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Exploitation of perceptual information by 9.5 month old infants in search tasks

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EXPLOITATION OF PERCEPTUAL INFORMATION BY 9.5-MONTH-OLD INFANTS IN
SEARCH TASKS

by

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(Bachelor of Science, McMaster University, 2007)

A thesis

presented to Ryerson University

in partial fulfillment of the
requirements for the degree of

Master of Arts

in the Program of

Psychology

Toronto, Ontario, Canada, 2009

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ABSTRACT

EXPLOITATION OF PERCEPTUAL INFORMATION BY 9.5-MONTH-OLD INFANTS IN SEARCH TASKS

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2009

The relationship between object-knowledge and goal-directed action is critical to understanding cognitive development in the first year of life. Examining the organization of action, perception and cognition in 9.5-month-old infants, the current study first investigates the effects of manipulating perceptual information when searching for a goal-object by coordinating a bi-directional detour reach around transparent, opaque and 50%-graded occluders to obtain a goal-object. Second, the study explored how changes in cognitive complexities via a manipulation to the number of hiding-locations (three-vs. five-) affect infants' problem-solving abilities. Results-demonstrate infants' impressive ability to initiate a mental plan of action and subsequently execute appropriate motor actions. Infants' search benefited most when the object was visible through the occluder and some information about the occluder's solidity was provided. The findings support the lack of memory-inhibition accounts (Diamond, 1991) and shed light onto previously unexamined elements of perceptual-cognitive development during the first year of life.

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DEDICATION

To the loving memory of my beloved mother, ZAHRA HODAEIAN, whose legacy shapes my life to this day; And to the three pillars of my life who have supported me through all my endeavors: My Father, My Sister and My Partner.

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I. INTRODUCTION

The everyday observation of infants in their natural home surroundings provides a rich arena for thinking about the origins of development. Imagine a typical 10-month-old infant in a room filled with toys, play sets to crawl around, places to climb on, objects to explore, to bang on, throw and furniture to hide behind. In the first year of life, the scenarios are ubiquitous and—from the infant's point of view—enormously exciting! Yet within these everyday occurrences lies a psychologically challenging task for the infant: how to make sense of all this. How do they visually sort out the complex scene? How do they anticipate events and understand the physical characteristics of space and motion? How can they mentally represent their parent who walks behind a room divider and reappears on the other side? These questions are at the heart of a well established research field exploring the foundations of development and a core component of this thesis.

Search-tasks are an ideal method to investigate problem-solving abilities. Even as adults, success at problem solving requires the integration of a number of cognitive skills such as attention (i.e., engagement and resistance to distraction), visual exploration, memory and the ability to carry out a sequence of motor actions to manipulate the necessary objects (Greenwood, Walker, Carta, & Higgins, 2006). Similarly, newborn infants explore their environments visually by following and tracking objects and people and by the middle of the first year, infants are actively searching and acting on objects in their surroundings. These cognitive skills are rooted in infancy and develop throughout childhood, affecting children's success in academics and in later years of life; making problem solving abilities an adaptive skill.

Emulating a natural setting where moving objects and people frequently appear into- and out-of-sight in a cluttered environment, this thesis presented infants with a moving ball passing under a series of tunnels. The properties of the tunnels were manipulated in such a way that when the ball came to rest underneath a tunnel, it was either fully hidden, partially hidden or fully visible. The objective of this research was to examine how infants use visual

information to guide their actions in coordinating a reach around the tunnel in order to search and retrieve the goal-object (i.e., the ball). Second, the study explored how changes to the number of hiding locations under these perceptual manipulations affect infants' problem-solving abilities. However, in order to identify the structure and organization of infants' decision-making and action-planning that relate to their understandings of object knowledge and representation, it is important to first examine previous scientific studies and experiments. It is also important to note that this thesis will examine a comprehensive literature on human infants' perceptual, motor and cognitive developments in the first year-of life, and while areas of evolutionary psychology (see Bjorklund, 1997) and neurophysiology (see Case, 1992; Michel, 2001) are relevant and influential, these will not fall within the scope of this review and thus will not be examined.

1.1 HISTORY OF SENSORIMOTOR DEVELOPMENT

Prior to the 1980s, the human neonate was largely viewed as a reflexive creature with a very simple repertoire of sensorimotor behaviours and fixed action patterns that gradually became coordinated and internalized. However, more recent findings have revealed that the infant is considerably more competent, capable of goal-directed and spatially coordinated actions. It is nevertheless important to consider early views of development as many of these ideas have directly influenced how we view the infant and most are still relevant to the current and on-going investigations about the infant's mind and cognitive knowledge.

Some of the early pioneering leaders in the field of motor development such as Arnold Gesell and Henry Marc Halverson, argued primarily that development was guided and influenced by maturation of the central nervous system and was controlled by unfolding genes (Ball, 1977). Gesell's most influential contribution was his derivation of a normative motor timetable describing when children first show particular behaviours as well as the time range that such motor behaviours first appear. Similar to Gesell's work of describing

behaviours as it happened, Halverson (1931; 1933) specifically examined the development of prehension in 4- to 60- week-old infants by recording their reaching and grasping actions on a movie film which he analyzed frame-by-frame. Through his remarkably detailed depiction of infants' early coordinated actions, he described four steps involved in prehension: "(a) the visual location of the objects, (b) the approach by the hand, (c) the grasp, and (d) the disposal of the object" (Halverson, 1931, p. 270). Halverson believed that reaching proficiency was due to anatomical growth of the hand and arm, maturation of the neuromusculature as well as training (Berthier, John, & Vivian Packard, 1997). It is evident from these "micro genetic" studies that all infants initially face similar motor constraints in executing a coordinated reach for a desired object, but that such difficulties were overcome with time. These detailed studies provided foundational observations about motor control and development as well as highlighting the role of maturation and experience in the infant's changing behaviours.

Another iconic figure in developmental psychology is Jean Piaget (1952, 1954) who suggested four basic stages of development that capture a child's growth into an intellectual being, capable of thought and reasoning. He believed that few behaviours in the first stage (i.e., sensorimotor period) were indicative of true cognitive or conceptual understanding; nevertheless he stated that the first stage served as a critical foundation for future development of cognitive functions. Thus, with the introduction of the term *sensorimotor* development, Piaget described the development of basic sensory, perception and motor capacities in the first two-years of life. The term *sensory* refers to the incoming visual, auditory and tactual information while *motor* refers to the actions of reaching, grasping, locomotion and active manipulation of objects. Perhaps most importantly, though, Piaget directly linked sensation and action with intellectual advancement of the infant. Through detailed observations of his own children, Piaget provided data that from birth, infants actively interact in their surrounding using sensori-motor processes that originate from innate reflexes. Such reactive responses permit the child to engage in manipulation and handling of

objects (e.g., grasping and mouthing in particular), leading Piaget to describe the infant as the actor or agent in their environments. Based on the infant's own active exploration and body movements, he argued that the child forms a repertoire of mental structures or schemas that allows for the contents of the mind to develop through gradual assimilation and accommodation. Subsequently through repetition and modification of those actions, the infant formulates a more complex representation of their environment and ways of understanding and interacting with the world. In one now famous observation, when a toy was covered, infants up to 7- to 8-months behaved as though the toy no longer existed. Extending from these observations, Piaget reported that infants' object concept and problem-solving abilities emerge at 8-months of age when the infant is able to hold a mental representation of the hidden object and is aware that it continues to exist, despite its disappearance. Indeed, it is now widely believed that the ability to mentally represent and retain information about a hidden object while coordinating an appropriate action to search and retrieve it, involves complex cognitive abilities. Although the infant is effectively unable to generate words to describe their understanding of thinking and planning, studies in motor control and development have re-emerged with new rigor suggesting that the infant's actions are in fact reflective of their knowledge about the world. Several key ideas of Piagetian theory have been incorporated into other accounts and descriptions such as the dynamic systems theory to better understand (or explain) movement and motor actions.

Dynamic systems theory has been most useful in understanding rhythmic or cyclic actions such as kicking, stepping and bouncing; however one of this theory's most relevant aspects to the current study is its emphasis on learning by exploration. This approach has been greatly influenced by the work of Eleanor Gibson (1984) who argues that infants actively exploit their environments through three basic activities: 1) *exploratory activity* of the visual perceptual systems, 2) *extraction of distinctive feature* in the visual field and 3) *observation of consequences* of exploratory actions (Rosser, 1994). The first two processes are strictly perceptual and the latter relates to active motoric exploration. In other words, a

young infant's initial exploratory activity with the world occurs primarily through visual perception (and other incoming sensory input) which is integrated, processed, and ultimately, it gives shape to the decision made by the infant about the appropriate course of action. From early in life, infants use vision to explore the environment, recognize objects and extract information relevant to their activities. Visual information is also critical for guiding action whereby one's movements are continuously adjusted and controlled in response to the incoming visual information (Bertenthal, 1996; Gibson, 1979). In the words of James Gibson, "We must perceive in order to move, but we must also move in order to perceive" (1979, p. 223). It is clear that infant's goal-directed actions rely heavily on the coupling of perceptual and motor abilities that equip them with tools to engage and bring about interesting events, sensations and situations. In fact, nearly all spatially coordinated behaviours such as visual tracking, reaching, grasping, sitting and walking require that visual perception and action operate together as a system which is an essential component for developing knowledge. The ability to carry out a coordinated action promotes active exploration while the gained cognitive knowledge about the world serves as a motivator to continue the interaction in one's surroundings. Consequently, not only are action and perception dynamically coupled in a continuous cycle, but it is this very coupling that provides the key "input drivers" for determining cognitive developmental outcomes in the first year.

In revisiting the infant placed at the centre of a cluttered room with objects and people constantly appearing and disappearing, it is important to consider the components involved in searching for a goal-object (i.e., a ball) stopped behind a barrier and to examine the four sources of manual search difficulties that the infant must overcome in order to successfully retrieve the desired object (see Figure 1 from Williams, 1983).

First, the infant must be able to perceive and process the incoming visual information via sensory input. As the ball moves in and out of occlusion, the infant must selectively attend and visually track the ball and construct a mental representation of its physical

properties, trajectory and location. The term *representation* is typically used to refer to knowledge and memory of an object's features (i.e., colour, shape) and spatial properties (i.e., speed, direction and hiding location). Second, the infant must integrate and interpret the incoming sensory information in order to conduct a course of action. The infant's past experience and memory of objects and people moving in- and out-of-occlusion will strongly influence the decision on how to organize an appropriate motor response. It is at this third stage that the infant will decide how, when and where to execute the motor behaviour. Once the object has come to rest (or no longer reappears from occlusion), the infant must coordinate and carry out a reach towards the correct location and either remove or detour around the barrier blocking the ball. Finally, as the action is being conducted, information about the nature of the ongoing behaviour, visual and auditory information as well as movement of the infant's own body through space is continuously fed back into the system allowing the infant to make 'online' modifications and motor adjustments. Moreover, on subsequent hiding events, infants must inhibit a reach towards the location where the object was last seen or rewarded and instead direct their attention towards the most recent hiding location and execute the appropriate action plan (Moore & Meltzoff, 2008). Therefore, it will be important to consider each of these components as well as the scientific literature that accounts for the underlying development of object knowledge.

1.2 EARLY OBJECT KNOWLEDGE

From birth, infants have the capacity to visually explore their surroundings and with the coupling of perceptual-action systems, they begin to form very early representations of objects. Several studies have documented newborns' early abilities in discriminating forms such as circles, squares and triangles as well as size and shape constancy (Slater, Mattock, & Brown, 1990; Slater & Morison, 1985; Slater, Morison, & Rose, 1982). Through the use of innovative methodologies like the *violation of expectancy* (VOE) pioneered by Renée Baillargeon and Elizabeth Spelke (1985), studies have been designed to tap into young

infants' knowledge of physical laws and hidden objects who are otherwise unable to demonstrate their true knowledge due to uncoordinated motor skills. It is argued that infants younger than 8-months are overwhelmed by Piaget's hiding tasks because the infant is required to plan and execute complex patterns of behaviour in order to retrieve the hidden object (Spelke, Breinlinger, Mancomber, & Jacobson, 1992; Willatts, 1984). Therefore, instead of "obligating" the infant to use manual action, Spelke and Baillargeon proposed that infants' understanding of the world be evaluated by recording their visual fixation responses on the target-object.

VOE is based on the idea that infants, like adults, should convey a surprised response when objects in the world defy expectations of everyday physics, such as an upward movement of an object when it is dropped; as a result, infants demonstrate longer looking times to the *unexpected* (objects defying gravity) events in comparison to *expected* (objects falling with gravity) events within the laws of physics. In fact, infants under 6-months of age have yielded impressive evidence of awareness of object permanence and rules governing objects' movements (Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992). In one key study, Spelke, and colleagues (1992) tested 2.5- to 4.5-month-old infants' reasoning about the continuity and solidity of objects by habituating them to various events. During habituation trials, infants were shown a ball rolling left to right and disappearing behind a screen. Once the screen was lifted, infants in the test condition saw a ball resting against a wall and infants in the control group saw a hand lower a ball beside the wall. After several habituation trials, a second wall was introduced in front of the original wall and infants in the test condition were presented with both consistent and inconsistent events. In the consistent event, the ball rested against the near wall (novel position, but consistent with physical laws), whereas in the inconsistent event, the ball rested against the far wall (old position, but violating the physical laws). While infants in the control group looked equally at both events, 3-month-old infants in the test condition looked longer at the inconsistent event where the ball rested in one position, implying that it had passed through the first wall on the

track. Spelke et al. (1992), including additional experiments (Baillargeon, 1987), converge to show that young infants have innate cognitive representations of the world and are able to reason about the physical laws of *continuity* (objects moving on connected paths and do not jump from one place and time to another) and *solidity* (objects moving on unobstructed paths). Others have contested the notion that infants possess core knowledge and argue that findings from VOE studies merely indicate that infants are able to detect changes and are sensitive to early perceptual experiences (Bertenthal, 1996; Oakes & Cohen, 1990). Nevertheless, even such visual discrimination or implicit sensitivity to physical attributes and laws highlights an important foundation for object development that allow the infant to learn about the world. After all, higher-order thinking is dependent upon the development of lower levels of functioning and that the processing and integration of perceptual information is the initial step towards object knowledge (Williams, 1983). In this section, the role of perception in prospective behaviours will first be reviewed in the context of infants' visual tracking, anticipatory reaching and visually guided reaching skills. Subsequently, literature on infant and toddler's abilities in searching and retrieval tasks will be considered.

1.2.1 Sight of Hand and Object

In the first months of life, infants are already working as "active scientists" who spend many hours persistently engaging and exploring their surroundings. The dynamic system between visual perception and action develop through these everyday experiences and activities, thereby allowing the interaction between the two systems to become well-coordinated and purposefully directed. Therefore, it is important to understand how infants use perceptual cues and information in order to coordinate and execute their actions appropriately towards a target-goal of interest.

Based on early research studies, it was observed that infants between 3- and 5-months of age would often glance between the target object and their reaching hand during the course of their reach (Piaget, 1952; White, Castle, & Held, 1964). Piaget (1952)

proposed that infants younger than 5-months require the sight of their hand and the target in the same field of view in order to guide their reach. Based on this concept, Bushnell (1985) provided a richly detailed account of the development of 'visually guided' reaching, stating that the initial "prereaching" movements are characterized as visually elicited or preprogrammed. In other words, reaching in infants up to 4-months of age is based on a rough mapping between vision and proprioception whereas the visual information about the location of one's hand in space, and its relative position to the body, plays a key role in early reaching. By 8-months of age, the mapping between the systems is well coordinated and infants no longer use vision of their hand to correct movements and guide their reach to the target (Carrico & Berthier, 2008). Nevertheless, Bushnell (1985) speculated that when a task becomes too complicated, even older infants will resort to using vision of their hands to obtain the object. Therefore, the development of reaching initially depends on the infant's ability to coordinate vision to the relative position of their hand and that through the maturation of neuronal networks and practice, this mapping becomes more sophisticated and less dependent on monitoring of one's hand position to the target.

However, more recent research indicates that visual feedback of hand position increases, rather than decreases with development. Ashmead, McCarty, Lucas, and Belvedere (1993), presented a glowing target to 5- and 9-month-old infants in the dark. Testing infants in the dark is beneficial because visual 'noise' in the environment is eliminated and investigators can manipulate what the infant can see using glow-in-the-dark materials. In half of the trials, the target-objects either remained lit throughout the course of the reach (i.e., no-switch trials) or that it darkened during the infant's reach and reappeared in a novel position (i.e., switch trials). Furthermore, half of the infants completed the trials wearing a luminescent marker attached to their reaching hand, serving as a cue to proprioceptive information. The authors reported that 5-month-olds were generally inaccurate in reaching and that the presence of the hand marker did not aid their performance. In contrast, they reported that 9-month-old infants partially adjusted to the target-toy appearing

in a new position only when wearing the hand-marker, but not without it. What's more, when the target remained lit through the entire trial, 9-month-olds performance was comparable to adults with and without hand markers and infants correctly reached for the target. Overall, it appears that with development, visually guided reaching becomes an important factor in attaining a target particularly when the task requires immediate motor adjustments. The findings suggest that infants (at least by 9-months of age) are more successful in reaching for an object that remains stationary or visible during the reach in comparison to when object location and visual information are perturbed. Similarly, McCarty (1993) found that when sight of a stationary illuminated object is completely eliminated during the latter part of infants' reaches, 7-month-olds failed to contact the target than when it darkened midway through the reach while this difference disappeared by 9-months of age. In another study, 6-month-old's reaches for a glow-in-the-dark object were similar to reaches made in the light leading to the conclusion that the sight of target-object may also be critical to younger infants (Clifton, Rochat, Robin, & Berthier, 1994).

In general, visual information is of particular importance when infants engage in precision eye-hand-coordination tasks—vital ingredients, as noted above, for cognitive advancement. Based on the studies in this field, it appears that the sight of target is crucial in planning a reach to the correct location and that sight of hand is particularly helpful in coordinating the latter parts of reaching to the target, particularly when the task requires precision. Consequently, it is also important to consider the specific role vision has on infants' prospective behaviours.

1.2.2 Perception in Prospective Behaviours

The human infant along with comparative infant species, come into the world adapted to perceive motion (Sekuler & Sekuler, 1993). From birth to 8-weeks of age, the human infant is capable of detecting and localizing motion using saccadic eye movements and by 3-months, they are able to track motion using smooth pursuits at an adult level

(Nelson & Horowitz, 1987; von Hofsten & Rosander, 1997). In general, these developments are crucial to controlling one's actions prospectively; that is, using feedback from the visual field to *anticipate* future position and motion of the object and control one's actions accordingly.

Perceptual information about a moving target in the environment is often interrupted by other entities in the visual field. In order to maintain attention across such occlusions and track the object successfully, the observed motion of the object must be represented during the occluded portions (von Hofsten, Kochukhova, & Rosander, 2007). Interestingly, infants do not track an object over occlusion with smooth eye pursuits but rather by 4 months of age, infants stop and fixate on the occluder's edge for a brief time and prospectively shift their gaze using one or two saccades, to the reappearance side just before the object reappears (Bertenthal, Longo, & Kenny, 2007; von Hofsten, 2005). Von Hofsten expresses that infants represent the object's velocity during occlusion and "track the object behind the occluder in their 'mind's eye'" (2007, p. 56). Although the author notes that this ability is not necessarily indicative of infants' knowledge of permanent objects' existence over time, he suggests that the "object velocity may rather be represented by some kind of buffer during visible as well as non-visible parts of the motion" (von Hofsten et al., 2007, p. 637). Such predictive visual tracking involve higher-level cortical pathways and not low-level retinal signals indicating that infants are able to hold a mental representation of an object when it is out-of-sight (Bremner, 2000). But with increasing visual target speed at shorter occlusion intervals, an infant's ability to shift their gaze to the other side of the occluder ultimately deteriorates (Gredebäck, Hofsten, & Boudreau, 2002). It appears that under these circumstances, there is a lack of sustained attention that does not provide the infants with enough time to evoke representations of the hidden object and subsequently execute an overt gaze shift (or action) (Bertenthal et al., 2007). Therefore, infants can perform at adult performance levels so long as the limits of the visual system are not greatly exceeded.

Another prominent example of future-oriented behaviours by infants is illustrated through visual expectation paradigm by Marshall Haith (1988). In this eye-movement paradigm, infants' eye movements are tracked as they observe small pictures alternating between the left- and right- side of the centre of the screen. From this, it appears that 2- and 3- month-old infants begin to show anticipatory fixations and saccades to the reappearance locations of pictures, even when timing and location of the pictures become more complex (Dougherty & Haith, 2002). In other words, infants can detect spatiotemporal regularities in visual targets and form expectation for what visual targets appears next and subsequently (re)act on those expectations to make anticipatory eye movements to the site of upcoming targets (Wentworth, Haith, & Hood, 2002). The success of pursuit tracking at such an early age is especially impressive given that the infants' heads were unrestrained during testing; yet infants were still successful in tracking objects with a combination of head and eye movements.

The observation of predictive reaching for moving targets appears developmentally after predictive visual tracking due to the increased dynamical difficulty of coordinating one's reach to one's vision. As previously discussed, the execution of a successful reach is nested in a hierarchy of behaviours such as eye movements, eye-head coordination and eye-hand coordination. Von Hofsten was the first to study infants reaching for objects moving at various speeds in a horizontal arc (von Hofsten, 1980; von Hofsten & Lindhagen, 1979). The studies found that infants as young as 18-weeks of age reach for moving targets in a predictive way and are capable of catching objects moving up to 30 cm/sec by 5-months and 125 cm/sec by 8- months of age (von Hofsten, 1983; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). The success of catching the moving object requires that the infant predict the anticipated position of the moving object and initiate arm and hand movements so as to intercept the object, instead of chasing or waiting for the target (Robin, Berthier, & Clifton, 1996; von Hofsten, 1983; von Hofsten & Lindhagen, 1979). Furthermore, the reaching hand also needs to be adjusted to the orientation, form and size of the object (von Hofsten, 2007).

Therefore, infants from an early age are able to prospectively control their eye-movements to changing patterns of information in their environment and quickly learn to control their reaches in anticipation of the target's future position while representing the target's spatiotemporal features when it undergoes occlusion. Despite infants' abilities and apparent knowledge of objects and prospective behaviours from early on, infants are not always successful in their efforts to visually track and retrieve hidden objects. Notwithstanding this, even such errors shed a light into infants' cognitive functioning and development that is critical to object knowledge and understanding.

1.3 FACTORS AFFECTING SUCCESS IN SEARCH-TASKS

While success in any task can potentially explain what infants (and adults) are capable of performing and planning, their errors also reveal what factors interfere with their action and cognitive processing in support of coordinated outcomes. Infants make interesting errors particularly when searching for hidden objects which are typically posed by three constraints: the environment, lack of motor coordination and/or conceptual ability to problem-solve.

Piaget invented many "hide-and-seek" or searching games in order to examine infant's knowledge about object permanence. One of his signature games that has now become an experimental focal point of infant cognition is known as the A-not-B task (Piaget, 1954). In this classic example, Piaget hides a watch from his 9.5-month-old son under cover A, Laurent is successful in removing the cover and retrieving the watch. After repeating this game several times, Piaget then hides the watch at a location B and describes his son's behaviour: "Laurent watches this maneuver attentively. But at the moment the watch has disappeared under garment B, he turns back towards coverlet A, and searches for the object under the screen" (1954, p. 58). Based on this erroneous search back to location A where the watch was originally hidden and retrieved, Piaget concluded that Laurent did not completely differentiate that objects exist independent of where it was last successfully

found. Based on these striking observations with his children, Piaget concluded that infants lack the concept of object permanence; a conclusion that has been challenged under controlled laboratory conditions in recent decades.

However, it also appears that the physical act of reaching and coordinating the arm towards the target-goal seems crucial to error (Smith, Thelen, Titzer, & McLin, 1999). Using methodologies such as the violation-of-expectancy paradigm and other measures of looking time previously discussed, infants have demonstrated some expectations of object behaviours and hiding properties however, when infants are asked to demonstrate their knowledge through action, they often fail. An experimental account by Hofstadter and Reznick (1996) provided a direct comparison between performances in A-not-B task where infants either responded by reaching for the hidden object (as per the original A-not-B tasks), or by looking to the hiding location. The study found that infants made more errors when required to actively search for the object (by reaching) than in the looking task. Many developmental scientists have attributed discrepancies between young infants' looking behaviour on occlusion tasks and the older infants' failure on manual search-tasks to a deficit in the means—end planning (Baillargeon, 1986; Baillargeon, Graber, Devos, & Black, 1990; Bower, Broughton, & Moore, 1971).

A means-end sequence typically involves acting on an initial object (e.g., pulling a cloth, displacing a stimulus), and then acting on a subsequent object (e.g., removing a cover, pushing a button) to obtain (or reveal) an end-goal. A deficit in this account means that young infants are aware of the hidden object's location but cannot coordinate their motor behaviour to remove the intermediate obstacle(s) or sub goals that then allow them to search and obtain the desired end-goal object. The ability to differentiate between and choose appropriate sequences of action (and tools) to achieve the ultimately end-goal emerges at about 8- to 9-months of age. Prior this age, infants are unable to conjoin actions to manipulate the barrier to get to the occluded object. In addition to VOE paradigm's support for this account, studies conducted in the dark also support the means-end deficit account. In

this paradigm, the object is concealed by darkness rather than a physical barrier allowing the infant to directly reach for the target instead of a means-end actions sequence resulting in greater performance levels in infants younger than 8-months of age (McCall & Clifton, 1999). Therefore, when the object is available via a direct reach, infants are successful even if direct visual information about the object is not present, thus suggesting a means-end deficit for infants' search difficulties.

Other studies have questioned the role of memory and inhibition to interpret infants' performance on these search tasks (Moore & Meltzoff, 2008). For instance, it has been found that once the infant is correct at the new location, if the toy is hidden at the original location, the infant will make an error by reaching back to the location most recently correct (Cummings & Bjork, 1983a, 1983b). Generally, the literature reports that these errors are exacerbated when a delay is imposed between the hiding event and infants' action, and that the amount of delay necessary to inflict error increases with age. The literature suggest that 8-month-olds make more error with delays of at least 3-seconds, whereas 10-month-olds make errors with delays of at least 5-seconds which strongly implicates that memory (or the ability to maintain attention) is a key factor in successful object retrieval (Diamond & Goldman-Rakic, 1985; Smith et al., 1999). The likelihood of errors increases with longer delays because the memory for the most recent hiding location declines but that such limitations are overcome with age. In this light, Adele Diamond (1991) has proposed that the immaturity of the frontal cortex (i.e., prefrontal cortex) in infants leads to poor performance. There is a general agreement that these regions serve higher cognitive functioning, planning, reasoning and attention that does not fully mature until puberty. The frontal cortex is critical in reducing distractibility and promoting inhibitory control in order to focus on one event as well as the ability to expand one's attention beyond that one event, all of which are crucial aspects in successful problem-solving abilities (Diamond, 1991).

In one prominent study, Diamond, Cruttenden, and Neiderman (1994) examined the role of memory and inhibition in 9.5- to-10-month-old infants using multiple hiding wells. To

eliminate any biases to the midline (Butterworth, 1975), the 7-hiding wells were embedded in into a table and arranged in a semi-circle. The infants were tested for their abilities in retrieving the goal-object in three different conditions. In the first condition, the object was placed into a well and a tray was pushed forward covering the wells simultaneously. In the second condition, the toy was hidden by lowering it into a well. In the third condition, a cloth over a well was removed, the toy was lowered into a well and the well was re-covered by the same cloth. In both the second and third conditions, the last action was conducted at the correct well where the toy was hidden, whereas in the first condition, the last action was the pushing of the tray to cover the wells all at once and did not draw attention to the correct hiding-location. Findings revealed that performance in the first condition (i.e., wells covered simultaneously) was significantly worse than performance in the other two conditions. In addition, infants' performance on the 7-hiding locations covered at the same time was significantly below the performance in 2-hiding locations (i.e., A-not-B task). Not surprising, when attention is drawn to the correct well, performance on 7-hiding locations is as good as 2-hiding locations. Interestingly, the types of errors infants conducted in this study were not random. When the new hiding location is not an endpoint (i.e., well 1 or well 7), infants make errors by reaching to either side of the correct well, and disproportionately err in the direction of the previously correct (and rewarded) location. These results have led Diamond (1991, 1994) to hypothesize that lack of performance on multiple-hiding locations is due to a combination of weak memory and inhibition. Therefore according to the hypothesis about frontal cortex immaturity, the infants' inability to retrieve objects and problem solve is not due to a lack of conceptual understating but due to an inability to remember and inhibit previously correct responses.

As previously argued, sensory information from the environment must be integrated and processed in order for other series of events (i.e., action planning) to occur. When faced with a challenging task of retrieving a target-object under occlusion, sensori-information about the object and its location are critical in successful retrieval. Some scholars have

argued that as with the A-not-B task, infants' search errors occur because hiding locations are visually similar and close in proximity (20- to 30-cm from centre to centre with adjacent edges 2- to 5-cm apart) (Bremner, 1985; Butterworth, 1977). Infants' visual attention to the hiding location has also been raised as another factor contributing to errors in search-tasks. Infants who maintain visual fixation with the object and intently look in the direction of the hiding location are much less likely to make errors than those whose gaze is broken with the target or its location (Butler, Berthier, & Clifton, 2002; Smith et al., 1999). Therefore, infants' errors decrease when perceptual information from the object and its location are visually distinct, spatially further apart and visual distractions are limited so that visual fixation with the target can be maintained (Smith et al., 1999). Improvement of such environmental cues and tasks help the infant to better integrate and process sensory information.

In conclusion, although active search and retrieval increases between 6- and 12-months of age (Shinskey, Bogartz, & Poirier, 2000; Willatts, 1984), Piaget's (1954) claim that infants below 8-months fail to search for hidden objects is readily replicated. Indeed, to plan and execute a search for a hidden-ball requires complex motor planning that is clearly more difficult than the looking-tasks. Therefore under such circumstances, infants may remember the mental representation of the hidden-task but cannot simultaneously coordinate and execute an action to retrieve the target-object (Mash, Keen, & Berthier, 2003). Alternatively, it is possible that infants are capable of coordinating a means-end sequence but that they simply forget the relevant features of the task or are unable to use their mental representation for the object and its location to act appropriately. Despite such accounts that can potentially improve or impede infants' performance in search-tasks, the manipulation of visual information maybe the pivotal component at the heart of how infants integrate demanding sensory information and execute an action that will best support their successful search for a hidden object.

1.4 MANIPULATION OF VISUAL OCCLUSION IN SEARCH-TASKS

Search-tasks are an ideal method to investigate many aspects of cognitive development, such as memory, logic reasoning, spatial representation and problem-solving (Butler et al., 2002). Everyday environments are filled with barriers and obstacles presenting a complex scenario, rich with sensory and perceptual information that must be integrated and processed. This task is often challenged when the direct visual view of targets are partially or completely blocked by other nearer objects and surfaces. Not only does the structure of perceptual information change as the infant and objects continuously move, but with such active exploration, the infant is further challenged in coordinating their movements to reach for objects that cannot be directly obtained. One method to test infants' abilities in search-tasks is to manipulate the object's perceptual information using transparent or opaque occluders. This represents an interesting approach for the study of infants' searching behaviour because transparent barriers still engage the infant in the same necessary motor actions as objects behind opaque barriers, but provide the added advantage of having direct visual of the target throughout the course of action. Conversely, opaque barriers eliminate all perceptual information about the object and the infant must navigate their actions based on a mental representation (or memory) of the object. With the above, it becomes imperative to examine experimental research on infants' performance under various visual manipulations when searching for stationary and dynamic objects and understand how infants problem-solve when attempting to retrieve objects that are not directly within their reach.

1.4.1 Searching for Stationary Objects

The review of literature on infants' performance in search and retrieval tasks based on manipulations of perceptual information is divided. A clever series of studies by Shinksky and colleagues (2000) has found that 5- to 8-month old infants retrieved a toy from behind a transparent curtain more often than from behind a semi-transparent or opaque curtain and that such difficulties were more apparent in younger infants (i.e., 5- to 7-month-olds) than 8-

month-olds. Furthermore, Shinskey (2002) eliminated means-end demands in both opaque and transparent conditions altogether, where 6- and 10-month-old infants were asked to retrieve target-objects placed in water (transparent condition), milk-hidden (opaque condition) or milk-visible, where the object protruded 1-cm above the milk's surface. The study found that the object's visibility of the target plays an important role in infants' search such that 6-month-olds were more likely to make contact with the object and retrieve it in the visible events (i.e., water and milk-visible) than in hidden event (i.e., milk-hidden); however this difference was not evident in 10-month-olds. These important findings led Shinskey and colleagues to disagree with the means-end deficit account, arguing that successful retrieval of visible objects behind transparent barriers suggests that possess the necessary motor skills to obtain the target (Shinskey & Munakata, 2001). The authors hypothesized that there are several capacities that may ultimately be responsible for infants' failure in the hidden-conditions such as memory deficits, lack of spatial knowledge or lack of object permanence.

Notwithstanding the above, further examining of the literature on search-tasks behind transparent and opaque occluders does contradict the findings that implicate infants' greater success in retrieving visible-objects in comparison to those hidden behind opaque barriers. A longitudinal study by Lockman (1984), for example, examined the generalization of detour across different motor responses and barrier types. From 8-months of age, infants were required to reach or locomote (i.e. crawl) around a clear-transparent or solid-opaque barrier to obtain a goal-object. In this task, Lockman presented an object to the infant that was then taken away and placed behind the barrier by taking it up and over the centre of the barrier. The study showed that even when both motor skills had been acquired, infants made detour reaches prior to locomotor detours but that such differences were not due to barrier length or infants' position relative to the barrier or the goal. Interestingly, the sequence in which the infants solved the detour problems was not random. All infants solved the opaque reaching task first (9.7-months) and the transparent locomotor task last (11.9-months), while the relative positions of the transparent reaching and locomotor detour were more variable (10.7-

and 11.2-months respectively). However, infants generally experienced less difficulty with opaque barriers than with corresponding transparent ones, as many infants attempted to reach or locomote directly through the transparent screens or by shaking the edges of the screen. Lockman (1984) concluded that these difficulties suggest a conflict between visual and other perceptual information (i.e. tactual perception) for making a detour around the transparent barrier, and most often the visual information predominates making detours around transparent barriers unsuccessful. In other words, infants must first recognize that they cannot reach or locomote through the transparent barrier, then suppress the strong tendency to reach directly for the object and subsequently plan an indirect (i.e. detour) reach to the target-object. Given that infants have a limited pool of processing resources, the increased amount of planning and inhibition of executing a direct reach through the transparent barrier results in deteriorating cognitive planning and motor action.

A subsequent study by Lockman, and Adams (2001) tested detour ability of 10- and 12-month-old infants around barriers that differed in transparency. Once again, infants made reaching and locomotor detours to retrieve a target-object around a clear-transparent barrier or a clear-transparent barrier overlaid with a grid-pattern using black tape; the net effect was to create a transparent barrier with partial information suggesting occlusion. The authors reported that older infants were more successful and required less time to retrieve the object from behind the barriers than their younger 10-month-old counterparts. They go on to report that both younger and older infants were faster and more successful when making detour reaches around the barriers (vs. locomoting) and demonstrated more success and less time to retrieve objects from behind grid-like barriers. Interestingly, Lockman's analysis of exploratory attempts with the barriers indicated that younger infants attempted to contact the object *through* the barriers more often than the older infants but that in general, avoiding a reach through transparent barriers was not learned as quickly as with the grid-like barrier across both age groups.

These findings are consistent with a longitudinal study by Diamond (1990) investigating how the manipulation of visual perception affects 6- to-12-month-old infants' success in retrieving an object. The retrieval-task is administered with a clear-transparent or a white opaque box (4.5 x 4.5 2 inches) and the opening to the box is rotated so that infants must reach into the box at different spatial arrangements. The study revealed that infants from 9-months of age were quicker to succeed in retrieving the object from the opaque box than from a corresponding transparent box.

Similar observations by Schonen and Bresson's (1984:111; see Diamond 1991) led them to make a summative conclusion that, "programming a reach on the basis of a mental representation (opaque screen) seems to be easier, at 9-months, than to program a hand path which makes a detour relative to the line of sight to the object (transparent screen)." Although these findings seem counterintuitive and contradictory to studies by Shinskey and colleagues (2002; 2000), Adele Diamond (1991) argues that despite lower demands placed on memory when the barrier is transparent, infants have full visual of the desired toy which makes it difficult for them to "pull-away" and instead reach around to the opening (Diamond, 1990). Whereas in opaque conditions, infants are not require to resist (or inhibit) a direct reach to where they see the toy and as a result, 9-month old infants are better able to guide their actions based on their mental representations for the object. These findings have been linked to the immaturity of the prefrontal cortex based on studies with monkeys who had lesions in this brain region and who similarly attempted to reach straight through the transparent barrier to obtain food (Diamond, 1990). However, in order to gain better insight into infants' problem-solving abilities under various visual manipulation, it is also important to examine literature on how these types of visual manipulations affect infants' actions of retrieving and intercepting moving objects that have undergone occlusion.

1.4.2 Searching for Dynamical Objects

In contrast to search-tasks for stationary objects, an object that continues to move hinders search performance as it has to be continually represented as it undergoes occlusion. As discussed in earlier sections, when acting on a moving object, it is not only necessary to use visual information to coordinate a reach ahead of the moving object, but it is also important to use perceptual information to estimate the future position and motion of the object. Such prospective control is fundamental in the execution of purposeful behaviour and is particularly salient during early development.

Through a series of studies, Berthier (2001), Keen (2003), and their colleagues directly assessed representation of hidden objects with 9-month-old infants. Berthier, Bertenthal, Seaks, Sylvia, Johnson and Clifton (2001) investigated infants' visual tracking or reaching for a ball that rolled down a ramp (from left to right) behind a solid-opaque occluding screen. On some of the trials, the path of the moving ball was blocked by a wall positioned behind the opaque occluder which protruded several centimeters above the occluder. If infants represent the object moving and reasoned that it would be stopped by the wall, they would not expect the object to emerge from occlusion. After presenting infants with random Wall and No-Wall trials, it was found that although infants made more anticipatory reaches to intercept the ball when no-wall was present on the track, infants often shifted their gaze and executed a reach to the right of an occluder when in fact a wall was present on the track. Consequently the examination of the kinematics of reaches on wall and no-wall trials indicated that once a reach was initiated, it continued all the way to the track. Based on these findings, it was suggested that the infants were so "intent" on catching or pursuing the moving ball that they simply could not keep track of whether or not a wall was present (Keen & Berthier, 2004).

Moreover, the wall's top portion protruding above the occluder did not serve as an obvious cue to its presence and the authors rationalized that the wall's limited visibility with the opaque screen placed additional burden onto the already difficult perceptual-motor task.

That is, infants were not only required to take the ball's trajectory and speed into account but to also represent the wall blocking the ball's path while coordinating their motor abilities to plan a reach at the same time.

Therefore in a subsequent study, Keen, Carrico, Sylvia, & Berthier (2003) replaced the opaque occluding screen with a fully clear-transparent Plexiglas so that infant would not be required to remember the wall's presence on the track. The study found in no-wall conditions, infants made more contact with the moving ball as it moved behind the transparent occluder (65%) in comparison to the condition with the opaque occluder (40%), suggesting that information from the ball's trajectory leading up to the disappearance of the moving ball is valuable for a continuous control of the reach. Furthermore, when a wall was present behind a transparent occluder, infants correctly made less anticipatory reaches than when it was situated behind the opaque occluder. Therefore, 9-month-old infants are capable of inhibiting a reach when enough information is provided about the wall and its effects on the ball. Nevertheless, it was not apparent which of the two visual information (the complete sight of the ball's trajectory or the visibility of the wall in its entirety) helped infants adapt their reaching behaviour from the opaque to the transparent occluding tasks.

Keen et al. (2003) attempted to separate the two sources of visual information by using an opaque occluding screen with a transparent vertical 'window' (where the wall was positioned). The study reported that even when the ball's trajectory was occluded as it disappeared behind the screen, the visual information of the wall's extension onto the tracks aided 9-month-old infants to make more anticipatory reaches on no-wall than when the wall was present. In comparing anticipatory reaching to the right side of the occluding screen for wall-trials, the results indicate that infants made more anticipatory reaches when the occluder was fully- opaque (22%), but dropped to 15% and 2% in the 'window' and fully-transparent conditions respectively (Keen et al., 2003). In other words, infants took advantage of the moving ball's trajectory before its disappearance, but sight of the wall alone (either the top portion or its full length through the window) was not sufficient to prevent

reaching on wall-trial. Moreover, in comparing infants' ability to search for the ball resting against the wall, the results indicated that more infants in the window condition correctly directed their first search for the stationary ball to the left of the occluding screen in comparison to the other two conditions. The authors' speculation behind infants' greater search success in the 'window' condition is that in comparison to the fully transparent screen, the window in the occluding screen provides information about the solidity and impenetrable nature of the wall that helps infants plan a detour reach. Thus, in comparison to the fully opaque screen, a window in the opaque screen serves as a reminder of the wall's presence (Keen et al., 2003). Based on these results, it can be argued that such "reminders" serve to reduce the cognitive load because infants do not have to remember the solidity of the occluding screen or the vertical extension of the wall that extends down to the track and can therefore, coordinate and execute an appropriate reach to find the ball. Just as it appears that we understand infant cognition that infants by 9-months of age are beginning to express some rudimentary knowledge that of physical laws (i.e., *solidity*, and *continuity*) through their actions, several studies with children 2- to 3-years of age indicate that toddlers are not able to successfully problem-solve when asked to search for hidden-objects.

1.4.3 Developmental Discontinuity – Review of Toddlers' Performance

Given the rich literature on young infants' abilities to search for hidden objects behind barriers, occluders, among a variety of hiding locations (even if the object is in motion), it is perhaps reasonable to assume that these skills should be well developed in toddlers. This said however, in examining the literature on toddlers' search-task performance, it is apparent that there is a discontinuity in the development of visuospatial reasoning and physical knowledge.

In a study based Spelke (1992) on the VOE paradigm, Berthier, DeBlois, Poirer, Novak and Clifton (2000) presented 2-, 2.5-, and 3-year-olds a ball rolling down a ramp behind an occluding screen with four doors. Prior to rolling the ball down the ramp, children

watched as the experimenters placed a barrier on the track, followed by lowering a wooden screen with four doors so that the track and the lower portion of the wall was concealed, leaving the top portion of the wall always visible above the door. The experimenter drew the toddler's attention to the location of the wall, released the ball (in full-view) at the top of the track and pushed the apparatus forward before inviting the child to retrieve the ball by opening the corresponding door. The study showed that it is only after 3-years of age that infants begin to successfully retrieve the ball by opening the correct door (Berthier et al., 2000).

The authors of the study argue that 2- and 2.5-year-olds errors were not random, as some children selected a "favourite door" and chose it on more than 50% of the trials, whereas other children perseverated and tended to only search at the previously correct door. The investigators reasoned that perhaps the 2- and 2.5-year-old children's performance was due to difficulties with visuospatial reasoning about the doors' position relative to the wall and that the hidden movements of the further taxed toddler's performance in retrieving the ball. Subsequent studies using the door-task attempted to aid toddlers' performance by providing more information about the ball's movements as well as enhancing different aspects of the apparatus. Specifically, a study enhanced the door's appearance by using different colours (recall that colour-coding hiding locations improved younger infants' performances), named each door and asked children to merely point to the correct door (Bausch, 2003). This was done to decrease perseveration on a "favourite door" and to avoid the tendency to repeat a particular motor act. Unfortunately, these efforts did not exert any changes in the poor performance of 2-year-olds.

More recently Keen and her colleagues (Keen, Berthier, Sylvia, Butler, Prunty, & Baker, 2008) conducted a series of studies to enhance various aspects of this task. In the first study, investigators added auditory cues to the ball where it made noise as it travelled down the ramp colliding with the wall on the track. The addition of auditory cues to the ball did not aid 2- to 2.5-year-olds performance in solving the task. In the second study, Keen et

al., (2008) modified the wall such that the entire length of the wall was visible as it overhanged the occluder screen (with doors) as it had proved successful for 9-month-old infants (Keen et al., 2003).

The investigators also attempted to increase children's motivation by providing stickers as rewards on correct trials. The increased visibility of the wall and reward on correct responses helped only some of 2.5-year-old children. In the third study, the experimenter's hand was used as the wall to stop the ball based on the notion that infants are very sensitive to the intention of other's manual acts (Woodward, 1999). Once again, it was found that the switch to a human arm and hand did not significantly improve 2.5-year-olds' performance on finding the ball. Subsequently, the investigators examined if 3-year-olds success on the search-tasks was based on a simple associative strategy (i.e., learn to open the door to the immediate left of the wall on the track) or whether their success was based on a deeper cognitive achievement about physical laws of rolling balls and barriers. Therefore in the fourth study, the ball was rolled down the track from left-to-right as well as right-to-left. It was reported that 3-year-olds performance was significantly above chance and that the wall is an important cue in guiding their reach. The last study investigated if toddlers could maintain memory of a much shorter wall's position on the track. After showing the position of the wall, the occluding screen (with doors) was lowered to completely obscure both the track and the wall and then the ball was rolled down the track undergoing invisible displacement (as per Berthier et al., 2000). The study found that remembering the ball's location without any direct visual cue (of the wall) placed an additional burden on their memory that still proved to be too difficult for 3-year-olds as it had been for 9-month-old infants (Berthier et al., 2000). The authors concluded that the toddlers' failure in these search-tasks appears to lie not in the failure of attention to the barrier, but more related to lack of visuospatial reasoning about the layout of the ball, wall and the doors as well as a failure in the planning and organization of the search behaviour itself. That is, 3-year-olds poor performance relates to the dual task of

imagining the special layout of the apparatus (i.e., ramps, track, wall, occluding screen, ball and doors) while engaged in planning where an appropriate action sequence.

1.5 GOALS OF THE CURRENT STUDY

1.5.1 Issues to Address

Proficiency in problem solving skills has important significance in early childhood suggesting that it is necessary for cognitive development and essential to logical reasoning and analytical thinking later in life (Greenwood et al., 2006). In a problem-solving task, infants and adults engage challenging tasks similarly by integrating various fundamental components such as attention, memory, visual exploration, cognitive planning and coordination of motor actions. For instance, object knowledge and its relationship within purposeful (goal-directed) action is critical to human intellectual development. Based on VOE and other looking studies, infants from 3- to 4-months of age appear to have some rudimentary object knowledge and are capable of integrating sensory information to execute prospective behaviours via visual tracking and predictive reaching. Although active search and retrieval increases between 6- and 12-months of age, infants still display difficulties in successfully searching for visible and hidden-objects. The literature on this issue is divided and it is not clear why knowledge about objects' motion that seem to be present earlier is not guiding 9- to 10-month old actions in search-tasks. What do 9-month-olds understand about hidden objects and how do they coordinate and plan an action based on mental representations? The prevailing conclusions drawn about infants' cognition and search behaviours are not comprehensive and recent research in this context has not systematically looked at the relationship between cognitive and motor development.

Grounded in the above debates, the current study is designed to address the question: how does manipulation of visual information affect infants' abilities to guide their action towards an occluded goal? Specifically, this study will determine whether object visibility (i.e., behind a transparent barrier) aids infants' performance in successfully

retrieving the toy, in comparison to a search for a hidden object (i.e., behind an opaque barrier). In addition, this study will determine whether partial sight of the target (behind a semi-occluded barrier) is sufficient for infants to perform a successful search, and if not, looks at the extent to which infants' performance is disrupted in terms of success rates at retrieving the ball, reaching frequency, reach initiation, search errors and examine exploratory behaviours with the occluders (e.g., patting, banging etc.). In the current study, infants must not only plan and problem-solve for a means to get to the target, but motoric demands are equated such that infants are required to execute and coordinate a bi-directional action sequence (i.e., detour reach) to attain the target-object where a direct reach is not a possible route.

While 9- to 10-month-old infants have been shown to search for hidden and visible objects in multiple hiding-locations, it is not clear how changes in cognitive complexities via increase to the number of hiding locations will affect infants' performance in search-tasks particularly when coordinating complex sequences of action. As a result, the current study changes task demands by presenting infants with two sets of hiding conditions with increased or decreased number of hiding locations that will ultimately address the nature of problem-solving abilities in infants. Additionally, the role of the occluder as a distracter and as well as an obstacle is also investigated with regards to its effect on infants' reaching and performance.

Lastly, there are several proposed accounts of infants' performance in manual-search tasks that are ultimately responsible for infants' improved or failure in search skills including means-end deficit, problem-solving abilities, spatial knowledge as well as memory and inhibition. This thesis attempts to address these concepts and potentially shed light onto previously unexamined elements of perceptual-cognitive development in the first year of life—a period where subtle shifts in perceiving and acting have critical impact on the child's cognitive life and understanding of the world around them.

1.5.2 Rationale and Predictions

Objective #1: How does manipulation of perceptual information affect search-tasks?

This study presented 9- to 10-month-old infants with three occluding tunnels of varying levels of transparency: Solid-Opaque, 50% Graded, and Clear-Transparent. The rationale for incorporating a 50% graded condition into the study was to determine how infants' performance differed in comparison to the transparent and opaque tunnels when the object was only partially-hidden. Only one other studies by Shinskey and colleagues (2000; 2002) is known to have tested all three perceptual manipulations in one comprehensive study. Even so, Shinskey and colleagues used a "semi-transparent" curtain (made of a gauzy fabric) where infants often directly touched the object through the curtain and did not always carry out the same action sequence in comparison to the transparent and opaque curtains. In the current study, the occluders were made of rigid a material such that infants could not execute a successful direct reach for the goal-object (i.e., a ball), thereby compelling the infants to coordinate a (bi-directional) detour reach to the right or left of the occluder to obtain the ball. It is hypothesized that the 50% graded occlusion will provide the optimal amount of visual information about the solidity of the occluder as well as the object; hence, infants should be faster in coordinating a detour reach and display most success when retrieving the partially-hidden ball. Moreover, these factors should allow the infant to inhibit a direct reach into the graded occluder as well as towards any incorrect hiding locations and engage in the least amount of exploratory behaviours with the barrier.

Even though the literature on object retrieval behind transparent and opaque occluders are divided, consistent with the studies by Lockman (1984; 2001), it is also expected that infants in the transparent condition will attempt to reach through the occluders and engage in the most exploratory behaviours in comparison to the other two-types of occluders. As a result, such behaviours will lead to less success and slower object retrieval times in comparison to the 50% graded and opaque occluder conditions. However in the opaque condition, it is expected that infants will be more successful and faster in obtaining

the ball in comparison to the transparent conditions but less so, in comparison to the 50% graded occluders.

Objective #2: How does cognitive manipulation via increased hiding locations affect performance in search-tasks?

A secondary goal will determine how infants' problem-solving ability changes as cognitive demands of the task are manipulated. To test this question, infants' attentional and problem-solving performance will be observed by manipulating the number of possible hiding locations (three- vs. five) under each set of the occluder types described above. It is rationalized that a three-hiding task will effectively alleviate any random searching where the success of retrieving the ball cannot occur by chance alone. On the other hand, a five-hiding task is rationalized to be significantly more difficult than a three-hiding location, but is less likely to cause fatigue and that any search errors can be more easily discovered between the two hiding-tasks. It is hypothesized that in general, infants should perform significantly better and display faster ball retrieval in the three-hiding locations. Specifically, search-success would be greatest under the three-hiding locations with graded occluders in comparison to the opaque or transparent counterparts.

Objective #3: Potential explanations and accounts for infant difficulties in search-tasks

Currently, there are four potential explanations on 8- to 10-month-old infants' difficulties in search-tasks. One interpretation of infants' difficulties has been the notion that although infants between 8-to 10-month-old demonstrate object permanence, they often search in the wrong location due to a lack of object permanence or deficits in problem-solving abilities because infants may not fully understand that hidden objects continue to exist (Butterworth, 1975, 1977; Piaget, 1954; Shinskey & Munakata, 2003; Smith et al., 1999; Willatts, 1984). Alternatively, difficulties in search-tasks may be due to infants' lack of spatial reasoning or visual salience particularly when searching between multiple-hiding locations.

Another prevailing explanations for infants' search failures before 8- to 10-months of age is that infants lack means-end skills and as a result are not able to coordinate appropriate sequences of action to retrieve objects from behind occluders (Baillargeon, 1986). Lastly, infants' difficulties in search-tasks maybe due to a lack of memory provided that infants' errors are exacerbated with time delays or the failure is attributed to lack of inhibition towards the previously rewarded response (or an inability to avoid a direct reach for an occluded visible object) (Diamond, 1991; Diamond et al., 1994).

It is believed that 9.5-month-olds should have already achieved object permanence and are their abilities of coordinating a means-end sequence is emerging (Bower & Wishart, 1972; Shinskey, 2002). That said, if infants' difficulties is due to a lack of object permanence or an inability to act on their mental representations (i.e., lack of memory), then it is hypothesized that infants should exhibit greater difficulty in opaque conditions in comparison to transparent and graded occluders. Still, if infants' failure is due to lack of problem-solving ability relating to an inability in coordinating and executing a detour reach (a means-end deficit), then all infants should fail to execute any coordinated action to retrieve the objects and should be equally unsuccessful under all occluder conditions. Similarly, if infants' difficulties are due to their lack of spatial reasoning, then their performance should be particularly hindered in the five-hiding task. If infants' difficulties are due to a lack of inhibition, then infants should be less successful under transparent occluder conditions. Conversely, if success under both transparent and graded conditions is greatest, then visual information from the target-object would be a key aspect driving infants' action planning. Finally, a greater success exclusively under the 50% graded occluder condition would imply that infants are sensitive to the amount of visual information and require "ideal" conditions in coordinating both cognitive and motoric plans. Ultimately, this study raises fundamental questions about the nature and development of early cognition and will be important in determining the shape of early knowledge around objects, task planning, anticipation, memory, and attention related to these proposed explanations.

II. DESIGN AND METHODOLOGY

2.1 PARTICIPANTS AND RECRUITMENT

Thirty-eight 9.5-month-old infants (23 females; 15 males) from 37- to 44-weeks contributed to the study. The sample consisted of infants from Caucasian ($n = 27$), Asian ($n = 7$), Black ($n = 2$) and Latin American ($n = 2$) ethnic descents. Of this total, 18- babies were tested but not included in the analyses due to pilot testing ($n = 3$), fussiness ($n = 7$), lack of interest in the task ($n = 3$), lack of object tracking ($n = 1$) and prematurity greater than 15- days ($n = 4$). As a result, only 20-infants (10 females, $M = 9.43$ months; 10 males, $M = 9.67$ months) were include in the analyses who were all in good health on the day of testing. The age range of the infants was selected based on prior work which had shown that by this age, infants are also intrigued by hidden-events, display motor control and pay close visual attention to hidden events which should in turn promote the motivation to search (Diamond, 1991; Lockman, 1984; Shinskey, 2002).

Participants were drawn from a variety of locations within the Greater Toronto area through an extensive network of local community partners including family resources centres, libraries, recreational, developmental and fitness classes in the community as well as the Baby Time Show, a convention providing parents with education, feature products and entertainment for their babies. Representatives from the CHILd (Cognition, Health, Infancy, Learning and Development) Laboratory at Ryerson University (including the author of this thesis) gave brief presentations at these organizations as part of research dissemination and community outreach. These presentations discussed current projects, shared research findings as well as broader categories of research being conducted in the CHILd lab and other infancy labs around the world. Interested parents provided their general contact information into a confidential and protected list to participate in the study and subsequently they were contacted to schedule their appointments for a visit. Participant recruitment represented an extensive graduate student training component (over several months) that

was directly associated with the author's laboratory training in developmental science at Ryerson.

2.2 STUDY DESIGN AND ANALYSES

To understand infants' abilities in search-tasks, the study was designed such that the cognitive complexity of the apparatus could be manipulated by presenting either five or three-hiding locations. The increase or decrease in the number of hiding locations manipulates the cognitive demands when searching for the object. What's more, the study examined the influence of visual occlusion by hiding the goal-object behind sets of clear-transparent, solid-opaque or 50% graded occlusions under each of the two hiding-tasks at random locations.

The presentation of the two types of hiding-location was counterbalanced, where five-females and five-males began the study with three-hiding locations and subsequently completed the five-hiding task, while the other five females- and-males completed the reverse. Moreover, if an infant began the session with one-type of hiding task a switch to the other hiding-task did not occur until the infant had completed all the occluder types within that hiding task. That is, an infant began the study in with a five-hiding task, all sets of opaque, transparent and graded occluders would be (randomly) presented before a switch to the three-hiding task was made.

Furthermore, the occluder types were shown as groups or sets and never mixed; once presented with a set of occluders, a switch to the next occluder set was made only after the infant had completed all trials within that occluder condition. Specifically, if an infant was exposed to a set of opaque occluders, the ball was randomly hid under all occluder opaque occluders before a switch to a different occluder type was made. In all hiding-tasks and within each randomly presented set of occluder types, the trials' ramp-side and occluder location (where the ball would stop) were randomized. In fact, the randomization of the occluder types within each hiding task, the hiding location underneath each occluder and the

ramp side in which the ball would be presented to the infant were computer-generated prior to the start of each session. In each session, infants completed 9-trials in the three-hiding location tasks (3-trials per occluder type) and 15-trials in the five-hiding location tasks for a total of 24-trials.

Infants were allowed to search for the ball without any time constraints until the infant gave-up their search or became fussy. Because the peg and the ball were in such close proximity to each other, the trial terminated once the infant contacted either the ball or the peg. The inter-trial interval was approximately 10-seconds and the entire experimental session took approximately 20-minutes to complete.

Based on numerous pilot study observations for this study, it was rationalized that analyses on the following dependent variables should be conducted in order to better understand and evaluate infants' performance in search-tasks. First, the study will determine the occluder type and hiding task in which infants are fastest and most likely in initiating an action (i.e., reach initiation) to search for the object. This behaviour will be indicative of infants' comprehension, motivation and cognitive processing of the task when searching for objects. Second, the same independent variables will be examined to determine the conditions in which infants are most successful in making contact with the correct occluder that houses the object; this will be indicative of infants' true knowledge for the object's location particularly when the object is fully-hidden. Moreover, their success in making contact with the ball and their subsequent success in obtaining the object will also be measured under the proposed manipulations. Lastly, the manner in which infants search, reach and obtain the ball will be examined with regards to exploratory activities made towards the occluder and object under each of the proposed independent variables. As a result, a 2 (gender) X 3 (occluder type) X 2 (Hiding-task) mixed factorial ANOVA will be conducted, where any gender difference in the analyses of the dependent measures can be parsed out. Therefore, each sequence of action over time intervals will be analyzed in order

to effectively understand how each manipulation affects infants' motor and cognitive planning.

2.3 APPARATUS DESIGN AND RATIONALE

This will be one of the first studies of its kind to examine infants' abilities to search for dynamically moving object behind various occluder types while manipulating cognitive complexities using multiple-hiding locations. Therefore, upon describing the design of the apparatus, the rationale used to construct this particular design will be discussed. Indeed, the apparatus for this study was designed from the "ground up" over a period of several months with careful attention paid to key task parameters from the previous studies outlined in the thesis introduction.

All infants were seated on their parent/ guardian's lap during the entire testing phase in front of a custom built table. A small attractive ball (i.e., a golf ball) rolled along a straight ramp (75 cm) that allowed the researcher to roll the ball at an average speed of 63.5 cm/sec from either the right or left-side towards the infant. The table's edge closest to the infant was cut in a manner whereby the table surrounded the infant on both sides forming a semi-circle. Both types of hiding-tasks (i.e., three- and five-hiding locations) were set on the circular portion of the track (30 degrees apart) and each within the infant's 29-cm reaching radius, with the straight edges of the occluder closest to the infant set within infant's 20-cm reaching radius (see Figures 1 and 2). Butterworth (1975) has suggested that arranging hiding locations in a semicircle effectively offsets the tendency to reach to the midline.

Figure 1: Schematic drawing of the Ramp Task apparatus

Figure 2: View of the Ramp Task apparatus with the three sets of occluder types in five-hiding task.

Using a small clear-transparent peg (2 cm x 3 cm x 1 cm), the ball was stopped at a random pre-determined locations behind one of the three sets of Plexiglas occluders (10 cm width x 9 cm height): clear transparent, solid-opaque or graded with 50% occlusion constructed by overlaying a transparent Plexiglas with blue tape (18-mm). During the 'warm-up' phase, infants were familiarized with the apparatus and the occluders using a different ball and occluder type (see Figure 3).

Figure 3: Types of test occluders. (Left to Right) Solid-Opaque occluder, Clear-Transparent occluder, 50% Graded occluder.

During the testing phase six possible sets of occluders in the two types of hiding-tasks were presented to the infants (see Figure 4 and Study Design for occluder presentation).

Figure 4: Ramp Task experimental setup. (Top, Left to Right) Three-hiding task with sets of Solid-Opaque, Clear-Transparent and 50% Graded Occluders. (Bottom) Five-hiding task with corresponding sets of occluders.

All materials were designed and built to be infant safe with smooth rounded edges, carpeted surfaces, and the use of non-toxic paint. Two cameras were positioned such that infants' visual tracking and engagement with the apparatus was captured, while another camera was situated at an angle and recorded the top-view of the entire apparatus as well as infants' behavioural responses and reaches. The data was determined from the post-video coding, raw data refinement, and analyses.

Indeed, placing objects in dynamic conditions (movement) does present an intriguing arena for which to study infants' representational knowledge. Additionally, the curvilinear trajectory of the ball across the semi-circular table was also rationalized to increase motivation yet ease tension of reaching as the object is equidistant to the infant in comparison to a linearly moving object. In essence, these manipulations are more applicable to real-world events as objects continuously appear and disappear and often in non-linear trajectories. Infants are also more increasingly engaged in these types of tasks in comparison for a search directed to static objects.

The target-object (i.e., the golf ball) was purposely chosen to emit no auditory cues as it travelled down and across the infants' visual field. Although research with infants shows

that their attention is captured by corresponding information presented in more than one sensory modality (for a review see Bahrick, Lickliter, & Flom, 2004), the current study's aim was to specifically examine the manipulation of visual information and tease apart any cues and aiding factors to infants' searching abilities.

Furthermore, with regards to the visual manipulation, there are two potential concerns with previous literature's apparatus designs when testing infants' visual tracking, detour problem-solving and search tasks. First, the infants are placed in front of a large occluding screen that eliminates critical visual information about the track and the ball's physical motion and trajectory (Berthier et al., 2001; Keen et al., 2003). Second, infants and toddlers may not always take the presence of the occluders and barriers into account due to the sheer proportion of these structures (Berthier et al., 2001; Keen et al., 2003; Lockman, 1984; Lockman & Adams, 2001). This is of particular concern as the transparent occluders' edge maybe too wide and not salient enough to be taken into consideration whereas a solid-opaque wall may appear as a difficult obstacle causing the infant to give-up their search prematurely. Therefore, scaling-down the size of the occluders was rationalized to alleviate these issues as more information would be available in the infants' visual field at one-time. In this study, the occluders were constructed to be significantly smaller than barrier and walls used in other studies measuring at 14 cm × 30.5 cm (Lockman, 1984; Lockman & Adams, 2001) and 13.5 cm × 19 cm (Berthier et al., 2001; Keen et al., 2003).

The apparatus was designed such that the occluders were placed on the table using Velcro. The main rationale for using Velcros was so that infants are only required to make a bi-directional sequence of action (i.e., reach to the side of the occluder and then around) where the "game's" objective is to retrieve the ball instead of manipulating or removing the occluder. Thus, any exploratory behaviour with the occluder will most likely be due to infants' persistence in uncovering the ball rather than playing with the occluder itself. The use of Velcro also made it physically difficult, but not impossible, for the infant to remove the occluder in order to obtain the ball. Therefore, persistent infants could achieve their goals

using a means-end task (i.e., remove obstacle to reach object), but it would not be the easiest nor the most efficient way to achieve the goal. In fact, a detour reach in comparison to a means-end action sequence is also a simpler two-step process which 9- to 10-month olds should have minimal difficulties in performing. As a result, this manipulation is thought to aid infants in using their cognitive skills in problem-solving as opposed to action planning. Lastly, the requirement to make a detour reach is consistent with the motor demand requirements used in other studies by Lockman (1984, 2001) and Diamond (1994).

2.4 PROCEDURE

On arrival at the CHILD Lab, the participant and the parent were met by a CHILD lab member who provided the parent with the informed-consent form describing the study's purpose and procedure (see appendix 1). Parent/guardians were provided with option of completing the CHILD Pre Observations Questionnaire (CPOQ) pertaining to their infant's motoric development and milestones (see appendix 2). The time spent in this pre-observation period is very critical to the success of any infant study; that is, infant and parent "lab/experimenter acculturation" must be established in the first 30 minutes of arrival in the lab. Once the researcher assessed that the infant was ready to begin the study, the parent and the child were invited into the testing room, where the infant was seated on the mother's lap behind the semi-circular table so that all the hiding locations were equidistant from the infant. A collection of toys (squeak toys, rattles etc.) were available so that the researcher could attract the infants' attention where necessary and keep the child's level of interest high. A research assistant was also present in the room monitoring the video and was responsible for providing the researcher with information about the trial types that were being presented, but did not interact or make any eye-contact with the infant. The researcher kneeled on the other side of the table, opposite the parent and infant and was responsible for keeping the infant interested in the apparatus as well as removing and installing the occluders and

releasing the ball. All sessions were recorded on videotape capturing dual camera views with an advanced time code stamp.

In the pretesting or 'warm-up' session, the occluder and the balls used were different than those in the testing session. The warm-up occluder was graded at an angle and the testing stimulus was a significantly larger and multi-coloured ball presented to the infant at midline (see Figure 5).

Figure 5: Warm-up occluder presented to infant at mid-line.

Infants were first familiarized with a ball behind the warm-up occluder and their ability to reach around the occluder to touch the ball was tested. This was a "giveaway" trial in that the researcher often reached to either side of the occluder and pushed the ball around. This was done to help the infant overcome initial reluctance to reach behind the occluders. In the event that the infant's hand could not physically reach the ball, they were propped up using pillow on their parent's lap. Once the infant was shown how to retrieve the ball from both the right and left-side of the occluder, the warm-up ball was taken to one side of the ramp and the infants' attention was drawn to the ball's location of release using the collection of noise making toys or by tapping the ball at the edge of ramp. The ball was released and the baby was assessed in their abilities to track the ball's trajectory across the table. The participants were allowed to retrieve the ball from the track and received social encouragement from the researcher and their mother. The social encouragement was introduced because infants seemed not to understand the "game" without it and would often take interest in manipulating the occluder. If there was any doubt about whether the infant was reaching for the toy, the

trial was repeated. All infants succeeded here except for one infant who did not visually track the ball; the 'warm-up' phase last approximately 2-minutes.

A test-trial began with the appropriate random occluders placed on the table and the peg placed underneath where the ball would come to rest. The baby was distracted the entire time so that they were not aware of the peg's placement. Subsequently, the researcher placed the golf-ball on the ramp (that were randomly selected at right or left-side) and attracted the infant's attention by tapping the ball and said, "*Look (baby's name)! Look at the Ball. Here it goes!*", and released the ball. The parent were asked to gently restrain the infant's arms and torso as the ball rolled down the track, to prevent reaching, leaning towards the moving ball or to the correct hiding location. On average, the ball's travel from its initial release to its resting location lasted approximately 4-seconds (depending on the occluder). Once the ball came to rest, parents were allowed to verbally encourage their children in retrieving the ball but where instructed to not point or lead their child's arm or body towards the correct locations. Specifically, parents were asked that all movements had to be initiated by the infant but that they were allowed to prop-up their children throughout the course of the testing phase. The infant's reach to the correct location and success in obtaining the ball or the peg was rewarded by a play period with the toy and social-encouragement from both the researcher and the parent. If the infant reaches incorrectly, they were allowed to self-correct and reach to another location. However, if the infant gave up searching or was unsuccessful in obtaining the ball, the researcher took the ball from behind the occluder and said, "*Here is the ball, I found it!*" and the infant was allowed to take the ball and social encouragement was once again rewarded.

2.5 CODING SCHEME

In both proposed studies, infants were video-taped to measure their core performance where the initial scoring of the data was done by viewing the videotapes from pilot subjects. Overall, there were 4 passes made when coding each trial.

The first pass essentially recorded all relevant information about the trial, such as *Trial number* (1-24), *Occluder Type* (opaque, transparent, graded), *Hiding Task* (three or five), *Occluder number* (1-3 or 1-5) and *Ramp side* (right or left) as well as if the infant was *visually tracking* the ball (yes or no) as it rolled across the table. When tracking the object behind opaque occluders, infants tended to make rapid saccading head-shifts as the object appeared and disappeared. As a result, head movements were used more than eye movements towards the direction in which infants were looking to score for *visual tracking*.

The second pass recorded that *Start Time* as indicated by when the ball made contact with the stopper (i.e., a clear-transparent peg) and *Reach Initiation*, indicating the beginning of a purposeful movement of the hand towards the object or the occluder that was not part of a turning motion or torso rotations. In fact, a valid reach onset was required to make contact with either the occluder or the object. This measure is designed to determine how infants integrate and process the visual information and make a cognitive decision to coordinate an action.

A third pass through the data concentrated on the infants' interaction with the occluder. The time at which the infant made *Contact with Correct Occluder* and *Contact with Incorrect Occluders*, as well as the *Frequency of the Correct Occluder Touch* was counted. Contact was defined as the point at which the infant's hand first touched the respective occluder or object. The frequency measure was indicative of infants' intention as well as their understanding of the occluder as an obstacle. Careful notes were made of the *Occluder Removal* (occluder number with hand used) as well as all *Exploratory Behaviours* at the occluder space, as follows:

- *Edge Grasping*: Infant grasps the left or right curvilinear edges of the occluder between fingers and/or palm
- *Direct Reaching*: Infant reaches and grasps as though attempting to directly make contact with the ball through the occluder, naturally with no success

- *Contour Following:* Infant glides their hand over the occluder and follows its contour with one continuous motion
- *Banging:* Infant patting or banging on the occluder
- *Pressing:* Infant attempts to press the occluder in forward and backward motion (i.e., push and pull) with one motion.
- *Clear Reaching:* Infant makes a detour reach around the occluder without making contact (i.e., all digits and hands clear the occluder).
- *Corrected Reaching:* Infants hand or finger is caught onto the edge of the occluder but no intentional occluder exploration is witnessed.
- *Non-Occluder Exploration:* Infant does not explore the occluder and engages in other forms of activities (i.e., playing with the table etc.).
- *Peeking:* Infants lean to either right or left side in order to gain visual sight of the ball, or gain visual of their hand reaching behind the occluder.
- *Hand-Tracking:* The infant has broken out of their mother's gentle-restraint and has initiated an anticipatory reach by following the ball's trajectory by floating their hand above along its motion to the resting location.

The fourth and final review of the videotape determined the time whereby a *Contact with the Ball* or the peg was made. In addition, the *Type of Reaching* infants made when executing a detour reach around the occluder was also recorded where infants could perform five types of reaching to search for the ball:

- *Right-Contralateral:* Infants' right hand enters the left side of the occluder
- *Left- Contralateral:* Infants' left hand enters the right side of the occluder
- *Right Ipsilateral:* Infants' right hand enters the right side of the occluder
- *Left Ipsilateral:* Infants' left hand enters the left side of the occluder
- *Removal:* Infant removes the occluder

In general, a trial was excluded if the infant was not engaged in the task and did not intentionally interact with the apparatus. More specifically, the infant was required to visually track the ball's trajectory as well as initiate a purposeful reach towards either the object or the occluder. If the infant was not looking in the direction of their reach or did not appear to intentionally make contact with the occluder or the ball, then the reach was not coded and the trial was excluded.

The data was coded between two coders, one blind to the purpose of the study and to the experimental manipulations. A reliability analysis was completed on 25% of random selection of trials for the dependent measures of time intervals for *Reach Initiation* ($r = .991$), *Correct Occluder Touch* ($r = .984$), *Time Touch Ball* ($r = .971$), which are considered to be compatible and strong for search-tasks involving infants in this age group.

III. RESULTS

All parents completed a Child Pre-Observations Questionnaire (CPOQ) pertaining to their infant's motoric development. Based on the CPOQ, it was apparent that all infants were developed in their gross and fine motor skills when reaching for and holding onto large and small objects. All infants were capable of sitting independently and all but one baby was capable of crawling; however none of the infants were capable of walking independently. During the pre-testing phase, all infants included in the analyses were assessed to be capable of object tracking and able to reach around the occluder. In general, infants were quite engaged in the task and often broke out of their mother's restraints in attempts to catch the moving ball as it travelled across the table.

Exploratory analysis of the data revealed 154- 157- and 154-counts of trials in the graded, transparent and opaque conditions, indicating an equal distribution of trials among the three occluder types surmounting to a total of 465 valid-trials. In other words, all babies completed at least 22-out of 24-trials. Additionally, the ramp-side where the ball was released indicated a distribution of 43.2% and 56.8% on the left- and right-side respectively. Although the ramp sides are not evenly split to either side due to randomization, no significant differences between the sides was found. Furthermore, the current study's sample was not culturally diverse enough to conduct any detailed analyses and determine if differences in socio-cultural backgrounds influenced infants' searching abilities. Therefore, all results were collapsed across this variable and ramp side.

3.1 REACH INITIATION AND OCCLUDER CONTACT

Reach Initiation. The *start time* is a measure of the time the ball made contact with the peg and the *reach onset* was a measure of the time the infant made the first motoric twitch towards the occluder or object and eventually made contact. A mixed factorial ANOVA for Gender X Occluder Type X Hiding-task, revealed a significant main-effect for occluder type for infants' reaction time, $F(2, 36) = 11.10, p < .001$ (see Figure 6). Bonferroni *post hoc* test

revealed that infants' reaction towards the opaque occluders ($M= 4.07$, $SE = .54$) are significantly slower in comparison to graded ($M= 2.11$, $SE = .39$, $p<.05$, $r = .68$) and transparent occluders ($M= 2.53$, $SE = .48$, $p<.05$, $r = .65$). However, the reaction time between transparent and graded occluders was not significantly different. There was also no significant effect of gender indicating that the reaction times from male and female infants were in general the same, $F(1, 18) < 1$, $p>.05$, $r=.02$. Therefore, independent of the number of hiding-locations and gender, infants' reaction initiation once the ball has stopped is significantly slower when the ball is out-of-sight under opaque conditions.

Figure 6: Reach initiation time between occluder types and hiding-tasks

Start Time to Correct Occluder Touch. The *start time* is a measure of the time the ball made contact with the peg and the *correct occluder touch* was a measure of the time the infant first made contact with the correct occluder where the ball was behind. A mixed factorial ANOVA for Gender X Occluder Type X Hiding-task, revealed that the Mauchley's test indicated that the assumption of sphericity had been violated for occluder type ($X^2 (2) = 6.57$, $p<.05$); therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .76$). The results of the ANOVA revealed a significant main-effect for occluder

type, $F(1.51, 27.26) = 10.45, p < .001$ (see Figure 7). Bonferroni *post hoc* test revealed that touching the correct occluder under opaque conditions ($M = 5.31, SE = .716$) are significantly slower in comparison to graded ($M = 2.80, SE = .41, p < .05, r = .73$) and transparent occluders ($M = 3.29, SE = .47, p < .001, r = .63$). However, the time different between transparent and graded occluders was not significantly different. There was also no significant effect of gender indicating that the reaction times from male and female infants were in general the same, $F(1, 18) < 1, p > .05, r = .07$.

There was also a significant main-effect for hiding-task, $F(1, 18) = 9.84, p < .05, r = .59$. Bonferroni *post hoc* test revealed that touching the correct occluder under three-hiding task ($M = 2.73, SE = .47$) are significantly faster in comparison to the five-hiding task ($M = 4.86, SE = .63$). Therefore, independent of gender differences, infants are generally faster at touching the correct occluder when the ball is behind the transparent or graded occluders and perform faster under three-hiding task conditions, but the interaction between the type of occluder and hiding task are not significant.

Figure 7: Correct occluder touch time between occluder types and hiding-tasks

Frequency of Correct Occluder Touch. A mixed factorial ANOVA for Gender X Occluder Type X Hiding-task was conducted to determine any differences in the frequency of times infants touched the correct occluder. The analyses revealed that the Mauchley's test indicated that the assumption of sphericity had been violated for occluder type ($X^2(2) = 8.84$, $p < .05$) as well as for the interaction between hiding-task and occluder type ($X^2(2) = 13.427$, $p < .001$); therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .71$, $.65$ respectively). The results of the ANOVA revealed a significant main-effect for occluder type, $F(1.42, 25.62) = 15.49$, $p < .001$ (see Figure 8). Bonferroni *post hoc* test revealed that the transparent occluder conditions are more frequently touched ($M = 3.54$, $SE = .352$) in comparison to the graded ($M = 1.90$, $SE = .17$, $r = .68$) and opaque ($M = 1.77$, $SE = .24$, $r = .68$) occluders. However, the frequency of touching the correct occluders between graded and opaque occluders was not significantly different. There was also no significant effect of gender indicating that the reaction times from male and female infants were in general the same, $F(1, 18) = 1.32$, $p > .05$, $r = .26$. Therefore, regardless of hiding task or gender, all infants more frequently touched the correct occluder under transparent conditions when the object was fully-visible in comparison to the other conditions.

Figure 8: Frequency of correct occluder touch between occluder types and hiding-tasks

3.2 OBJECT CONTACT AND RETRIEVAL

Ball Touch. A mixed factorial ANOVA for Gender X Occluder Type X Hiding-task was conducted to determine any differences between start time and the time when the ball was touched. The analyses revealed that the Mauchley's test indicated that the assumption of sphericity had been violated for occluder type ($X^2 (2) = 6.47, p < .05$); therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .76$). The results of the ANOVA revealed a significant main-effect for occluder type, $F(1.59, 27.34) = 9.62, p < .05$ (see Figure 9). Bonferroni *post hoc* test revealed that touching the ball under graded conditions ($M = 8.09, SE = .93$) are significantly faster in comparison to transparent ($M = 14.01, SE = 1.87, p < .05, r = .69$) and opaque occluders ($M = 12.92, SE = 1.09, p < .001, r = .76$). However, the time different between transparent and opaque occluders was not significantly different. There was also no significant effect of gender indicating that the reaction times from male and female infants were in general the same, $F(1, 18) < 1, p > .05, r = .04$. Therefore, from the moment the ball stopped against the peg to the time the infants successfully touched the ball (or peg), infants demonstrated faster performance only when part of the object was visible but not when it is fully visible or hidden.

Figure 9: Ball touch time between occluder types and hiding-tasks

Interval between Occluder and Ball Touch. A mixed factorial ANOVA for Gender X Occluder Type X Hiding-task was conducted to determine if any differences between the time infants contacted the correct occluder and touching the ball had occurred. The analyses revealed a near significance for occluder type $F(2, 28) = .325, p = .064$, and no significant main-effects for hiding task $F(1, 18) = .69, p > .05$, or an interaction between occluder type and hiding-task $F(2, 36) = 1.02, p > .05$. There was also no significant effect of gender indicating that the male and female infants' performance were in general the same, $F(1, 18) < 1, p > .05$. Therefore, once infants made contact with the correct occluder, they are just as likely to touch the ball regardless of where the object is visible, partly-visible or fully-hidden.

Figure 10: Ball touch time after correct occluder Touch between occluder types and hiding-tasks

Ball Retrieval. Chi-square test between occluder-type and success in obtaining the ball indicated a significant association ($\chi^2(2) = 6.26, p < .05$), such that of the 264-counts (56.8%) of success in obtaining the ball, 37.5% was obtained under graded occlusion trials (see Figure 11). Moreover, there was greater success obtaining the ball from underneath graded occluder trials (64.3%) in comparison to success in the opaque (55.8%) and transparent

(50.3%) conditions. The effect size associated with this relationship as measured by Cramer's V was 0.12 which suggests a small effect size. However, no significant association between hiding-task and success in obtaining the ball was found ($X^2 (1) = 0.002, p > .05$).

Figure 11: Occluder types and success of obtaining the ball

However, a significant association between occluder number and success in obtaining the ball was found at the five-hiding task ($X^2 (4) = 14.51, p < .05$) with an effect size of 0.22 (as measured by Cramer's V), but not in the three-hiding task ($X^2 (2) = 3.133, p > .05$; see Figure 12). Specifically, infants were most successful in retrieving the ball under the fourth occluder (26.5%) and third occluder (22.3%). Therefore, it infants are more likely to successfully retrieve the ball or peg from underneath the third and fourth occluder locations with least success at the extremities (i.e., occluder number one and five) as well as the second occluder.

Figure 12: Occluder number and success of obtaining the ball in five-hiding task

3.3 EXPLORATORY BEHAVIOURS

Exploration with Occluders. From a total of 468-trials, infants grabbed the edges of the occluder on 185-trials (24.2%), followed the contours of the occluder by gliding their hands on 126-trials (16.4%) and attempted to push or pull-off the occluder on 120-trials (15.7%). A chi-square test revealed that there was a strong association between the occluder type and the type of exploratory behaviours made on the occluders ($X^2(14) = 99.58, p < .001$) with a small effect size of 0.26 as measured by Cramer's V (see Figure 13). Overall, 43.5% of their exploratory behaviours occurred under the transparent occluders in comparison to the graded (28.3%) or opaque (28.2%) conditions. In the transparent condition specifically, infants were more likely to attempt to reach directly for the ball through the occluder (23.7%) and engaged in frequent hand gliding (19.2%). Overall, grasping the curvilinear edges of the occluder was the most common exploratory behaviour across all occluder types (24.4%, 25% and 23.4% in the graded, opaque and transparent conditions respectively).

Figure 13: Types of exploratory behaviours with occluder types

Peeking. In general, only 174-peeks (37.4%) were made across all occluder types. A three-way loglinear analysis between peeking, occluder-type and hiding-task revealed significant two-way associations (peeking $\times$ hiding-task and peeking $\times$ occluder type). To further explicate this effect, a separate chi-square test on peeking and hiding tasks revealed that infants were more likely to peek in the five-hiding task (69%) in comparison to the 31% in a three-hiding task ($X^2(1) = 4.53, p < .05$). The effect size associated with this relationship as measured by Phi was 0.10 which suggests a small effect size (see Figure 14, top). A chi-square test on peeking and occluder-type revealed a significant association ($X^2(2) = 114.02, p < .001$) with a medium effect size of 0.50 as measured by Cramer's V (see Figure 14, bottom). Interestingly, 63.2% of peeking occurred in opaque occluder conditions with 17.2% and 19.5% peeked in the transparent and graded occluder conditions (respectively). A separate chi-square test also indicated that there was no significant association between occluder number and peeking ($X^2(4) = 0.978, p > .05$). Therefore, infants are more likely to peek when there were increased numbers of hiding locations. Moreover, this behaviour

increased under opaque occluder conditions to gain direct visual sight of the ball, whereas peeking under the transparent and graded occluder conditions was less likely.

Figure 14: Hiding-task and peeking (top); Occluder types and peeking (bottom)

Reach-Type. Chi-square tests revealed a significant association between occluder type and the manner in which infants executed their detour reach around the occluder to search for the ball ($X^2 (8) = 26.48, p < .001$) with a small effect size of 0.18 as measured by Cramer's *V* (see Table 1). In general, majority of reaches were either right-ipsilateral (31.0%) or right-contralateral (24.8%). Specifically, under graded occluder conditions, right-ipsilateral and right-contralateral searches occurred at 34.7% and 25.2% respectively; under transparent occluder conditions, majority of infants were more likely to make right-ipsilateral reaches (37.8%). Lastly, under opaque occluder conditions, infants were more likely to make right and left-contralateral (awkward) searches at 31.1% and 27.8% respectively. Therefore, a greater proportion of infants made ipsilateral-reaches when full- or partial visual access of the object was granted, and that awkward or contralateral reaches were more likely when visual information about the object was denied.

Table 1: Percentage of search types across occluder types in five-hiding task

SEARCH TYPE	OCCLUDER TYPE		
	Graded	Transparent	Opaque
Right- Contralateral	25.2%	18.9%	30.1%
Left Contralateral	15.0%	11.8%	27.8%
Right Ipsilateral	34.7%	37.8%	20.3%
Left Ipsilateral	9.5%	15.0%	6.0%
Occluder Removal	15.6%	16.5%	15.8%

The same type of analyses were conducted between occluder number and search type, but only the association in five-hiding task was found to be significant ($X^2 (16) = 59.12, p < .001$), with a small effect size of 0.24 as measured by Cramer's *V* (see Table 2). The analysis indicated that a majority of reaches behind the occluder was once again initiated by the right hand. Interestingly, infants used contralateral or awkward reaches when searching for the ball at the first or fifth occluders (i.e., extremities of the table). Specifically, at the first

occluder (located to the infant's left side), 34.7% of search types were left-contralateral while at the fifth occluder (located to the infant's right side), and 48.1% of search types were carried out using a right-contralateral reach. At the second occluder, infants were also more likely to use left-contralateral reaches (27.5%); searches at midline (third occluder) and slightly to the right (fourth occluder) were dominated by the right- ipsilateral (33.3%, 42.9% respectively) and right-contralateral reaches (29.4%, 32.1% respectively). Infants were also more likely to remove the occluder towards at the first (24.5%) and second (23.5%) occluders.

Therefore, infants made more awkward (i.e., contralateral reaches) for occluders towards at the end hiding locations, but that ipsilateral reaches were more likely to occur at midline towards the infants' right.

Table 2: Percentage of search types across occluder numbers in five-hiding task

SEARCH TYPE	OCCLUDER NUMBER				
	1	2	3	4	5
Right- Contralateral	10.2%	11.8%	29.4%	32.1%	48.1%
Left Contralateral	34.7%	27.5%	9.8%	3.6%	3.8%
Right Ipsilateral	18.4%	21.6%	33.3%	42.9%	28.8%
Left Ipsilateral	12.2%	15.7%	9.8%	8.9%	7.7%
Occluder Removal	24.5%	23.5%	17.6%	12.5%	11.5%

Chi-square tests analyses between hiding-task and the dependent measures of hand-tracking, occluder removal, search type and success in obtaining the ball were all non-significant. The chi-square tests between occluder type and independent measures of hand-tracking and occluder removal were also non-significant as well.

3.4 SEARCH ERRORS

Infants performed search action at the correct occluder location on 398-trials (85.6%) and searched at the wrong occluder on only 67-trials (14.4%). In all consideration, this is a small sample size when it is analyzed against occluder type and occluder number suggesting that some categories consisted of only a few cases. Therefore, the results reported in this section are considered preliminary data and require more data collection to solidify its findings.

The Chi-square test analyses revealed no significant association between search errors locations and occluder type ($X^2(8) = 7.90, p > .05$). Nevertheless, across all occluder locations, 52.2% of errors occurred under opaque occluder conditions while only 23.9% of errors occurred at each of the other two occluder conditions.

Chi-square tests between the correct location of the ball and the wrong occluder at which infants erroneously conducted their search revealed a significant association ($X^2(16) = 43.90, p < .001, r = .405$), whereby search errors were proportionately made to either side of the correct occluder. Frequency analysis of the types search errors made revealed that infants performed more perseverative search errors towards a previously correct location under opaque occluder (54.17%) in comparison to transparent (29.16%) and graded (16.67%) occluder conditions. Moreover, random search errors were also most likely to occur under opaque conditions (48.39%) in comparison to transparent (24.19%) and graded (27.41%) occluder conditions. Therefore, most errors occur with opaque occluders but that infants search in the wrong location within close vicinity (i.e., to either side) of the correct locations. Finally, when the object is out-of-sight, they are more likely to randomly search for the hidden object but also persevere towards a previously correct and rewarded place.

Figure 15: Perseverative and Random search errors across occluder types

3.5 LEARNING

The study also examined whether performance was better across trials ($N=24$) for infants who began the study with five-hiding tasks and subsequently completed the three-hiding task, in comparison to those who participated in the reversed order of hiding tasks. The difference between the two counter-balanced hiding task groups were conducted based on only two dependent variable measure (i.e., reach initiation and ball touch) because these two measures would indicate if infants' performance improved across trials from start to touching the ball or peg. A repeated measures ANOVA for Trials X Hiding Task Grouping was conducted. The analyses revealed that the Mauchley's test indicated that the assumption of sphericity had been violated for trials, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .321$). The results of the ANOVA revealed a significant main-effect for trials, $F(7.38, 132.79) = 2.57, p < .05$, but that there was no significant differences between the groups $F(1, 18) = 2.34, p > .05$ (see Figures 16 and 17). Bonferroni *post hoc* test revealed that the first trial ($M = 24.16, SE = 2.61$) is

significantly slower in comparison to the ninth ($M= 7.08$, $SE = 1.26$, $p<.05$), fifteenth ($M= 8.46$, $SE = 2.11$, $p<.05$), sixteenth ($M= 8.74$, $SE = 1.86$, $p<.05$) and twenty-fourth ($M= 11.47$, $SE = 1.75$, $p<.05$) trials. However the pattern across the trials collapsed across occluder type, gender and hiding tasks indicates a steep learning curve in the first 9-trials where performance plateaus until the end of the session. In parsing-out the two counter-balanced hiding-task groups, it appears that in general, infants who began with the five-hiding task learned the task faster across trials in comparison to those who began with the three-hiding tasks. Interestingly, when the hiding-task group is switched to a different hiding task (see filled marker in plot at trial #10 and #3 for groups beginning with three- and five-hiding tasks respectively), a general change in the curve is witnessed indicating a slight change in learning behaviour. Therefore, infants learn quickly how to search under various occluder types and hiding task and that regardless of their first experience with a particular hiding-task, both groups follow similar learning curves.

Figure 16: Overall learning in time touch ball across trials

Learning across Trials to Touch Ball in Hiding Task Groups

Figure 17: Learning across trials to touch ball in hiding task groups

IV. DISCUSSION

First, infants performed impressively in the core task and revealed a remarkably adept motivation to follow, search, and retrieve objects; that is, despite the novel environment and laboratory conditions, the level of task engagement was much higher than expected. Based on the many innovative ways that infants approached the tasks, there was clear evidence that infants “inhabited” the task and largely “made it their own” which is important for determining maximum effort and engagement. Almost equally important for infant studies, the parents were engaged, supportive, and played a vital motivational support role in study. In short, infants demonstrated a very powerful “cognition in action” pattern of behaviour which was not lost on the parents who were very engaged by the research and underlying questions.

Second, the results of this study taken together across different analysis approaches, successfully document a critical relationship between thinking and moving at 9.5-months of age. That is, as the human infant learns to attend to moving objects that appear in and out of sight, they are actively problem-solving—seeking a best fit action path—to help them achieve their goals and overcome possible obstacles in their immediate environments. In the study, visual information about the object was deliberately manipulated to create a special context where infants were required to search behind clear-transparent, solid-opaque or 50% graded occluders or barriers. Keeping in mind that the visual manipulations were presented to infants in either three or five possible hiding locations and examined its influences on infants’ problem-solving abilities, this discussion section will first review the main results of the current study and provide interpretations of the findings related to these key experimental manipulations. Finally, the organization and coordination of action, cognition and perception as they relate to the proposed accounts on infant search-task difficulties are discussed within the context of possible improvements to the current study as well as a proposal for future direction studies.

4.1 GENERAL FINDINGS

While infants performed remarkably well overall, not all infants were successful in making a detour reach around the occluder to touch the ball and/or to obtain it. In fact, in a majority of trials infants persistently and at times vigorously made numerous attempts to obtain the ball without any success. Therefore, the dependent measures of initiating a reach and making contact with the correct occluder were considered to be two of the most informative variables measuring infants true motivation, determination, conceptual understanding and cognitive planning in this search-task.

The results of the current study indicated that infants' reach initiation as well as contacting the correct occluder was significantly faster when the ball was either partially-visible or fully-visible (under graded and transparent occluders respectively) than when it was completely obscured by an opaque occluder. Prior work with infants' reaching for stationary objects have similarly shown disruptions in reaching when the sight of target was blocked (Ashmead et al., 1993). The analyses of each trial in its entirety, from the time the ball came to its hiding location to the time that the ball was touched, revealed faster contacts under 50% graded occluder conditions. In other words from start to finish, infants' performance in coordinating a detour reach around the occluder to touch the ball was fastest when the object was only partially-visible. Furthermore on more than half of the trials, infants went beyond the required criterion of making a detour reach to touch the ball and coordinated a grasp in order to retrieve it from under the occluder. For these infants, their success was also greatest under 50% graded conditions. These findings are nicely consistent with Lockman and Adams (2001) study, where infants were more likely to retrieve the goal-object from around a grid-like barrier than a corresponding transparent barrier. The current research also support Keen and colleagues' (2003) findings that infants' demonstrate greater success in making less anticipatory reaches and greater success of obtaining the ball under 'window' conditions where dual-information about the wall (through the occluder) and solidity of the occluder itself were provided). The availability of both information about the occluder and the

object aids infants in coordinating an appropriate detour reach and also to guide their action (and make online correction) in order to get to the ball successfully.

Interestingly, once infants had made contact with the correct occluder, neither the amount of visual information through the occluder or the hiding task had any impact on how quickly the ball was touched. That is, after touching the correct occluder, infants demonstrated equal performance in planning and coordinating a detour reach around the occluder to touch the ball. In essence, once the critical efforts of locating the ball and moving one's body to close proximity of the goal is achieved, the types of occluders or number of hiding locations did not influence infants' performance in any meaningful way.

The manipulation of the number of hiding locations also brought about interesting behaviours and differences in performance speed. Specifically, the five-hiding task served its purpose of making cognitive planning more difficult for infants and placed an observable strain on infants' cognitive planning and problem-solving. For instance, contact with the correct occluder was significantly faster under three-hiding task than in a corresponding five-hiding regardless of the occluder type.

The role of perception and action are critical component to this study and understanding infants' cognitive problem-solving, and action planning. Since an over-arching principle focus of this research has been to investigate how visual manipulation influences infants' abilities in search-tasks at variable cognitive complexities, it is appropriate to discuss these general findings and attempt to decipher between currently proposed accounts on infants' search task limitations in the context of cognitive, visual and motor organization.

4.2 ORGANIZATION OF ACTION, PERCEPTION AND COGNITION

As chronicled in Chapter 1, Piaget and other early theorists had attributed infants' lack of problem-solving for objects behind obstacles to a lack of object understanding. However in light of the current study and more recent literature (Shinskey, 2002; Shinskey & Munakata, 2001; Sophian & Wellman, 1983), it is apparent that infants possess the cognitive

competence about hidden objects and can coordinate the appropriate sequence of actions to search for the target. However, infant's ability to gain new cognitive milestones is *dependent* on motor skill and particularly vision; this is not an insignificant comment when viewed against the backdrop of the more traditional approach that views cognition as "driving" action. The results reported above provide some reinforcing support for this position that is now well established in the developmental literature (cf. Thelen, 2001, 2005; Adolph, 2008). Similarly, findings from the current study also suggest that object visibility (i.e., the visual object at the center of the child's motivation) plays an important role in shaping cognitive decision-making and in formulating and executing a reach. Collectively, these points help echo the importance of the dual power of the perception-action-coupling in development discussed at length at the outset.

In addressing the scholarly debates on infants' understanding of transparency, the current study supports arguments from both sides presented earlier. In support of Lockman and colleagues work (1984; 2001), infants in the current study managed to conduct detour reaches around all occluder tunnels but performed more exploratory behaviours around transparent occluders in comparison to any other occluder. However, infants' success of touching and/or obtaining the ball was more reflective of findings by Shinskey and colleagues. This latter point requires further explication.

In two studies, (Shinskey, 2002; 2000) 6- and 10-month-olds' search abilities were tested for objects in milk, water or a "visible-milk" as well as behind transparent, semi-transparent or opaque curtains where 6-months olds reached, touched and retrieved visible- or partly-visible object more often than when it was fully-hidden; however, 10-month-olds succeeded under all hiding conditions. These findings support this study's observations that visual information about a goal-object (even if it is partial) is the key factor in how quickly infants process and subsequently act on objects behind barriers. In fact in the current study, once the ball came to rest underneath the opaque occluder, infants appeared to contemplate about the ball's whereabouts and took more time to 'figure-out' where to launch a search

action. Infants often looked away, refocused on the correct occluder and sometimes peeked under the occluder before initiating a reach or touching the correct occluder. Shinskey et al. made parallel observations to the current findings and have reasoned that the lack of visual feedback from a hidden-object functions as a “distracter or repeller of attention” (2000, p. 337). Particularly in younger infants (i.e., 6-months), “infants looked away about as fast as they could” due to the fact that infants were more readily distracted when less visual information about the object was available. Indeed, infants are capable of searching and obtaining objects from behind barriers under all occlusion conditions; however the findings of this study seem to implicate that even by 9.5-months of age, infants are generally slower in processing the visual information (or lack-there-of) about fully-hidden object in comparison to when some visual information is present.

Perhaps one compelling explanation for why infants in the current study displayed similar search difficulties as reported by Shinskey et al., 2002; 2000 (i.e., they only observed such errors in 6-month-olds) is that the goal-objects in the current study were occluded autonomously and dynamically in comparison to traditional searching-tasks where a “static” goal-object is hidden by a human agent (i.e., the experimenter). It has been suggested that infants as young as 5-months are sensitive to purposeful actions and intentions of other humans (Woodward, 1999). The role of the experimenter and their interaction with the ball was minimized in this study such that, once the ball was released at the top of the ramp, it moved independently of the experimenter, providing no clear indication as to where it would ultimately stop. This parsed out the experimenters’ goal-directed actions thereby potentially making the search task in the present study more difficult and cognitively challenging.

Cognitive Load Hypothesis. Infants’ differential success and limitations with hidden objects may also be explained by experimental and theoretical work by Boudreau and colleagues (2008; 2000). They have posited the argument that motor development *is* cognition within an embodied cognition framework—a position that is supported in experimental work in other

developmental areas such as in crawling (Berger, 2004), reaching (Needham & Kaufman, 1997), and searching (Berthier, 2002) behavior. Collectively, these authors argue that infants and adults have limited cognitive resources to attend to the various stimuli in their environments and must allocate it differentially—especially critical for infants who are continually immersed in learning new ways of acting on their environments.

Indeed, neuroimaging research with adults has demonstrated that performing two cognitive tasks simultaneously generates increased activation in the region of the brain associated with the tasks rather than new brain regions being activated (Berger, 2004); thus the brain does not recruit new resources to cope with the increased demands suggesting a limitation to the available cognitive resources. However, adults are skilled at dividing their attention to the most relevant stimuli and features in the environment and their motor coordination is well-practiced. For the infant, everything in their surroundings is new and effectively demands attention for exploration. Even more challenging is the notion that infants are not yet proficient in multi-tasking and have not mastered their reaching skills (particularly important for the task in this study); consequently, infants' cognitive resources or attention are depleted (or re-allocated elsewhere) faster, in comparison adults. Given the limited pool of processing resources, increased demands in one perceptual channel (such as vision) results in compromised performance in another channel (such as cognition). More specifically, anticipating and planning for goals can compromise action skills that are required to perform the intended task. Likewise, planning for and deploying (complex or novel) action skills can also compromise the cognitive attention and problem-solving abilities in infants. The 'action-cognition trade-off' hypothesis (Boudreau & Bushnell, 2000) as they termed it, outlines a critical relationship between thinking and perception (i.e. visual or motor) during the rapidly changing sensorimotor period of human development. Therefore according to this hypothesis, infants' task difficulty can relate to their limited cognitive processing which in turn leads to a trade-off between action and cognition, such that when either one becomes more difficult (consuming *more* attention), the other suffers (receiving *less* attention).

The results of the current study are interestingly supported by this hypothesis in that the opaque occluder conditions require more cognitive planning and 'contemplation', thereby straining the infant's limited cognitive resources; hence, infants reach initiation and contact to the correct occluder are slower and less successful. With the transparent barrier, the infant often attempts direct reaches through the occluder because they must allocate more resources and attention to remembering that the transparent barrier is in fact present and solid, leaving a limited resource to appropriately plan an action to retrieve the toy. In other words, the transparent barrier is more "forgettable" and hence more cognitive resources are recruited to remember its physical qualities and as a result, planning a detour reach for the goal-object is compromised. Meanwhile, the grid-pattern provides just enough visual information about the impenetrable nature and the object's presence behind the occluder (thus decreasing the cognitive load) and thereby opening up the "action channel" to make an appropriate detour action in addition to freeing up attentional resources to execute appropriate higher-order cognitive planning.

Means-End Deficit. One of the proposed accounts has been the means-end deficit account where it is argued that infants lack the ability to demonstrate their knowledge through action. Based on the findings of this study, the means-end deficit is not supported. Although a bi-directional detour reach is not truly a means-end task, infants nevertheless were still successful at coordinating and executing this action sequence around the occluder to retrieve the ball on more than 50% of the trials. As a result, while it is possible that this explanation can make significant contribution to other literature (particularly with younger infants), this was not an influencing factor to 9.5-month-old infants' performance levels in this study. Thus it appears that other factors are involved and directly influencing infants' lack of success particularly when searching for hidden objects.

Lack of Spatial Knowledge. Another proposed explanation for infants' difficulties in search-and retrieval-tasks is the notion that infants lack spatial knowledge and reasoning. With the

exception of faster performance in touching the correct occluders, the results of this study did not reveal a significant difference in infants' performance in reach initiation, ball touch or any variability in the types of search errors across hiding tasks. It is important to note however that once infants are self-propellant and capable of locomotion, there is a rapid increase in their abilities to discriminate among perceptually similar locations and their representations of multiple hiding locations becomes more specialized based on such experiences of self-locomotion (Smith et al., 1999). In this regard, the current findings do not consistently support the notion that 9.5-month-olds' success or failure was attributed to their lack of spatial knowledge or reasoning provided that all were capable of self-locomoting.

It is possible however, that infants performed significantly worse under the opaque condition because continuous sight of the ball (and its trajectory) was interrupted. Indeed, work with moving targets (as per Berthier et al., 2001; Keen et al., 2003) has revealed that infants' reaches are disrupted when the object passes behind an opaque barrier such that infants often fail to anticipate its reemergence. If this is the case, then it would be expected that when only some information about the ball's trajectory is missing (via the graded condition), that infants' reach initiation and correct occluder touch would fall between the performance levels of transparent and opaque occluder conditions. However, the mean response of initiating a reach and touching the correct occluder was fastest under graded occlusion (see figures 6, 7 and 9). Even though this difference was not statistically significant, the plot patterns suggest that it is highly unlikely that lack of visual information about the ball's trajectory was the only factor that interfered with infants' response times.

Lack of Object Permanence. These results are also inconsistent with the account that infants do not fully understand the concept of object permanence before 8- to 10-months of age (Piaget, 1952, 1954). Although infants displayed significantly more difficulties when the object was fully-hidden, the fact that 9.5-month-olds ever contacted or retrieved a hidden object from behind opaque occluders suggests that they were aware of the object's

presence. These findings in combination with the literature on infants' increased sensitivity and success in retrieving objects hidden in the dark (Clifton, Perris, & McCall, 1999) and consistent longer looking times demonstrated by VOE paradigm (Baillargeon et al., 1985) do not adequately support the Piagetian account.

Search Error Responses. As previously reviewed in Chapter 1, one key technique for understanding infants' object knowledge and development is by examining their search-error. The findings of the current study revealed that although infants made far fewer errors (14.4%) in comparison to choosing the correct occluders when searching for the ball, the distribution of errors was not entirely at random. Indeed, when infants committed errors, it was often clustered around the correct occluder. Moreover, majority of search errors were conducted at the opaque occluder conditions such that infants most often perseverated to the previously correct and rewarded hiding locations; however a greater proportion of errors under graded occluders were not perseverative and were conducted at random. Sophian and Yento (1985) have similarly observed comparable behaviours in 9-month-olds' searching abilities for hidden and visible objects in containers. The authors report that when the object was fully-hidden, errors were more prevalent but also more systematic in that infants were more likely to perseverate and search in the previously correct hiding location. That said, infants made fewer errors when the object was visible, but that when these errors did occur, they were more random in nature and were not systematically perseverative. These results, in addition to the current findings, indicate that infants' search errors are due to the combination of *weak memory and lack of inhibition*.

Figure 18: An infant's search error on a five- hiding task with opaque occluders. The infant's search is directed to an immediate hiding location next to the ball.

Based on the Diamond's well-study (Diamond et al., 1994) the memory demands posed by total occlusion of objects (in multiple-hiding tasks) is too great, causing infants to forget the object's location. But a perseverative search is due to a combination of weak memory plus inhibition of the pull to reach back to where the toy was previously found. Notwithstanding the above, if infants' difficulty was strictly due to a weak memory, then all search-errors should have been randomly conducted with no significant pull towards the previously correct location. There is no evidence in this study to support this contention.

In full consideration of the arguments presented, it is not clear why the distribution of errors under transparent occluders (albeit fewer) even occurred and why some were perseverative in nature. It was expected that when visual information about the object is visible, errors should systematically occur at random as there are no conflicting information between the current and previous hiding locations. Although this pattern is evident in the graded occlusion, the search pattern for fully-visible objects does not follow this trend. It is possible that the lack of "visual salience" may have exacerbated the manner and the location at which errors were made. Indeed, all occluder sets in the current study were identical in physical features, size and were not uniquely distinguishable. However, given that very few errors are committed in the transparent conditions (7-trials in perseverative and 15-trials in

random) in comparison the other occluder types, search errors may have simply been due to infants' interest in playing with the occluder rather than a true response bias.

The Dynamic Systems Theory (Smith et al., 1999; Thelen, 2000; Thelen & Smith, 1994) accounts for perseverative responses by stating that although in the window from 7- to 12-months infants gradually become skilled reachers, it is not until the end of the first year of life that infants have truly mastered the coordination and organization of a reach sequence to obtain objects. When faced with a difficult and novel reaching task, these reachers try to control their reaches by limiting the degrees of freedom in the movement and with increased motor movements and the repetitions of these highly similar motor patterns, strong motor memories are created in the body (muscles) as well as in the brain. Strong motor memories in turn, make perseveration more likely when the task requires a different direction of movement. In the present study since the hiding locations were equidistant to the infant, it is possible that infants' perseverative responses were due to their engagement in similar motor patterns as DST describes. But it is also worth noting that the ball was continuously hidden at a different location thus infants did not engage in repetitive motor patterns to the same location on any successive trials. In other words, even though the spatial relation between the hand and hiding locations are consistent and repetitive in nature, infants are still required to search in novel locations on every trial and do not repeat the specific motor pattern at the same location. Conversely in A-not-B tasks, infants practice the same motor plan to the same location several times (at A) before the location changes (to B). Based on this account, it is unlikely that DST and its description for motor memory appropriately explains infants' search errors in this particular search-task.

A closely related element to DST's emphasis on the importance of development and mastery of reaching skills is the Cognitive Load Hypothesis referenced earlier. According to Boudreau and Bushnell's account (2000), once infants' reaching has become a well-practiced skill, they no longer have to "think about" the execution of their motor act, thereby allowing more attention to be dedicated to cognitive planning. Therefore, search errors on

hidden events occur due to the fact that since attention is the “rate-limiting” factor, infants who have not yet mastered their reaching skills tend to allocate more attention to either a mental planning act or an actual motor execution act thereby leading to the poor performance and increase in search error responses. Expressed differently, this model and approach can also explain aspects of the novice-to-expert-shifts frequently reported in developmental scholarship.

Curiously, one particular reason why search errors in general did not occur as often as correct responses was partly due to infants’ smart and innovative actions to “keep track” of the ball. As the ball travelled across the table, infants engaged in a behaviour that was termed, *hand tracking* on 24.7% of the trials. That is, infants extended their arm out towards the ball’s release point and subsequently followed the ball’s trajectory down the ramp and across the table, directly stopping above the occluder where the ball came to rest. The engagement of this behaviour by some infants was not statistically significant in initiating faster reaches or touching the correct occluder; nevertheless, it seemed as though infants used this behaviour to “double-check” or make certain of the ball’s motion in addition to visual tracking. It is plausible that infants used this behaviour as a means to lighten the cognitive complexity or to bypass memory weaknesses in forgetting the ball’s hiding location as it moved under the occluders.

Furthermore, another smart-action that infants deployed was peeking behaviour, particularly in five-hiding tasks and when visual perception of the object was obscured. Under these conditions, infants often peeked underneath ‘potential’ occluders prior to initiating a reach and other times infants searched for the ball using contra-lateral (or awkward) reaches that naturally invited a peeking response. Interestingly, however, this behaviour was not exclusive to opaque occluders; rather, under transparent and graded occluders, infants often engaged in full-body leans or peeks towards the opening-side of the occluders as they reached for the ball. Essentially, leaning and peeking under transparent and graded conditions is visually guided reaching. As reviewed in Chapter 1, infants (and

even adults) utilize visually guided reaches in tasks that require precision, where the sight of the hand and target in the same field become crucial factors in making immediate and 'online' motor adjustments (Bushnell, 1985).

Figure 19: Infants' Peeking Behaviours in five-hiding tasks. (Left): Infant peeking under opaque occluder prior to initiating a reach. (Centre): Infant peeking and making a right contralateral reach under opaque occluder. (Right): Infant peeking under graded occluder.

In other works, Diamond (1990, 1991) has observed that 6.5-months olds can retrieve a toy inside a transparent box only if the toy is seen through the opening of the box. The author notes that by 8.5- to 9-months, infants bend down to gain direct visual sight of the object when they reach into a front opening and by 9.5- to 10-months, they continue in the same strategy of leaning and looking into the opening when retrieving an object from left or right-side openings. Still, it is not until 11- to 12-months of age when the vision and reaching can be broken.

Exploratory Behaviours. The lack of inhibition was further observed in the current study with other exploratory behaviours around the occluders. Consistent with previous findings by Lockman (2001; 1984), nearly half of the exploratory behaviours were conducted around transparent barriers where infants often followed the contours of the occluder and attempted to reach directly through-not-around the occluder in order to obtain the ball.

Figure 20: Infants' direct reaching attempts through transparent occluder types.

The behaviour of reaching through transparent occluders is not a peculiar behaviour, but an amusing one to observe, as infants persistently attempt to reach directly for the ball while their hand continuously collides with the occluder. Even adults often “walk through” glass doors and clear-transparent walls despite their extensive experience with these types of materials. Therefore, it is possible that infants simply do not notice the occluder's presence when they are intensely engaged in obtaining the object. The current study particularly made certain to construct the occluders such that more information would be available in the infant's visual field at any one time. Specifically, the smaller sizes of the occluders meant that both edges of the occluder were available in the infant's perceptual field, which ultimately serves as an important visual cue regarding the occluder's boundaries.

The direct reaching attempts for the ball can also be attributed to infants' inability to inhibit the prepotent direct reaching response. Similar to peeking behaviours, action at this age (or with this particular search task) may be so heavily dependent on perceptual information to guide action that infants lack inhibitory control to resist a direct reach in the direction they are looking. In other words, successful performance in search tasks behind transparent barriers is closely linked to success in inhibiting a direct reach. As previously cited in Chapter 1, such performance deficits have similarly been shown in infant monkeys with lesions in the prefrontal cortex whereas those monkeys without lesions, with lesions only in the parietal cortex, or with lesions only in the hippocampal region of the brain, do not make direct reaching attempts or perseverative responses on reaching tasks (Diamond, 1990).

This inter-species comparison highlights the importance of the prefrontal cortex in regulating attention and reducing distractibility from the salient goal (behind transparency) in order to successfully take into account the larger context and consider other routes to the achieving the goal.

In another interesting observation that is relevant to the current findings, infants frequently hit their hands to the side of the occluder's edge but did not do so in an intentional manner to explore the occluder. A study using bi-directional reaching reported similar observations on (7-month old) infants' difficulty in getting to the target 'cleanly' without accidental touches to the edges of the occluder en route to their goal (Diamond & Lee, 2000).

Figure 21: Infants' corrected reaching attempts.

Such *corrected reaching* (or "clumsy" reaching) was evident across all occluder types as infants exclusively focused on the goal and appeared to ignore the manner in which their reaching arm and hand approached the occluder. This finding is in agreement with Diamond (1991) and Lockman's (1984; 2001) views that *seeing* the goal is distracting to how infants plan a detour reach; but at the same time, visual feedback from the target is what seems to be driving search-behaviours in the first place. Moreover, it has been suggested that the mapping between vision and proprioception is well coordinated by 8-months of age (Carrico & Berthier, 2008), but the current study's observations of 9.5-month-olds' hand coordination seems to indicate that a rough mapping between the two systems still seems to exist.

Perhaps “clumsy” reaching occurs because once again the line of sight is so powerful that even feedback from tactile information provided by the occluder is ignored. When an adult’s hand grazes a neighboring object, they simply continue on to the goal-object. However, once the infants in the current study made contact with a curvilinear edge of the occluder, their fingers were often ‘caught’ on the edge of the occluder or they reacted in grasping the edge with their palm or fingers. Diamond and Lee (2000) have suggested that 9.5-month-olds exhibit a difficulty in inhibiting a grasp which is thought to be deeply rooted in the reflexive reactions of the hand (i.e., grasping reflex). Although these reflexes are not the sole cause of infants’ difficulty in making a detour (or bi-directional) reach, it nevertheless provides a small window into the unique challenges infants face of inhibiting primitive reflexes. This observation in particular sheds light on the complexity of executing and coordinating a detour reach and the importance of avoiding the obstacle itself when it is contiguous with the goal-object. Taken as a whole, these findings shed light on the close pairing of vision and reaching as well as emphasizing the importance of the sight of the target-object and the hand in guiding action and motor control.

Even though this study was not intended to investigate infants’ success of learning this task, it is very impressive that infants at this age are able to solve such advanced problems and display one of the most important characteristics of human intelligence and knowledge. It is particularly fascinating to witness infants’ learning of a novel and demanding task in a matter of minutes. These observations have been previously documented, where infants younger than 12-months of age are able to exhibit planned and purposeful solutions to problem-solve in search tasks (Willatts, 1984). Indeed, infants’ short-term experience over the course of one session resulted in certain forms of exploratory behaviours to decrease particularly direct reaches through transparent occluders. Additionally, on many individual reaching trials in the current study, infants displayed variability in their reaching strategies and attempted to reach through the occluder and detour around it as well (see also Lockman & Adams 2001). Overall, infants engaged in the task, but they learned and improved on their

abilities to detour around barriers and search for visible- hidden- and partially-hidden objects. In this light, it is important to make clear that infants did not simply “fail” with any particular occluder type or hiding-task; rather infants merely demonstrated differential performance times and behaviours (often unique and innovative in form) when faced with various manipulations that are only reflective of how infants integrate, process and subsequently choose to act.

4.3 LIMITATIONS AND LOOKING AHEAD

In the current study, on nearly every trial infants correctly tracked the ball from its release point down the track and underneath an occluder. They often demonstrated impressive prospective control by engaging in a smart-action we termed *hand tracking*, where the path of the ball was followed as it moved across the table. Though infants touched and often succeeded in obtaining the ball, it is difficult to isolate how visual information was processed once the ball came to rest underneath a tunnel. That is, despite impressive anticipatory eye and hand tracking abilities, it is not clear what information (i.e., the ball, the occluder’s edge, the occluder’s surface etc.) precisely guided infants in planning and subsequently executing a motor action. As one of the limitations of the current study, the use of a corneal reflection eye-tracking system would have effectively revealed this information. After all, a part of infants’ perseverative and random search errors (particularly under opaque conditions) may have been due to a break in gaze fixation on the correct hiding location, a notion that Butler et al., (2002) eluded to in their search study with toddlers.

The study also did not take into account how various infant-mother attachment styles and socio-cultural differences may have produced varying performance outcomes. As previously presented, the ethnicity of this sample was not diverse enough to conduct analyses on how performance differed. However, there is a strong literature supporting the notion that mother-infant attachment styles influence infants’ cognitive development (see Donovan, Leavitt, Taylor, & Broader, 2007). In this regard, the study also did not adequately

account and control for how much social reward and encouragement mother and the experimenter provided to infant individually. Though mothers never gestured or overtly pointed to the ball's hiding location, they did often—but inadvertently—verbally inform their children where the ball was hidden. However, it is not believed that this factor would have contributed to infants' differential search success.

By examining infants' behaviours in the current study, there are still some unanswered questions that require further investigations as well. Infants in the current study engaged in more exploratory behaviours with transparent occluders in comparison to graded or opaque occluders. Naturally, these extensive explorations in the transparent condition consumed much of infants' time in quickly touching the ball and lead to a slower performance time in comparison to the other conditions. Indeed, Yates and Bremner (1988) have showed that increased exploration with transparent barriers may be due to their distracting effects of novelty that are puzzling for infants. The authors noted that familiarizing infants with the occluders reduces these effects and decreases search errors at the wrong location. It is possible to investigate these findings with the current study in order to understand how familiarization with the occluder types would affected the results. In so doing, however, the novelty and exploration that are the core component of infants' behaviours and characteristics is no longer captured. Furthermore, infants improved performance and success after such exposures with the task would not be surprising; after all, infants clearly demonstrated this advantage through their rapid learning of the task only after 9-exposures (i.e., trials).

With regards to the current accounts of infants' search-task abilities, the current study was not able to definitively exclude the means-end deficit as a limitation factor. Therefore, a comparative study should be conducted whereby infants are required to perform a means-end task (i.e., remove the occluder in order to obtain the target) with each combination of occluder type and hiding-task. Such means-end task difficulties are more

apparent in younger populations (i.e., 6-month-olds), thus investigating a younger age group will more thoroughly put forward this account to experimental test.

There does remain one unexamined proposed account on difficulties with searching for hidden objects has been proposed by Munakata (1997), in which the knowledge underlying infants' behaviours is viewed as graded in nature and strengthens with development. The authors argue that infants use weak internal representations to show sensitivity to hidden objects in certain paradigms (e.g., VOE) early in life, while other tasks require a stronger representation that evolved with experience (e.g., search). In this light, it maybe that infants' lack of success under the current opaque conditions is due to the increased amount of distractions in the visual surround that maybe interfering with this 'fragile' representation. Therefore, to investigate and understand infants' cognitive planning and searching-abilities for hidden objects, a future direction for the current study is to examine the same measures in the dark. Consequently, the elimination of all distracting "elements" in light environment can be eliminated (i.e., global darkness) and compared to performance in absence of target-object's visual input alone (i.e., local darkness) as was the focus of the current study. Thus, any differences in performance will highlight infants' true cognitive knowledge in search-tasks

Furthermore, the comparison between the two age groups will reliably outline how infants' cognitive and motor developments change and subsequently affect their performance. In other words, testing younger infants will determine if the ability to inhibit develops gradually as infants' cognitive capacity for performing higher level cognitive processes increases and how the mastery of reaching skills supports infants' performance.

Finally, given that similar search studies conducted with toddlers have generated counterintuitive results (cited at the outset), it has yet to be determined why primary knowledge about hidden objects and permanence this is present in 3-month-olds is not guiding behavior in more skilled toddlers. A study by Butler, Berthier, and Clifton (2002), offered additional information during the ball's movement by replacing the wooden opaque

screen with a tinted Plexiglas screen, while the four doors remained opaque. The authors argued that if toddlers' difficulties with search tasks are due to lack of visuo-spatial knowledge, then the additive information about the ball's trajectory rolling between the doors as well as its failure to re-emerge from behind the door with the wall, would serve as cues and improve search abilities in toddlers. This manipulation is very similar and comparable to the opaque conditions in the current study; however, 2-year-olds were still unsuccessful in choosing the correct door. Comparatively, the current study's findings revealed that although infants' performance was slower when the ball was fully hidden in comparison to the other occluder conditions, infants were nonetheless successful in touching and obtaining the ball while under full visual occlusion. Therefore, a future direction for this research would be to conduct a study that would attempt to address the perplexing discrepancy in the development of object knowledge between 9.5 months and 24 months of age.

V. CONCLUSION

The current study's manipulation of perceptual information and cognitive complexities affected infants' performance in different ways. Overall, infants benefited from the sight of target behind the occluder relating to faster reach initiations and contact with the correct occluder while the increase in the number of hiding locations slowed infants' performance of touching the occluder. However, infants performed faster in making contact with the target when it was partially visible from behind 50%-graded occluders. In this regard, infants engaged in more peeking behaviours in five-hiding tasks and opaque occluder types but attempted more exploratory behaviours such *direct reaching* and *edge grasping* when the object was fully-visible.

With regards to the previously proposed accounts of search-task failure, the current study did not support the means-end deficits, the lack of spatial knowledge or the lack of object permanence accounts; this thesis research did however lend support to the weak memory and lack of inhibition account. In general, Diamond's account based on the prematurity of the prefrontal cortex nicely captures 9.5-month-old infants' many peculiar search errors, intriguing smart actions and the uncoordinated reaches witnessed in the current research study. Specifically, infants' apparent inability to remember the current information about the hidden ball and perseverative errors to the previously rewarded location suggests that significant progress is yet to be made in overcoming weak memory and inhibiting predominant response tendencies. Infants' difficulties in avoiding a direct reach through the transparent occluders particularly highlight their inability to inhibit attention to the salient dimension of the ball which leads to their subsequent lack of success in retrieving the ball. Lastly, infants' organization of awkward reaches on opaque conditions, as well as their difficulties in inhibiting the reflexive grasping of occluders' curvilinear edges, were clearly observed in this study and have been similarly accounted for in monkeys with frontal lesions. However, the Cognitive Load Hypothesis reported by Boudreau and Bushnell (2000) agreeably highlights the pattern of infants' successful search actions observed in this

study. With infants showing greater success in touching and obtaining the ball under the 50% graded occluder condition, the present study illustrates the delicate nature and balance of infants' attention and cognitive capacities while processing visual information for goal-target search. In other words, information about the solidity of the occluder, as well as visual sight of the ball, reduced infants' cognitive processing load thereby enabling infants to dedicate more attention and resources to successfully coordinate a reach around the barrier. When cognitive resources are depleted due to competing mental (i.e., cognitive planning and problem-solving) or physical (i.e., planning and coordinating motor actions) demands, infants are not able to inhibit distracting information and divert their attention appropriately to avoid errors and successfully obtain their goal-target objectives.

This study also makes important methodological contributions to the field by emulating infants' natural environments where objects often appear in-and-out of sight and immersing the infant at its centre. That is, while developed under controlled laboratory conditions, the approach taken in this study was ecologically sensitive and thus may allow us to extend the range of the findings. In addition, this is the first study to have simultaneously manipulated both cognitive complexities and perceptual information in this type of problem-solving context to demonstrate the tight coupling of action and perception and its role in shaping cognition. The findings further highlight 9.5-month-olds' impressive ability to focus on a goal, initiate a mental plan of action and subsequently execute an appropriate motor action, thereby illustrating how problem-solving abilities in adults is deeply rooted in infancy.

Embedded in this account is the close interaction between the perception action systems that provides a context in development for demonstrating the complex trade-offs between these systems which ultimately allow infants to successfully engage their world of objects. Visual information from the target, sight of hand and the occluder were all crucial components in infants' success of making precise detour reaches. Infants were greatly advantaged by having visual sight of the object (partial or full) when planning a course of action. Visual connection with the target was so powerful in guiding action that infants often

failed to pay attention to the proprioceptive feedback from their reaching arm such that their hand would often collide with the occluder. Infants were incredibly goal-driven in planning a detour reach and their engagement in the task was evident in their leaning and peeking behaviours through the occluder openings that truly reflects on their smart-action planning and problem-solving abilities.

The multiple strategies infants employed over a short period of time are indicative of infants' nature as active explorers, persistently approaching the problem for solutions. Through these exploratory efforts, learning was the ultimate goal for the infant who learned to exploit perceptual and cognitive information in making appropriate (and smart) motor actions, which in turn help shape and define the cognitive architecture of early development.

VI. APPENDICES

Appendix 1: Consent Form

Cognition • Health • Infancy
Learning • Development

INFORMED CONSENT TO PARTICIPATE

Reaching and Searching Abilities in Infants 8-to-12-Months of Age

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Psychology Department, Ryerson University
(416) 979- 5000 ext. 6191

PURPOSE OF THE STUDY

The purpose of the study is to help us understand babies abilities to coordinate their action to reach and search for objects hidden behind barriers.

PROCEDURE INVOLVED IN THE STUDY

Your baby will sit on your lap in front of a testing table. A small attractive ball will roll down a track, appearing in and out-of-sight as it moves behind a series of small partitions. Your baby will be searching for the moving ball at various locations on the track. We are interested in measuring your child's abilities in planning her/his reach towards the ball's location and searching for it once it has disappeared out-of-sight. There are no right or wrong answers. Sometimes infants are very interested and successful in reaching and searching for objects, sometimes they are not interested or successful. Both of these are normal responses and do not say anything about your child's development. We ask that you sit quietly during the observation periods when your baby is engaged in reaching and searching for the ball. However, after each toy retrieval trial, we encourage you to interact with your baby and provide social reward. The entire session should last approximately 30-minutes. All materials are designed and built to be infant safe with smooth rounded edges, carpeted surfaces, and the use of non-toxic paint. All toys are sterilized with a baby-safe cleaning agent after each session with an individual infant.

POTENTIAL RISKS AND BENEFITS

There are no risks associated with this study. Occasionally, infants may feel uncomfortable, tired or lose interest during the observation and display fussiness. Your participation is voluntary. You are free to take a break to address any special needs your infant may have (i.e. feeding etc.) or you may choose to discontinue your infant's participation at any time during the study session with no consequences. We hope that you and your child will find participating to be an enjoyable experience. Although the research will not provide meaningful information about your child's individual development, your generous participation will be crucial in our understanding of infant's normal development from 8-to-12 months.

CONFIDENTIALITY

Any information that is obtained in connection with this study, including the information you provide in the questionnaire, will remain strictly confidential. Your privacy and that of your infant will be respected. All records will be referred to in the study using pseudonyms and study codes which will be securely stored on password-protected media. 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 still-photographs and 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. 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.

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 experimenter. You also have the option of removing your infant's records of observation from the study.

INFORMATION ABOUT THE STUDY

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.

E-mail Address

Phone Number

This study has been reviewed and approved by the Ryerson Research Ethics Board (REB 2009-035). If you have concerns or questions about your child's rights as a participant or about the way the study is conducted, you may contact:

Dr. Nancy Walton
Chair of the Research Ethics Board
(416) 979-5000 ext. 6300
nwalton@ryerson.ca

Alex Karabanow
Research Ethics Coordinator
(416) 979-5000 ext. 7112
alex.karabanow@ryerson.ca

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.

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. I realize that I may withdraw my child from the study at any time if I wish to do so.

Name of Participant (child)

Signature of Parent/Guardian

Signature of Researcher

Date

Appendix 2: CHILD Pre-Observation Questionnaire (CPOQ)

Cognition • Health • Infancy
Learning • Development

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 Niusha Ghazban (416-370-5000 ext. 4859 or nghazban@ryerson.ca), the researcher listed on the copy of the consent form you were given to take home.

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: _____

Age of siblings: _____

SECTION III: CURRENT ABILITIES OF YOUR SON/DAUGHTER

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? _____
7. Is your child able to crawl?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge? _____
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? _____
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? _____
10. Is your child able to walk independently without any assistance?	☐ Yes ☐ No	If yes, at what age (in months) did this ability emerge? _____

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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