. Infants were allowed approximately twenty seconds to contact an object. The twenty-second rule was excepted if infants showed clear disinterest in the toys (e.g. by whining and walking away). In this case, the infant's attention was recaptured and new toys were presented. After the infant selected an object by contacting it, the choice was repeated for a total of four choices per pair of toys: twice in each left-right orientation. The four-choice procedure was repeated until all the experimental toys had been used in a pair.

Phase 3. Travel phase. Infant-parent dyads were moved to a small, dimly lit room that adjoined the testing room. The doorway joining the two rooms was blocked by a dark curtain that was opened and closed by the RA to demarcate trials. Infants stayed with their seated parent immediately behind the curtain while toys were placed in the trial-specific layout by the experimenter. Each trial began with the experimenter signaling her readiness by saying, "Are you ready (baby's name)? One, Two, Three, Go!" at which point the curtain opened. It was opened by the RA who was standing or seated to the left side of the doorway beside the parent. The experimenter remained in the testing room seated against the centre of the wall opposite from the infants' starting position. Originally, the procedure was designed to take place in a room without potential social partners; however, extensive pilot testing revealed that infants were much more willing to enter the testing room and contact objects when the room contained another (minimally responsive) person. In each trial, as per the reaching phase, two toys were simultaneously presented to the infant. However, unlike Phase 2, toys were presented at distances requiring the infant to crawl or walk to obtain them. The infant was allowed to enter the room and contact a toy. No constraints were made on the infant's body position at the start of the trial. The spatial layout of the toys varied across twelve trials that were presented in random order (see description of trial layouts below). Infants were given one minute to contact a toy, after which point a new trial began. If infants contacted a toy early on in the trial, the trial was capped at twenty seconds post-contact to minimize boredom with toys due to over-familiarity. When infants contacted a toy, the experimenter and the parent gave a brief cheer and clapped for the infant. Other than this, throughout trials the experimenter and parent responded to the infant as needed, but minimally (further discussion of this is found below).Toy pairs were used across multiple trials as long as the infant maintained interest in them, but were switched for "fresh" pairs if the parent or experimenter felt that the infant was becoming disinterested. If the infant refused to contact either toy across multiple trials even after novel pairs were introduced, breaks were taken or in extreme cases (serious fussiness or strong reactions to the possibility of losing contact with the parent) the study was ended.

Cool-down. At the end of the visit, all infants were presented with a certificate and a small gift. All parent questions were answered.

Minimal communication. During phases two and three, the experimenter, research assistant, and parent were minimally communicative with the infant but did respond normally if the infant initiated contact through gestures, vocalizations, or social looks. Two representative examples are provided:

> Infant walks part-way into the room, then looks back towards parent with a concerned expression. Parent says, "It’s okay!"
>
> Infant begins crawling towards the toys, but stops and looks at experimenter, extends arm and makes a grunting sound (overall effect resembles a "bring that to me" gesture). Experimenter says, "Can you pick one?"

In all cases, parents and experimenter did not use the names of the toys, describe their features, or point to them between toy presentation and the infant's choice of a toy.

Trial layouts. On each trial, objects occupied two of six possible locations (see Figure 2).

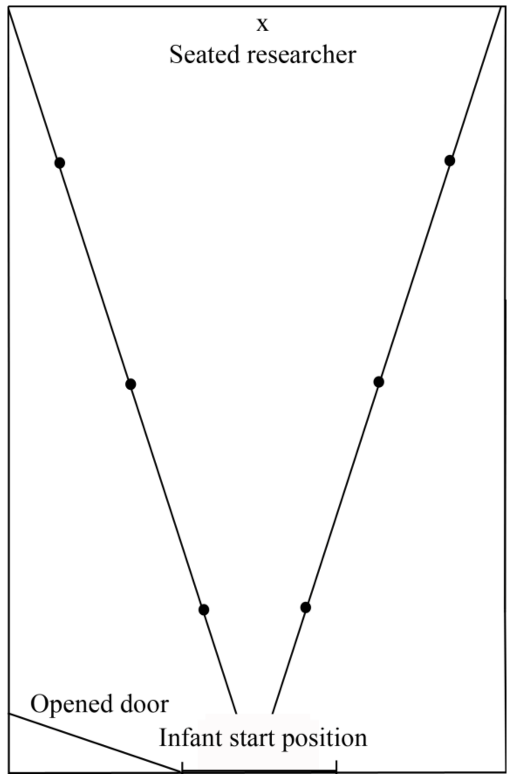


Figure 2. The six possible object locations in the testing room. Black dots represent possible object locations.

The six possible locations were placed in the room such that there were left and right positions at each of three distances (see Figure 3). These distance positions were (1) Proximal: approximately 1 foot from the infant, within reach but requiring a postural adjustment, (2) Near Distal: approximately 5 feet from the infant, requiring locomotion, and (3) Far Distal: approximately 9 feet from the infant, requiring locomotion.

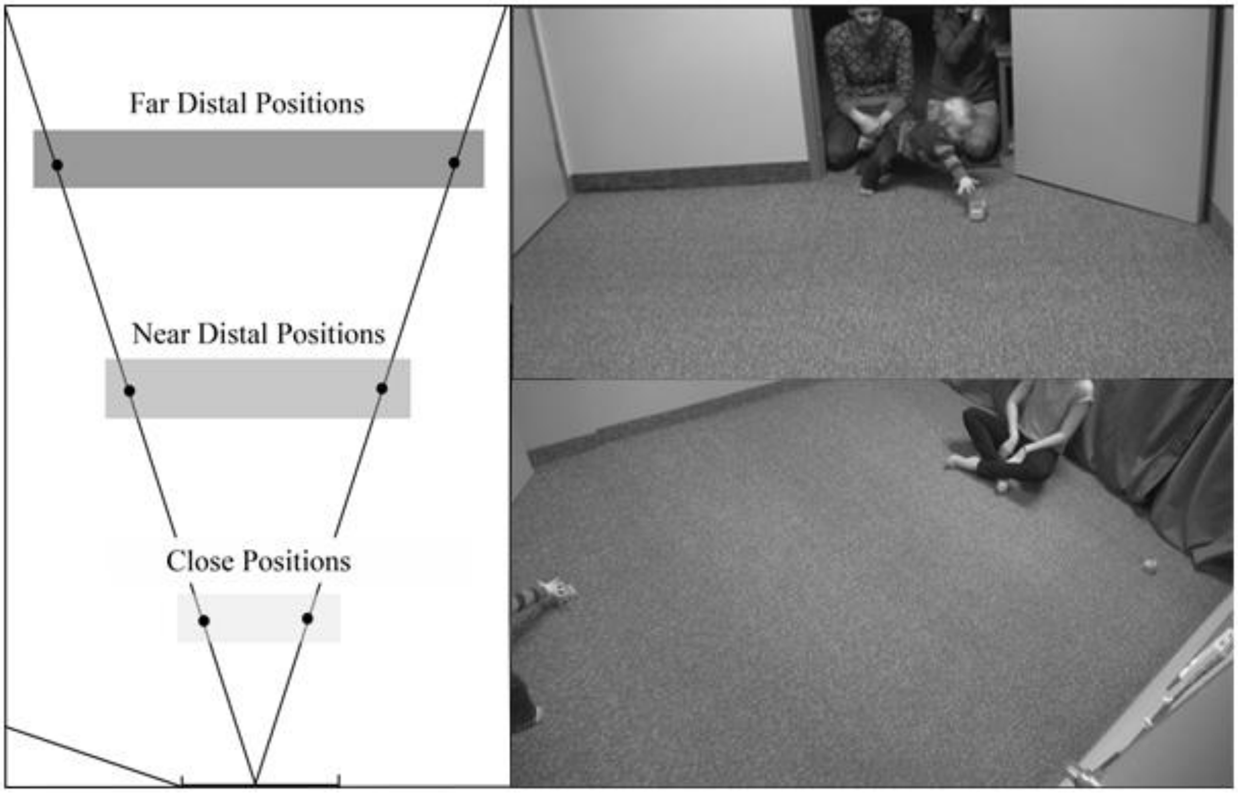


Figure 3. The three absolute object distances from the infant's starting position with a sample infant presented with objects at close (infant's left) and far distal (infant's right) positions.

Each trial had one object to the left of the infant and one object to the right. Objects were placed approximately 30° either to the right or to the left from straight ahead. Choice trial layouts (Figures 4 and 5) were set up in such a way that all possible layouts were performed that fit the criteria: (1) two of the six possible locations are occupied, (2) the objects are not equidistant from the infant, and (3) the objects are not on the same side of the infant.

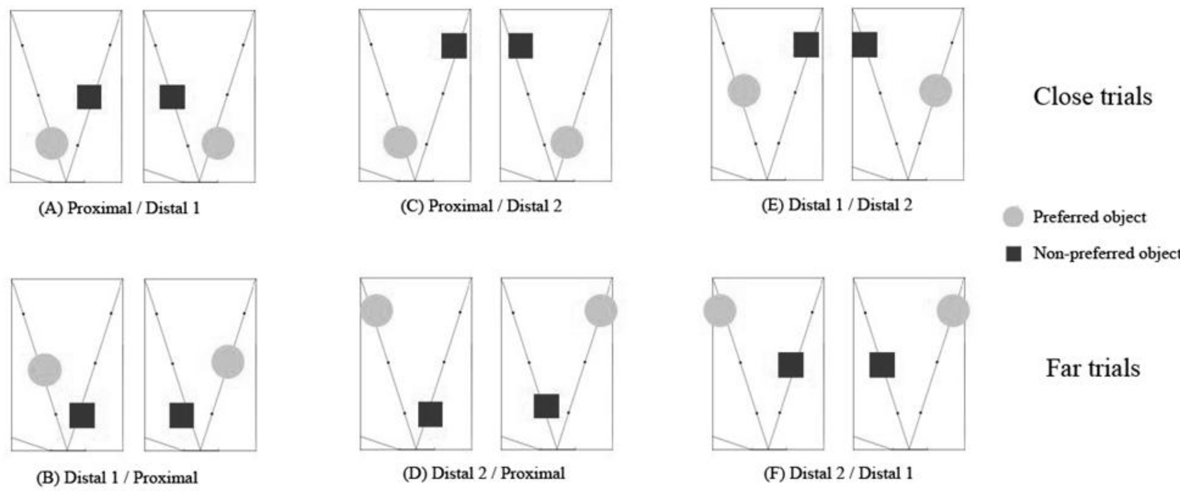


Figure 4. The twelve trial layouts, grouped by relative distance of the preferred object.

Coding. Videos from the two perspectives were synced into a single multi-view video using Adobe Premiere. Premiere-generated videos were then coded by two trained coders using the video coding software program Avidemux 2.6.1. Since infants in Study 1 and Study 2 performed the same procedure, inter-rater reliabilities and distribution of labour for both studies are both presented here. 47% of the videos were coded by Coder SH alone, 33% were coded by AK alone, and 20% were independently coded by both coders. After indices of inter-rater reliability were calculated, data from coder SH were used in the final analysis for the double-coded videos. For each video, coders recorded the following information for each trial: absolute trial number (i.e. from this infant's perspective, is this is the first trial or the fifth?), layout presented, time from trial onset to infants' first entrance of the room, time from trial onset to infants' first object contact, which object was contacted (i.e. was it preferred or non-preferred?), the level of preference for that object the infant had displayed in the reaching phase (i.e. if an infant had chosen that object 3/4 times when it was presented in the reaching phase, the level of preference would be recorded as 0.75), the distance of the chosen object from the start position, the side of the infant on which the chosen object was presented, and whether the infant was still engaged with the first-chosen object at the termination of the trial.

Inter-rater reliabilities (Studies 1 and 2 pooled). Eighty percent of all study recordings were randomly assigned to one of two coders, while twenty percent were assigned to both. Coders were blinded to which videos were being used to calculate inter-rater reliability. Since infants in both studies performed the exact same procedure, inter-rater reliabilities were calculated based on the entire pool and are presented here.

Time from trial onset to object contact was coded at a reliability of r=0.985, p<.001. Interrater agreement for identifying the trial layout on a given trial was r=0.989, p<.001. Time from trial onset to infant entering the room was coded at a reliability of r=0.715, p<.001. Infants' exact level of preference for objects during the reach phase was coded at a reliability of r=0.725, p<.001; however, classifying objects as preferred versus non-preferred was coded with 100% agreement. Inter-rater agreement when classifying the outcome of a trial as preferred, non-preferred, or refusal was K=0.886, p<.001. Kappa values above 0.80 are considered to be outstanding (Landis & Koch, 1977). Inter-rater agreement on the distance (1, 2, or 3) of the ultimately chosen object was K=0.88, p<.001. Inter-rater agreement on the side of the infant where the ultimately chosen object was located was K=0.822, p<.001. Inter-rater agreement on whether the infant was still engaged with the object at the end of a given trial was K=0.538, p<.001. Kappa values between 0.40 and 0.59 are considered to represent moderate agreement (Landis & Koch, 1977).

Analyses and Results

The association between infants' choices and properties of the infant and the environment were investigated using a variety of analyses. A summary of the statistically significant Study 1 results can be found in Table 1.

Table 1

Significant Statistical Effects, Study 1

Potential effect	Statistical test	*p*<.05
Main effect of choice	Mixed-measures ANOVA	Yes.
Choice x engagement at trial end	Chi square test	Yes.
Choice x movement x sex	Mixed-measures ANOVA	Yes
Choice x relative distance x movement	Mixed-measures ANOVA	Yes.
Choice x absolute distance x movement	Mixed-measures ANOVA	Yes.
Choice x relative distance x age	Mixed-measures ANOVA	Yes.
Relative distance x choice	Mixed-measures ANOVA	No[a]
Absolute distance x total objects chosen	Series of t-tests	Yes.
Chosen object side x total objects chosen	Series of t-tests	Yes.
Choice x preferred object side	Chi square test	Yes.

[a] trending, p=.051

Layout, movement, and age. The twelve trials could be grouped in two ways for analysis:

(1) by *relative distance* of the preferred object: the preferred object was the closest thing to the infant in six trials and was further from the infant than the non-preferred object in six trials (see Figure 4),

(2) or by *absolute distance* of the preferred object: the preferred object was positioned for four trials each at each of the three possible distances, Close, Near Distal, and Far Distal (see Figure 5).

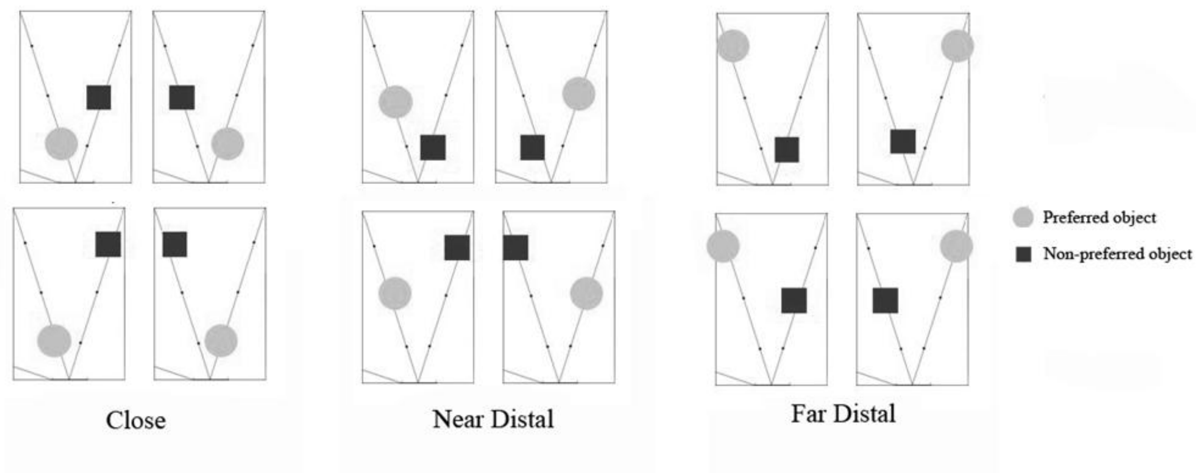
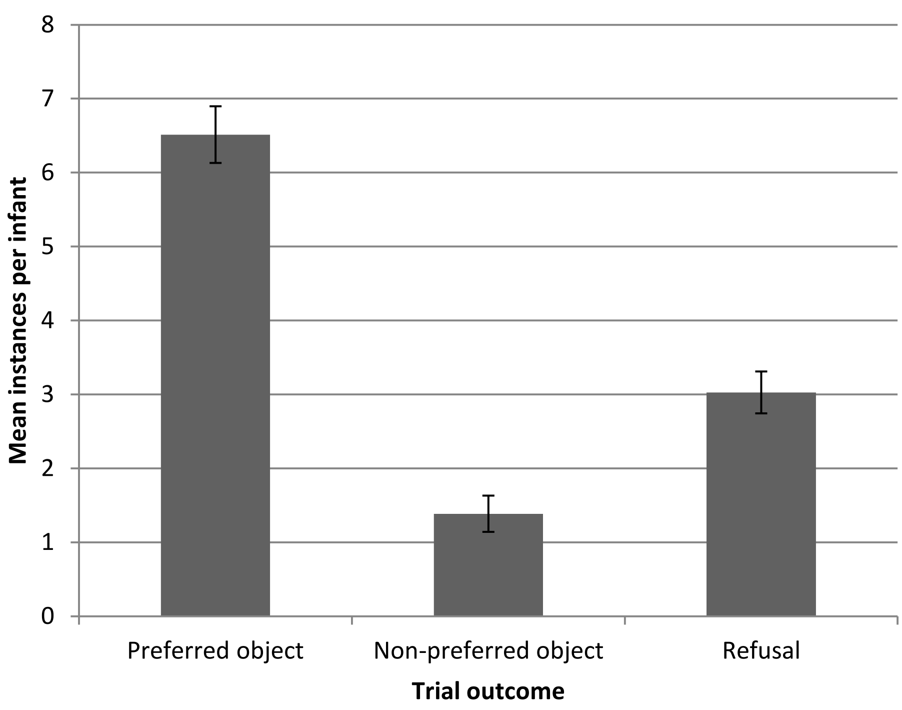


Figure 5. The twelve trial layouts, grouped by absolute distance of the preferred object.

Two mixed measures ANOVAs were carried out. Age (grouped into 11 and 14) and movement (crawling versus walking) served as between-subject variables. Distance (either relative or absolute) and choice[1] (preferred object, non-preferred object, or refusal) served as within-subject variables.

Two findings were true across both types of trial groupings. First, there was a significant main effect of choice [$F(2, 64)=19.5$, $p<.001$ for absolute distance groupings; $F(2, 64)=18.9$, $p<.001$ for relative distance groupings], see Figure 6. Infants chose their reach-preferred object more than they performed any other action in the travel pairings. The average infant produced 6.51 preferred object trials, in addition to 1.38 non-preferred trials and 3.05 refusal trials. Follow-up Bonferroni corrected t-tests demonstrated that all frequencies significantly differed from one another at the $p \leq 0.001$ level.



[1] It is also possible to analyze this data by running individual ANOVA analyses with each trial outcome serving as a dependent variable. Such an analysis permits a finer focus on each outcome but describes fundamentally the same effects and interactions. These analyses have been completed and can be produced upon request; however for the sake of simplicity they are not presented here.

Figure 6. Mean instances of each trial outcome in Study 1 per infant. Note that contact with the object preferred during the reach phase is the most frequent outcome.

There was a significant association found between trial outcome and whether infants were still engaged with their choice at the end of the trial, (χ^2[2]=13.5, p<.001), see Figure 7. Examination of the standard residuals revealed that, at the end of a trial, non-preferred objects were engaged with less than would be expected if there were no association between outcome and engagement.

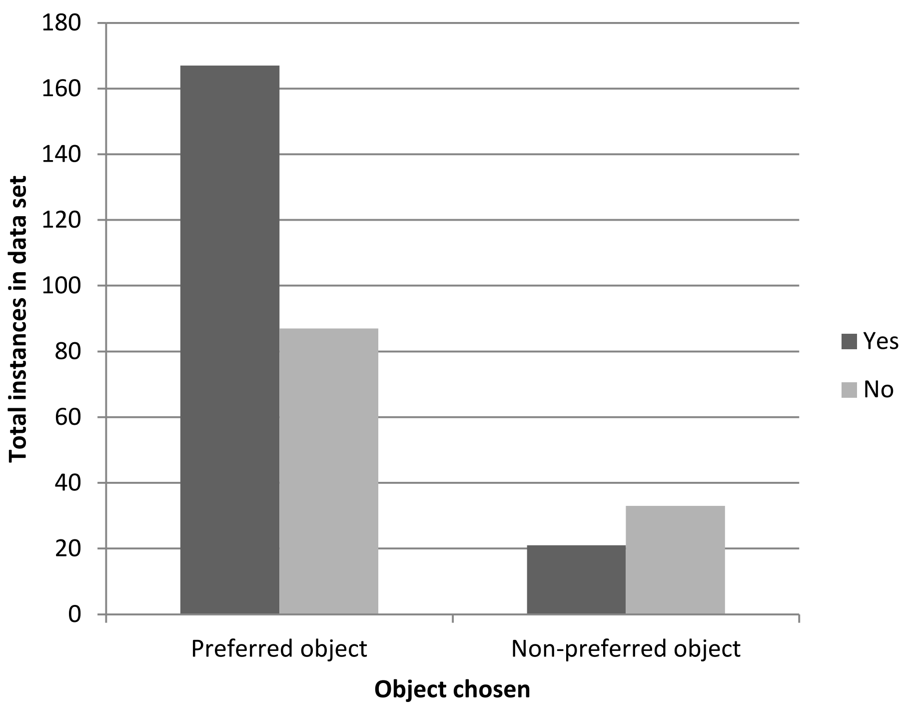


Figure 7. Total instances in Study 1 of object choices with respect to whether infants continued to engage with the object throughout the trial.

Second, there was an interaction between choice, movement,[2] and sex [F(2,64)=3.7, p=0.03 for absolute groupings and F(2,64)=3.5, p=0.036 for relative distance groupings], see

[2] For the purposes of the reported analyses, infants were classified as "crawlers" or "walkers" based on their dominant mode of locomotion throughout testing. The vast majority of infants were consistent in employing a single

Figure 8. Follow-up t-tests revealed that female walking infants produced a non-significant increased number of preferred object choices compared to their crawling peers ($p>0.05$) while male walking infants produced a non-significant but decreased number of preferred object choices compared to their crawling peers ($p>0.05$).

mode of locomotion during testing. A trial-by-trial examination of infants' use of crawling and walking was deemed to be beyond the scope of the current work; however, it would make an interesting topic for future investigation.

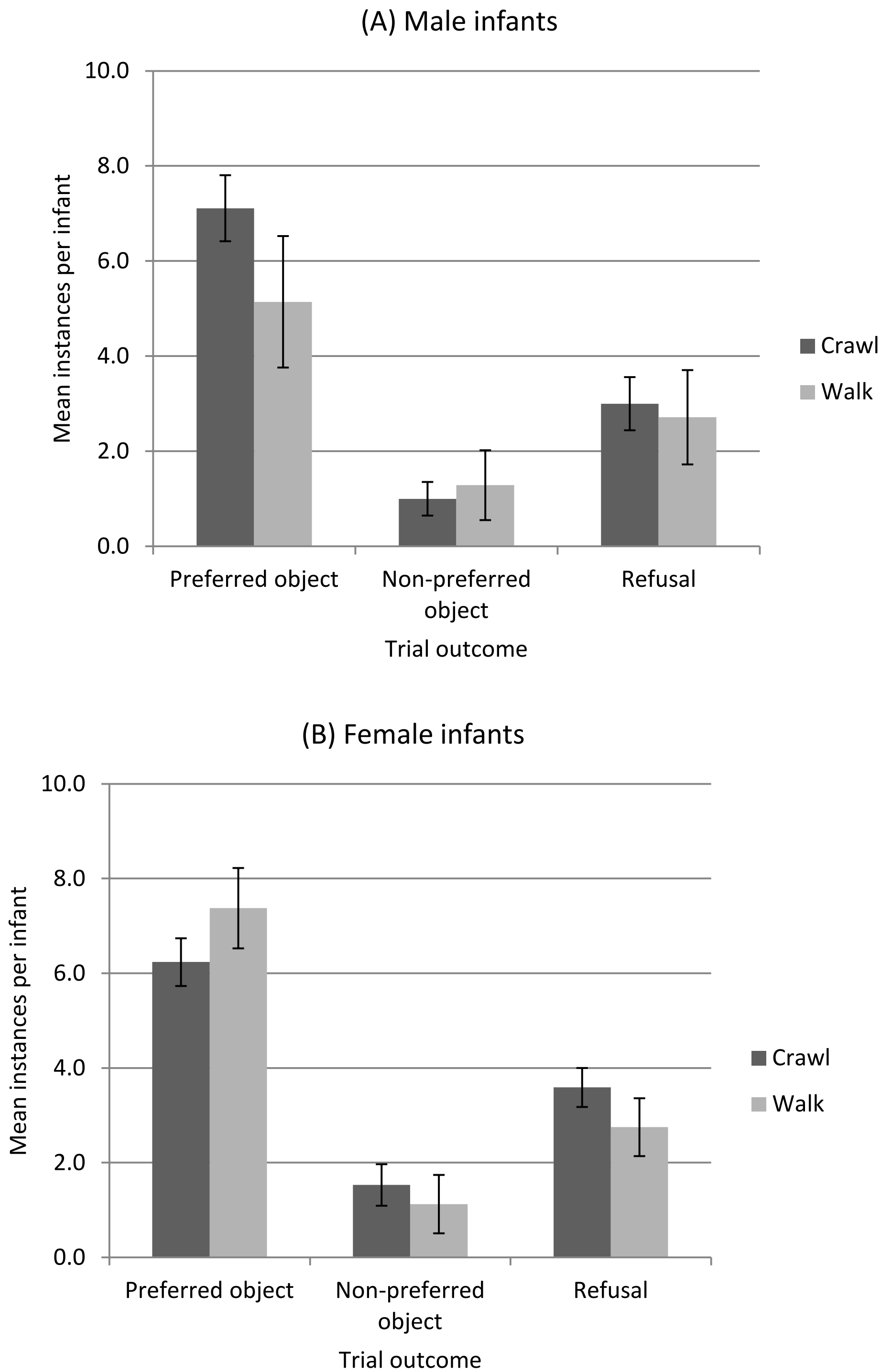
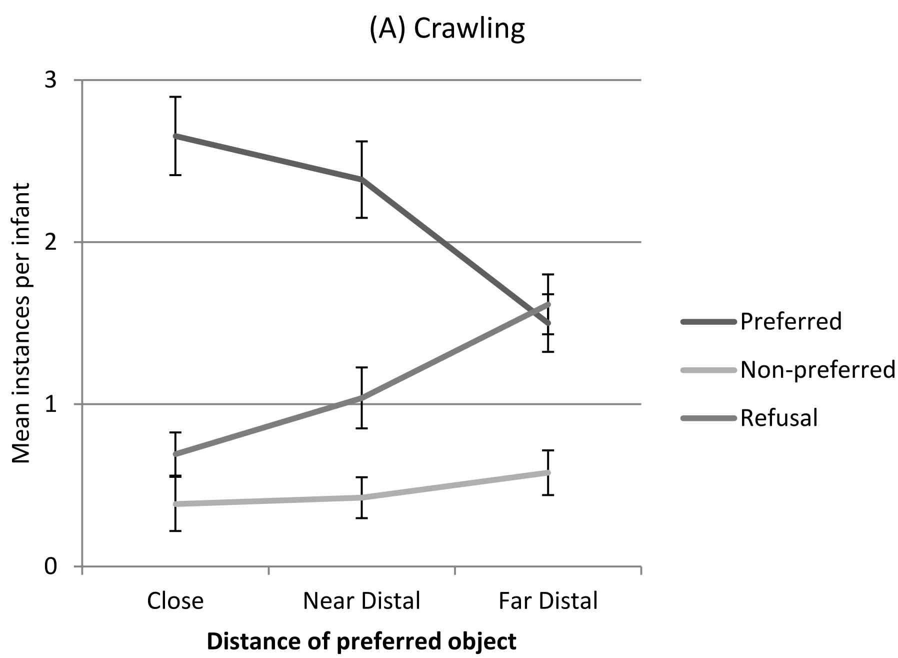


Figure 8. Mean instances of each trial outcome per infant for male (Panel A) and female (Panel B) infants.

Third, there was an interaction between distance, choice, and movement [$F(4, 128)=3.05$, $p=.019$ for absolute groupings and $F(2,64)=12.04$, $p=<.001$ for relative groupings]. Follow-up analyses on the distance, choice, and movement interaction for absolute groupings (Figure 9) revealed that for crawlers (Figure 9A), preferred object selections occurred more frequently at the close distance than the far distal distance. The preferred object was selected more frequently at the close distance than the near distal distance. Refusals were also less common at the close distance when compared to the far distal condition conditions (all $p<.0055$). 0.0055 was selected as the Bonferroni-adjusted alpha value by correcting a typical alpha of 0.05 for nine tests (comparing each trial outcome's frequency against itself at two other absolute distances.) For walkers (Figure 9B), follow-up analyses revealed no significant differences in object selections at any of the three absolute distances (all $p>.0055$).



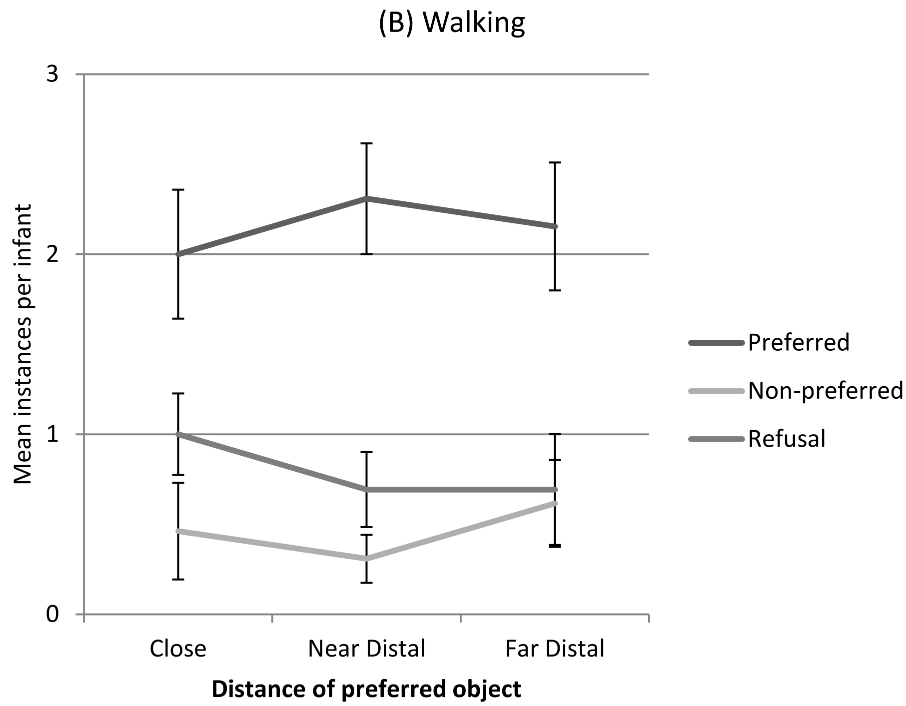


Figure 9. Mean instances among crawling (Panel A) and walking (Panel B) infants of each trial outcome with respect to the absolute location of the infant's preferred object.

Follow-up analyses on the distance, choice, and movement interaction for relative groupings (Figure 10) revealed that for crawlers (Figure 10A), the choice of the preferred object was made significantly more frequently when the preferred object was relatively close and the choice to refuse was made significantly more frequently when the preferred object was relatively far, with both $p<.0167$. 0.0167 was selected as the Bonferroni-adjusted alpha value by correcting a typical alpha of 0.05 for three tests (comparing each trial outcome's frequency against itself at the other relative location.) Parallel follow-up analyses for relative groupings revealed that for walkers (Figure 10B), all choices were made with equal frequency across relatively close and relatively far conditions, all $p>.0167$.

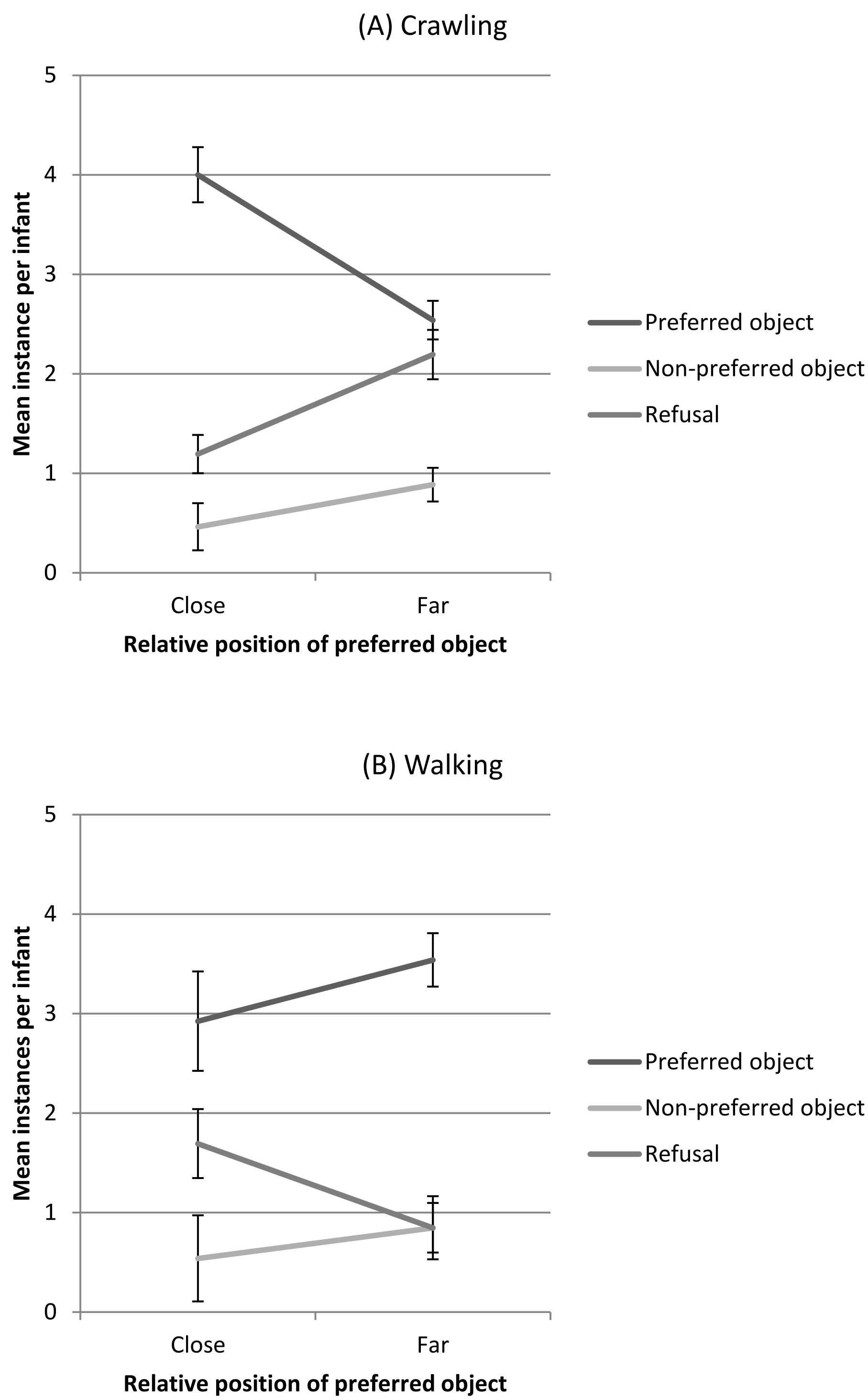
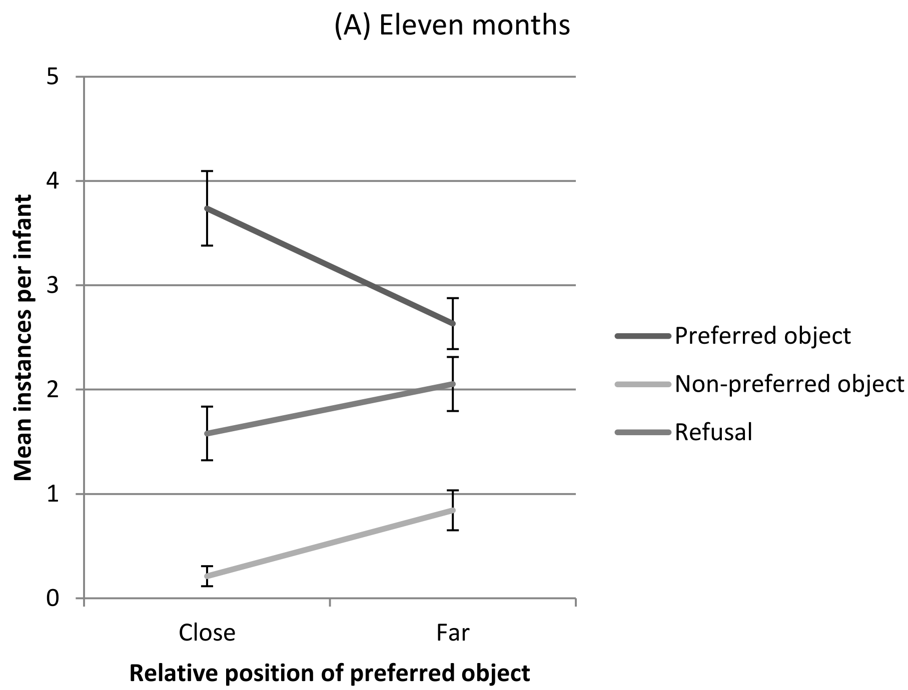


Figure 10. Mean instances among crawling infants (Panel A) and walking infants (Panel B) of each trial outcome with respect to the relative location of the infant's preferred object.

The relative distance groupings (Figure 4), but not the absolute distance groupings (Figure 5), also showed an interaction between distance, choice, and age [$F(2,64)=3.75$, $p=.029$], see Figure 11. Follow-up analyses for relative groupings revealed that for eleven-month-olds (Figure 11A), the choice of the preferred object was made significantly more frequently when the preferred object was relatively close and the choice of the non-preferred object was made significantly more frequently when the preferred object was relatively far, with both $p<.0167$. A value of 0.0167 was selected as the Bonferroni-adjusted alpha value by correcting a typical alpha of 0.05 for three tests (comparing each trial outcome's frequency against itself at the other relative location.) Parallel follow-up analyses for fourteen-month-olds (Figure 11B) revealed no differences in choices across the two relative positions (all $p>.05$).



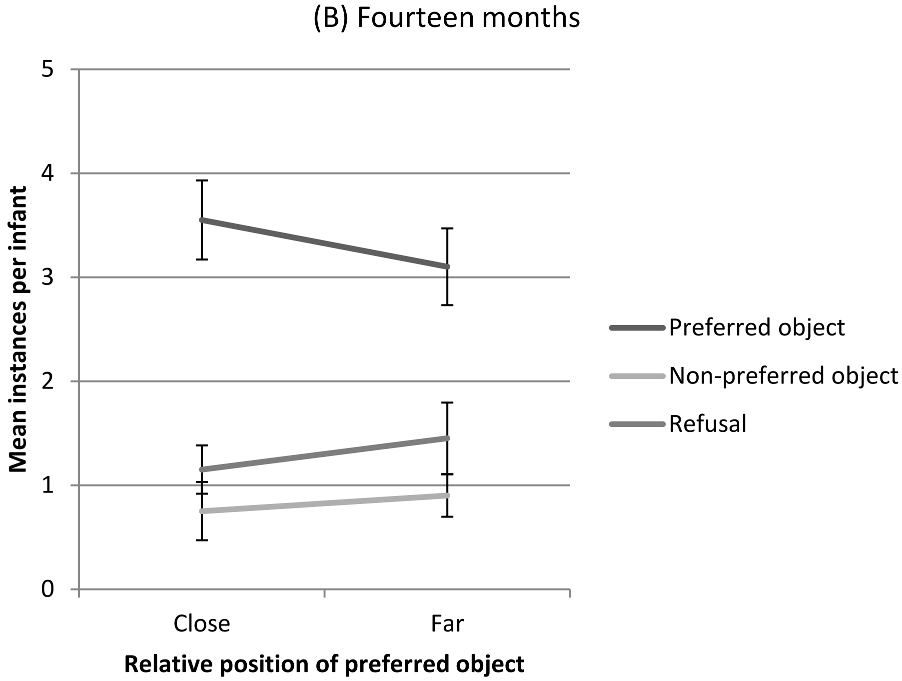


Figure 11. Mean instances among eleven-month-old (Panel A) and fourteen-month-old (Panel B) infants of each trial outcome with respect to the relative location of the infant's preferred object.

There was also a trend towards an interaction between distance and choice for the relative groupings (Figure 4) only [$F(2,64)=3.12$, $p=.051$, data not shown].

Object position. To address the role of object location without considering the infant's object preference, t-tests were conducted to investigate whether objects, regardless of their preference status, were chosen with equal frequency across the three distances. T-tests revealed that nearby objects were chosen more frequently than distant objects. The average infant selected 3.15 close objects, 2.79 near distal objects, and 1.95 far distal objects. Selections of close versus near distal objects did not differ in frequency ($p>.05$), but both close and near distal objects were selected more frequently than were far distal objects (both $p<.001$), see Figure 12.

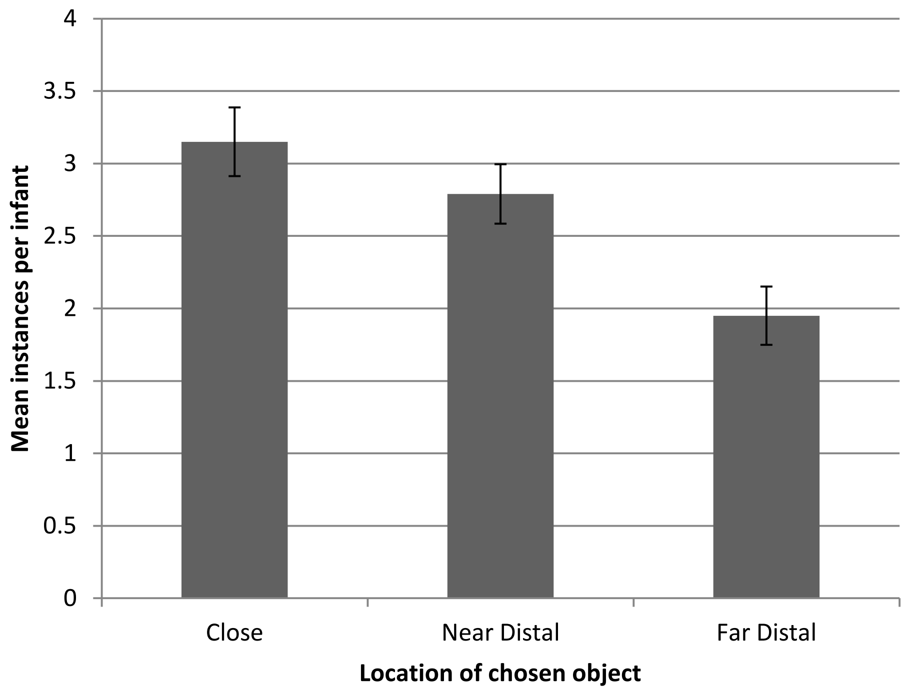


Figure 12. Mean instances of selecting an object at a given distance per infant, Study 1. Note that the general trend favours objects closer to the infant.

To address the potential role of side bias, *t*-tests were conducted to investigate whether objects, regardless of preference status, were chosen equally often on the two sides of the room. A *t*-test revealed that infants selected objects located to their right more often than they selected objects located to their left (p=.015), see Figure 13.

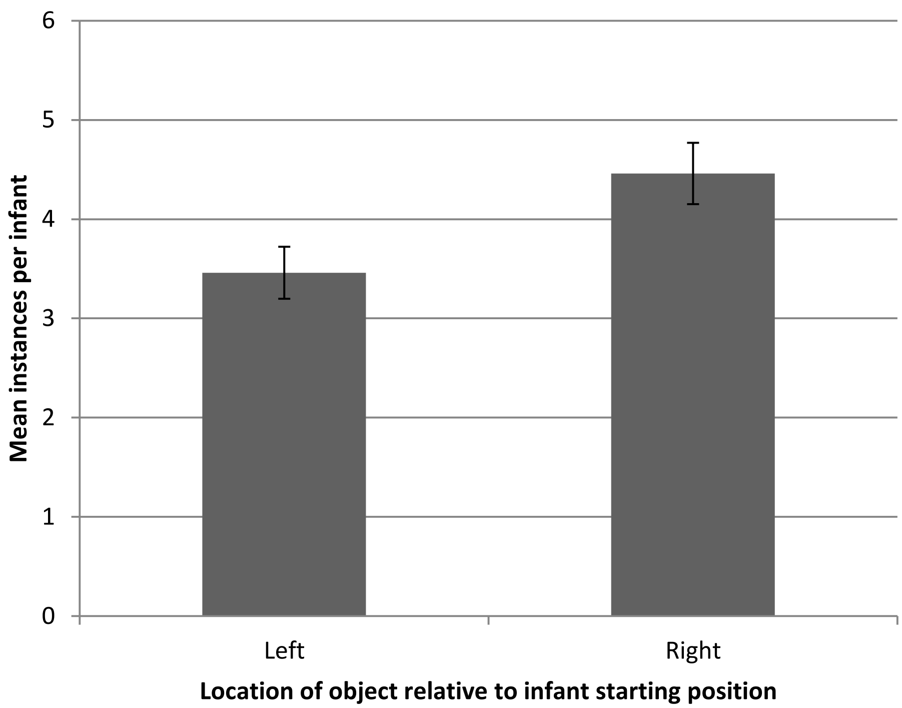


Figure 13. Mean instances of object selections in Study 1by location relative to infant start position. Note that right-located objects are selected more frequently than are left.

Furthermore, a chi-square test revealed that there was a significant association between the preferred objects' side and the infant's choice ($\chi^2[2]=7.78$, p>.02), see Figure 14.

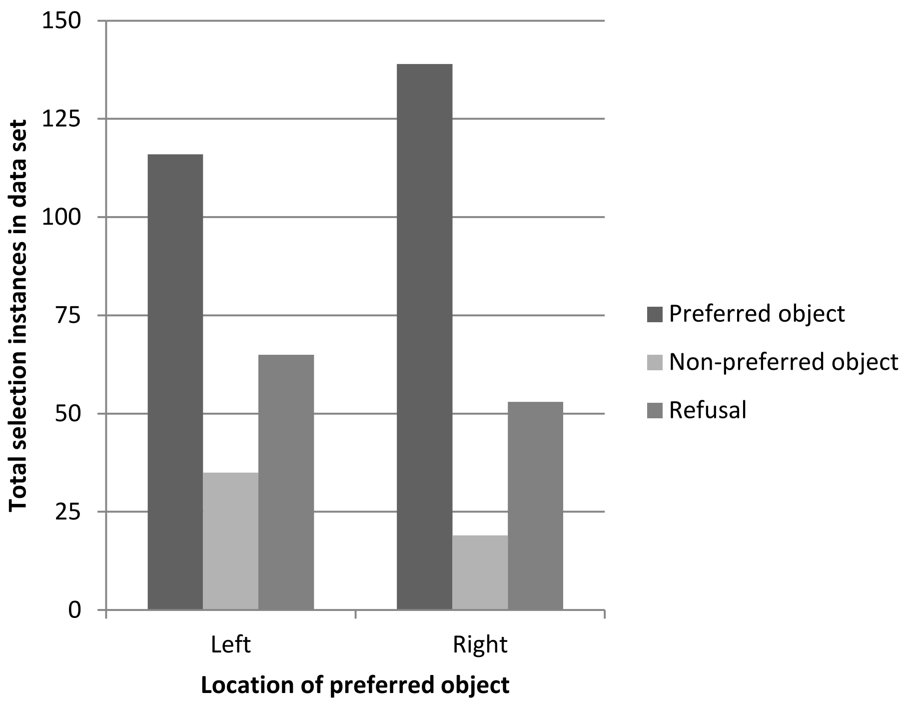


Figure 14. Total instances in Study 1 of each trial outcome with respect to the location of the preferred object.

Infant movement experience. A one-way ANOVA revealed no differences in total self-produced locomotion or experience in a specific locomotor mode that related to choices made. Further examination of crawlers alone and walkers alone found no such effects as well (all p>.05, data not shown).

Timing of movement initiation and object contact. A series of one-way ANOVAs were performed to examine whether the choice made in a trial was associated with time taken to enter the room or time from trial onset to object contact. Both were not associated with ultimate trial outcome (both p>.05, data not shown).

Practice and exposure. Finally, a one-way ANOVA showed that the number of trials an infant had already performed (a proxy for fatigue) was unrelated to ultimate trial outcome on a given trial (p>.05, data not shown).[3]

Discussion

This study was designed to explore how crawling and walking infants make choices when allowed to direct their own locomotion in a multi-target environment. To investigate this question, 11-month-old infants, the majority of whom were crawlers, and 14-month-old infants, the majority of whom were walking, were recruited to participate in a twelve trial free choice task. First, infants' spontaneous object preferences were identified by noting the direction of their spontaneous object-directed reaches when presented with two appealing toys. Next, infants were presented with a series of twelve trials during which they chose between the same pairs of objects they had reached towards, but at distances that sometimes required locomotion. The study found that overall, infants' traveling choices were consistent with their reaching choices (so, objects that they frequently selected when reaching were also the objects that they frequently selected when traveling). It was also found that infants' preferred close-by objects over more distant objects. However, these two phenomena (the preference for previously preferred objects and the preference for close objects) were independent when all infants were considered together as a group. Interestingly, though, when crawling and walking infants were considered separately, it was found that crawling infants alone did show choices that traded off initial preferences for objects against the travel distances they required.

[3] In order to rule out the possibility that the procedure of switching out object pairs when infants became bored was confounding infants' choices, the relationships between total number of unique pairs presented to an infant and various features of the infant and his/her behaviour were investigated using a series of one-way ANOVAs. The total number of unique pairs presented to an infant was not associated with infant age, their total number of preferred or non-preferred selections, or their locomotion experience (in either their specific mode or in total) (all p>.05). It was, however, related to total number of refusals produced by the infant (F[4]=3.5, p=.016). This is logical, since infants who became bored with certain pairs were given new pairs.

There is good evidence that the study procedure was suited to the participants' skill and attention span. Overall, only 16 of the 55 infants tested failed to meet the performance criterion or gestational age requirements set for inclusion, a 29% attrition rate. The performance criterion was: the participant must enter the room and contact an object on four or more trials. The attrition rate attained is comparable to that found in similar literature. For comparison, Clearfield (2004) did a search task with identical age groups with attrition rates of 13/27 infants (35%) and 11/35 infants (31%) in Experiments 1 and 2, respectively.

Within the data from infants who were included in the final sample, 426 code-able trials were obtained from a possible 468 (12 trials each across 39 infants). This leaves 42 trials-worth of missing data, which is 9.1% of the total data that could be obtained under ideal conditions. Missing data were excluded on a case-by-case basis during the analyses.

The number of trials used in this study likely represents the upper limit of the attention span of the groups that were tested. The average infant (all ages pooled) completed 10.9 of a possible 12 trials that could be coded. Trials were not coded if the infant showed distress to the point that the trial was prematurely terminated, or trials were sometimes not conducted if infants were too tired or fussy to continue the study (or in the rare instance that experimenter error led to trials being missed). However, it should be emphasized that the majority of infants (23/39) contributed data for all twelve trials, and the vast majority (33/39) contributed 10 or more trials.

Throughout the travel phase, the experimenter was seated in the testing room. While this is a source of additional information for infants performing the task, it was deemed unavoidable. Pilot testing revealed that encouraging infants to select between the two toys by entering an empty room caused significant distress for infants. It was unclear why this was the case -- it is possible that infants interpreted the empty room as prohibited, or the situation enhanced their reticence to make a short trip away from the parent. These preliminary tests demonstrated that the presence of a minimally responsive experimenter in the room eliminated these concerns, and the situation seemed to be treated by most infants as neutral.

The decision to allow the experimenter and the parent to communicate (in a limited way) with the infant was also made after careful deliberation. Pilot testing was conducted in which the experimenter was entirely non-responsive to the infant between toy presentation and toy contact. However, testing revealed that the non-responsive experimenter was a significant distracter to infants and greatly decreased the likelihood of infants choosing between the objects. Instead, several instances were observed of infants abandoning all objects in favour of attempting to re-engage the experimenter, using strategies like putting their faces directly in front of her face or rubbing her head (the experimenter was seated on the floor). It appeared that the minimally responsive experimenter was treated by infants as neutral or uninteresting, but a non-responsive adult was an anomaly and therefore worthy of pursuit. In light of these results, it was decided that minimal responses from the experimenter were most appropriate for this procedure in order to keep infants "on task". There is also a precedent for allowing mothers to participate in unstructured exploration tasks by refraining from comment but responding to requests from their children in a normal manner, as was done by Mayes et al. (1993) in a drawer-exploration task.

This study found a number of interesting relationships (and, in a manner equally interesting, failed to find several expected relationships). Recalling with the predictions made in the Research Questions section (p. 27), we see that three of the four anticipated findings were made.

Firstly, as was predicted, infants were found to be consistent in selecting objects that they had preferred in the reach condition frequently in the travel condition as well. Choosing a previously preferred object was the most common trial outcome, followed by refusing to contact an object altogether, with contacting a previously non-preferred object appearing as the least frequent outcome. The maintenance of their preference for these previously preferred objects is also confirmed by the fact that infants were also more likely to remain engaged with a previously preferred object through to the end of a trial than a previously non-preferred object.

Secondly, an interaction between choice, movement, and sex was noted. While the three-way interaction was statistically significant, follow-up comparisons were not, making it difficult to interpret this result. However, analyses suggested a trend for male infants to select preferred objects less frequently as walkers than as crawlers, with the reverse being true for female infants (i.e. female infants select preferred objects more frequently as walkers). The author is aware of no theoretical basis which predicts this type of finding; however, those involved in testing for Study 1 noted anecdotally that walking male infants tended be quite motivated to "cover a lot of ground" during their trials, while the same was not said of female walking infants. One could speculate, then, that male walking infants may have selected previously preferred objects at a lower rate because producing a lot of locomotion became an exploratory goal that was more salient or more "heavily weighted" in their choices than was the pursuit of interesting or preferred objects.

It was also found that, as predicted, more objects were chosen at close rather than more distant distances from the infants' start position. More detailed comparisons found that the decrease in frequency of object selections for this population actually occurred between objects in the near distal (~five feet) and far distal (~nine feet) positions. This finding is interesting because it replicates Karasik et al.'s 2011 finding that infants interact with proximal objects more frequently than distal ones. The present result suggests that the proximal versus distal distinction may actually be driven by factors other than reach-ability of objects for crawlers and walkers (since objects at five and nine feet are equally unavailable using only a reach movement).

The third prediction that was made was that choices would be distributed differently as distance varied. Surprisingly, when all infants were considered together, distance and choice were not found to significantly interact. This means that, while infants selected close objects more frequently than far and preferred objects more frequently than non-preferred, these two choice dimensions were independent. If an interaction were to be documented, this could be interpreted as these two dimensions "working together." For example, close, preferred objects might be selected more often than expected based on simply the "sum of the parts" of the two dimensions. However, the interaction did not meet the preset criterion for statistical significance in this analysis. This lack of interaction was true both when considering the absolute distance of the preferred object from the start point as well as when considering the relative distance of the preferred object when compared to the non-preferred object. However, relative distance and infant choices interacted at a level of statistical significance that barely exceeded the preset acceptable level (p=.051 and criteria for acceptance was set at p<.05), so it may be premature to conclude that the two factors were completely independent.

In addition, while this relationship was not detected among the sample as a whole group, it was detected among the crawling infants (but not the walking infants) for both relative and absolute trial groupings and among the 11-month-old infants (but not the 14-month-old infants) for the relative trial groupings only. While it is difficult to interpret null findings, the number of crawlers in the sample was double the number of walkers (n=26 versus 13), so it is possible that a larger sample of walkers would show this effect as well. Similarly, the 11-month-old group was more homogenous in their movement style than the 14-month-old group (the younger group was 94.7% crawling, while the older group was 60% walking), which could complicate the detection of small effects in the older group.

Nevertheless, the fact that crawling and walking infants display differences in the way that they trade off distance and preference (with crawlers apparently modulating their choices by distance and walkers apparently making choices in a distance-independent manner) fulfills the fourth prediction.

Laterality was shown to have an (unanticipated) effect on infant choice. The side of the infant on which the preferred object was located was found to be associated with the distribution of trial outcomes that infants produced. Similarly, if all choice made by all infants across all trials are tallied, more right-located objects were selected than were left-located objects. While this finding was unexpected, there are some potential explanations that can be offered. First, it is unlikely that the rightward preference emerges from a pre-existing bias within infants. This is because the two sides of the testing room were not, in fact, symmetrical. The right side of the room, despite the best efforts of the researchers to standardize conditions, did contain two interesting features that the left side did not. The first was a one-way mirror. While the mirror was too high in the wall for infants to examine themselves, it may have still attracted infants' investigations. There were also a few cases where infants visited the lab with two parents/guardians, and one of these adults was watching from behind the mirror. While, in theory, these individuals should have been undetectable by infants during the testing period, some may have made noises or turned lights on and off and attracted their infant's attention rightward temporarily. The other attraction on the right side of the room was one of the video cameras, which was attached to a door hinge high in the right-hand corner of the room. This object was not available to infants for manual exploration, but it was still visible to them and may have played a role in orienting their attention preferentially to the right side of the room. In addition to these interesting features of the right side of the room, the left side of the room provided slightly less space for infant exploration because a small portion of the front left hand corner of the room was blocked from infants' investigations by an open door.

In summary, Study 1 confirmed the majority of the predictions inspired by foraging theory and delay discounting. Overall, infants interacted with objects in a way that suggested a preference for previously selected objects and for close-by objects. These two preferences interacted for crawling but not walking infants, suggesting that these two groups of infants may be sensitive to and exploit different features of the same environment when directing their own locomotion in a multi-target environment.

Study 2

Introduction and Research Questions

Study 1 revealed that crawling and walking infants differ in their object choices under conditions where preferred objects were far from the infant's initial position. However, the crawling and walking infants used in the analysis were of different ages. It cannot be ruled out that age, rather than locomotor status, is driving the group differences that were observed. A second study was therefore conducted to disentangle the potential roles of age and locomotor status in shaping choice in this paradigm.

It is worth noting that the examination of age is not, in itself, very interesting. However, in developmental research, an infant's age or the time since the onset of a skill is often used as a proxy for the accumulated experiences that take place over time that are the actual drivers of the change of interest. For instance, it could be that the group difference documented in Study 1 is actually the result of neurological maturation that takes place between the ages of 11 and 14 months of age. We cannot measure this maturation directly (or even comment on its nature), but if it occurs roughly incrementally across time, it should manifest in an effect of age on choices measured. We predict that the crucial difference between the two groups is the difference in the distribution of crawlers and walkers (recalling the findings of Karasik et al., 2011).

Study 2 compared crawling and walking infants on the same choice-across-distance task in a sample that was age-matched. It was hypothesized that the between-group differences in choices made are due to locomotor status and not age; therefore we predict that controlling for age using age-matched groups will leave the between-group difference intact. Consequently, the same four predictions made in Study 1 (p. 27) were again made for Study 2.

Additionally, it was noted that Study 1 contained relatively few walking infants, and those infants had, on average, already achieved a certain mastery over the walking movement. Study 2 therefore also had the secondary goal of recruiting walking infants with a wider range of walking experience, with the hope of capturing any interesting modifications to behaviour on this task that might characterize the transition from crawling to early walking.

Methods

Study 2 sought to obtain groups of crawlers and walkers that were all the same age. Twelve- and 13-month-old infants were chosen as the groups of interest in order to fulfill this goal since, on average, at the beginning of their thirteenth month half of all Western infants have begun to walk (Karasik et al., 2011).

Participants. Twenty-six 12- and 13-month-old infants participated in testing for Study 2. Five of these infants were excluded from the final analysis for making fewer than four choices (n=4) or for being born preterm (n=1). This left twenty-one infants to be included in the final data analysis. Of these infants, five were female and sixteen were male. (This uneven representation was also true of the five excluded infants, of whom four were male. There was no intentional selection for male infants at any point in the recruitment process, so the distribution is assumed to be random.) Their ages ranged from 11.5 - 13.3 months-old (12.5±0.70, *M*±SD). None were reported by their parents to be overdue or premature (defined having a birth date within 21 days before and 14 days after their due date), and all made object selections on a minimum of four trials and produced a minimum of eight trials that could be coded. Parent-reported ethnicities in the final sample were Caucasian (n=7), Mixed (n=6), Chinese (n=2), Iranian (n=1), Greek (n=1), Black (n=1), or not reported (n=3). Twelve infants completed the task crawling (with 4.3±2.3 [*M*±SD] months experience) while nine completed it walking (with 2.3±1.3 [*M*±SD] months experience), see Figure 15. The average infant in Study 2 selected an object on 8.8 trials and completed 11.6 out of a possible 12 trials total including refusals.

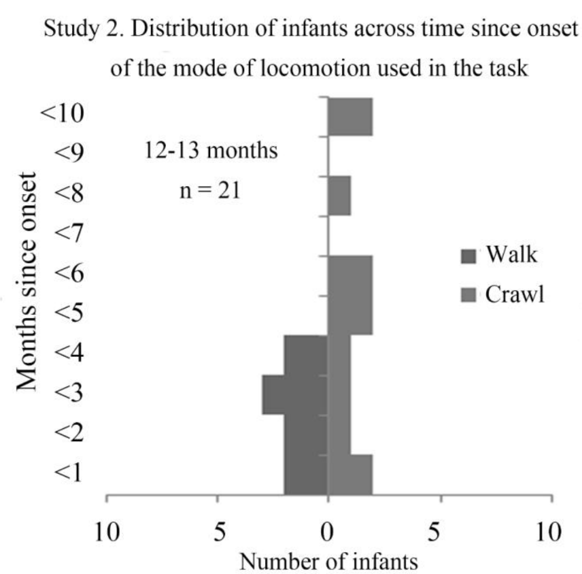


Figure 15. Distribution of Study 2 infants across time since onset of the mode of locomotion used in the task.

Intergroup differences. The crawling and walking groups did not differ in age (*t*[19]=-0.853, *p*>.05; M=12.4, 12.6 months respectively) nor did they differ in total self-produced locomotion experience (*t*[19]=-0.143, *p*>.05; M=4.3, 4.4 months respectively). They did differ in months of experience in their respective movements, with crawlers having more months since crawling onset than walkers months since walking onset (*t*[19]=2.2, *p*>.05; M=4.2, 2.3 months respectively).

Design and procedure. The procedure employed for Study 2 was identical to that used for Study 1.

Analyses and Results

A variety of statistical analyses were employed in order to investigate several factors thought to potentially affect infants' choices in interconnected ways: trial layouts, infants' movements, and infants' ages. The roles of object position and infants' level of movement experience were also examined. The question of whether different trial outcomes were associated with unique patterns of infant time allocation was assessed. Finally, the potential role of infant fatigue over the course of the study was assessed. A summary of the statistically significant Study 2 results can be found in Table 2.

Table 2

Significant Statistical Effects, Study 2

Potential effect	Statistical test	p<.05
Main effect of choice	Mixed-measures ANOVA	Yes
Choice x engagement at trial end	Chi square test	No[a]
Main effect of relative distance	Mixed-measures ANOVA	Yes
Relative distance x sex	Mixed-measures ANOVA	Yes
Relative distance x choice	Mixed-measures ANOVA	Yes
Absolute distance x choice	Mixed-measures ANOVA	Yes
Main effect of movement	Mixed-measures ANOVA	Yes
Absolute distance x movement	Mixed-measures ANOVA	Yes
Absolute distance x total objects chosen	Series of t-tests	Yes
Specific movement experience x choice	One-way ANOVA	Yes
Total self-produced locomotion (SPL) experience x choice	One-way ANOVA	Yes
Specific movement experience x choice (crawlers only)	One-way ANOVA	Yes
Total SPL experience x choice (crawlers only)	One-way ANOVA	Yes

[a] trending, p=.053

Layout and movement. The associations between infants' choices and object distance, infant, sex, and infant movement type were explored. As with Study 1, analyses were performed twice: once with trials grouped according to the relative distance of the preferred object in relation to the non-preferred object (Figure 4), and once according to the absolute distance of the preferred object relative to the infant's starting position (Figure 5).

Two mixed measures ANOVAs were carried out. Movement (crawling versus walking) served as a between-subject variable. Distance (either relative or absolute) and choice (preferred object, non-preferred object, or refusal) served as within-subject variables.

A main effect of choice was found (*F*[2,34]=7.7, *p*=.002), see Figure 16. Follow-up t-tests revealed that both non-preferred object outcomes (M=2.6) and refusal trial outcomes (M=2.8) were significantly less frequent than preferred object trial outcomes (M=6.2) (*t*[20]=3.7, *p*=.001 and *t*[20]=3.9, *p*=.001 respectively).

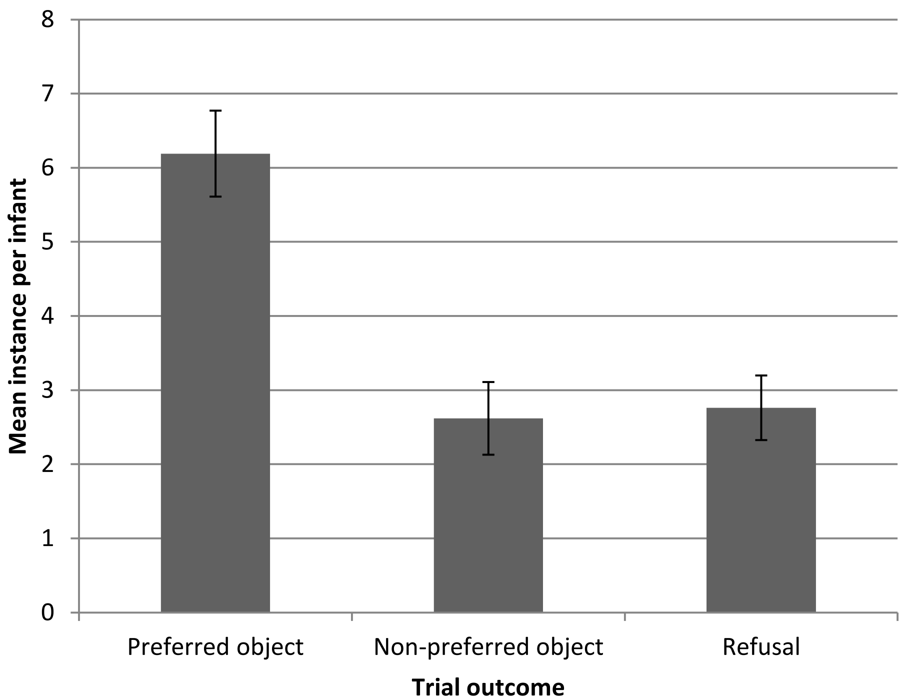


Figure 16. Mean instances of each trial outcome per infant in Study 2.

Chi square tests also revealed a trend towards an association between choice made on a trial and whether infants remained engaged with their chosen object at the end of the trial (χ^2[1]=3.75, *p*=.053).

Within the mixed-measures ANOVA concerned with the absolute distance groupings, a main effect of movement was found (*F*[1,17]=4.6, *p*=.046). A follow-up independent samples revealed a non-significant difference in the number of trials completed by crawlers (M=11.8 trials) and walkers (M=11.2 trials) (data not shown).

Both types of trial groupings also revealed interactions between preferred object distance and infant choice (*F*[2,34]=8.8, *p*=.012 for relative groupings; *F*[4,68]=5.1, *p*=.001 for absolute groupings).

Follow-up analyses for the relative groupings (see Figure 17) revealed that when the preferred object was relatively close, preferred objects were chosen more frequently (*t*[20]=3.4, *p*=.003) and non-preferred objects less frequently (*t*[20]=-4.1, *p*=.001) than when the preferred object was relatively far (both comparisons remained significant after Bonferroni corrections for three comparisons were applied).

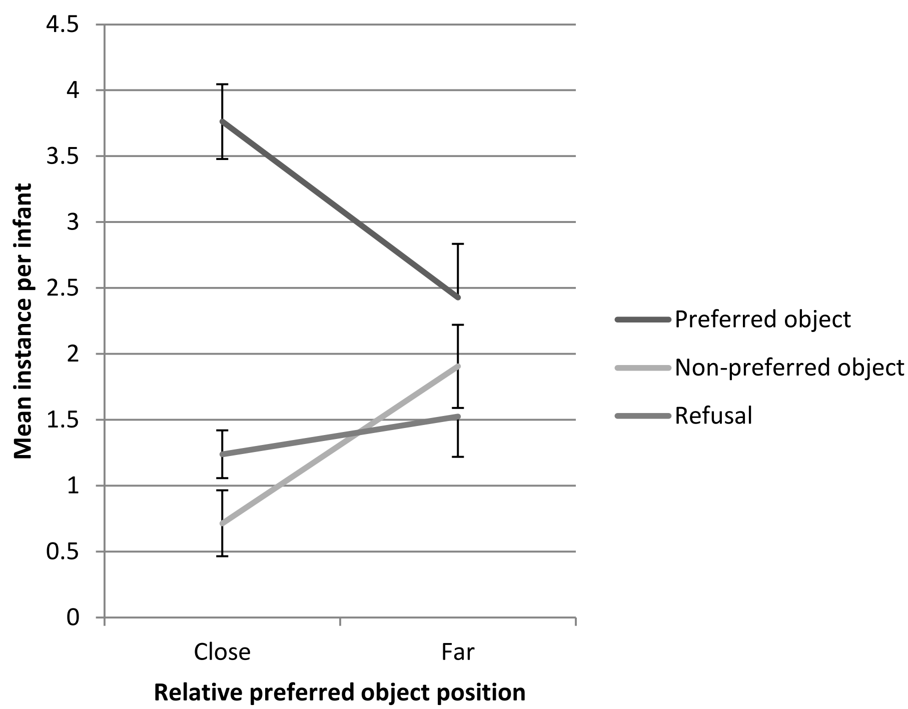


Figure 17. Mean instances of each trial outcome per infant in Study 2 based on the relative position of the preferred object.

Follow-up analyses on the absolute trial groupings (Figure 5) revealed that, using an adjusted alpha level of 0.0056 to adjust for multiple comparisons, the preferred object was selected more frequently when in the close compared to the far distal position (*p*<.001; M=2.95, 1.43 times respectively), see Figure 18. Non-preferred object selections also varied across close and far distal conditions. Non-preferred objects were selected more frequently when the preferred object was in the far distal position (M=1.38) rather than in the close position (M=.48) (*p*=.001).

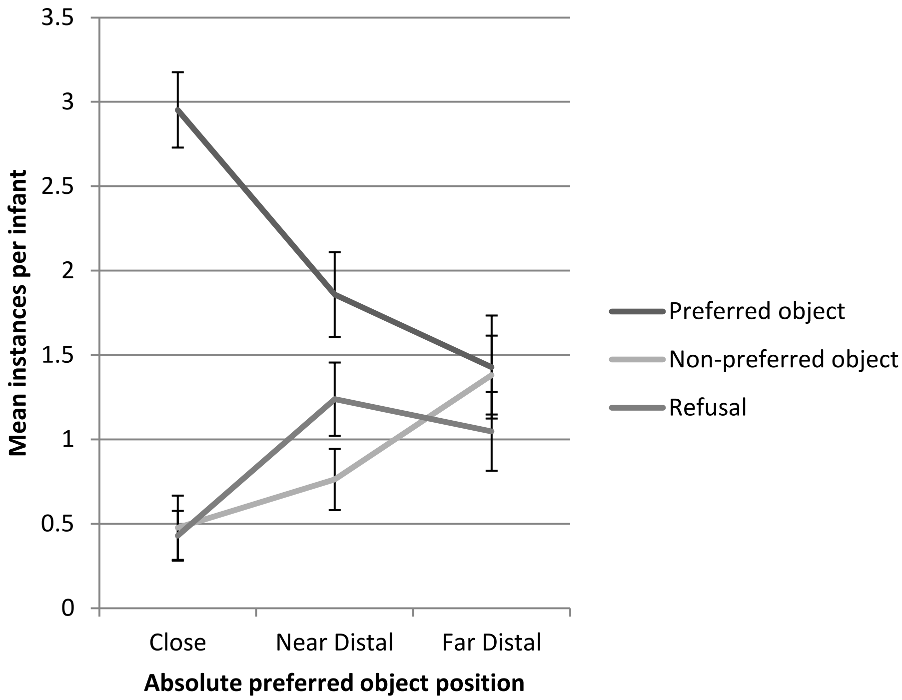


Figure 18. Mean instance of each trial outcome per infant in Study 2 based on the absolute position of the preferred object.

Within the mixed-measures ANOVA examining the relative distance groupings, there was a documented main effect of relative distance (*F*[1, 17]=6.0, *p*=.025). A follow-up t-test revealed a non-significant difference in the number of relatively close (M=5.7 trials) versus relatively far trials (M=5.9 trials) completed by the average infant (data not shown).

Finally, within this same analysis there was a documented interaction between absolute distance (Figure 5) and movement (*F*[2,34)=3.97, *p*=.03). Follow-up analyses revealed non-significant differences between the total number of trials completed at each of three absolute distances for both crawlers and walkers (all $p>.05$, data not shown).

Unlike Study 1, there was no significant choice x movement x distance (either relative or absolute).

There was a documented interaction between number of each type of relative distance trial and sex ($F[1, 17]=6.6$, $p=0.02$). Follow-up analyses revealed a non-significant difference in the total number of relatively close and relatively far trials completed for both male and female infants (both $p>0.05$, data not shown).

Object position. Chi square tests revealed that choice was associated with neither the side of room with the ultimately chosen object nor the side of the room with the preferred object ($p>.05$ in both cases).

T-tests were used to compare the total number of objects selected from the three possible distances from the infant's starting position. After using Bonferroni corrections for multiple comparisons, two comparisons still met criteria for significance. Close objects were selected more frequently than near distal objects ($t[20]=3.65$, $p=.002$), and close objects were also selected more frequently than far distal objects ($t[20]=5.97$, $p<.001$), see Figure 19.

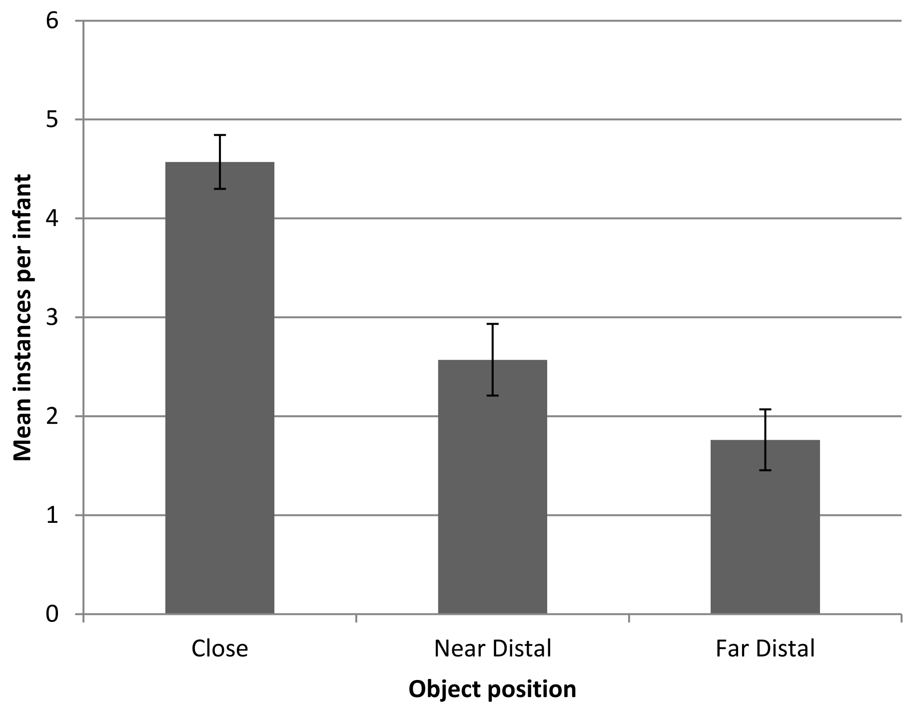


Figure 19. Mean instances per infant of selecting an object (regardless of its preference status) at a given distance from the starting position in Study 2.

Infant movement experience. One-way ANOVA analyses found that experience in the infants' employed movement style was significantly related to infants' choices ($F[2]=3.2$, $p=.044$). Likewise, infants' total self-produced locomotion experience was related to their choices ($F[2]=6.3$, $p=.002$). Follow up analyses examining crawling and walking infants separately found that both effects (that are actually the same effect for crawlers only because their crawling experience is the sum total of their self-produced locomotor experience) were true only of crawlers and not of walkers (for walkers both $p>.05$), see Figure 20. So, for crawlers, crawling experience was related to their choices ($F[2]=4.8$, $p=.01$).

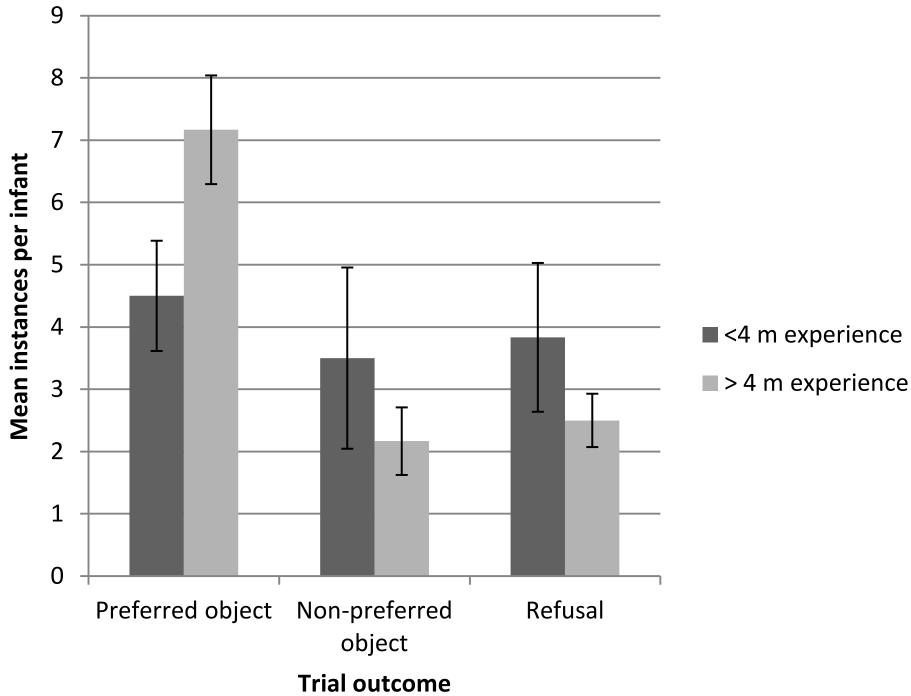


Figure 20. Mean instances per infant of each trial outcome in Study 2. Infants are grouped by months since crawling onset using a median split (for demonstration purposes only. Statistical analyses retained crawling experience as a continuous variable.)

Timing of movement initiation and object contact. One-way ANOVA analyses revealed no effect of object choice on time to enter the room on a given trial or on time to contact an object on a given trial (both $p>.05$).

Practice and exposure. A similar one-way ANOVA found no relationship between trial outcome and number of trials already elapsed during the visit ($F[2,243]=0.416$, $p>.05$).

Discussion

Study 2 sought to replicate the results from the first study and to further clarify the roles of age and locomotor status in shaping infant choice behaviour in a complex environment that affords locomotion. To accomplish these goals, a new group of infants participated in a procedure identical to Study 1. Twelve- and thirteen-month-old infants were recruited in hopes of obtaining similar numbers of crawlers and walkers while holding age constant (remember that in Study 1 crawlers and walkers differed in age but had comparable amounts of experience in their respective modes of locomotion). In this sample, then, crawlers and walkers were equivalent across age but differed in the amount of experience they possessed in their mode of locomotion, with crawlers possessing more experience crawling than walkers walking.

This study successfully elicited similar patterns of behaviour among infants to the first study. Infants' previously preferred objects continued to be the most attractive outcome across trials. Object distance was a significant determinant of infant behaviour on a given trial, with nearby objects contacted more frequently than more distant objects. The frequency of contacting an object decreased as the object moved from one to five feet from the infants' start position.

These two potential determinants of behaviour on a trial (which objects infants' had previously preferred and the distance of those objects) interacted together to shape infants' ultimate choice across the whole population. Preferred objects were chosen more frequently when close (either in terms of absolute distance from the infant or in relation to the position of the non-preferred object) than when far.

Across the entire sample of infants, increasing experience in one's mode of locomotion was associated with a higher rate of preferred object selections. This relationship was detectable among crawling infants when considered in isolation but not for walking infants under the same consideration.

In this study, no differences were observed between crawling and walking infants except on total number of trials performed. It is difficult to interpret these findings. The reason for these differences may be due to variation in parent or experimenter willingness to continue testing with a child who is mildly distressed. Perhaps fussing was more likely to be interpreted as an indication not to continue for crawlers as opposed to walkers. It is also possible that these differences in total trials completed are spurious.

Sex was predicted to have no role on infants' choice in this paradigm. Interestingly, in Study 1, a sex by choice by movement effect was found. However, the uneven sampling of male and female infants in Study 2 makes it difficult to evaluate this prediction with statistical robustness. Increasing the number of female infants in the Study 2 sample would allow for a better evaluation of whether the interaction found in Study is replicable.

This study failed to detect differences between crawlers and walkers on choices made across trials. This is surprising, since such differences were present in Study 1. There are several possible explanations. First, it may be that such differences exist, but the analyses lacked sufficient power to detect them. With twelve crawling and nine walking infants included in the analysis, a small sample size could contribute to this problem. Another possible explanation is a potential role of experience. Crawling infants select more preferred objects as they gain crawling experience (Figure 20) and the infants included in this study had a relative large amount of crawling experience (4.3 months since crawling onset was the mean). It is reasonable to speculate, then, that crawler/walker choice differences may be reduced in this sample characterized by relatively experienced crawlers.

In summary, Study 2 found that a sample of twelve- and thirteen-month-old infants made directed locomotor choices that were sensitive to object preference, object distance, and the interaction of these two factors. Their choices were shaped by experience in their locomotor mode, but not their locomotor mode itself.

General Discussion

The present research investigated the targets of infants' self-directed locomotion in object-populated environments as they acquire and perfect the skills of crawling and walking. In order to investigate the roles of age and locomotor status on the way that infants made these choices, two studies were conducted. Study 1 compared crawling and walking infants who differed in age but were equivalent in experience in their respective modes of locomotion. Study 2 compared crawling and walking infants who were equivalent in age but differed in locomotor experience. Results from the two studies provided insight into the way that infants selectively allocate their locomotion. The role of object distance in shaping infants' choices varied across development. Understanding how infants approach and experience space informs our understanding of their developing agency and the information available to them in the environment.

Several bodies of literature informed this research. Developmental researchers have examined the way that infants direct their movements in multi-target reaching environments (Smith et al., 1999) and the way that they exploit space in pursuit of specific hidden targets (Acredolo, 1990; Clearfield, 2004). However, none (to our knowledge) have explored the ways that infants spontaneously orient their locomotion between multiple available targets in an environment. Other fields of research that have examined similar questions were referenced in order to make reasonable predictions on how infants might approach the task. After consulting adult decision-making literature and models of how animals organize their behaviour in complex multi-target environments, four inter-related predictions were made. It was anticipated that infants would selectively locomote towards objects that they had previously preferred, that they would prefer nearby objects, that previous preference and nearness would interact in driving choice, and that locomotor status would play a role in how the two factors were weighted to produce infant behaviour. In order to assess these predictions, an experimental situation was designed to elicit many instances of object-directed, spontaneously oriented locomotion from infants.

Infants were recruited from a database of interested parents kept by developmental researchers in a psychology department in a large urban, Western, industrialized city (Karasik, Adolph, Tamis-LeMonda, & Bornstein, 2010). Caution should therefore be used in generalizing results found in this sample to developing infants in other settings. The sample was relatively diverse with respect to comparable infant samples in similar literature. Across the two studies 45% of infants included in the final analyses were identified by their parents as Caucasian. The city of Toronto reports that 47% of people living in Toronto in 2011 self-identified as a "visible minority," meaning non-Caucasian and non-Aboriginal (City of Toronto, 2013). These two data points, taken together, suggest that ethnically the sample was fairly representative of the larger population in the city of Toronto. Of course, it is still likely that specific groups were not proportionally represented in the sample. The socio-economic composition of the families represented in the sample was unknown; however, all families were able to travel downtown to participate in research without monetary compensation, suggesting that low-income families may have been under-sampled. However, one study found no effect of SES on age of walking onset (Stanitski, Nietert, Stanitski, Nadjarian, & Barfield, 2000), so this variable was not addressed in the present studies.

Infants' initial object preferences were assessed by providing them with the opportunity to direct spontaneous reaches towards members of object pairs. It was assumed that infants' preferences (inferred from their reaches in the first phase of the study) would be stable through the rest of testing. The method aimed to minimize opportunities for infants to tire of individual objects by providing equal opportunities to contact both members of an object pair at all times. However, differential experience actually contacting the two objects was unavoidable once infants began to make choices. Two results support the validity of the assumption that preferences did not change significantly over the course of the study due to accumulated exposure. First, infants' engagement with objects at the end of a given trial varied depending on whether the object they were interacting with was initially preferred or non-preferred. The difference in likelihood of engagement across object type was significant in Study 1 and trended towards significance (with p=.053) in Study 2. Second, if infant preferences were malleable, we might expect that their preference for a given object would weaken with repeat exposure or strengthen with practice. To see whether this was the case, each trial was given an "absolute trial number" that corresponded to the number of trials that the infant had already completed prior to this presentation. Tests revealed that absolute trial number did not interact with infants' choices in either study. While it is difficult to interpret null results, the fact that the number of trials an infant had completed prior to a given trial did not predict their choice suggests that infants are not decreasing their preferred object selections due to boredom or strengthening their preference through repetition.

Parent report was used to obtain records of the time since crawling and walking onset for each infant since this was the most easily available record. Time since onset is commonly used as a proxy for experience in a locomotor mode (e.g. Adolph et al., 2008) despite the fact that the amount of actual locomotor experience gained by an infant in a given day is quite variable (Adolph et al., 2012). Future studies are recommended that can more precisely track infant motor experience in connection with their directed choices. One interesting question for future research would be to investigate whether days of crawling experience and days of walking experience are "in the same units" in terms of their contributions to infants' other skills.

The studies examined where infants would choose to travel when allowed to enter a room containing two potentially interesting toys at different distances. Three distances were used in order to investigate whether infants' choices surrounding distance were dose-dependent or based on a proximal versus distal dichotomy. Twelve trials were created in order to obtain infants' choices for all possible combinations of the two objects' positions where the objects were unequally distant and one per side. As mentioned earlier (p. 53) twelve trials seemed to represent the upper limit of infants' willingness to participate in the study. Objects were placed either 30° to the right or to the left of the infants' starting position. Locations based on angle were chosen in order to control for the amount of head rotation required for infants to see an object from their starting position. This meant that, regardless of the distance of the two objects, neither required a greater degree of head or body rotation for visual detection. It was not possible to simultaneously control both the degree of rotation required for infants to see objects and the distance of objects from the midline of the room, so the six positions were not equivalent on this measure (see Figure 21).

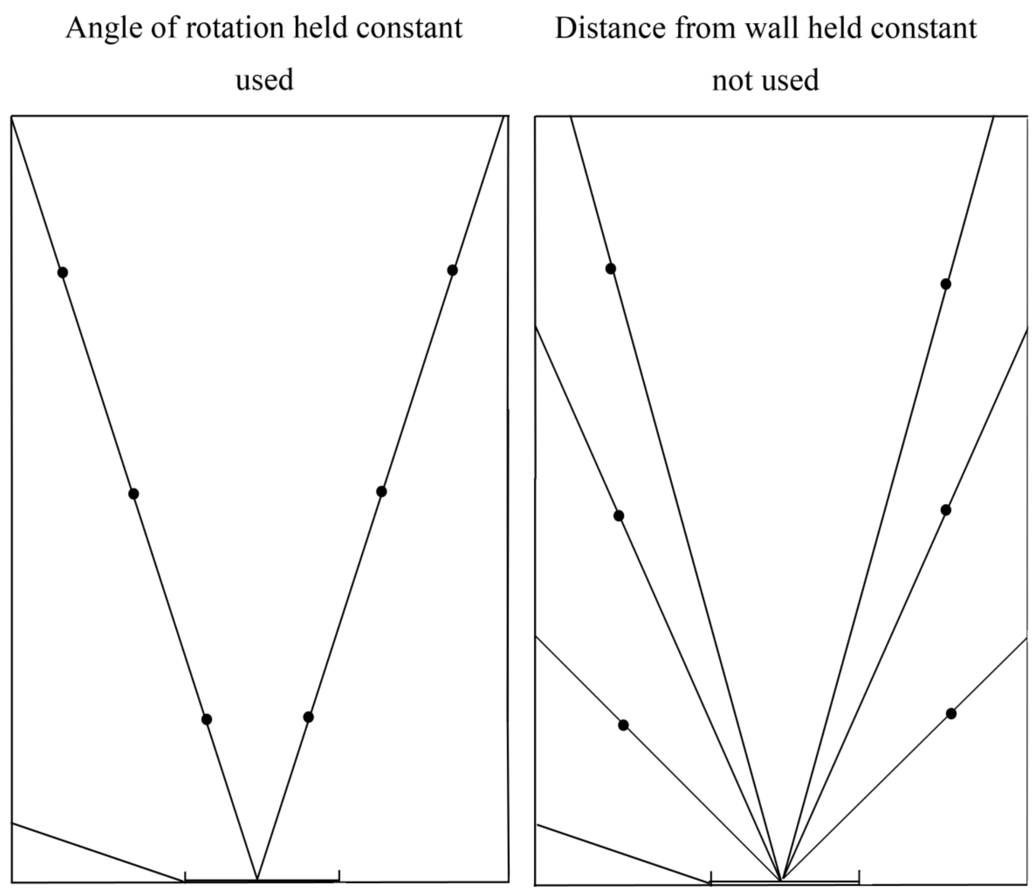


Figure 21. Two possible floor layouts considered during the design of the current studies. In the first layout (left panel), the angle of rotation from the start position is held constant across each of the three objects per side. In the second layout (right panel), the distance of each object from the nearest wall is held constant across each of the three objects per side, but angle of rotation from the start position varies. The first layout was used during the current studies.

A given pair of objects was used with an infant repeatedly unless the infant became disinterested and began refusing trials. In this case, a new pair of toys (for which a preference had been established in the reach phase) would be used. Experimenter and parent judgment was sometimes used in deciding when to persevere with a set of objects and when to switch. This system was selected due to variation in infants' actual behaviour on trials when they contacted neither object. Some refusal trials had infants fussing and turning away from the testing room while others had infants happily entering the room but becoming distracted (e.g. banging the walls or practicing standing). In some cases, the judgment was made that a distracted infant would not benefit from a new pair of toys, and so toys were not switched. The use of a judgment- rather than firm rule-based system was used in the hopes of maximizing infants' likelihood of completing all the study trials and maintaining engagement.

The studies used infants' previous behaviour towards objects as an index of preference (a presumed internal state of the infant). It is assumed that the degree to which infants preferred one toy over the other in a given pair is similar across pairs and across infants. This assumption is difficult to verify and this limitation must be acknowledged. Evidence is strong that preferred objects were, on the whole, chosen much more frequently than non-preferred. On trials where one of the two objects was chosen, in 79% of cases across the two studies the object was preferred. Additionally, if we consider infants' behaviour across the whole visit, only three of the 60 infants who participated in the two studies chose the non-preferred object on more than 50% of their object contact in the travel phase.

The individualized measure of object preference, while admittedly not ideal, was chosen after extensive pilot testing. Pilot testing revealed that there were large individual differences in infants' reactions to all objects in the set. For example, one child cuddled and carried a stuffed starfish toy while another appeared afraid of it and took circuitous crawling paths to avoid it. For this reason and because motivation was a factor that this research aimed to explore, the "previous behaviour" measure of preference was used.

Infants' performance on each trial was video-recorded and coded. Coders recorded the layout of the objects, the first object contacted, the infant's level of preference for that object based on the reaching phase, and the distance from start position and side of the room for the chosen object. The majority of these measures were coded with high levels of reliability; however, infant's level of preference for the ultimately chosen object (based on reaching phase data) were reliable at a level of r=0.715, which was lower than hoped. This was due to ambiguity in the coding instructions on what constituted an opportunity to reach in the reaching phase; one coder coded any adjustment of the objects by the experimenter as a new opportunity for the infant to reach, while the other coder did not. However, the two coders were in 100% agreement in classifying objects as preferred or non-preferred by the infant. For this reason, analyses were not performed using the fine-grained level of preference, but instead used the dichotomy preferred/non-preferred.

For each trial, coders also recorded the time from the start of each trial to infants' first room entry and to infants' first object contact. Object contact proved much easier to reliably code than room entry because many infants made ambiguous movements that were difficult to classify as they considered entering the room. There were no significant results involving these time measures but if they were deemed important in future research a more detailed coding manual for room entry would be recommended.

The final coded item was whether infants remained engaged with object through to the end of the trial. Engagement was defined as contact with the object at the time of trial termination or, if the object was recently thrown or dropped, infant looks to object. Agreement on this item was moderate. Engagement was found to be related to infants' choices. Coding discrepancies were likely due to ambiguous cases. For example, some infants would crawl over objects, and it was unclear whether or not the object was engaged. It is recommended that future work strive for clearer coding definitions to improve reliability.

The results of each study have been discussed individually (p. 56, 72), however, when taken together larger conclusions can be drawn (see Table 3).

Table 3

Significant Statistical Effects Across the Two Studies

Potential effect	Statistical test	Study 1 p<.05	Study 2 p<.05
Main effect of choice	Mixed-measures ANOVA	Yes	Yes
Choice x engagement at trial end	Chi square test	Yes	No[a]
Choice x absolute distance x movement	Mixed-measures ANOVA	Yes	No
Choice x relative distance x movement	Mixed-measures ANOVA	Yes	No
Choice x movement x sex	Mixed-measures ANOVA	Yes	No
Choice x relative distance x age	Mixed-measures ANOVA	Yes	No
Main effect of relative distance	Mixed-measures ANOVA	No	Yes
Relative distance x choice	Mixed-measures ANOVA	No[b]	Yes
Absolute distance x choice	Mixed-measures ANOVA	No	Yes
Relative distance trials x sex	Mixed-measures ANOVA	No	Yes
Main effect of movement	Mixed-measures ANOVA	No	Yes
Absolute distance x movement	Mixed-measures ANOVA	No	Yes
Absolute distance x total objects chosen	Series of t-tests	Yes	Yes
Chosen object side x total objects chosen	Series of t-tests	Yes	No
Choice x preferred object side	Chi square test	Yes	No
Specific movement experience x choice	One-way ANOVA	No	Yes
Self-produced locomotion (SPL) experience x choice	One-way ANOVA	No	Yes
Specific movement experience x choice (crawlers only)	One-way ANOVA	No	Yes
Total SPL experience x choice (crawlers only)	One-way ANOVA	No	Yes

[a] trending, p=.053
[b] trending, p=.051

First, the two simplest predictions (p. 27) were confirmed in both studies. It was found that infants contacted their previously preferred object more frequently than they contacted objects they had not previously preferred and more frequently than they refused to contact either object. It was also found that objects were not chosen at equal rates across all distances from the infant's start position; instead, infants contact nearby objects more frequently than more distant objects.

Recall that it was also predicted that object choices would be made based on the interaction of distance and preference for all infants, and that this interaction was further predicted to be moderated by locomotor mode. Each of these predictions was confirmed by one of the two studies but not the other. There was no overall interaction between distance and preference in predicting infants' choices in Study 1 when crawlers and walkers had similar levels of experience in their respective modes. However, it was found that this interaction did exist for crawlers only. So, infants with three months of crawling experience made distance/preference trade-offs in their choices, while infants with three months of walking experience did not. In contrast, among the age-controlled group of infants used in Study 2 the three trial outcomes (preferred object contact, non-preferred object contact, or refusal) were unequally distributed across trials that differed in object distance (both relative and absolute). Preferred objects were chosen more frequently when they were relatively close, while infants "switched" their choices and more frequently contacted non-preferred objects when the preferred objects were too far away. The moderation by movement style seen for this effect in Study 1 was not found in Study 2.

Why do the two studies differ in their findings? The two studies used populations that differed in two ways: in the level of experience that the infants had in their locomotor mode, and in their sample size. There seem to be three possible explanations for the findings.

First, it could be that with a larger sample size Study 2 would replicate Study 1. Perhaps the overall interaction between distance and choice is, as in Study 1, driven by crawlers. However, it is possible that a low sample size does not allow separation of crawlers from walkers, resulting in an overall effect but no detected moderating effect of locomotor status.

Second, it could be that crawlers and walkers display different patterns of choice when they are equivalent in locomotor experience, but with experience crawlers employ patterns of choice that look more and more walker-like (i.e. are distance insensitive and preference driven). This would produce the observed pattern of results whereby comparing experienced crawlers with new walkers (as in Study 2) results in no difference in their pattern of choices.

Third, it could be that locomotor status does not drive the observed changes in choice at all, rather, the effect is driven by age. This interpretation is supported by the choice x distance (relative) x age interaction in Study 1 and the lack of choice x distance x movement interaction when age is held constant (Study 2). A number of changes accumulate with age and could participate in this effect. Synaptogenesis takes place in many brain areas over the first several years of life (Huttenlocher & Dabholkar, 1997). The way that infants engage with objects, termed "level of play," becomes increasingly sophisticated with age (Schneider, 2009). With age, infants also add to the total time they have possessed the ability to control their location in space (regardless of modality).

To summarize, the current studies suggest that crawling and walking infants are sensitive to both the distance and preference status of objects as they direct their locomotion in environments. There is evidence that at least some infants trade these two factors off against each other, with preferred, distant objects sometimes being abandoned in favour of nearby, non-preferred objects. 11-month-old crawling infants make these trade-offs while their experience-equivalent walking peers do not. However, when relatively experienced crawlers are compared with their age-matched, early walking peers, no differences in strategy are detectable. The exact role of locomotor status and experience are still therefore excellent candidates for further study.

Other differences in the results of Studies 1 and 2 deserve discussion. First, Study 1 found an effect of object side on likelihood of being contacted, while Study 2 did not. Since there was no theoretical reason to expect this finding, its occurrence in one study only supports the possibility that it is spurious and not due to a systematic preference of infants for objects placed on their right. Second, Study 2 but not Study 1 found an interaction between infants' crawling experience and their choices, with more experienced crawlers producing more preferred object selections. It is likely that Study 2 was better able to detect this effect because the crawlers assessed in Study 2 had a larger range of experience crawling (with a standard deviation of 2.3 rather than 1.5 months crawling experience), making this effect easier to detect.

With these results in mind, what can be said about the theories that were initially reviewed? The current work provided mixed support for the transition into walking as a "setting event" in the way that infants direct their locomotion. The parameters that infants used to make choices changed as crawling experience was accumulated and differed between crawlers and walkers. However, whether the transition into walking leads to an immediate reorganization of choice-making remains an open question.

The literature suggests several mechanisms by which a crawling/walking difference could occur. Previous work (Clearfield et al., 2008; Kretch et al., 2012) has provided support for the finding that crawlers and walkers look to different things in their environment. A observation made during Study 1 supports this possibility. The crawling infant with the most distance-independent pattern of results (a pattern that was more typical of the walking infants in the study) stood up on her knees to survey the room several times both before and during her travels to objects, affording her with a viewpoint similar to what a walker might experience. It is logical, then, that her walker-like viewpoint allowed her to produce a walker-like pattern of choices. Mothers of walkers have been found to be less praising (Biringen et al., 1995). All infants in the current studies were praised for contacting any object. It is possible that for walking infants this praise was more motivating because the level of praise in the home environment was lower than it was for crawlers. Under motorically difficult conditions, infants have also been shown to take inappropriate, perseverative paths (Berger, 2004). Could it be that crawlers in both studies and new walkers in Study 2 failed to travel long distances for preferred objects because the motor difficulty of the task interfered with their ability to hold their destination in mind?

The current studies partially supported the predictions made based on the fields of delay discounting and foraging theory. Both fields suggested that infants were likely to produce choices that were consistent in their expression of object preference and consistent in minimizing distance travelled.

Research centered on the phenomenon of delay discounting is interested in cases where individuals must make choices in which the two options differ across multiple dimensions. Typically, these dimensions are the value of the two outcomes and the delay imposed between an individual selecting an option and receiving the outcome. In the experimental set-up used, infants were able to choose between two objects; one object had been the target of exploratory movements in the past, and one had not. The two objects were also placed at different distances from the infants' starting point, meaning that there were different delays imposed between when the infant could see the objects from the starting position and when they could be contacted. Knowledge of the field of delay discounting led to the prediction that, in this paradigm, the choice between two objects would be made differently depending on the delay associated with each object. The trade-off between distance (i.e. delay) and choice was observed for crawling infants in Study 1 and all infants in Study 2, suggesting that infants do in fact display behaviours that are sensitive to two choice parameters simultaneously. It was also predicted that crawlers and walkers would differ in their choices because they travel at different speeds and therefore would reach their targets with different levels of delay. This prediction was confirmed in Study 1 when crawlers and walkers with similar levels of movement experience were compared. It was not confirmed in Study 2. This suggests that perhaps the two groups used in Study 2, experienced crawlers and early walkers, did not differ in their travel speed.

Research in the area of foraging theory also predicted that infants would make choices that would maximize the value they obtained from their environment per unit effort. Rather than emphasizing delay as delay discounting does, foraging theory models assume that actors will seek to minimize travel distance or sometimes caloric expenditure. In this experiment, it was assumed that infants would maximize their reward by seeking stimulation from toys that they previously sought out, presumably because those toys were more pleasurable or interesting. This reward-maximizing heuristic predicted that infants would pursue previously preferred toys more often than producing other behaviours, and this prediction was confirmed in both studies. It was also assumed that infants would minimize their travel distance by selectively pursuing nearby objects and again this prediction was confirmed in both studies. The more sophisticated prediction made in the spirit of foraging theory, though, was that infants would trade these two factors against one another and an interaction between an objects' distance and its preference (or "value") would be seen to drive infant choices. This interaction was observed for crawling infants in Study 1 and for all infants in Study 2. The lack of interaction for walking infants in

Study 1 could be taken to mean that these walking infants no longer sought to minimize travel time at the expense of seeking out preferred objects. It could be that travelling becomes so "cheap" for walking infants (presumably in terms of some units measuring effort or caloric expenditure) that it no longer plays a role in shaping behaviour. For instance, it could be that walkers' ability to keep objects in view as they travel towards them reduces the cost of travel in terms of difficulty keeping targets in mind and thus reduces the cost of travel. Alternatively (but not mutually exclusively) it could be that the reward-maximizing side of the equation becomes more salient to infants and outweighs the incentive to minimize travel. For instance, it could be that the upright, walking stance frees up infants' hands to manipulate objects in more complex or interesting ways, thus increasing the infants' interest in those objects.

While the transition from crawling to walking was of interest in this study, the cross-sectional nature of the study design did not allow for systematic investigation of how infants' choices change while in the midst of this transition. Future longitudinal work to this effect would be illuminating. Based on the results of the current work, it could be predicted that as infants transition from crawling to walking the distance they are willing to travel in pursuit of interesting objects will increase.

It is important to remember that infants' choices controlled their location in their environment and the stimulation and opportunities for action available to them. An infant who refused to enter the room and instead turned towards the parent would have been exposed to a dynamic, expressive adult face and perhaps some language. In contrast, an infant who entered the room and interacted with a toy received locomotor experience, feedback from muscles and joints, and the toy's response to being touched, hefted, or even thrown. These two infants, in selecting different behaviours are in a way also selecting different environments. The study of infants' self-directed locomotion is also then the study of the information and feedback available to them. The finding that under certain conditions crawlers and walkers make choices differently can also be viewed as the finding that crawlers and walkers experience the world differently and have different opportunities for learning. This work further clarifies the mechanism by which the transition to walking acts as a "setting event" across various psychological domains for the infant. The way that children occupy their space allows for large variability in what their world affords to them, and must be considered when examining how and what children learn and do.

Limitations

The current research has certain limitations that should be acknowledged. The procedure relied on infants to self-report their preferences for objects with their reaching patterns. It was assumed that infants' patterns of reaching during the reaching phase of the experiment reflect object preferences that will shape behaviour throughout the rest of the study. Further discussion of this assumption is found on page 74. The research is currently unable to comment on infants' self-guided locomotion towards objects in total isolation from the social landscape; infants were asked to travel from a starting point near a parent into a room that contained the experimenter. Further work is needed to examine the role that the social landscape may play in shaping the choices observed in these studies. Additionally, little is known about the potential role of attachment in shaping infants' choices in this experimental context. Furthermore, the question of how properties of the objects themselves (e.g. their colourfulness, size, and shape) may have driven infants' preferences or motivation to pursue them is still open for study.

Future Directions

There are a number of interesting directions that this area of research could pursue next. First, there is an opportunity for further experimental control. Parents in the current studies were not instructed how to hold their children between trials. They were, however, instructed to try to maintain their infant's attention on the temporarily hidden testing room. This meant that infant body position at the start of each trial was dictated by parent and infant, not experimental control. This approach was selected in order to maximize infant compliance, but it does leave open questions about how different start positions may have affected infants' willingness to leave the parent and pursue the target objects. Experimental control or even manipulation of starting body positions would therefore be informative.

Second, the currents studies are well suited to adaptation for further examination of infants as route-planners. In conditions where the preferred object was more distant than the non-preferred object, infants' routes can be conceptualized as requiring an extra step. This step is to bypass the non-preferred object en route to the preferred object. Previous work has suggested that 30- and 45-month-old toddlers are only able to make one-step plans when they must coordinate picking up a ball and dropping it in a different location (Hunnius, Verlaan, & Rosenbaum, 2012). Experimental manipulation of distracters or obstacles between infants and potential targets could provide interesting data on how infants incorporate these factors into their choices.

Third, these studies provided excellent opportunities for infants to reference their parent and/or the experimenter for feedback on their actions. Previous research has examined the way that infants use maternal affect in guiding their object exploration (Hornik, Risenhoover, & Gunnar, 1987) and infants' spontaneous looks to parents under conditions of uncertainty (Hornik & Gunnar, 1988). Both of these could be measured as they occurred naturalistically in the current study or under conditions specifically designed to elicit, suppress, or manipulate them.

Fourth, a number of interesting possible explanations of the results were raised through consideration of the delay discounting and foraging literatures. One question of particular interest is, what is the particular property of distance that makes infants less likely to pursue objects? Delay discounting would lead us to believe that distant objects are selected less frequently because of the delay associated with retrieving them. Foraging theory would suggest that distant objects have an energy cost associated with them. Those with other theoretical backgrounds could suggest that distant objects provide less perceptual information because they appear smaller on the retina. Carefully constructed conditions could be used to tease these factors apart, and are strongly recommended in future research.

Conclusion

In conclusion, this work provided the first description that the author is aware of to examine factors influencing infants' choices in directing their own locomotion in a multi-target environment. Infants' choices were shown to be sensitive to their previously expressed preferences towards objects as well as to object distance. Conditions were created in which preference and distance were incongruent and infants were obligated to rely on one of the two factors in selecting objects. For intermediate and expert crawlers and early walkers, both preference and distance were used to make choices. For intermediate walkers, preference alone was used to direct locomotion towards objects. Both adult decision-making literature and animal models of foraging were discussed as lenses through which the results could be interpreted. Infants were framed as agents capable of selectively allocating locomotion in order to exploit their environments for exploration and action.

Appendix 1: Recruitment Phone Script

Hello, may I please speak to ____?

Hello, my name is ___ and I am from the CHILD lab at Ryerson University. We met you at ___ (or you recently participated in a study on ___) and we wanted to let you know that your child is eligible for one of our new studies!

(If not interested, see below. If interested, continue.)

First can I just confirm that (baby's name) was born (birthdate)?

(*If infant is not eligible:* Thank you. Unfortunately, at this point your son/daughter is not eligible for this study that we're running. But we've got some coming up that they'll grow into, so we'll be sure to give you a call then!)

Beautiful! Can I tell you a bit more about what this specific study involves?

This study is very simple. It involves the baby freely exploring a new environment by crawling or walking. They will be presented with a variety of interesting toys which are spread out in the room and will be able to direct their own exploration. Your role is just to be present in the room and encourage your child! This study should take about 30-minutes, and we expect that the entire visit will last no more than an hour. Would you be interested in participating in this study?

Beautiful! We'd love to have you visit at a time of day when (baby's name) is more active and alert. Some upcoming times could be ____. When would you like to come in?

Sounds great. So the CHILD Lab is located at 105 Bond St. on the Ryerson Campus. We are in the heart of downtown Toronto right next to the Eaton Center and Dundas Square, at Young and Dundas TTC. When you come to the lab you will first enter our child-friendly waiting room where you will also have access to a private changing and feeding facility. A researcher will then explain the study with you in detail and ask you to fill out a small pre-observation questionnaire and a consent form. These questionnaires will inquire about your child's development (e.g., milestones etc.) so that the researcher can best gear the experiment to your infant's ability. I should let you know that during the questionnaire you will be asked when your child began crawling and walking (if applicable) so if you have ages or dates written down at home we would really appreciate if you took a look at them before your visit!

The consent form will outline the fact that all information gathered is private and confidential, and that you have the option to withdraw from the study at any time. You are with your infant at all times. Just to let you know that all of the sessions will be video-taped in order to allow the researcher to examine the records of observations at a future date. Is that alright with you?

Once the study has been completed (typically one-hour in total) you and your infant will receive a token of our appreciation. Do you have any questions about the CHILD lab or the nature of this study?

(*Any questions posed by the parent will be answered*).

Excellent! Thank you for your willingness to participate! We look forward to having you. I will send you an email with all the information on how to get to the lab right after this, just so you have it. If you have any further question, please feel free to call or e-mail us at any time. Thanks so much! See you soon.

(If not interested)

That's just fine! Would you like to be contacted about new studies as they come up in the future, or would you like to be removed from our list?

(If they would like to still be contacted)

Sounds great. We will keep you posted as new studies come available. Thanks so much for speaking to me today. Have a great day.

(If they would like to be removed)

No problem. I will remove your name from our list. Thanks so much for speaking to me today. Have a great day.

Appendix 2: Parent/Guardian Consent Form

Cognition • Health • Infancy
Learning • Development

Study Name: Researcher: Participant Number: Trial Order Code: Date:

PARTICIPANT CONSENT FORM

RESEARCH PROJECT TITLE: Exploring New Environments

PURPOSE: The purpose of this study is to help us understand how infants direct their exploration in complex environments.

This consent form, a copy of which will be left with you for your reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask at any time before, during or after the study. Please take the time to read this carefully and to understand any accompanying information. If you have questions or concerns regarding your participation in research, please contact the Ryerson University Research Ethics Board.

PROCEDURE: We are developing a new study to explore how babies between 10-20 months explore a new environment containing many interesting things. After a brief warm-up period, you will be asked to take a seat in the exploration room and hold your baby while the researcher shows him or her some interesting toys, spread throughout the room. You will be asked to encourage your child to investigate the room and the toys. Since we are interested in how babies make choices when exploring, we ask that you provide general encouragement to your child but that you not point to specific toys or name them until the child has chosen them on their own. During the child's exploration there are no right or wrong answers. Sometimes babies are very interested in the toys at the lab and sometimes they are not as interested. Both of these are normal responses and do not say anything about your child's development. At some points, you may be asked to remove a toy from your child in order to encourage them to keep exploring. The researcher may also play some games with you and your child designed to look at which toys your child prefers and their skill at navigating the room. Lastly, you will exit to the waiting room and debrief with the researcher for a few minutes. Between the warm up period and the debriefing, the semi-structured part of the study should last approximately 30 minutes and will be video-taped for analysis purposes at a later date. Including the warm up and debriefing, we expect that you would be in our lab for no more than 1 hour.

POTENTIAL RISKS AND BENEFITS: The only potential risk for participation is that your baby may become disinterested in the task and display more fussiness than is usual for him or her. However, you are free to take a break to address any needs of their infant or to discontinue the session at any time. The researcher will also closely monitor your infant's readiness to continue.

As for the potential benefits, you have the opportunity to learn more about infant development! In addition, we expect that this session will be fun for your infant as he or she can explore various toys with you. Importantly, although not a direct benefit to participants, the findings from this session will help us in developing our future studies of infant exploration. This has the potential to extend previous research and contribute to the question concerning how infants organize their search behaviour.

CONFIDENTIALITY: Any information that is obtained in connection with this study will remain strictly confidential. Your privacy and that of your infant will be respected. Should you at any time wish not to be contacted for future studies, please tell a member of the lab, and we will be happy to remove your name from contact list. All records will be referred to in the study using pseudonyms and study codes which will be securely stored on a local password-protected network and locked in the CHILD lab. The questionnaires and any other hard copy information pertaining to this study will be stored in a separate locked filing cabinet from the consent forms in the laboratory. Sessions are video-taped in order to allow the researcher to examine the records of observations at a future date. All video-recordings will be used strictly for research purposes and can only be accessed by those directly involved in the study. These images, like the rest of your child's information, are stored separately from information identifying your child. Most academic journals require raw data to be stored for 5 years post-publication. Therefore, the data will be stored for this period of time before it will be destroyed.

PARTICIPATION: Your participation is voluntary. You are not under any obligation to answer any questions. If at any time you wish to withdraw from this study and session, you may do so without any consequences by simply notifying the researcher. You also have the option of removing your infant's records of observation from the study or requesting that the session not be video-taped. Your choice of whether or not to participate will not influence your future relations with Ryerson University.

ADDITIONAL INFORMATION: Because of the unique needs of infants, a variety of special procedures are in place to ensure your baby is safe and comfortable during each component of the study. In the waiting area, the toys provided for the infants to play with are age-appropriate. All of the materials used during the experiment are designed and built to be safe for babies with smooth rounded edges and the use of non-toxic paint. All toys are sterilized with a baby-safe cleaning agent after each session with an individual infant. In addition, the tasks are designed to be very engaging for infants at this age. The trials are conducted in a "game-like" fashion which infants typically enjoy. Infants will remain with their caregiver at all times. The caregiver and researcher will continually monitor the baby's emotional state and readiness to continue. The sessions can also be paused to address any feeding or changing issues that arise and a clean and private area of the lab is provided for these purposes.

FEEDBACK: We hope that you are interested in the research and we will be happy to answer any further questions you might have about it at any time. If you wish to be informed about the results of this study, please leave your phone number and/or e-mail address and you will be contacted upon the completion of this project. If you do not wish to be contacted and are still interested in the results of the study then you may obtain information about the results by contacting us.

COMPENSATION: As a token of our appreciation for taking part in our study, you and your child will receive a small gift bag containing a small children's book or toy to take home with them for their efforts. You and your child will receive this complimentary gift regardless of whether your child completes the study.

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CONSENT: I agree to have my son/daughter ______________________________ participate in the study described above. I have read the description of the study and I understand the details of the procedure. As part of my consent, I agree to be videotaped during the experimental session. I realize that I may withdraw my child from the study at any time if I wish to do so.

______________________________	______________________________
Name of Parent/Guardian	Signature of Parent/Guardian
______________________________	______________________________
Signature of Researcher	Date

Appendix 3: Motor Milestones Questionnaire

Study Name: ________
Researcher: __________
Participant Number: ___
Date: ________________

PRE-OBSERVATION QUESTIONNAIRE

Welcome to the CHILD Lab! Before we begin our session, we ask that you complete this simple questionnaire regarding your child's early development. We will use your responses to help us to better answer our research questions. Please answer the following as accurately as possible. You are not obligated to answer any of the questions you do not feel comfortable with and may stop participating at any time without penalty. All questionnaire responses will be entered into a secure database and will be kept private and confidential. If you have any questions, please contact the researcher listed on the copy of the consent form you were given to take home (Jill Dosso 416-370-5000 ext. 4859 or jill.dosso@psych.ryerson.ca).

SECTION I: PERSONAL INFORMATION

Parent's Name: ______________________________

Address: ______________________________

Telephone: ______________________________

☐ I would like to receive your newsletter featuring updates about the lab and results from previous studies

☐ Please contact me if my son/daughter is eligible to participate in future studies

May we contact you by email? ☐ Yes ☐ No Email address: ______________

How did you hear about our lab? ______________________________

☐ Brochure / Poster ☐ Website ☐ Friend ☐ Resource Centre: ______________

☐ Other: ______________________________

SECTION II: INFORMATION ABOUT YOUR INFANT

Name: ______________________ Gender: ☐ Male ☐ Female

Date of Birth (dd/mm/yy): ______________ Expected Date of Birth: ______________

Were there any complications during pregnancy or delivery? ☐ Yes ☐ No

If yes, can you note the nature of complication? ______________________________

Ethnicity: ☐ South Asian ☐ Black ☐ Caucasian ☐ Filipino

☐ Latin American ☐ Chinese ☐ Aboriginal ☐ Other: __________

Birth Order (e.g. only child, first, second…): ______________________

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Age of siblings: ____

SECTION III: CURRENT ABILITIES OF YOUR INFANT

1. Is your child able to reach for objects?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge?
2. Is your child able to hold objects without dropping them?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge?
3. Is your child able to pick up very small objects (example: Cheerios cereal) with their fingers?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge?
4. Does your child use his/her hands and mouth to explore objects?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge?
5. Is your child able to roll over (from back to stomach <u>or</u> stomach to back)	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge?
6. Is your child able to sit up independently without any assistance?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge?

SECTION IV: RECENT AND UPCOMING ABILITES OF YOUR INFANT

We would like to estimate these onset times as closely as possible. If you have additional information (such the exact or approximate date an ability was first observed or how many weeks ago you first noticed it) please note it.

7. Is your child able to crawl?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge? ______________________	Additional notes (if any):
8. Is your child able to pull themselves up to a standing position using furniture?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge? ______________________	Additional notes (if any):

9. Is your child able to walk using support (example: furniture or help from a parent)?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge? ____________________	Additional notes (if any):
10. Is your child able to walk independently without any assistance?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge? ____________________	Additional notes (if any):

Do you have any concerns or general comments regarding your child's development?

____

____

Thank you! The next session will begin shortly…

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