THE EFFECTS OF MOTOR CONSTRAINTS ON INFANT SEARCH BEHAVIOUR

by

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Abstract

Two studies investigated the effects of various motor constraints of reaching on infants’ search performance on the A-not-B task. These studies were motivated by the idea that motor memories for reaching lead to A-not-B errors. The 2 motor constraints that were evaluated included barriers that blocked the path of the hand and hand-use preferences. Each of these motor constraints was examined separately.

In Experiment 1, infants (N = 40, 20 8-month olds, 20 16-month olds) were given the A-not-B task twice. One condition was analogous to the traditional A-not-B task (i.e., using 2 hiding locations) and the other was modified such that a barrier (i.e., an opaque screen) blocked the infants’ reaching path of location A on A trials only. On A trials, all infants searched correctly less often when a barrier was present, and younger infants searched correctly less often than older infants. On B trials, younger infants made more errors in the no barrier condition, whereas older infants did not show any significant difference in B trial performance across conditions.

In Experiment 2, infants (N = 51) completed an adapted handedness test (Michel, Ovrut, & Harkins, 1985) followed by a modified A-not-B task. The test assessed infants’ hand-use preferences for reaching, which was used to group infants into their respective preference group (i.e., consistent or inconsistent). Infants with a consistent preference were randomly assigned to a hiding side group (i.e., A on preferred side or A on non-preferred side). Infants searched correctly more often when hiding side was congruent with their
preferred reaching hand, and older infants searched correctly more often than younger infants. On the B trial, neither age nor hiding side affected the production of the A-not-B error.

Collectively, these studies present data that address the theory that motor memories for reaching are the cause for the production of A-not-B error. These studies provide novel evidence that motor memories for reaching are present in infants aged 8- and 16-months, and that motor memories can influence the production of such errors in certain A-not-B contexts. Implications and directions for future research are also discussed.
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CHAPTER 1

Infants Search Behaviour on the A-not-B Task

The ability to manually search for an object is a useful skill for developing infants. This ability allows infants to retrieve objects that are not directly within their reach because the objects are concealed, because they have been moved, or possibly because objects are farther away from their preferred reaching hand. Studying both the ability and the inability to recover hidden objects provides valuable information about infant development, such as the understanding of object existence, motor skill, and natural tendencies (e.g., motor habits).

One of the most common demonstrations of infants’ inability to recover a hidden object is an error made by very young infants on the A-not-B search task, first introduced by Piaget (1954). The A-not-B error occurs when infants, after having successfully seen and retrieved a toy from one location, search incorrectly when the toy is later hidden, in plain view, at a different location. In the decades since Piaget first reported the A-not-B error, researchers have explored two different avenues: a) what infants know about hidden objects and b) what infants do when searching for such objects in the A-not-B task.

For researchers interested in what infants do on the A-not-B task, the act of reaching is of particular interest; reaching can be used for most manipulatory actions, including recovering hidden objects (e.g., in an object search task in which infants must retrieve an object that is hidden either because the object is concealed by an occluder or because someone has moved the object to another location). The A-not-B task is a classic example of a manual object search task that requires reaching. In a typical A-not-B task, the experimenter hides an attractive toy at a particular spatial location (e.g., location A), and the infant is allowed to search and retrieve the toy. This hide and retrieve sequence is repeated a variable number of times. The experimenter then hides a toy at a second, identical location
(e.g., location B), and again allows the infant to search and retrieve the toy. As mentioned briefly before, an error in search is made when a suitable delay is imposed between hiding and searching. Young infants fail to retrieve the toy at location B and instead perseverate and search for the toy at location A. This error in search is known as the A-not-B error.

The A-not-B task is fundamentally a reaching task – one that measures infants’ ability to manually search for a hidden object. Despite this fact, however, very few studies implementing the A-not-B task have explicitly assessed motor constraints on reaching behaviour (e.g., a screen blocking the path of the reaching hand), even though such constraints can have profound effects on infants’ reaching, and consequently their searching behaviours. Thus, additional research that examines motor constraints on reaching in the A-not-B context is warranted; this research will allow for a better understanding of whether or not motor constraints on reaching affect object search ability (i.e., the production of the A-not-B error) in infants.

**Theoretical Perspectives**

Continued interest in the A-not-B error remains strong even after several decades of research. This interest is most likely because our understanding of the A-not-B task and its associated error is robust, but far from complete. Explanations for the occurrence of the error can generally be divided into three main categories focusing on (1) object representations; (2) spatial concepts; and (3) some form of response inhibition and memory, including the influence of motor history memories. Each of the explanations of the error is discussed in detail below.

**Object Representations Account.** Piaget (1954) offered the classic explanation of the A-not-B error, one that involves object representations. According to this account, infants make the A-not-B error because they lack a complete notion of object permanence
(i.e., the understanding that an object continues to exist even though they cannot see it).

More specifically, infants make the A-not-B error because of an egocentric (i.e., body-centered) bias when searching; they believe that the object’s reappearance is solely contingent on their action (Piaget, 1954). Accordingly, on B trials, young infants (around 9 months of age) will search incorrectly at location A because that location is where they first found the hidden object. Essentially, the infants expect that by reproducing their action at A they will again produce the hidden object. According to Piaget, it is not until around 12 months of age that infants are successful on this task and understand that the hidden object is a separate entity whose location is independent of their own actions.

Another object representation explanation, known as the active-latent account, is found within the adaptive processing framework and uses simulations from the parallel distributed processing model (i.e., a neural network that describes mental phenomena or memory) to predict why the A-not-B error occurs. According to this account, object representations are embedded in two specific processes called active and latent traces (Munakata, 1997;1998; Munakata, McClelland, Johnson, & Seigler, 1997). Active traces are created when infants maintain representations of the hidden object; these representations can be accessed by infants even in the absence of later presentations of the stimulus. In contrast, latent traces are created when infants change their search behaviour towards a stimulus such that they can respond differently to it on later presentations. Infants’ performance on the A-not-B task is thus based on the relative strength of active and latent traces. The error will occur when there is a weakened object representation of the hidden object, or in other words, when there is competition between latent traces for A and active traces for B (Munakata,1998).
Overall, theories for the production of the A-not-B error that are based on object representation concepts are problematic because they do not fully account for many other A-not-B findings. For example, the lack of object permanence does not explain the fact that search errors may be explained by other factors such as memory demands (Cummings & Bjork, 1983; Diamond, 1985) and/or motor skill (Thelen, & Smith, 1998). In addition, subsequent studies have demonstrated that younger infants are sensitive to object permanence when looking time is used as a dependent measure instead of reaching (Baillargeon, 1993; Baillargeon & Graber, 1987; Baillargeon & De Vos, 1991; Kellman & Spelke, 1983) and that search errors can be elicited in older infants who do not have trouble with the concept of object permanence (Marcovitch & Zelazo, 2006; Sophian & Wellman, 1983; Zelazo, Reznick & Spinazzola, 1998). Thus, object representation accounts of the A-not-B error do not fully explain the occurrence of the error.

Spatial Account. An alternative category of explanation for young infants’ erroneous behaviour on the A-not-B task involves the infants’ understanding of space. One spatial explanation involves the place hypothesis, which suggests that infants may make errors on the B trial because they perseverate to a specific place or hiding location (i.e., the A location) at which they had previous success at finding the hidden toy (Gratch, 1975). In this case, perseveration implies that infants are literally going back to a previous successful location in space. In an early demonstration of this hypothesis, Evans and Gratch (1972) observed this ‘place going error’ by using a toy for the B trial that differed from the one used for the A trial. Results indicated that infants continued to search perseveratively at location A, despite the fact that there could not be an object-based reason to look for this object in the old location (because it was a new object). Accordingly, these authors concluded that their data were evidence that the production of the error is spatial in nature.
Other ‘place going’ explanations for the A-not-B error focus on the absolute and relative positions of the A and B hiding locations (Bremner 1978; Bremner & Bryant, 1977; Butterworth, 1975; Harris, 1973, 1974). Harris (1973) noted that in Piaget’s task the objects’ absolute position was confounded with the objects’ relative position (i.e., the change in the left-right position of the A and B locations across trials). Harris’ proactive interference account suggests that perhaps infants code the relative position of the object during A trials, only to have it switched on B trials, and it is this switched spatial cue that leads to the A-not-B error. However, Harris (1973) could not support this explanation of the A-not-B error, in that there was no difference in error rate when the A and B locations were switched. Harris attributed this finding to the lack of delay between hiding and searching events.

In a subsequent study, Butterworth (1975) addressed the limitation of no delay between events by implementing the proper delays and by switching the A and B location across trials (i.e., relative and absolute positions were changed separately or jointly on B trials). Butterworth found that infants made A-not-B errors most often in conditions where the object moved away from the midline. However, when location proximity was held constant, any bias for reaching to the midline was eliminated, with infants in all conditions making the same number of errors. Likewise, when spatial relations in the infants’ visual field were held constant but the hidden object was moved, A-not-B errors were completely eliminated. Butterworth concluded that there was some support for Harris’ claim that A-not-B errors were due to some change in the relation between old and new hiding locations; however, neither the change in relative nor absolute position was solely responsible for the occurrence of the error. Butterworth further suggested that infants are identifying objects through space and time, using visual frames of reference that remain invariant with movement.
The most common spatial explanation for the A-not-B error focuses on the use of egocentric (i.e., related to the self) or allocentric (i.e., related to the environment) location codes for spatial localization. Much of the supporting evidence can be found in studies on the development of spatial orientation more generally (Acredolo, 1978; 1979; Acredolo & Evans, 1980; Acredolo, Adams & Goodwyn, 1984; Lew, Bremner, & Lefkovitch, 2000; Lew, Foster, & Bremner, 2006; Lew, Foster, Crowther, & Green, 2004). Previous research has shown that the use of egocentric or allocentric location cues depends on factors such as landmark salience and the environmental context (Acredolo, 1979; Acredolo & Evans, 1980; Bremner 1978; Bremner & Bryant 1977; Wang & Spelke, 2000). For example, to investigate which location codes are used by infants, Acredolo (1978) trained infants to expect an event to occur either on their left or on their right side. Infants were then moved in the room such that their view of the room was reversed. Acredolo found that 6-month old infants relied more on an egocentric rather than an allocentric frame of reference when trying to place themselves in space, but that 16-month old infants did the reverse. These results, and other findings (Acredolo, 1979; Acredolo & Evans, 1980; Lew et al., 2000), support the theoretical assumption that there is a developmental change in the ability to represent spatial orientation from egocentric to allocentric.

In the A-not-B context, egocentric and allocentric location codes have likewise been implicated in the production of search errors. One suggestion is that A-not-B errors can be attributed to a lack of coordination between egocentric and allocentric location codes such that when an object moves, infants fail to update their position in space in relation to the displaced object (Butterworth, 1976). In one experiment, Butterworth arranged the A and B locations vertically such that A and B locations were either up or down, and found that infants made more A-not-B errors when A trials were located in the up position. Similar to
the research on spatial orientation, Butterworth interpreted this finding to mean that errors in manual search are spatial in nature, with the up location corresponding to an egocentric frame of reference.

Related to the use of egocentric or allocentric location codes are specific spatial manipulations such as moving the infant between events (i.e., self-movement) or moving the object (i.e., object movement), often referred to as self/object displacement tasks. Benson and Uzgiris (1985) found that 11-month old infants made significantly fewer egocentric choices after active movement (i.e., walking themselves) than after passive movement (i.e., being carried). Acredolo et al. (1984) also found that at 12-months of age, infants searched better and visually tracked the object more often, after active movement than after passive movement. Additionally, infants responded more egocentrically when they could not see the target object directly compared to when it was visible. These effects disappeared, however, when the infants were re-tested at 18-months, suggesting that older infants acquire mental representational skills such as perspective taking (Acredolo et al., 1984). Taken together, self- and object- movement studies have shown that different factors are important at different ages of development. Infants use direct perception at 12-months of age but use more internal representations around 18-months of age. These findings also indicate that the use of egocentric location codes decreases with active movements.

Self- and object-movement manipulations have also been investigated in the A-not-B context more directly (Bremner, 1978; Lew, Hopkins, Owens & Geer, 2007, Schmuckler & Tsang-Tong, 2000). In an earlier study, Bremner (1978) argued that search errors are due to a competition between egocentric and allocentric spatial coding. To support this argument, Bremner (1978) used two strong spatial cues on the A-not-B task and found that infants made fewer A-not-B errors after they moved to the opposite side of the table. This finding
supports the idea that infants use allocentric cues to search for hidden objects at a particular place in space. Moreover, infants’ activity at the new location is related to their previous experience with a landmark rather than a specific motor habit.

Another way to examine self- and object-movement in the A-not-B context is to manipulate spatial relations to the hiding location. Recently, Lew et al. (2007) examined the effects of postural changes between A and B trials. This study involved three conditions: a) infants were seated for A trials but then stood up just before the B trial (infant up condition), b) infants stood up just before the B trial and the table top was raised such that there was no change in the spatial relation to the locations (infant up/table up condition), or c) infants received the standard A-not-B task. The results showed that there was no difference in error production between the standard and the infant up/table up condition, and that infants made fewer A-not-B errors in the infant up condition relative to the standard and infant up/table up conditions. These findings suggest that change in the spatial relation between the hand and the location is responsible for improved performance on B trials. Lew et al. further implied that perhaps perseveration occurs at the level of movement planning rather than at the level of reach execution, as suggested by Berger (2001) and Munakata, Sahni, and Yerys (2001). Additional research is needed to address whether perseveration occurs in terms of planning and execution of action. However, the studies on self- and object-movement that use postural changes highlight that allocentric location codes lead to improvement in search performance on the A-not-B task.

**Memory and Inhibitory Control Account.** A final class of explanations for the occurrence of the A-not-B error focuses on cognitive mechanisms (e.g., memory, inhibitory control, or a combination of both). The central idea behind this account is that interfering memories (or some variant), and not knowledge or representations of hidden objects, are the
reason behind A-not-B errors (Bjork & Cummings 1984; Cummings & Bjork, 1981, 1983; Diamond, 1985; Smith, Thelen, Titzer, & McLin, 1999). According to the memory deficit account, infants make the A-not-B error because of a problem with simple working memory. As a classic example of this idea, Cummings and Bjork (1983) found that in search tasks with multiple hiding locations, although infants make the A-not-B error, they rarely searched at the original A location on B trials. Instead, infants tended to search at locations that were clustered around the correct B location. Cummings and Bjork interpreted these results to mean that A-not-B errors are due to a memory deficit, with errors occurring because infants vaguely code the position of B in memory. Similarly, Diamond (1990) suggested that the A-not-B error occurs through a combination of memory deficit and problems with response inhibition. According to Diamond, infants make the A-not-B error because their prefrontal cortex is not developed enough to do two things at once – keep the hidden object in mind and inhibit the incorrect manual search response.

Smith and her colleagues (Clearfield, Dineva, Smith, Diedrich, & Thelen, 2009; Diedrich; Highlands, Spahr, Thelen, & Smith, 2001; Diedrich, Thelen, Smith, & Corbetta, 2000; Smith et al., 1999; Thelen, Schöner, Scheier, & Smith, 2001; Thelen & Smith, 2006) have suggested yet another explanation for the A-not-B error, which is based on motor memory. According to the dynamic systems account, the A-not-B error is both time and context dependent resulting from the interaction of a memory of previous action and perceptual cues (Schöner & Dineva, 2007; Smith et al., 1999; Smith & Thelen, 2003; Thelen & Smith, 2006). For example, when infants reach to the A location, a memory of that reach is activated. Over many A trials, infants develop a strong motor memory of previous reaches, with each ensuing trial strengthening the activation of the motor history of the previous trial; this explains why infants continue to reach to A. Then on the B trial, the
lingering motor memory of the action at A dominates and eventually leads to a reach towards the more habitual A location. This explanation of the error suggests that the occurrence of the A-not-B error has nothing to do with (traditional) memory or representations of the object at A, but rather that it is a function of the development of a reaching habit.

Several studies support the notion of a motor memory for reaching. In one of the experiments conducted by Smith et al. (1999), infants were given four training trials and two A trials while they sat on their parent’s lap. Just before the B trial, half of the infants were stood up and remained that way for the remainder of the experiment; the other half remained seated for B trials (i.e., standard version of the A-not-B task). This manipulation differs from those used to test the spatial account of the A-not-B error, mentioned previously, as this manipulation only involved changing the posture of the infant such that infants’ reaching trajectories, which are of primary interest, would differ between trials. The authors found that infants in both groups performed similarly on A trials; however, infants who were switched to the standing posture reached correctly more often on B trials than those who remained seated. Smith et al. concluded that the A-not-B error was a result of a reaching habit and that perhaps motor memory of reaching to A included a proprioceptive memory of a felt posture.

In a subsequent study, Diedrich, Thelen, and Smith (1999) changed the postural dynamics of reaching movements and the A-not-B task more generally by adding extra weight to the infants’ arms on the B trials. When the weights were 100% of the body mass, infants no longer perseverated on the B trial. These authors suggested that because different forces are required to execute the reach trajectory, a reprogramming of the reach takes place on the B trial. Taken together, these experiments, and others (e.g., Diedrich et al., 2000), demonstrate that motor memories contribute to infants’ performance on the A-not-B task.
Thus, the memory and inhibition accounts have been widely used to explain why the A-not-B error occurs. As with the other theoretical perspectives, there is evidence suggesting that memory-based explanations of the A-not-B error are also limited. Evidence against Diamond’s memory and inhibition account and against the dynamic systems theory comes from studies showing that infants can make the A-not-B error even after observational A trials (i.e., when there is no prior action at A to inhibit; Butterworth, 1975; Bremner & Knowles, 1984). Studies finding that infants make errors even with transparent covers (i.e., the toy is always visible) also challenge the memory account (Butterworth, 1977; Yates & Bremner, 1988). The study of the A-not-B task is, therefore, of continual interest to researchers interested in discovering the origin of this search error.

Factors that Influence the A-not-B Error

Over the past several decades in which the A-not-B error has been studied, researchers have found that this error can be influenced by a number of factors. Some of these factors include the age of the infant, the time delay between hiding and searching events, the object’s visibility including visual attention to hiding events and visual distinctiveness, the act of reaching versus looking at the hidden object, and the number of A trials. A brief discussion of each of these factors is provided below.

Age. It has been well established that the occurrence of the A-not-B error is age dependent and primarily occurs in infants between 8- to 12-months of age (Butterworth, 1975, 1976; Diamond, 1985; Munakata, 1997; Piaget, 1954; Wellman, Cross, & Bartsch, 1987). There is, however, some evidence that infants beyond 12-months of age may continue to make perseverative errors in the classic A-not-B task (Espy, Kaufmann, McDiarmid & Glisky, 1999). Moreover, similar perseverative search errors have been produced by older infants when age-appropriate tasks are used (Berger, 2004; Butler et al.,
There are several reasons for why the A-not-B error occurs within the 8-12 month age period. The first reason comes from Piaget (1954), who suggested that it was only at 12-months that infants understand that objects can exist independently of their own actions. Accordingly, infants younger than this age that do not have this understanding tend to err on the task. The second reason involves the emergence of spatially-directed motor actions (e.g., crawling and walking) around 12-months of age. Studies have found that the emergence of these actions tend to improve infants’ spatial memories such that fewer A-not-B errors are produced after this age period (Bertenthal & Campos, 1990) and that crawling and walking are correlated with infants’ success in the A-not-B task (Horobin & Acredelo, 1986; Kermoian & Campos, 1988). Locomotor experience also leads to better performance on other search tasks, such as the self/object displacement task in which either the self or the object are moved after the object is hidden in a container (Bai & Berthenthal, 1992). Altogether, these reasons suggest that around 12-months of age, infants are no longer stationary beings and they understand that objects exist even when they are hidden. Both experiences help infants to remember where objects are hidden and contribute to their success on the A-not-B task.

**Time Delay.** Another factor known to influence the occurrence of the A-not-B error is the time delay between hiding and searching events. Several studies have shown that the A-not-B error does not occur when there is no delay between events (Diamond, 1985; Gratch, Appel, Evans, LeCompte & Wright, 1974; Harris, 1973; Wellman et al., 1987). When a delay is implemented between hiding and searching events, Harris (1973) reported that the rate of the A-not-B error increased. Specifically, Harris observed that 10-month old
infants produced more A-not-B errors when there was a 5-second delay between events than when there was no delay. Harris suggested that when a delay was imposed, there was interference in memory such that information about the present location was interrupted with information about the past location.

The length of the delay between hiding and searching events in the A-not-B task is also important, and it should vary with the age of the infants tested. Earlier studies reported that older infants tended to need longer delays between hiding and searching events in order to produce the error (Diamond, 1985; Harris, 1973). Diamond, for example, found that a delay of 2 seconds was needed to produce the error at 7.5 months, whereas a delay of 5 seconds was needed at 10-months. Like Harris’ interference explanation, Diamond suggested that the production of the error was due to the failure of a memory-based intention to inhibit a response habit for returning to the A location, and that older infants required longer delays between events to ensure that their short-term memory for where the object was hidden was being taxed. Thus, a delay between hiding and searching events is important in order to see the A-not-B error, and longer delays are needed with older infants.

Object Visibility. Object visibility is another factor that has been widely investigated in the A-not-B literature. A review of studies focusing on object visibility revealed that the A-not-B error can still occur if the object is unhidden (Bremner & Knowles, 1984; Butterworth, 1977), and/or if transparent covers are used to hide the object (Butterworth, 1977; Harris, 1974; Sophian & Yengo, 1985; Yates & Bremner 1988). In one experiment, Sophian and Yengo (1985) placed a visible object at a third control location within the A-not-B paradigm. Results indicated that the A-not-B error was as likely to occur at either the control location or location A. However, when a hidden object was used, the error occurred more often at location A than at the control location. The authors suggested
that the errors produced when an object is visible are different from the ones produced when an object is hidden. Namely, errors associated with visible objects are occasional (i.e., random errors due to a host of factors), whereas errors associated with hidden objects are perseverative (i.e., systematic errors when infants search for the object at a previous hiding location).

Related to object visibility is whether or not the presence of a hidden object influences the production of the A-not-B error. To date, there is mixed evidence on the importance of this factor (Appel & Gratch, 1984; Bremner & Bryant, 2001; Munakata, 1997; Smith et al., 1999). In one of the experiments conducted by Smith et al. (1999), the experimenter got the infants attention by picking up the A lid and waving it. Then after several A trials, the B lid was waved. These authors found that infants often returned to the A location and suggested that the occurrence of the A-not-B error was due in part to reaching (i.e., motor memories) and had very little to do with the presence of an object.

In contrast, Munakata’s (1997) early work has demonstrated that the presence of a hidden object is important for the production of the A-not-B error. In experiment 1 of the study by Munakata, all A trials consisted of only a visible lid that was waved by the experimenter. Then on B trials, either the lid of location B was waved (B lid trials), or a toy was hidden at B and then the B lid was waved (B toy trials). The results indicated that after two A trials, infants made more errors on B lid trials than on B toy trials. In experiment 2, a toy, plus a lid, was hidden on all A trials. The results indicated that after a hidden toy plus visible lid A trial, infants made similar error rates on B lid trials and B toy trials. Based on these findings, Munakata suggested that similar rates in the A-not-B error cannot be explained by reinforcement, novelty, or motor histories of reaching; instead, similar error
rates are the result of some specific information (i.e., a hidden toy) that is repeatedly shown on A trials to which infants become sensitive on subsequent B trials.

The visual distinctness of covers (or lids) and/or hiding locations are also factors thought to contribute to the occurrence of the A-not-B error. Several studies have reported reduced numbers of errors when distinctive covers and/or hiding locations are used (Bremner, 1978; Bremner & Bryant, 2001; Butterworth, Jarrett, & Hicks, 1982; Cornell, 1981; Diedrich et al., 2001; Noland, 2007; Schmuckler & Tsang-Tong, 2000). Bremner and Bryant (2001) used distinctive cover groups (e.g., same or different lids) and gave infants two conditions of the A-not-B task: a lids-only and a hidden-object condition. These authors found that different lids in the hidden-object condition led to fewer A-not-B errors compared to when the same lids were used, whereas different lids in the lids-only condition led to more errors compared to when the same lids were used. Bremner and Bryant (2001) suggested that while infants make search errors in both conditions, infants are motivated by different reasons in each condition. In the lids-only condition, search errors are likely due to lower motivation levels to change search locations, whereas in the hidden-object condition search errors are likely due to a failure to update the object’s location in space.

In a recent study, Noland (2007) also found that distinctive shape covers contributes to the production of the error, even more so than object location. That is, when a differently shaped cover was used on B trials, 8.5 month-old infants made more errors on the B trial. From this finding, Noland suggested that visual features of the cover (i.e., the shape) may be embedded in infants’ memory for the hiding and retrieval of the toy on the A trial, which is why more perseveration was observed.

Similarly, visual attentiveness (i.e., where infants look) during the hiding events has also been found to influence whether or not the A-not-B error will occur (Diamond,
Horobin and Acredolo found that infants who looked attentively during the hiding events were less likely to make the A-not-B error than those who did not look attentively. This finding suggests that infants were using a ‘keeping an eye on the target’ strategy when searching. Moreover, infants learned that paying attention to the location improved their ability (i.e., spatial encoding) to find the toy again.

**Measuring Looking versus Reaching.** The occurrence of the A-not-B error is also dependent upon what type of behaviour is being measured. Typically, infants can successfully look for hidden objects long before they can manually search for them (Ahmed & Ruffman, 1998; Baillargeon 1987a; 1987b; Baillargeon, Graber, DeVos & Black, 1990; Baillargeon, Spelke, & Wasserman, 1985; Bell & Adams, 1999; Hofstadter & Resnick, 1996). One explanation for why infants may do worse on manual object search tasks is that infants lack means-end ability, which is the notion that infants cannot remove the physical occluder (the means) in order to retrieve the hidden toy (the end). According to this idea, infants younger than 8-months know that an object still exists but lack the motor coordination (i.e., means-end ability) to uncover it. Therefore, looking paradigms have been used to investigate infants’ knowledge of the existence of hidden objects.

In what has become a classic study, Baillargeon et al. (1985) examined infants’ knowledge of objects hidden by occluders by habituating 5-month olds to a solid screen rotating in a 180° arc. In test trials, a box was placed behind the screen and infants were shown either an impossible event in which the screen rotated a full 180° as if the box was no longer behind the screen, or a possible event in which the screen rotated until it reached the occluded box. Infants looked longer at the impossible events compared to the possible events, suggesting that these infants understood that an object continues to exist even after
being occluded by the screen. Several studies have since replicated and extended these findings using the same paradigm (Baillargeon, 1987b; Baillargeon & Graber, 1987; 1988; Baillargeon et al., 1990).

Studies that used the violation-of expectation paradigm such as the ones by Baillargeon and colleagues assessed infants’ looking behaviour rather than their manual search behaviour. This paradigm can therefore be thought of as one that assesses infants’ beliefs about hidden objects, providing insight related to how infants represent and use information about hidden objects when subjected to looking tasks. In fact, looking studies do not confirm Piaget’s theory of object permanence; instead, they reveal that infants younger than 8-months understand the existence of objects. More critically, looking paradigms do not tell us about what infants do on hidden objects tasks. Accordingly, studies comparing infants’ performance on looking and reaching versions of hidden object search tasks are needed.

To date, there have been numerous studies that have directly compared infants’ performance on both looking and reaching versions of object search tasks (e.g., Ahmed & Ruffman, 1998, Bell & Adams, 1999, Hofstadter & Resnick, 1996). For instance, Ahmed and Ruffman gave infants two versions of the A-not-B task. In the reaching version, infants searched for the hidden object themselves, whereas in the looking version, infants watched as an object was hidden by an experimenter. Furthermore, the looking version was similar to the paradigm used in earlier object search studies (Baillargeon et al., 1985). That is, infants were shown either an impossible event (i.e., the toy was retrieved from location A after having been hidden in location B) or a possible event (i.e., the toy was retrieved from location B after being hidden there). Results indicated that infants between 8- and 12-months of age looked longer at impossible events, suggesting that they understood the
existence of the object at B and that they were surprised when it was retrieved at A on the B trial. These same infants also searched incorrectly on the reaching version of the task, suggesting that they did not have the manual ability to produce successful retrieval. It was concluded that differences in the production of the A-not-B error across the different versions of the task may be because looking tasks involve recognition memory whereas reaching tasks require working memory. Ahmed and Ruffman further indicated that perhaps looking tasks are not susceptible to perseveration in the same way as reaching tasks. That is, infants may be prevented from using their knowledge of the hidden object when manually searching because of the requirement to produce a reach response.

Thus, our knowledge of what infants understand conceptually about the existence of a hidden object has been well documented in various ages of the first year of life. Much less is known about what infants do on hidden object tasks in which only their manual search ability is assessed. In light of this gap of knowledge, a closer look at motor constraints of reaching, as well as the reaching behaviours themselves, may provide additional insight regarding the type of knowledge needed to execute a successful manual search for a hidden object on the A-not-B task.

**Number of Prior Reaches.** The number of prior reaches to A is also believed to influence the production of the A-not-B error, although evidence for this belief has produced mixed results. Piaget (1954) originally claimed that the occurrence of the error was independent of the number of prior reaches to A, a claim arising from his observation that a single A trial may be enough to produce the error. Wellman et al. (1987) conducted a meta-analysis of the A-not-B error and after reviewing 57 studies they too found that the number of prior reaches to A did not increase the probability of the error. However, Wellman et al.’s meta-analysis did not take into account the fact that procedures used to study the A-not-B
error sometimes make it difficult to obtain a true history of the number of prior reaches to A. For instance, some procedures used a training phase either to a center location (Gratch et al., 1974; Horobin & Acredolo, 1986) or one to the same side as location A (Butterworth, 1977; Butterworth et al., 1982; Bjork & Cummings, 1984; Harris, 1973; Frye, 1980; Munakata, 1997; Ruffman, Slade, Sandino & Fletcher, 2005) or even to an unspecified location (Evans & Gratch, 1972; Cummings & Bjork, 1983; Sophian & Wellman, 1983). As a result, it is difficult to compare findings across studies as training may result in a strong bias to reach to A, which is an effect that may not be apparent in studies without these additional reaches.

It has also been noted that other task variations can make it difficult, but not impossible, to obtain a true measure of prior A activity. Such variations include repeating A trials until infants reach some criterion of consecutively correct reaches to A (Butterworth, 1977; Evans & Gratch, 1972; Frye, 1980; Gratch, et al., 1974; Harris, 1973; Horobin & Acredolo, 1986), and/or using multiple reversals (Ahmed & Ruffman, 1998; Appel & Gratch, 1984; Diamond, 1985; Hofstadter & Resnick, 1996).

Researchers have noted other ways to obtain a true measure of prior A activity. For example, in their meta-analysis of the A-not-B error, Marcovitch and Zelazo (1999) found that when certain studies were excluded from the analysis (i.e., studies that used one hiding location, studies that did not report the number of A trials, or studies that employed criteria for the number of correct reaches to A), the effect of prior reaches to A on the occurrence of the A-not-B error became more clear. The effect was due to the fact that the history of prior reaches to A was confined to a two location A-not-B task with hidden objects in which the true number of cued reaches to A could be calculated (including training trials). In this context, researchers found that the number of prior reaches to A influenced the production of
the A-not-B error (Bjork & Cummings, 1984; Butterworth 1975, 1976; Butterworth et al., 1982; Bremner, 1978; Bremner & Bryant, 1977; Diedrich et al., 2000; Smith et al., 1999).

Marcovitch, Zelazo, and Schmuckler (2002) directly assessed the effect of the number of A trials on B trial performance by varying the number of A trials given to infants (1, 6, or 11 A trials) and found an effect of the number of A trials. Specifically, Marcovitch et al. found an inverted U-function, with a small number of errors after 1 A trial, a larger number of errors after 6 A trials, but a reduced number of errors after 11 trials. These authors suggested that repeated reaching after 6 A trials increased habit strength, so infants perseverated on the B trial; however, after 11 A trials, habit strength and the infants’ ability to reflect on the task increased, which together led to less perseveration on the B trial. These finding are the first to provide direct empirical support for the notion that under certain conditions, a history of prior reaches to A plays an influential role in the occurrence of the A-not-B error. Infants who received more reaching experience, to a certain point, were able to develop motor habits for reaching that were then carried forward and used on B trials. Collectively, these findings demonstrate that having a history of prior reaches to A is an important motor aspect of infant behaviour that affects manual search performance.

A number of empirical studies have now shown that motor memories, which are related to the number of prior reaching movements, contribute to infants’ perseverative error production (Diedrich et al., 2000, 2001; Munakata, 1997; Smith et al., 1999). Diedrich and colleagues (2000) used a reaching task analogous to the A-not-B task to assess infants’ performance as they repeatedly reached to a single target or two identical targets. It was found that 9-month olds who made perseverative errors were also the ones who repetitively reached to one direction during the A trials and who developed stronger motor memories for reaching. Infants also made stronger reach trajectories during the two target condition.
Diedrich et al. (2000) suggested that repetition of the same reaching direction on A trials was critical to the production of perseverative responses. Moreover, the presence of multiple targets indirectly helped in the formation of motor habits because, unlike a single target where infants could have many different reach trajectories of which one is eventually successful at touching the target, with multiple targets infants must reach in a way that is successful despite the presence of distracters. These findings demonstrate that at least some activity is needed at the A location in order for infants to make the A-not-B error, and that more experience repeating a reach in a particular direction leads to more manual search errors.

In sum, all of these factors – the age of the infant, the time delay between hiding and searching events, the object’s visibility including visual attention to hiding events and visual distinctiveness, the act of reaching versus looking at the hidden object, and the number of A trials – have been implicated in influencing the production of the A-not-B error. It is important to note, however, that while these factors are among the most commonly investigated in the literature, other factors may also be important to the production of the error. Given the inherent reaching nature of the A-not-B task, an additional factor worthy of investigation is the motor process of a presentation side bias (i.e., when infants repeatedly reach in a particular direction).

**Re-examining Presentation Side Biases**

In the A-not-B literature, presentation side typically refers to the side on which each hiding location is situated. Usually to avoid presentation side biases, the A location is counterbalanced such that there are equal number of presentations on the left and right sides. The same is done in other areas of study (e.g., laterality, the development of reaching) where it is also common to have equal presentations of the stimulus to the person’s left and right
sides (Bryden & Roy, 2006; Gabbard, Tapia & Helbig, 2003; Goldfield & Michel, 1986). However, it is reasonable to believe that repetitively reaching to the right side (or to the left side) might signify the presence of an inherent reaching asymmetry, one that would be similar to human infants’ preference for rightward head-turning in the womb (Hepper, McCartney, & Shannon, 1998) and at birth (Cornwell, Barnes, Fitzgerald, & Harris, 1985; Ecklund-Flores & Turkewitz, 1996; Goodwin & Michel, 1981). If presentation side biases work in this way, then repetitive reaching to one direction may create and/or strengthen manual motor habits, which then may or may not influence infants’ search performance on the A-not-B task. For example, presentation side biases may lead to more ipsilateral (i.e., on the same side as) movements that are congruent with the preferred hand and, thus, more motor memories for reaching to the correct A location.

Gathering empirical evidence for presentation biases in the A-not-B context has been documented previously, but often haphazardly (for an example, see Diamond, 1985). These previous studies often report that findings cannot be accounted for by biases to presentation side because their methods use counterbalancing. However, these finding do not take into account the presence of inherent reaching asymmetry, which may be influencing such presentation side biases. This methodological limitation has motivated some other researchers to investigate inherent reaching asymmetry and object search.

To date, the investigation of reaching biases in the A-not-B task specifically is rather limited, with only a few known published studies (Burdukova & Stroganova, 2008; Longo & Bertenthal, 2006). In an indirect fashion, Longo and Bertenthal examined whether or not ipsilateral biases in reaching exist in the A-not-B context. To do this, the search performance of infants who searched actively was compared to those who watched passively. Results indicated that infants in both groups showed an ipsilateral bias in their reaching and that
infants made search errors after observing the experimenter reach ipsilaterally, but not contralaterally. Essentially, infants copied their own ipsilateral bias for reaching when asked to retrieve the toy on the B trial.

From this study, it is apparent that infant responses tend to vary with those of the experimenter if infants watch an experimenter perform the task, and that infants have an inability to reach across the midline in the A-not-B task (i.e., perform a contralateral reach). Although not conclusive, these findings support the notion that infants will perseverate on the A-not-B task if they experience a history of motoric memories for reaching to the A location. Thus, future A-not-B studies should address the idea of motor memories for reaching and the effect of ipsilateral biases more directly.

Similar presentation side biases have been observed among aphasic patients, who, when asked to copy an experimenter, failed to cross the body midline and performed an ipsilateral action when a contralateral one was modeled (Head, 1926). Like the infants in Longo and Bertenthal’s study (2006), aphasic patients displayed the ‘mysterious midline barrier’ when asked to reach for objects presented contralaterally (Bruner, 1969). These findings are similar to those found in studies from other domains that have reported ipsilateral biases in infants and in older children (Bruner, 1969; Morange & Bloch, 1996; van Hof, van der Kamp, & Savelbergh, 2002). This finding further suggests that ipsilateral biases of reaching may also be present on the A-not-B paradigm.

The Influence of Motor Constraints on Search Behaviour

After a comprehensive review of the A-not-B error and its influencing factors, it is clear that many studies focus on explaining what infants know about the hidden object and fewer studies focus on what infants do during the task. It is surprising that very little emphasis has been placed on the actual act of reaching, even though this motor process could
have a direct impact on infants’ search performance. Currently, the only works looking at what infants do during the A-not-B task are studies comparing looking and reaching versions, studies demonstrating the importance of motor histories, and the more recent studies focusing on presentation side biases. Even within these works, the focus has rarely been on the actual motor process of infant reaching and how it may influence performance on the A-not-B task. A systematic investigation looking at actual motor constraints of reaching is therefore warranted.

There are two motor constraints of reaching that may be particularly influential with respect to infants’ performance on the A-not-B task. These include 1) having to negotiate barriers in the path of one’s hand and 2) the influence of hand-use preferences. Both of these motor constraints have been shown to influence other manual actions, such as bimanual reaching (Goldfield & Michel, 1986) and general motor proficiency (Gabbard, Hart & Gentry, 1995). Accordingly, it is likely that these motor constraints of reaching will have similar effects on manual search performance on the A-not-B task. These two motor constraints of reaching are the focus of the current investigation, which is comprised of two experiments.
CHAPTER 2

Experiment 1: The Influence of Barriers on the A-not-B Search Task

Obstacles (also called barriers) can often prevent direct paths to objects. An opaque screen that prevents an infant from directly retrieving a hidden object is an example of an obstacle that modifies the motor aspect of reaching behaviour. This type of obstacle is often used to study detour ability and object retrieval more generally. An opaque screen can also occlude the sight of a hidden object, with no emphasis being placed on the motor aspect of the occluder. This conceptualization of an obstacle is often used in looking versions of the A-not-B task.

Several studies have examined the influence of a barrier on the A-not-B task (Baillargeon, 1987a; Bremner & Bryant, 1977; Bremner & Knowles, 1984; Butterworth, 1977; Diamond, 1985; Harris, 1974; Gratch, 1972; Piaget, 1952; Sophian & Yengo, 1985; Ugris & Hunt, 1975; Yates & Bremner, 1988); however, none of these studies have directly examined barriers as motor constraints of reaching. Instead, many of these studies used the presence of barriers as evidence that infants can hold object representations of non-visible targets, or that infants have moments of limited attention that lead to problems in locating the targets. Accordingly, in order to better understand infants’ ability to manually retrieve an object hidden by a physical barrier, it is important to review studies of object retrieval more generally.

To date, there have been numerous empirical studies on the effect of barriers on object retrieval (Bojczyk & Corbetta, 2004; Bower & Wishart, 1972; Diamond, 1990; Dunst, Brooks, & Doxsey 1982; Goubet & Clifton, 1998; Hood & Willatts, 1986; Matthews, Ellis, & Nelson, 1996; Munakata et al., 1997; Shinskey, 2002; Shinskey, Bogartz, & Poirier, 2000; Shinskey & Munakata, 2001) and infant reaching or detour ability (Goldfield & Michel, 1986;
Lockman, 1984; Lockman & Adams, 2001; Noland, 2008). Generally, these studies suggest that successful retrieval of an object hidden by a barrier is possible in infancy. Specifically, the findings conclude that by the end of their first year, infants can manually search for objects that are occluded by some type of barrier, and that the ability to manually search varies as a function of age and barrier type. For example, several studies have found that infants between 8- to 10-months of age can manually search for an object hidden by an occluder, such as objects hidden underneath a cloth or behind a screen (Piaget, 1952; Ugris & Hunt, 1975). Additional studies have found that infants can also successfully retrieve moving objects that are hidden by a barrier or by darkness (Berthier et al., 2001). However, younger infants (e.g., 6-months of age) have trouble reaching for an object when it moves behind an occluder (Munakata, Jonsson, von Hosfsten, & Spelke, 1996). These findings suggest that infants do not require constant visual information about a target’s position in order to enact a proficient reach towards a hidden object.

Successful object retrieval is also dependent upon the physical properties of the barrier. Transparency, for example, poses an interesting challenge to younger infants, as it may present a special spatial problem wherein infants need to first discover the properties of the barrier before they are able to be successful in retrieval tasks. Previous studies have shown that infants can retrieve hidden objects when transparent or opaque barriers are used as occluders (Diamond, 1990; Goldfield & Michel, 1986; Lockman, 1984; Lockman & Adams, 2001; Matthews et al., 1996; Noland 2008; Shinskey et al., 2000; Shinskey & Munakata, 2001), although infants are much more successful at retrieving an object when it is hidden by a transparent barrier than by an opaque one (Bower & Wishart, 1972; Gratch 1972; Munakata et al., 1997; Shinskey et al., 2000). Munakata et al. (1997) trained 7-month old infants to pull a towel (either transparent or opaque) in order to retrieve an object resting
on it. It was found that infants were more successful at object retrieval with a transparent towel than with an opaque towel, and these authors suggested that this finding challenges the notion that infants make search errors with hidden objects because of the inability to remove the barrier in order to get to the target object. Similarly, Shinskey (2000) used a search paradigm that equated motor demands (e.g., objects were hidden in milk or visible in water) and found that 6-month olds retrieved visible objects more often than those hidden in milk, even though their reaching was unobstructed in both cases (Shinskey, 2000). Taken together, both of these results provide support for the transparent advantage in object retrieval contexts.

There are several suggestions as to why success on object retrieval tasks varies as a function of barrier transparency. It has been proposed that retrieving objects from transparent barriers may require more working memory to represent the transparent barrier (Lockman & Adams, 2001) or the need to detour around it (Diamond, 1990). Transparent barriers may also require more response inhibition to suppress the tendency to reach directly for a visible object (Diamond, 1990). It has also been suggested that transparent barriers can be overlooked by infants simply because they are see-through (Spelke, 1998). Infants can, thus, mistakenly knock over a barrier and retrieve the target object. Finally, the ‘wall alternative’ suggests that infants fail to retrieve toys from behind opaque barriers because they mistake the barrier for a solid wall. That is, infants know the toy is behind the wall but they decide that the toy cannot penetrate the wall and so they do not reach for it (Baillagareon, 1993).

To test some of these explanations of the transparent advantage, Shinskey and Munakata (2001) examined the ability to retrieve a toy (or no toy) from behind a screen that was either transparent or opaque. These authors measured how often infants pulled down the
screen to retrieve the toy in each condition. This method ensured that the motor demands were equated for each barrier type. The results revealed that 7-month old infants pulled down the transparent screen more often than the opaque screen in an attempt to retrieve the toy (63% of the time versus 45%, respectively). Moreover, infants frequently made direct reaches on transparent trials as if they were trying to reach through the barrier, a finding corroborated by Lockman and Adams (2001). To address any concerns that retrieval was accidentally occurring, trials in which infants made direct reaches were removed from the analysis. Shinskey and Munakata found that infants continued to pull down the transparent screen more often than the opaque one, again confirming that reaches on these trials were not accidental and that transparent trials were not somehow easier for infants to manipulate.

These authors suggested that failure to retrieve the toy when a barrier is present is not solely due to means-end deficiencies, nor is it due to ignoring the barrier when it is transparent. Instead, it is likely that for 7-month old infants, the transparent advantage occurs because at this age infants have difficulty representing objects behind an opaque barrier.

Naturally, there are also cases where infants are unsuccessful at retrieving a hidden object. In these cases, a motoric rather than a cognitive limitation is often used to explain their unsuccessful performance. In fact, the notion that younger infants do not possess the motor skill necessary to remove the occluder in order to search for the hidden object has been studied in the object search literature and with the A-not-B paradigm more specifically (Baillargeon et al., 1990; Bower & Wishart, 1972; Bruner 1970; Diamond, 1991; Munakata et al., 1997; Ramsay & Weber, 1986; Shinskey, 2000; Shinskey & Munakata, 2001).

However, this motoric limitation (also referred to as the means-end deficiency) is no longer believed to be a likely explanation for infants’ performance on the A-not-B task, as infants can successfully reach for hidden objects concealed by darkness and can reach for hidden
objects in the dark before they can reach for hidden objects concealed by a barrier in the light (Clifton, Rochat, Litovsky, & Perris, 1991; Hood & Willatts, 1986).

Overall, the effect of barriers has been thoroughly investigated in various areas of infant development, including object search. Infants have the motor skills needed to successfully retrieve objects that are hidden by barriers and barrier transparency influences object retrieval. Looking versions of the A-not-B task using barriers to block the sight of the object demonstrate that infants understand that objects continue to exist even in this context. What is less clear within the object search literature is how a barrier physically affects manual search performance on the A-not-B task specifically. Studies show that other motor constraints on reaching, such as a change in infants’ posture (Smith et al., 1999) and a change in their arm weight (Diedrich et al., 1999) on B trials facilitates manual search performance on the A-not-B task. Accordingly, in this investigation a barrier is not only just a visual occluder of a hidden object; it is also conceptualized as a motor constraint of infant reaching. This motor constraint is one that infants must learn to navigate in order to execute a successful search.

Rationale

An examination of barriers as motor constraints of reaching is important with respect to the A-not-B literature. If the A-not-B task is truly a reaching task, then it is important to empirically test motor aspects (i.e., the presence of barriers) that may potentially influence infants’ performance. Theoretically, an investigation of barriers is of interest because it has specific implications for the motor memories for reaching approach about why infants make the A-not-B error. The rationale of this experiment was fairly straightforward. If the placement of a barrier on A trials influences infants’ reaching behaviour such that on these initial trials the barrier leads to the formation of a particular motor memory for reaching, then
on the B trial when no barrier is blocking their reaching path, infants should not have any
motor memories for reaching because this is now a novel situation. As a result, there should
be a reduction in the occurrence of the A-not-B error, which would support the role of motor
memories as being important to the production of the error in the A-not-B paradigm.

Goals and Hypotheses

The primary goal of this experiment was to investigate whether or not the presence of
a barrier influences A-not-B performance. Of interest was whether or not there are age
differences associated with this relationship, specifically between 8- and 16-month old
infants. Inquiry about the age effect stemmed from studies showing that younger infants
have more difficulty retrieving an object hidden by a barrier than do older infants (for one
example see Shinskey & Munakata, 2001).

Based on previous studies that have used barriers, it was believed that the presence of
a barrier in the path of the infant’s hand played some role in infants’ manual search ability.
Specifically, it was hypothesized that older infants would be better than younger infants at
manually searching for the toy at A when a barrier was present. It was also hypothesized that
when a barrier was placed in front of the A location on A trials, but omitted on the B trial,
infants would make fewer A-not-B errors.

Method

Participants

Twenty 8-month old infants \( (M = 34.9\) weeks, \( SD = 1.81\) ) and 20 16-month old
infants \( (M = 68.9\) weeks, \( SD = 1.52\) ) participated in this study. Sixteen additional 8-month
old infants were tested but were not included in the final analysis because of failure to
complete the study (8), experimental error (7), and no data recorded (1). Usable infants were
full-term and did not have any developmental disabilities, all were recruited from the Greater
Toronto Area with parents first contacted by letter and then by telephone. All sessions took place at the Laboratory for Infant Studies at the University of Toronto Scarborough. Infants received a small toy and a certificate of participation.

**Tasks and Materials**

**Manual search task.** The task was a modified version of the A-not-B task in which a toy (i.e., a small rattle) was hidden in one of two identical locations and then an infant was encouraged to search for it. In the current study, the identical locations (also referred to as the A location and/or the B location) were upright cups (6” tall) that served as wells, and the distance between these two locations was 27.9 cm. The locations were affixed to a board (26.5” long x 15.5” wide) using Velcro strips such that they could easily be removed between trials. The board was also free to move and could easily be pushed across the table. On some trials an opaque barrier (6” tall x 7” wide) was placed directly in front of the A location. This barrier was attached to the board by sliding it into a groove located on the front of the board.

**Testing room and recording equipment.** Infants were tested in a curtained room (85” long x 87” wide) containing a small table and a chair. Movements were recorded using a SONY video camera, which was visible only through an opening in the curtain. The camera faced the entire testing area such that it recorded all hand movements.

**Conditions**

There were two conditions in the search task: the barrier condition and the no barrier condition. Condition was a within-subjects factor in this investigation, and was counterbalanced such that half of the infants received the barrier condition first, and the other half received the no barrier condition first. In both conditions, the left-right location of A was also counterbalanced across infants.
As depicted in Figure 1, the manipulation of the barrier occurred during A trials only. In the barrier condition, a toy was hidden at location A and then an opaque barrier was placed in front of location A. In the no barrier condition, a toy was hidden at location A, but no barrier was placed in front of location A. For both conditions, the toy was simply hidden at location B during the B trial.

![Figure 1](image)

**Figure 1.** Schematic drawing of the experimental conditions. *In the barrier condition, the toy (denoted by T) is hidden at the A location and then a barrier is placed in front of that location. In the no barrier condition, the toy is hidden at the A location. On the B trial (for both conditions), the toy is hidden in the other location.*

**Procedure**

Upon arriving at the laboratory parents were instructed about the task and asked to sign a consent form. During this time, infants were acclimated to the experimenter. In the curtained room, infants sat on their parent’s lap such that their arms could easily extend across a table on which the stimulus materials were presented. The experimenter sat across from the infant and parent. The parent was instructed to not influence or talk to the infant.

Each session began with a training phase (adapted from Bai & Bertenthal, 1992). The experimenter cued the infant by shaking the toy, or tapping it on the table. Once the infant
was attending to the toy, the training phase began. In the first training step, the toy was placed at the edge of a board which was pushed by the experimenter to within reach of the infant. The experimenter waited for the infant to show interest and to reach for the toy. In the second training step, the experimenter introduced a single hiding location at the infant’s midline. The experimenter placed the toy into the hiding location so that it was partially hidden, and then pushed the board closer to the infant. In the final training step, the toy was completely hidden, and the board was pushed closer to the infant. On all training steps, the infant was given 5s to find the toy. If the infant did not successfully find, or reach for, the toy in the allotted time, the experimenter directed the infant’s attention to where it was located and continued.

The training phase was followed by the experimental phase. In the experimental phase, the infant was cued in the same way as in the training phase. Once attending to the toy, the experimenter hid the toy at location A and a delay (3s for 8-month olds and 10s for 16 month olds, based on Diamond, 1985) was imposed. The experimenter then moved the board into the infant’s reaching space. This hide and retrieve sequence was repeated until 5 correct searches at A (or up to 10 trials) was achieved. The toy was then hidden once in location B and, after the same delay, the infant was encouraged to search. Each infant completed both the barrier and no barrier conditions.

**Data Coding**

A coder recorded infants’ search behaviour on A and B trials from a monitor outside of the curtained room. For all trials, the coder determined which location was first contacted by the infant; this response was deemed as the infants’ search response. For A trials, search at the A location was coded as correct (1), whereas search at the B location, or at both locations simultaneously, was coded as incorrect (0). A percent correct search score on A
trials was then calculated by dividing the number of correct searches at A by the total number of A trials received. For B trials, search at the B location was coded as correct (1), whereas search at the A location, or at both locations simultaneously, was coded as incorrect (0), indicating that the A-not-B error had occurred.

**Reliability**

Reliability assessments were conducted on whether or not coders agreed on infants search behaviour for both A and B trials. Reliability was conducted for the entire sample using a second blind coder; intercoder percent agreement was 100%.

**Results**

A series of analyses were conducted to investigate the effect of a barrier on the A-not-B task. First, infants’ search behaviour on both A and B trials were analyzed. Second, the idea that search errors are due to motor habits was analyzed using two aspects of motor habit formation: motor history and number of A trials received. Third, infants’ reaching behaviour was analyzed to verify that the presence of a barrier did in fact change the motor demands of the A-not-B task, particularly on A trials.

**Search Behaviour**

**A trial performance.** In keeping with more recent object search studies (Diedrich et al., 2001; Longo & Bertenthal; 2006; Marcovitch et al., 2002), A trial performance was examined on its own. The analysis of A trial performance is important due to the nature of this experiment, which investigates the influence of placing a motor constraint in front of location A in hopes of creating a certain motor habit when reaching at A on the task. A Mixed-Model ANOVA was conducted to evaluate the effects of hiding side, order of conditions, condition, and age on percent correct search on A trials. The within-subjects variable was condition (no barrier, barrier) and the between-subjects variables were: hiding
side (right, left), order of conditions (no barrier first, barrier first), and age (8-month, 16-months).

The analysis revealed no significant main effects of hiding side, $F(1, 32) = 2.07, ns$, or order of conditions, $F(1, 32) = 0.01, ns$. There was no mean difference in A trial performance when hiding side was on the right side ($M = .70, SD = .30$) compared to the left side ($M = .60, SD = .30$), nor was there a difference in A trial performance for those receiving the no barrier condition first ($M = .66, SD = .30$) compared to those receiving the barrier condition first ($M = .65, SD = .30$). There were, however, significant main effects of condition, $F(1, 32) = 20.73, p < .001, \eta_p^2 = .39$, and of age, $F(1, 32) = 19.92, p < .001, \eta_p^2 = .38$. Infants searched correctly on A trials more often in the no barrier condition ($M = .79, SD = .27$) than in the barrier condition ($M = .51, SD = .30$), and older infants searched correctly on A trials more often ($M = .80, SD = .30$) than younger infants ($M = .50, SD = .30$).

A significant interaction between age and order of conditions was also found, $F(1,32) = 9.21, p =.01, \eta_p^2 = .22$. Follow-up analyses revealed that there was a significant difference between 8- and 16-month olds who received the barrier condition first, with 16-month olds ($M = .90, SD = .11$) searching correctly on A trials more than 8-month olds ($M = .40, SD = .24), t(18) = -5.93, p < .001$. However, no significant difference was found between 8-month olds ($M = .61, SD = .21$) and 16-month olds ($M = .70, SD = .25$) in the no barrier condition, $t(18) = -0.91, ns$. Given these results, all subsequent analyses collapse across hiding side and order of conditions. None of the remaining interactions were significant, all $ps > .05$, including the interaction between condition and age, $F(1, 32) = 2.31, ns$, (see Figure 2).
An additional analysis was conducted on A trial performance because some infants only had 5 A trials (i.e., they reached the criterion) while others had up to 10 A trials (whichever came first). As a result, to test whether or not the overall number of A trials received varied as a function of condition and age, a Mixed-Model ANOVA was conducted on the number of A trials being the dependent variable. The analysis revealed a main effect of condition, $F(1,38) = 19.44, p < .001, \eta_p^2 = .34$, with a higher average number of A trials in the barrier condition ($M = 8.1, SD = 2.1$) than in the no barrier condition ($M = 6.4, SD = 2.0$), and a main effect of age, $F(1, 38) = 12.33, p = .001, \eta_p^2 = .25$, with younger infants ($M = 8.1, SD = 1.9$) having, on average, more A trials than older infants ($M = 6.5, SD = 1.8$). Also
of interest was the interaction between these two factors, which was not significant, $F(1,38) = 1.08, ns$ (see Figure 3).

**Figure 3.** *Mean Number of A trials as a Function of Condition and Age Group.*

**B trial performance.** A Mixed-Model ANOVA with the factors of condition and age was used to examine the B trial performance. The analysis revealed no main effect of condition, $F(1,38) = 0.95, ns$, with no mean difference in percent of perseverative errors between the no barrier condition ($M = .50, SD = .44$) and the barrier condition ($M = .40, SD = .51$). There was a significant main effect of age, $F(1, 38) = 7.60, p < .01, \eta_p^2 = .17$, with the younger infants ($M = .60, SD = .48$) making more perseverative errors on the B trial than the older infants ($M = .30, SD = .47$). There was also a marginally significant interaction between condition and age, $F(1, 38) = 3.80, p = .06, \eta_p^2 = .09$ (see Figure 4).
Subsequent analyses were conducted to explore the interaction between condition and age. A $t$-test revealed that 8 month olds made more perseverative errors in the no barrier condition ($M = .75, SD = .44$) than in the barrier condition ($M = .45, SD = .51$), $t(19) = 2.04$, $p = .05$. For 16-month olds however, the difference between the barrier ($M = .35, SD = .49$) and no barrier ($M = .25, SD = .44$) conditions was not significant, $t(19) = -0.70$, $ns$.

Comparisons between the age groups revealed that in the no barrier condition, more errors on the B trial were made by 8-month olds than 16-month olds, $t(38) = 3.56$, $p = .001$. In the barrier condition however, the difference in error production between 8-month olds and 16-month olds was not significant, $t(38) = 0.63$, $ns$.

![Figure 4. Percent of Perseverative Error on the B trial as a Function of Condition and Age.](image-url)
**Motor History**

The first way to look at the impact of the number of A trials on perseveration in the A-not-B task is to examine perseveration as a function of the motor history of reaching on the A-not-B task. In this experiment, motor history was measured using an adapted version of Diedrich et al.’s (2000) cumulative index of relative memory strength (RMS). The RMS index provides a combined cumulative record of reaching to both A and B locations, which can be advantageous over simply knowing the number of reaches to A only. The index is calculated at the end of each trial as the cumulative memory strength of past reaches to A minus the cumulative memory strength of past reaches to B. For example, if an infants’ reaching pattern over 5 A trials is ABAAA then their memory of reaches to A is: 1,1, 2, 3,4. Their memory of reaches to B over these same 5 trials is: 0, 1,1,1,1. The resulting RMS score would be calculated as cumulative reaches to A minus cumulative reaches to B, or in this case 3 (4 A reaches – 1 B reach), which signifies that the infant has a 0.6 (or 60%, 3 out of 5 reaches) motor history for reaching to A. This is different, and much more accurate, than if one were to look at the number of reaches to A, in which case the ‘motor history’ would be overestimated at 80% (4 out of the 5 reaches were to the A location). Thus, RMS scores range from +1.00 (maximum cumulative memory strength for reaches to A) to -1.00 (maximum cumulative reaches to B), with a zero score denoting either a beginning point when there is no memory for either location, or because there has been an equal number of reaches to both the A and B locations. An RMS score was calculated for each infant for each condition.

To evaluate the effects of condition (within-subjects factor) and age (between subjects factor) on RMS, a Mixed-Model ANOVA was conducted. The analysis revealed a main effect of condition, $F(1, 38) = 15.97, p < .001, \eta^2_p = .30$, with higher RMS scores for
the no barrier condition ($M = .58, SD = .62$) than the barrier condition ($M = .05, SD = .76$).

There was also a main effect of age, $F(1, 38) = 5.54, p = .02, \eta_p^2 = .13$, with higher RMS scores for the older infants ($M = .51, SD = .61$) than the younger infants ($M = .12, SD = .70$). The interaction between the two factors was not significant, $F(1, 38) = 0.12, ns$ (see Figure 5).

![Figure 5](image)

**Figure 5.** Relative Memory Strength for Reaching to A as a Function of Condition and Age.

To evaluate the hypothesis that infants would perseverate more on the B trial if they had a strong reaching history to A, as measured by the RMS score, as opposed to a weak reaching history to A, RMS scores were compared for infants who perseverated on the B trial versus infants who did not perseverate. These analyses were done separately for the barrier
and no barrier conditions and were collapsed across age groups because there were unequal numbers of infants who perseverated or did not perseverate at each age. For the no barrier condition, the independent-samples $t$-test was not significant, $t(38) = -1.15, ns$. As shown in Figure 6a, infants who perseverated did not have stronger reaching histories to A than those who did not perseverate. Similar results were found for the barrier condition, $t(38) = 0.82, ns$. As shown in Figure 6b, infants who perseverated did not have significantly stronger reaching histories to A than those who did not perseverate, although it was in the anticipated direction.

![Figure 6](image)

Figure 6. **Relative Memory Strength for Reaching to A as a Function of B trial Performance in the (a) No Barrier condition, and (b) Barrier condition.**
Number of A trials

A second way to look at the impact of the number of A trials on perseveration in the A-not-B task is to examine perseveration as a function of the overall number of A trials given to infants. In this experiment, infants were grouped based on the overall number of A trials that they received (i.e., 5 trials and more than 5 trials). In order to evaluate the relation between the number of A trials received and those who perseverated, Crosstab analyses were conducted separately for each condition and were collapsed across age groups. The analyses revealed no relationship between those who perseverated and the number of A trials received in the no barrier condition, Pearson $\chi^2 (1, N = 40) = 0.42, ns$, or in the barrier condition, Pearson $\chi^2 (1, N = 40) = 0.03, ns$. As shown in Figure 7a and 7b, the proportion of perseverators did not differ from the proportion of non-perseverators who received 5 A trials, nor was there a difference in the proportion of perseverators who received more than 5 trials compared to the proportion of non-perseverators who received more than 5 trials; this was true of both conditions.
Figure 7.  *Proportion of Infants who did or did not Perseverate on B as a Function of the Number of A Trials Received in (a) the No Barrier Condition and (b) the Barrier Condition*

One caveat to this analysis is that the number of A trials received overall represents the total number of A trials given to each infant, rather than the actual number of *correct searches* at A. For example, infants receiving 10 A trials did not necessarily get 5 correct searches at A whereas those receiving only 5 A trials always got 5 correct searches. Accordingly, it may be that the number of correct searches is a better indicator of motor history than the number of A trials overall. To test whether or not there was a relationship between the total number of A trials and the number of correct searches, correlations were conducted separately for each condition. The correlation between the total number of A trials and the number of correct searches in the no barrier condition was significant, $r(38) = -.74$, $p < .001$. The correlation was also significant between these two factors in the barrier
condition, \( r(38) = -.86, p < .001 \). These results suggest that the total number of A trials received and the number of correct searches are generally comparable.

**Reaching Behaviour**

As a final analysis, it is important to verify that the principal manipulation (i.e., the presence of a barrier in front of the A location) did in fact change the physical motor demands of the object retrieval task. To test this idea, infants’ actual reaching behaviour on both A and B trials was examined.

**Barrier Condition.** To be included in this analysis, infants needed to have had at least one occurrence of a correct search at A (i.e., reaching to the A location when the barrier was present); this requirement resulted in a sample of 33 infants. For A trials, reaching behaviours were classified as straight reaches (i.e., pushing the barrier to the side then reaching straight) or non-straight reaches (i.e., reaching around the barrier, reaching over the barrier, or reaching around the barrier with one hand and over the barrier with the other). B trials were also classified as either straight or non-straight reaches.

For each age group, a paired samples \( t \)-test was conducted to evaluate whether infants produced straight or non-straight reaches on A trials. Eight-month olds \((n = 14)\) produced significantly more non-straight reaches on A trials \((M = .75, SD = .42)\) than straight reaches \((M = .25, SD = .42), t(13) = -2.23, p = .04\). Similarly, 16- month-olds \((n = 19)\) produced significantly more non-straight reaches on A trials \((M = .95, SD = .13)\) than straight reaches \((M = .05, SD = .13), t(18) = -14.92, p < .001\). In contrast, all 32 infants (there was missing data for 1 infant) produced only straight reaches on the B trial.

**No Barrier Condition.** All infants used a straight reach on both A and B trials.
Discussion

This experiment examined whether or not the presence of a barrier influenced A-not-B search performance. Placing a barrier in front of the A location created a certain type of reaching behaviour on A trials, which was then altered by removing the barrier on B trials. This situation enabled an assessment of the impact of changing actual reaching behaviour on perseveration, which, ultimately, helped to test the motor memory account of the A-not-B error. Overall, this experiment uncovered a number of findings about A-not-B behaviour.

With respect to A trial performance, first, and not surprisingly, the presence of a physical barrier led to significantly fewer correct searches on A trials compared to when no barrier was present on these trials. Second, older infants performed better on A trials overall than younger infants. Third, the number of A trials needed to reach the criterion was affected by age and the presence of a barrier, with more A trials to reach criterion needed for the younger age group and when reaching around a barrier.

The findings on A trial performance suggest that changing the motor actions required for search on A trials (i.e., the presence of a barrier) may have interfered with the creation of typical motor memories for reaching to the A location. That is, the barrier may have interfered with infants’ motor memories of successful object retrieval of the hidden object. With the barrier blocking the A location, infants could not always make the same motor action on A trials. As a result, infants did not receive repetitive feedback about the outcome of their movements, and so they were unable to create strong motor memories about successful search at A. Without this feedback, infants could not learn the association between their reaching movements and the outcome (e.g., finding the toy at the A location). This learning process was thus disrupted by the presence of a barrier. Nevertheless, the presence of a barrier could have led to specific motor memories for reaching to the A
location more generally. That is, it is still possible that the barrier influenced infants motor memories for reaching, as infants often touched the barrier trying to figure out a way around it in order to get the toy. Even in the case of unsuccessful search on A trials, infants still interacted with the barrier in a way that that motor response could have been stored as part of their motor memory of their performance on A trials.

Moreover, it was assumed that the increased number of A trials (between 5 and 10 overall) would produce a reasonably strong, and specific, motor memory for reaching to A, based on the finding of Marcovitch et al. (2002). However, this was not the case in the present experiment. That younger infants needed many more A trials (e.g., more than 5 but up to 10) in the barrier condition compared to the no barrier condition provides additional support for the idea that the presence of a barrier interfered with the creation of motor memories for reaching to the A location. Put another way, an increased number of A trials in the barrier condition was not strengthening a specific motor memory for reaching to A but rather this increase in A trials was necessary because infants were not searching correctly on A trials to begin with, and so they received many more A trials as a way to give them an opportunity to develop a motor memory for correctly searching at the A location.

A number of findings about B trial performance were also observed. First, 8-month olds showed more perseveration than 16-month olds; this is a typical pattern of search behaviour on the A-not-B task (Butterworth, 1975; Diamond, 1985; Munakata, 1997; Piaget, 1954; Wellman et al., 1987). Second, and most importantly, 8-month olds had greater perseveration in the no barrier condition relative to the barrier condition, whereas the 16-month olds performed equivalently across the two conditions.

This latter finding suggests that for 8-month olds, but not for 16-month olds, performance on the B trial was affected by a motor memory for reaching. Namely, when
infants changed their motor behaviour responses from A to B trials, search performance improved for the younger infants, but stayed the same for the older infants. It is likely that the presence of a barrier on A trials allowed younger infants to build a motor memory that included the feel of their arms and hands as they touched the barrier and tried to manipulate it in order to retrieve the hidden toy at the A location. Then on the B trial, younger infants did not rely on any previous motor memories, as it was now a novel situation. Instead, younger infants used the immediate input rather than their past motor memories for reaching. This finding demonstrates that as a motor constraint on reaching, barriers affect the motor processes that are used when an infant is searching on the A-not-B task. It also provides strong evidence for the role of motor memory on the A-not-B task using an opaque barrier because when the motor movement requirements were changed from A to B trials, younger infants perseverated less often.

Additional analyses were conducted on infants’ motor histories for reaching using two quantitative measures, namely RMS scores and the overall number of A trials. These analyses revealed lower RMS scores in the barrier condition and for younger infants. This is not a surprising result given that infants could have made several different types of reaches during the A trials, and so they could have had weaker reaching histories to the A location. What is more surprising is that the production of the A-not-B error was unrelated to measures of motor history in both conditions. That is, infants who had stronger motor histories for reaching to A were not more likely to perseverate on the B trial. This result could be explained by several factors. First, there was not enough variability between those who were considered to have strong motor histories for reaching to A and those who were considered to have weaker motor histories for reaching to A. Therefore, no statistical difference would be found. Second, the motor histories that were created on A trials were not strong enough for
infants to firmly establish a solid motor memory for reaching to the A location specifically. This is a more likely reason given that weaker motor memories for reaching were found in the barrier condition, which was intended to create a certain type of reach that included the barrier.

Subsequent reaching analyses confirmed that the presence of a barrier did in fact change the physical motor demands of the task across trials. In the barrier condition, non-straight reaches were used by both age groups on A trials but straight reaches were used on the B trial. In contrast, in the no barrier condition, straight reaches were used by both age groups on A and B trials. These findings demonstrate that reaching movements are directly affected by the presence of an opaque barrier. In this case, infants could have used more than one type of reaching action to retrieve an object at the A location when a barrier is present (e.g., reaching around the barrier and reaching over the barrier are all considered non-straight reaches), but generally infants only used one type of reaching movement to retrieve an object at the B location, one that differed from the movement used to previously retrieve an object. Overall, these analyses support that reaching movements differed across each condition and each trial type, as was assumed.

Taken together, these findings highlight the idea that motor memories for reaching to the A location, at least in terms of repetitive physical action, plays a role on the production of the A-not-B error. In addition, motor memories for reaching to the A location seem have much more of an influence on younger children than older children, and seem to be weaker when a barrier is used compared to when no barrier is used on A trials. Barriers that block the path of the hands (and the target location) are thus one type of motor constraint on reaching that significantly affects infants’ A-not-B task performance. Barriers alter what infants do on the A-not-B task implying that motor constraints that influence motor processes
such as reaching are an influential factor for the production of A-not-B errors and on manual search performance, more generally.
CHAPTER 3

Experiment 2: The Influence of Hand-Use Preferences on the A-not-B Search Task

The second motor constraint on reaching that was explored is that of handedness. Handedness is an integral component in the programming of any goal-directed reaching action, yet it has rarely been examined in relation to the A-not-B task (Burdukova & Stroganova, 2008). Although seemingly straightforward, handedness has been defined in several ways. The more traditional and ubiquitous definition defines handedness in terms of the writing hand, even though people may have a different preferred hand for other activities such as eating or tool use (Dahmen & Fagard, 2005; Mamalo, Roy, Bryden, & Rohr, 2004). Researchers, however, often define handedness as either a preference or a skill. For instance, handedness can characterize someone’s preferential usage during manual activities (Roy, Bryden, & Cavill, 2003) or it can be defined as the hand that moves faster and more precisely during manual tasks (Annett, 1985; Bishop, 1989).

In some ways, there may be more to the distinction between preference and skill than a simple difference in definition. There now exists a number of studies demonstrating that preference and skill have only a modest correlation, each having its own population distribution. Therefore, preference and skill may be fundamentally different concepts (Porac & Coren, 1981; Triggs, Calvanio, Levine, Heaton, & Heilman, 2000). However, mathematical modeling has shown that different aspects of motor skill (i.e., speed or strength) may have differential importance in determining hand preference for different manual tasks (Bishop, 1989), suggesting a convergence between the preference and skill conceptualizations of handedness.

1 Several terms are used interchangeably in the handedness literature, including manual or hand-use preference, limb or motor dominance, and lateral dominance.
Currently, hand-use preference is classified as either dichotomous (i.e., left- or right-handed) or trichotomous (i.e., left-, right-, or mixed-handed). The mixed-handed category acknowledges the idea that strength is an important aspect of hand preference and that individuals without a definite hand preference should be recognized as a separate group (Swanson, Kinsbourn & Horn, 1980). Several studies on handedness (Gabbard et al., 1995; Gabbard, Hart, & Kanipe, 1993; Kaufman, Zalma, & Kaufman, 1978; Tan, 1985) support using the trichotomous system with younger children as well, as notable differences in motor coordination have been found between handedness groups.

Theoretical Perspectives

There are several theoretical perspectives for the development of hand preference including biological, environmental, and experiential theories. One of the most influential biological theories is Annett’s (1985) right shift theory, which assumes that handedness is a quantitative trait that depends on a single autosomal gene that has two ‘right shift’ alleles (i.e., rs- and rs+). People can have a strong bias for right-handedness (rs++), a moderate bias to right-handedness (rs+-), or a bias to either side (rs- -). Several studies have supported Annett’s right shift theory (Geschwind et al. 2002; Michel et al. 2002). Another idea grounded in biology is the fact that each side of the brain controls movement on the other side of the body (Josse & Tzourio-Mazoyer, 2004). A study on the functional asymmetries of the primary motor cortex revealed that the area of representation is larger in the dominant hemisphere, which for most individuals is the left hemisphere controlling the right hand (Hammond, 2002).

There are also a number of environmental theories of hand preference that are rooted in social influence. According to Hildreth (1949), “right-handedness is a cultural and [a] social convention to which most people are trained or find it expedient to conform” (p.206).
A similar theory known as the right-handed world hypothesis emphasizes religious ceremonies, military training, and familial pressure that favour the right hand (Porac & Coren, 1981).

Other environmentally-based theories are rooted in early perceptual-motor experiences. The modified progressive lateralized theory, for example, postulates that hand-use preferences are gradually shaped as a function of practice and experience (Provins, 1997). Hand preference for grasping develops from a series of earlier lateral experiences such as neonatal rightward biases for supine head orientation. In essence, turning to the right leads to greater amounts of right-hand hand/arm movements, which in turn creates more visual and proprioceptive feedback. Consequently, infants develop a grasping preference for that hand.

There are also theories of hand-use preference which suggest that both biological and environmental factors are important. One rather simple combination theory suggests hand preference is perhaps not a fixed trait but rather a flexible behaviour (Gabbard & Helbig, 2004). Accordingly, innate motor dominance is responsible for programming and executing reaches in most cases, but hand preference can also be modified by attentional information derived from particular task demands, such as object proximity, hemispheric biases, or comfort (Gabbard et al., 1997, 2001).

According to the object proximity explanation, programming which hand to use during a reaching task involves spatial reasoning based on proximity between the closest hand and the object. In ipsilateral space, infants use their preferred hand to reach for an object. However, in contralateral space, object proximity would essentially ‘override’ the motor dominance factor of which hand is used (Gabbard et al., 2003).
Similarly, the idea of hemispheric biases suggests that there is a bias favouring the use of the hand on the same side as the stimulus (Helbig & Gabbard, 2004). As such, placement of the object will strongly influence which hand is used to perform the reach (Harris & Carlson, 1993). Such predispositions are conceptually akin to the notion of ipsilateral biases found in reaching behaviours of children and adults (Bruner, 1969; Morange & Bloch, 1996; van Hof et al., 2002).

A contrasting idea used to explain manual preference is the comfort hypothesis, which suggests that reaching movements are driven mainly by postural dynamics. According to this hypothesis, reaches are made in the most efficient and comfortable manner possible such that single degrees of freedom (df) - reaches (e.g., the hand, forearm and upper arm act as one functional unit) rather than multiple df-reaches (e.g., like a single df-reach but additional body parts like leaning forward or twisting the shoulders are introduced) prevail (Carello et al., 1989; Marks et al., 1997).

Finally, the dynamic systems account is another combination theory that argues that handedness develops as a result of interacting reorganizations between many biological, environmental, and experiential factors that change and develop with age (Corbetta & Thelen, 2002; Thelen & Smith, 1994). As such, handedness may reorganize itself several times during the first year. For instance, an infant can show a right-handed bias after a few months of reaching and then change to a bimanual pattern around 13-months when learning independent locomotive action (Corbetta & Thelen, 2002).

**Hand-Use Preferences in Adults and Children**

To date, hand-use preference of adults and children has been examined across a variety of manual domains, including reaching and grasping (Bryden & Kay, 2002; Bryden & Roy, 2006; Fagard & Lockman, 2005; Gabbard & Helbig, 2004; Hinojosa, Sheu, &
Michel, 2003; Leconte & Fagard, 2004, 2006; Michel, Ovrut, & Harkins, 1985), bimanual coordination (Franz, Rowse, & Ballantine, 2002; Pellegrini, Andrade, & Teixeira, 2004; Ramsay, Campos, & Fenson, 1979; Ramsay & Weber, 1986), and of course, writing and drawing (Hugdahl, Zaucha, Satz, Mitrushina, & Miller, 1996). Studies of adult hand preference have reported that over 90% of adults are right-handed (Coren 1993; Coren & Porac, 1977) and that adults use their preferred hand the most when asked to do things simultaneously (Bryden & Kay, 2001).

For children, it is generally accepted that hand-use preference is established by 3 or 4 years of age (Corbetta & Thelen, 1999; De Agostini et al., 1992; McManus et al., 1988). While the incidence of right-handedness in children is similar to that of adults in that the majority are right-handed, children also tend to show more mixed-handed preferences. In a sample of 512 four-year olds, Tan (1985) observed that 87.5% of the children were right-handed, 8% were left-handed, and 4.5% were mixed-handed. Children with a consistent hand-use preference also tend to be motorically superior (i.e., have better motor coordination) relative to those with an inconsistent preference (Gabbard et al., 1995; Gottfried & Bathurst, 1983; Kaufman et al., 1978), with consistent right-handers outperforming those with an inconsistent preference on both gross and fine motor activities (Gabbard et al., 1995).

Factors that Influence the Expression of Hand-Use Preference

There are a number of factors that influence the expression of manual preferences, including the skill level of the manual activity, task complexity, and spatial location of the target object. Research by Steenhuis and Bryden (1989) demonstrated that adults used their preferred hand for skilled activities (e.g., writing) and their non-preferred hand for unskilled activities (e.g., petting an animal). Adults also performed better with their preferred hand
when engaging in skilled activities, but they performed equally well with the two hands when engaging in unskilled activities.

One aspect of skilled activity that moderates hand-use preference is task complexity (Bryden 1999; Bryden & Roy, 1999; 2006; Leconte & Fagard, 2004; Mamolo et al., 2004; Pryde, Bryden, & Roy, 2000; Steingrueber, 1975). Mamolo et al. (2004) reported that adults used their preferred hand more often as skill demands of the task increased (e.g., simply picking up a tool versus pantomiming using a tool). Likewise, Bryden (1999) found that adults used their preferred hand most often when the dexterity required for the task increased (e.g., when object size was made larger). Other studies (Bryden & Roy, 1999; Gabbard et al., 2003; Geerts, Einspieler, Dibiasi, Garzarolli & Bos, 2003) have found that tasks requiring greater spatial precision (e.g., placing pegs in a pegboard) resulted in greater timing differences between the hands, with the preferred hand performing faster and being used more often than the non-preferred hand. Gabbard et al.’s (2003) study, however, suggested that other aspects of task complexity such as deeper thought processing (and not spatial precision) may account for such changes in adult hand preference. Nevertheless, these findings demonstrate that task complexity moderates the expression of adult hand preference.

The effect of task complexity on children’s hand-use preference is less clear. There are inconsistent findings among the few studies on this topic (Leconte & Fagard 2004; 2006; Pryde et al., 2000; Steingrueber, 1975). For instance, one study found no effect of task complexity on hand-use preference in children aged 3 to 10 years (Pryde et al., 2000), whereas another study found that as task complexity increased, the use of the non-preferred hand decreased in children aged 3 to 4 years (Steingrueber, 1975). These findings seem to suggest that manual dominance for children may be task-dependent.
Spatial location of the target object has also been shown to influence adult hand preference (Bryden & Roy, 2006; Gabbard & Helbig, 2004; Gabbard & Rabb, 2001; Gabbard, Helbig, & Gentry, 2001; Gabbard, Iteya, & Rabb, 1997; Gabbard et al., 2003). For example, when objects are located ipsilateral to the preferred hand, adults often used the preferred hand to reach for the object (Bryden & Roy, 2006; Gabbard et al., 2003). However, when objects are located contralateral to the preferred hand some studies have reported that adults used the preferred hand to reach for an object, that is, they crossed the midline barrier (Bryden, Roy & Mamalo, 2003; Mamalo et al., 2004), whereas other studies have reported that adults used the non-preferred hand more often (Bryden & Roy, 2006; Gabbard et al., 1997; 2001; Helbig & Gabbard, 2004). Bryden and Roy (2006) suggested that adults are using a more cost-effective strategy, one in which they recognize that the non-preferred hand can move more precisely than the preferred hand in contralateral space. Overall, these results further indicate that, for adults, motor dominance may not be the primary factor at work when programming reaches in contralateral space, but rather that the spatial location of the target object may be more influential.

Unlike task complexity, the influence of the spatial location of the object on children’s hand-use preference has been thoroughly examined (Fagard, 1998; Gabbard et al., 2003; Gabbard & Rabb, 2001; Gabbard, Gentry, & Rabb, 1998; Hill & Bishop, 1998; Leconte & Fagard, 2004, 2006; Pryde et al., 2000; Stilwell, 1987); however, the findings are also mixed. Various studies reported that children generally used the hand ipsilateral to their hand preference to reach for a target object and that as hand preferences became more stable over time, children continued to grasp with their preferred hand even in contralateral space (Carlier, Doyer, & Lamard, 2006; Fagard, 1998; Gabbard et al., 2001; Hill & Bishop; 1998; Leconte & Fagard, 2006; Stilwell 1987).
Notably, the age trend for crossing the midline (i.e., reaching in space that is contralateral to your preferred hand) is not linear. Pryde et al. (2001) found that 6- to 10-year olds used their preferred right-hand to perform various actions in left space more than younger children and adults. Furthermore, the midline crossing pattern is true of right-handed individuals (Gabbard et al., 2003) but not of left-handed individuals, who instead do not use their preferred hand consistently across different object locations (Gabbard & Rabb, 2001).

Conversely, there are also studies that have found that children used their non-preferred hand more often when an object was in space contralateral to their preferred hand (Gabbard et al. 1998; Hill & Bishop, 1998; Leconte & Fagard, 2004; 2006), and that using the non-preferred hand in this space increased as the object moved farther away from midline (Gabbard & Helbig, 2004). In one recent study, Leconte and Fagard (2004) varied the location of the target object such that it was presented at midline, ipsilateral to their hand preference, and contralateral to their hand preference; task complexity was also manipulated. The results indicated that, in general, children used the preferred hand more often in ipsilateral space than at midline and in contralateral space. Older children, however, were more likely to cross the midline with the preferred hand than were younger children. The preferred hand was also used less often during the simple task relative to the complex task; a finding that was later replicated (Leconte & Fagard, 2006).

Thus, the three factors that are known to influence hand-use preferences of adults and children are: 1) the skill level required for the manual activity, 2) the complexity of the task, and 3) the spatial location of the target object. In general, there seems to be an ipsilateral bias for using the hand on the same side as the stimulus, which suggests that spatial location of the target object plays a larger role in determining which hand is used to execute a reach.
In fact, in some ways the existence of an ipsilateral bias in reaching challenges the biological theory of handedness being a fixed behavioural trait.

**Hand-Use Preference in Infants**

Despite the number of studies on adult and child hand preference development, much less is known about infant hand preference development. Previous research shows that there are signs of hand preference during the first year of life, and even possibly before birth (Hepper et al., 1998; McCartney & Heppler, 1999). There also seems to be the same bias towards use of the right hand in infants as there is in children and adults (Burdukova & Stroganova, 2008; Butterworth & Hopkins, 1993; Hinojosa et al., 2003; Michel et al., 1985; Stroganova, Pushina, & Orekhova et al., 2004) and a similar trend of increasing preferred hand use across the midline with age (van Hof et al., 2002)

Given that there appears to be observable hand preferences early in life, research has since focused on the stability of infant hand preference. Some of this work has shown considerable fluctuation in the stability of hand preference during the first year (Corbetta & Thelen, 1999; McCormick & Maurer, 1988). For example, one study reported fluctuating hand preferences at about 6-months (McCormick & Maurer) and another study found fluctuating hand preferences for spontaneous non-reaching actions throughout the first year of life (Corbetta & Thelen, 1999). Interestingly, Corbetta and Thelen also observed that as arm control got better, infants tended to use their more active arm for reaching. Although this finding did not correlate with the development of a stable hand preference (most likely due to their small sample of only 4 infants), it does suggest that hand preferences are, in fact, present in early infancy. Additional evidence for fluctuations in hand preference have been found in the second year of life (Corbetta & Bojczyk, 2002), occurring around the time when independent self-locomotive behaviours such as crawling and walking begin to emerge.
There are several empirical studies that document the stability of infant hand preferences during the first year (Carlson & Harris, 1985; Goldfield & Michel, 1986; Hinojosa et al., 2003; Michel, 2002; Michel & Harkins, 1986; Michel et al., 1985, 2006; Ramsay et al., 1979). For example, to assess infant hand-use preference, Michel et al. (1985) developed a test that involved presenting small toys at infants’ midline and recording the hand used to reach and grasp each toy. This test provided scores that denoted infants’ hand-use preferences for various manual skills, including reaching for objects and manipulating objects. Infants were also given a block-play activity as a validity measure. Results indicated that the majority of the sample (78%) showed a reliable hand preference for reaching, and that the proportion of infants with a hand preference did not change with age. Specifically, a stable right-hand bias through the 6- to 13-month period, with only one infant in their sample fluctuating from right- to no-preference, was observed. In addition, infants’ hand-use preferences for reaching were significantly related to their hand preferences for manual activity during block-play, and the majority (71%) also has hand-use preference for object manipulation, which again did not change with age. Moreover, the hand-use preferences for reaching were significantly related to those for manipulating. Taken together, the authors suggested that this test achieved acceptable levels of reliability and validity to test patterns of infant hand-use during the first year of life.

Since this study, many other studies have used the test developed by Michel et al. (1985) and have found comparable results for the stability of hand-use preference in infancy (Michel, 2002; Michel, Sheu, & Brumley, 2002; Michel, Tyler, Ferre, & Sheu, 2006). Michel (2002) further suggested that infant handedness can be reliable and stable, while at the same time showing definite developmental transitions during the first year. Michel noted that such findings support dynamic systems researchers, who reason that fluctuations in hand
preference are linked to developing motor milestones and novel sensory motor experiences such as learning to sit independently (Rochat, 1992), learning to crawl, (Corbetta & Thelen, 2002), and learning to walk (Corbetta & Bojczyk, 2002). Michel et al. (2006) subsequently investigated the reliability of hand-use preferences when reaching for objects during the period from 7- to 13- months of age. Like previous works, these authors found stable hand-use preferences in the majority of infants they tested (57%), and that there was a distinct bias in the distribution of hand preference such that more infants showed a right-hand preference than a left-hand preference. These results suggest that manual preferences for apprehending objects may be stable and reliable through this age period. From this work, Michel et al. further concluded that given that infants show such strong manual preferences when reaching, such preferences should be factored into studies of the development of laterality and in developmental studies of cognitive and sensorimotor functioning during infancy.

Additional studies that provide evidence for the stability of hand-use preferences are those that have shown that preferences in infancy predict preferences later in childhood and adulthood (Marschik et al. 2008; Michel et al., 2002). A longitudinal study by Marschik et al. (2008) tested infants at 5-months and then again at 5 years to determine whether manual preference in infancy was related to preferences at preschool age. At 5-months, infants were presented with objects at midline or in their right or left hemispaces. This paradigm was similar to that used with adults and children (Bryden, Pryde, & Roy, 2000; Leconte & Fagard, 2006). At 5 years, children were given a battery of motor tasks (e.g., grasping the doorknob or racing a toy car). The results revealed that at 5-months of age infants were unimanual reachers. That is, infants reached with the right-hand when objects were presented in right hemispace, infants used the right-hand more than the left-hand when objects were presented at midline, and infants were more inconsistent with what hand they
used when objects were presented in left hemispace. Also, infants did not generally engage in midline crossing (e.g., using the right-hand to reach for objects in left hemispace), nor did the size or the shape of objects influence the occurrence of unimanual or bimanual reaching. When tested at 5 years, the majority of the sample turned out to be right-handed, which is analogous to findings by Michel et al. (2002). More specifically, children who had used the right-hand in right hemispace as infants turned out to be right-handed at preschool age more than children who had shown inconsistent hand use in infancy. These results have a few important implications. First, preferential reaching is space-dependent at 5-months of age. Second, there is no midline crossing at 5-months of age. Third, there is a relationship between infant hand-use preferences and laterality at preschool age, thus providing further evidence for the stability of manual preferences documented in infancy.

A variety of developmental studies have recently incorporated manual preferences as a factor of interest (Burdukova & Stroganova, 2008; Goldfield & Michel, 1986; Van Hof et al., 2002). For instance, Burdukova and Stroganova examined the influence of hand-use preferences on A-not-B task performance in premature infants and infants who were born full-term; this latter group was 13-months old. The age of the premature infants was corrected such that matched that of the full-term group. Results indicated that full-term infants used their right-hand to search more than their left-hand, whereas premature infants tended to use their left-hand more than their right-hand. Additionally, only full-term infants used their preferred hand to reach ipsilaterally and contralaterally; this group also made more contralateral reaches with the right-hand compared to the left-hand. Premature infants, on the other hand, used both hands equally for contralateral reaches. These authors also found that performance on the A-not-B task was asymmetric for the premature group; that is, it depended on the side of presentation. Premature infants, thus, made more A-not-B errors
when the toy was hidden on the right side than on the left, and they were less stable in performance than full term infants, who tended to be more successful overall. These results suggest that premature infants have a lack of attention to the right side of their body (hence the higher error rate on the B trial) and that full term infants have more stable hand-use preferences for reaching, as demonstrated by reaching in contralateral space with the preferred hand.

To the author’s knowledge, the study by Burdukova and Stroganova (2008) is the first to examine the influence of hand-use preferences and the A-not-B task simultaneously. Importantly, the results showing a right-hand bias are consistent with several previous reaching studies using infants (Butterworth & Hopkins, 1993, Hinojosa et al., 2003; Stroganova et al., 2004). One methodological limitation of the study conducted by Burdukova and Stroganova is that hand-use was measured rather simplistically. Specifically, the authors noted how much each hand was used throughout the task. This method does not provide a reliable and valid measure of infant hand-use preference; instead, handedness tests created for such purposes should be used (Michel et al., 1985). That said, the most encouraging implication of the Burdukova and Stroganova study is that the presence of hand-use preferences influenced object search in a rather small sample and short A-not-B task. A more systematic examination of hand-use preferences is warranted. In order to better understand whether, and to what extent, the motor constraint of hand-use preferences influences manual search on the A-not-B task, an additional experiment, Experiment 2, was conducted.

**Goal and Hypotheses**

The primary goal of Experiment 2 was to examine the influence of hand-use preference on infants’ performance on the A-not-B task. This was tested by first assessing if
infants had a preference and then by randomly assigning them to a hiding side of A location (e.g., A was either congruent or incongruent with their hand-use preference). The secondary goal of this experiment was to examine hand-use preference development in 8- and 16-month old infants. These age groups were selected for this investigation because the A-not-B error can be produced reliably by both age groups (Schmuckler & Tsang-Tsong, 2000; Smith et al., 1999; Sophian & Wellman, 1983; Zelazo et al., 1998), and also because research on hand-use preference is limited in this age range.

It was hypothesized that hand-use preference would play some role in infants’ manual search ability, as it does in reaching and other manual tasks. Specifically, it was hypothesized that on A trials infants would be more successful on the search task when the object is hidden on their preferred hand side (e.g., the toy is hidden to the right of the infant when the infant prefers reaching with the right hand) rather than on their non-preferred hand side (e.g., the toy is hidden to the right of the infant when the infant prefers reaching with the left hand). In other words, infants should show an ipsilateral bias for reaching to their preferred side, which is an idea stemming from findings on young children’s hand preferences (Gabbard & Helbig, 2004). Additionally, infants receiving A on the preferred side should perseverate more than those receiving A on the non-preferred side because they should have stronger reaching histories for reaching to A when hiding side is congruent with their preference. Also of interest was whether or not infants would use their preferred hand to execute a reach; it was hypothesized that infants would use their preferred hand more often.
Method

Participants

Twenty-eight 8-month old infants \((M = 36.5 \text{ weeks}, SD = 1.37)\) and 23 16-month old infants \((M = 68.8 \text{ weeks}, SD = 1.24)\) participated in this study. An additional 9 infants (4 8-month olds) were tested but did not complete the study. Usable infants were full-term and did not have any developmental disabilities; all were recruited from the Toronto area with parents being contacted first by letter and then by telephone. Infants participated in this experiment at the Laboratory for Infant Studies or at the N’Sheemaehn Child Care Centre; both are located at the University of Toronto Scarborough. Infants received a small toy and a certificate of participation.

Measures

**Handedness assessment.** A modified version of the handedness test (Michel et al., 1985) assessed infants’ hand-use preferences. In general, an object was presented, mostly at midline, and the hand used to initially grasp the object was recorded. This test consisted of 16 trials, which differed from the original 26 trials. This modification was deemed necessary after pilot testing revealed that the length of the original test did not suit the older age group as they would not remain seated for the duration of the test. For 3 of the 16 presentations, pairs of identical toys were presented simultaneously such that each toy was in line with one of the infants’ shoulders. The simultaneous presentation of two objects was based on the original handedness test in which 20% of the trials were dual presentations (Michel et al. 1985). On the remaining 13 trials, toys were presented individually at the infants’ midline. Like the original test, trials were presented in a fixed order and a different toy was used on each trial (see Table 1). All toys were chosen to maximize the likelihood that infants would
reach and perform an action on them; thus, toys were easy to grasp, brightly coloured, and some made noise.

1. A flat rattle
2. A ribbon clip
3. A plastic key ring
4. A plastic bobble egg
5. A pink pig rattle
6. A pair of wooden blocks
7. A small plastic robot
8. A clear ball with toy inside
9. A pair of identical strands of large pop-it beads (3 beads in each strand)
10. A plastic push-toy, face changes as it is pushed
11. A hollow, cylindrical rattle with a small freely moving ball enclosed within
12. A rubber truck
13. A pair of mini stuffed toys
14. A rotary telephone
15. Stacking rings on a post
16. A push-button cube

Table 1. Order of presentation and description of toys used to assess infant hand-use preferences for reaching and manipulating.

Manual search task. The search task was the same as the one used in the no barrier condition of Experiment 1, although there was one exception. For all trials in this experiment, the A and B locations were positioned slightly off midline. Consequently, there was no distance between the two wells (i.e., they were adjacent to each other).

Parental handedness questionnaire. A hand-preference questionnaire (Van Strien & Bouma, 2000, see Appendix A) was used to confirm the hand-use preferences of at least one participating parent. This questionnaire was derived from the most valid and reliable items selected from various well-known handedness questionnaires (Annett, 1970; Oldfield, 1971; Raczkowski et al. 1974). It was comprised of 10 items, each asking about specific manual tasks and which hand(s) are used for each task.
**Testing room and recording equipment.** The testing room and the equipment were the same as those used in Experiment 1.

**Design**

For infants demonstrating a consistent hand-use preference, this experiment used a 2 x 2 between-subjects design in which the participant variable was age (8-months, 16-months) and the manipulated variable was hiding side of location A (on the preferred side, on the non-preferred side). Hiding side of location A was counterbalanced across age group such that half of the infants in each group received A on their preferred hand side and consequently received B on their non-preferred hand side (see Figure 8).

In contrast, for infants demonstrating an inconsistent hand-use preference hiding side of location A was randomly assigned such that half of this group received the A location on their right-hand side and the other half received it on their left-hand side. This design mimics traditional A-not-B studies in which the A location is randomly assigned to either the left- or right-hand side. Separate analyses were conducted for the inconsistent group however, these analyses were not of primary interest to the experimental hypotheses and so they are not reported.
Figure 8. Schematic drawing of both levels of the hiding side of A location factor for infants with a right-hand preference. Half of them received A on their preferred side and the other half received A on their non-preferred side. The same design was used for infants with a left-hand preference.

Procedure

Infants were acclimated to the laboratory and the experimenter while consent was obtained from the parent. In the testing room, the experimental session began with the handedness assessment. This assessment always preceded the search task as the results of this assessment were needed to randomly place infants into one of two conditions of the search task. The assessment was conducted on a table such that the experimenter sat across from the infant, while the research assistant, who was watching a monitor of the live video in an adjacent room, recorded all hand movements. The experimenter presented the toys, one or two at a time, when the infant was sitting quietly and did not have any arms outstretched. These criteria were used to log the start of each trial, and ensured an accurate record of the hand first used by the infant for their initial grasp. Then infants were given 20 s to play with each toy, which started as soon as the infant touched the toy; coding of this manipulation
phase was done after the session was complete. Overall, this assessment took approximately 15 min to administer.

Upon completion of the assessment infants and their parent took a 5 min break while the experimenter scored the infants’ hand-use preference. Following the break infants began the manual search task. As in Experiment 1, there were two phases of the experiment – training and experimental. Training was the same as in Experiment 1, with three presentations of the toy at midline (i.e., in front of the well, partially hidden in the well, and fully hidden in the well). The experimental phase differed somewhat from Experiment 1. In the current study, all infants received a total of 5 A trials followed immediately by 1 B trial. This number of A trials was chosen based on the results of the previous barrier experiment in which infants receiving 5 A trials did not differ in performance on B trials compared to those receiving more than 5 A trials. The search task took approximately 5 min to administer.

For the majority of the sample, the experimental session ended following the search task; but for 20% of the sample, test-retest reliability was conducted on the handedness assessment. Only hand-use preferences for reaching was re-tested such that once the infant reached out for the toy, the experimenter would take it away and start the next trial. This reliability was conducted directly after the search task, and took approximately 1 min to administer. The parental handedness questionnaire was administered at the end of the visit.

Data Coding

Hand-use preference assessment. Two hand-use preference scores were calculated for each infant for two manual skills, that of reaching and manipulating. The scores for reaching were obtained by first separately summing the right and left hand uses across the 16 presentations. Then the score was calculated using the following formula:

\[
\frac{(\text{TOTAL RH} - \text{TOTAL LH})}{\sqrt{\text{TOTAL HAND USES}}}
\]
This computation gives the equivalent of a z score, with negative scores signifying a left-hand-use preference and positive scores signifying a right-hand-use preference. While there is no evidence in the literature to suggest that the size of the preference scores is indicative of the strength of the infant’s preference, Michel et al. (1985) suggested that the size of the score may be used to classify infants into a trichotomous grouping. As such, infants with a preference score of +1.65 or more were classified as right-hand preferred, whereas those with scores less than -1.65 were classified as left hand preferred. Infants with a preference score in between +1.65 and -1.65 were classified as having mixed or no hand-use preference. These scores, also called unilateral indexes (ULI), were used to place infants into their respective hand-use preference group.

Hand-use preference scores for manipulating objects were obtained by counting the frequency of right- and left-hand uses during the 20 s of manipulation time for each trial. The hand used most often was deemed the infants’ hand-use preference for manipulating an object for that trial. Then hand-use preference scores for manipulation (e.g., ULI score) were calculated, again using the above formula.

**Search behaviour.** Search behaviour was scored separately for the A and B trials. For each trial, search was defined as the first hiding location touched by the infant. For A trials, search was divided into correct searches (i.e., at the A location) or incorrect searches (i.e., at the B location, or at both locations simultaneously). The percent correct score was calculated as the number of correct searches over the total number of A trials. For B trials, infants either made the A-not-B error (i.e., searched at A, or at both locations simultaneously) or they did not (i.e., searched at B).

**Reaching behaviour.** Infants reaching hand was recorded for all trials. Infants could have used either their right hand, left hand, or both hands to execute a reach. The hand used
for each of the 6 trials (5As, 1B) was recorded and a percentage of preferred hand-use was calculated for each infant.

**Parental handedness.** A score of 1 was given to each item that was answered as right, -1 to each item scored as left, and 0 to each item answered with both. Total scores of 10 indicated a right-hand preference while total scores of -10 indicated a left-hand preference.²

**Reliability**

A second coder provided inter-rater reliability for 20% of the sample. Cohen’s Kappa was the primary reliability procedure of choice for this experiment. Kappa was .83 for the hand preference assessment for reaching, .85 for the search performance on A trials, 1.0 for search performance on the B trial, and lastly .70 for the reaching behaviour observations. In general, Kappa values over .75 indicate excellent reliability (Fleiss, 1981). Test re-test reliability was also conducted for the hand-use preference assessment (reaching only). The analysis revealed a strong positive correlation between the first handedness test and the re-test, \( r(8) = .95, p < .001. \)

**Results**

The results are presented sequentially on the hand preference assessment, the search performance on A and B trials, the motor history and the reaching behaviour. Let us turn to each of these findings individually.

**Hand-Use Preference Assessment**

The assessment resulted in two sets of ULI scores, one for reaching and one for manipulating. Hand-use preferences may differ across manual actions (Fagard & Marks,

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² Parental handedness scores are not reported in this dissertation as they were not of primary interest. These scores are briefly mentioned in the hand preference assessment section.
2000; Goldfield & Michel, 1986), and so it is important to examine such preferences for various manual skills. In this sample, the majority (78.4%) had a consistent hand-use preference for reaching as measured by the ULI score. This sample also included infants with no hand-use preference, which is consistent with younger samples (Tan, 1985). The distribution of hand-use preference groups is depicted in Figure 9. There were no significant differences in ULI score for reaching between age groups in each of the three hand-use preference groups: right handed, $t(24) = -0.10, ns$; left handed, $t(12) = -1.43, ns$; and no preference, $t(9) = -0.69, ns$; this is likely due to the unequal $n$’s between age groups in each hand-use preference group.

Hand-use preferences for manipulation were also examined for those infants with a consistent preference. Exactly 50% of this sample ($n = 37$, with a consistent preference; missing data for 3 16-month olds) had a consistent hand-use preference for manipulation as measured by the ULI score, with 37.8% having a right-hand-use preference for manipulation. Overall, there was a significant difference in ULI score for manipulation across age group, $t(35) = 2.60, p = .01$, with higher ULI manipulation scores for 16-month olds ($M = 1.70, SD = 1.55$) than for 8-month olds ($M = 0.14, SD = 1.94$). There were no significant differences in ULI score for manipulating between age group in each of the hand-use preference groups$^3$: right handed, $t(12) = -0.79, ns$; no preference, $t(18) = -1.12, ns$.

$^3$ An independent samples $t$-test for the left handed group was not possible; no 16-month olds had a left handed ULI manipulation preference.
Figure 9. Distribution of Hand-use Preferences for Reaching of Infants aged 8- and 16-months \((n = 51)\).

The frequency of 16 unimanual actions (see Table 2) was also measured during the manipulation assessment; these actions were based on those used in Michel et al., (1985). As expected, most of these actions were correlated as shown in Table 3. Separate independent \(t\)-tests were conducted on each action and age. Four of the 16 tests revealed significant mean differences across age. Eight-month olds \((M = 10.70, SD = 9.70)\) mouthed the toys more often than the 16-month olds \((M = 2.18, SD = 3.91)\), unequal variances \(t(25.83) = 3.60, p < .01\), they banged the toys more often than the 16-month olds \((M = 9.70, SD = 8.27 \text{ and } M = 3.18, SD = 3.38, \text{ respectively})\), \(t(35) = 3.04, p < .01\), and they engaged in more hand swapping than 16-month olds \((M = 11.90, SD = 8.21 \text{ and } M = 6.00, SD = 2.83, \text{ respectively})\), unequal variances \(t(24.11) = 3.01, p = .01\). In contrast, 16-month olds \((M = 7.47, SD = 4.84)\)
placed the toys on the table more often than did the 8-month olds ($M = 2.15$, $SD = 1.73$), unequal variances $t(19.46) = 4.31$, $p < .01$. There was also a marginally significant mean difference in the number of scraping actions performed, with 8-month olds ($M = 8.50$, $SD = 5.22$) producing more scrapes than 16-month olds ($M = 5.65$, $SD = 4.32$) across trials, $t(35) = 1.79$, $p = .08$.

Lastly, infants’ hand-use preference scores for manipulation were significantly related to those for reaching, $r(35) = .80$, $p < .01$. This relationship was significant for both 8-month olds, $r(35) = .75$, $p < .01$, and 16-month olds, $r(35) = .86$, $p < .01$. Moreover, all mothers showed a right-hand preference, as measured by the adapted handedness questionnaire. Thus, there was no reason to believe that maternal handedness was related to infants’ hand-use preferences in this study.

Some infants ($n = 11$) were assessed as having an inconsistent hand-use preference. Due to the unequal sample sizes between this group and the consistent group ($n = 40$), statistical comparisons would not be meaningful. Therefore, all subsequent analyses only include those with a consistent preference for reaching.
### Table 2.

*Descriptions of the manual actions measured, their frequencies divided by age, and the t-values.*

<table>
<thead>
<tr>
<th>ACTION</th>
<th>DESCRIPTION (OPERATIONAL DEFINITION)</th>
<th>8 MOS.</th>
<th>16 MOS.</th>
<th><em>t</em>-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>Places object in mouth</td>
<td>10.70</td>
<td>2.18</td>
<td>3.60*</td>
</tr>
<tr>
<td>Finger</td>
<td>Fingers are moving and in contact with object</td>
<td>6.50</td>
<td>8.12</td>
<td>-0.93</td>
</tr>
<tr>
<td>Shake</td>
<td>Swinging object in hand; no table contact</td>
<td>5.80</td>
<td>4.41</td>
<td>0.93</td>
</tr>
<tr>
<td>Bang</td>
<td>Repeated abrupt contact with table; holding</td>
<td>9.70</td>
<td>3.18</td>
<td>3.23*</td>
</tr>
<tr>
<td>Hit</td>
<td>Abrupt contact with object, not holding object</td>
<td>9.20</td>
<td>7.41</td>
<td>0.54</td>
</tr>
<tr>
<td>Scrape</td>
<td>Movement of object across some surface</td>
<td>8.50</td>
<td>5.65</td>
<td>1.79*</td>
</tr>
<tr>
<td>Gather</td>
<td>Pulls object in toward body, with(out) holding</td>
<td>1.80</td>
<td>2.47</td>
<td>-1.14</td>
</tr>
<tr>
<td>Hand swap</td>
<td>Movement of object from one hand to the other</td>
<td>11.90</td>
<td>6.00</td>
<td>2.82*</td>
</tr>
<tr>
<td>Grasp</td>
<td>Grip object(s), movement ends in the air</td>
<td>24.25</td>
<td>27.94</td>
<td>-1.33</td>
</tr>
<tr>
<td>Place</td>
<td>Putting object(s) on the table and removing hand</td>
<td>2.15</td>
<td>7.47</td>
<td>-4.31*</td>
</tr>
<tr>
<td>Drop</td>
<td>Release of object down toward the table</td>
<td>3.15</td>
<td>4.18</td>
<td>-1.13</td>
</tr>
<tr>
<td>Throw</td>
<td>Object projected from hand away from infant</td>
<td>7.15</td>
<td>4.00</td>
<td>1.24</td>
</tr>
<tr>
<td>Flip</td>
<td>Turning object over on table</td>
<td>1.95</td>
<td>2.88</td>
<td>-1.52</td>
</tr>
<tr>
<td>Rotate</td>
<td>Wrist rotation, object in hand</td>
<td>8.60</td>
<td>7.94</td>
<td>0.45</td>
</tr>
<tr>
<td>No action</td>
<td>No action and no object</td>
<td>0.05</td>
<td>0.12</td>
<td>-0.74</td>
</tr>
<tr>
<td>Other</td>
<td>Miscellaneous activity with object</td>
<td>0.00</td>
<td>0.06</td>
<td>-1.09</td>
</tr>
</tbody>
</table>

* *p < .01
* *p = .08

**Search Performance**

**A trial performance.** A 2 x 2 (Age [8-months, 16-months] x Hiding Side of Location A [preferred side, non-preferred side]) between subjects ANOVA was performed on percent correct search behaviour on A trials. The analysis revealed a main effect of age, $F(1, 36) = 5.93, p = .02, \eta_{p}^2 = .14$, with older infants ($M = .59, SD = .35$) searching correctly on A trials more often than younger infants ($M = .34, SD = .34$). There was also a main effect of hiding side of location A, $F(1, 36) = 5.93, p = .02, \eta_{p}^2 = .14$, with infants searching correctly on A trials more often when A was located on their preferred side ($M = .59, SD = .33$) than when A was on their non-preferred side ($M = .34, SD = .36$). The interaction between age and hiding side of location A was not significant, $F(1, 36) = 0.24, ns$ (see Figure 10).
**Figure 10.**  
Percent of Infants who Searched Correctly on A as a Function of the Hiding Side of Location A and Age Group.
<table>
<thead>
<tr>
<th>Mouth</th>
<th>Finger</th>
<th>Shake</th>
<th>Bang</th>
<th>Hit</th>
<th>Scrape</th>
<th>Gather</th>
<th>Hand Swap</th>
<th>Grasp</th>
<th>Place</th>
<th>Drop</th>
<th>Throw</th>
<th>Flip</th>
<th>Rotate</th>
<th>No Action</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>0.279</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finger</td>
<td>-0.082</td>
<td>-0.307</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bang</td>
<td>0.235</td>
<td>-0.534</td>
<td>0.502</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hit</td>
<td>0.099</td>
<td>0.271</td>
<td>0.077</td>
<td>0.030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrape</td>
<td>0.129</td>
<td>-0.376</td>
<td>0.103</td>
<td>0.469</td>
<td>0.061</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gather</td>
<td>0.057</td>
<td>0.169</td>
<td>0.070</td>
<td>-0.101</td>
<td>0.083</td>
<td>0.320</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand Swap</td>
<td>-0.009</td>
<td>-0.184</td>
<td>0.556</td>
<td>0.303</td>
<td>-0.023</td>
<td>0.125</td>
<td>0.248</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grasp</td>
<td>-0.208</td>
<td>-0.137</td>
<td>0.135</td>
<td>0.007</td>
<td>0.016</td>
<td>-0.083</td>
<td>-0.051</td>
<td>0.249</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place</td>
<td>-0.354*</td>
<td>0.065</td>
<td>0.029</td>
<td>-0.229</td>
<td>-0.041</td>
<td>0.133</td>
<td>-0.057</td>
<td>0.378*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drop</td>
<td>-0.256</td>
<td>0.068</td>
<td>-0.095</td>
<td>-0.177</td>
<td>0.032</td>
<td>0.011</td>
<td>-0.243</td>
<td>0.050</td>
<td>0.598*</td>
<td>0.170</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throw</td>
<td>0.017</td>
<td>-0.147</td>
<td>0.138</td>
<td>0.057</td>
<td>0.234</td>
<td>0.084</td>
<td>-0.080</td>
<td>0.308</td>
<td>0.677*</td>
<td>-0.119</td>
<td>0.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flip</td>
<td>-0.086</td>
<td>0.021</td>
<td>-0.125</td>
<td>-0.128</td>
<td>0.042</td>
<td>0.229</td>
<td>-0.308</td>
<td>-0.169</td>
<td>0.138</td>
<td>0.294</td>
<td>0.192</td>
<td>0.033</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotate</td>
<td>0.016</td>
<td>0.345*</td>
<td>-0.233</td>
<td>-0.200</td>
<td>-0.017</td>
<td>-0.020</td>
<td>-0.032</td>
<td>-0.019</td>
<td>-0.022</td>
<td>0.139</td>
<td>-0.018</td>
<td>-0.138</td>
<td>0.103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Action</td>
<td>-0.213</td>
<td>0.369*</td>
<td>-0.233</td>
<td>-0.280</td>
<td>-0.162</td>
<td>-0.173</td>
<td>-0.018</td>
<td>-0.139</td>
<td>-0.140</td>
<td>0.142</td>
<td>-0.068</td>
<td>-0.066</td>
<td>0.099</td>
<td>0.071</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0.141</td>
<td>-0.072</td>
<td>0.293</td>
<td>-0.040</td>
<td>-0.091</td>
<td>-0.176</td>
<td>0.367*</td>
<td>-0.029</td>
<td>0.041</td>
<td>0.131</td>
<td>0.023</td>
<td>-0.124</td>
<td>-0.123</td>
<td>-0.127</td>
<td>-0.050</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

**Table 3. Correlations among the 16 Manual Actions performed during the Hand-use Preference Assessment for Manipulating**
**B trial performance.** The proportions of infants who search incorrectly on the B trial are found in Figure 11. To examine the effects of age and hiding side of location A on B trial performance, specifically an interaction between the two variables, a between-subjects ANOVA was conducted. Percent of perseverative error was the dependent variable. The analysis revealed no significant main effect for age, $F(1,36) = 0.10, ns$, or hiding side of location A, $F(1, 36) = 0.10, ns$, thus there was no mean difference in the amount of perseverative errors made between age groups or hiding side of location A groups. Although it visually appears that the two factors interact (see Figure 11), the interaction was not significant, $F(1, 36) = 2.42, p = .13, \eta_p^2 = .06$, as noted by its extremely small effect size.

![Figure 11](image_url)  
**Figure 11.** Percent of Perseverative Error on B trials as a Function of Age Group and Hiding Side of Location A.
Motor History

A relative memory strength (RMS) score was also calculated to quantitatively measure each infant’s motor memories for reaching to the A location. Recall that RMS scores incorporate reaches to both A and B locations in order to get a true measure of prior activity on A trials. A 2 x 2 x 2 (Age [8-months, 16-months] x Hiding Side of Location A [preferred side, non-preferred side] x B trial Performance [perseverators, non-perseverators]) between-subject ANOVA on RMS score was conducted. The analysis revealed a main effect of age, $F(1,32) = 8.69, p = .01, \eta^2_p = .21$, with older infants having stronger motor histories for reaching to A on A trials ($M = .42, SD = .59$) than younger infants ($M = -.12, SD = .57$). There was also a main effect of hiding side of location A, $F(1, 32) = 10.17, p < .01, \eta^2_p = .24$, with RMS scores being higher and positive (i.e., motor history for reaching to A) when hiding side of location A was congruent with the infants’ preferred side for reaching ($M = .45, SD = .57$) compared to when hiding side of location A was incongruent with preferred side ($M = -.14, SD = .59$). There was no significant main effect of B trial performance, $F(1,32) = 2.14, ns$, with infants who perseverated ($M = .29, SD = .58$) not differing in their RMS score compared to those who did not perseverate ($M = .02, SD = .58$). None of the interactions were significant, all $ps > .05$, including the age by b trial performance interaction, $F(1, 32) = 0.32, ns$ (as shown in Figure 12).
Figure 12.  *Relative Memory Strength for Reaching to A as a Function of Age Group and B trial Performance.*

**Reaching Behaviour**

To examine whether or not infants with a consistent hand-use preference (right or left) reached with their preferred hand, separate independent *t*-tests (collapsed across age group and trial type) were conducted on the percentage of each type of reach (right-handed, left-handed, bimanual). Results indicated that infants with a right hand-use preference (*M* = .46, *SD* = .35) reached with their right hand more often than those with a left hand-use preference (*M* = .20, *SD* = .23), *t*(38) = -2.49, *p* = .02. Likewise, infants with a left hand-use preference (*M* = .38, *SD* = .30) reached with their left hand more often than those with a right hand-use preference (*M* = .14, *SD* = .21), *t*(38) = 3.00, *p* = .01.
However, there was no significant difference between those who preferred the right hand ($M = .40, SD = .34$) and those who preferred the left hand ($M = .39, SD = .26$) in terms of the percentage of bimanual reaches, $t(38) = -0.07, ns$.

Subsequently, to examine whether or not age and hiding side of location A influences the percentage of preferred hand reaching, a $2 \times 2$ (Age [8-months, 16-months] x Hiding Side of Location A [preferred side, non-preferred side]) between-subjects ANOVA was conducted. The analysis revealed no main effects of either age, $F(1, 36) = 0.42, ns$, or hiding side of location A, $F(1, 36) = 0.24, ns$. However, there was a significant interaction between age and hiding side of location A, $F(1, 36) = 5.26, p = .03, \eta_p^2 = .13$. This interaction is found in Figure 13.

Simple main effects of age at hiding side of location A revealed a significant difference in preferred hand reaches when A was on the preferred side, $t(18) = -2.23, p = .04$, with 16-month olds producing more preferred hand reaches than 8-month olds. There was no significant difference in preferred hand reaches across the age groups when A was on the non-preferred side, $t(18) = 1.10, ns$. Simple main effects of hiding side of location A at age further revealed that 8-month olds made more preferred hand reaches when A was on the non-preferred side than when A was on the preferred side, $t(18) = -1.92, p = .07$; but this was not the case for 16-month olds, $t(17) = 1.49, ns$. 

**Figure 13.** Percent of Preferred Hand Reaches as a Function of Age Group and Hiding Side of Location A.

**Discussion**

This experiment investigated the effect of hand-use preference on infants’ A-not-B task performance, along with assessing the hand-use preferences of 8- and 16-month olds infants more generally. Converging with Experiment 1, as well as with previous works in this field (Diamond, 1985; Munakata, 1997; Piaget, 1954; Wellman et al., 1987), this study observed that manual search performance on A trials was significantly affected by age, with older infants once again outperforming younger infants. In a somewhat more novel way, this study also observed more correct searches on A trials when A was located on the infants’ preferred reaching side.
With respect to implications for A-not-B behaviour more generally, these results indicate that intrinsic motor tendencies (e.g., hand-use preferences) potentially play a role in A-not-B performance. That is, in a two-location search task where one location is on the “preferred side” and the other is located on the “non-preferred side”, as was the case in the present task, infants tend to reach towards the side that is congruent with their lateral preference. As such, if the A location is assigned to the right for an infant, and that infant has a right-handed bias for reaching, he/she will perform more successfully on A trials more often than an infant who is right-handed but the A location is assigned to the left location. Thus, intrinsic motor constraints on reaching, such as hand-use preferences are important to consider when conducting an object search task because if such preferences are present they can significantly affect infants’ motor movements including the development of motor memories for reaching, and thus how well the task is performed.

Furthermore, it is likely that when the object is hidden on the preferred side on a reaching task, continual reaching to the ipsilateral location could create a stronger motor habit for reaching than if the object were hidden contralaterally. In particular, infants with a right-hand preference could build up stronger motor memories for reaching if the A location was located on their preferred side because these infants are receiving high levels of proprioceptive feedback from their reaching. This feedback allows these infants to associate reaching to their preferred side with successful object retrieval. It is also quite likely that high levels of proprioceptive feedback will encourage infants to execute the same reaching behaviour repeatedly, which in turn would create stronger motor memories for reaching to location A. Supporting this speculation are the RMS findings,
which revealed that infants tended to have stronger motor histories for reaching to A when A was located on the infants’ preferred side. Therefore, it is clear that when measuring manual search on an object retrieval task such as the A-not-B task, that where the hiding location is placed is important, especially for infants demonstrating stable hand-use preferences for reaching.

In contrast to the findings regarding A trial performance, age and hand-use preference had little impact on B trial performance. In this regard it is notable that, although non-significant, the actual direction of the means for B trials is intriguing, with 16-month olds producing numerically fewer perseverations when A was on the non-preferred side (thus meaning that B was on the preferred side) than when A was on the preferred side, whereas 8-month olds produced the reverse pattern. Inspection of the data (see Figure 11) reveals high standard errors, which could easily have masked any effects. Accordingly, future work should explore this pattern of B trial performance within the context of increased power.

Lastly, the findings from the handedness assessment confirm the presence of hand-use preferences in 8- and 16-month old infants, converging with previous handedness studies with infants (Carlson & Harris, 1985; Goldfield & Michel, 1986; Hinojosa et al., 2003; Michel, 2002; Michel et al., 1985). There were several noteworthy findings from this assessment. First, there is a rightward bias in hand-use preference that is evident by 8-months of age. This finding replicates past findings (Fagard, Spelke, & von Hofsten, 2009). Second, the ULI scores (i.e., the scores that measured whether or not infants were left-preferred, right-preferred, or had no preference) for 8- and 16-month olds did not differ for reaching but were different for manipulating objects. This
finding suggests that older infants tend to use their preferred hand more consistently when manipulating objects relative to younger infants. This finding also suggests that there is a more consistent hand-use preference for reaching for objects than for manipulating objects. One reason that hand-use preferences might not be observable in object manipulation for 8-month old infants is that younger infants are more likely to employ alternative basic forms of exploratory behaviour, such as mouthing to manipulate objects, and not rely on their hands as much. The handedness assessment results are thus indicative of the progression of the development of manual preferences, with older infants showing this preferred-hand preference more often when manipulating an object. Manipulation of an object is one motor skill that likely requires the use of a stable, steady hand, and so older infants may use the hand that they use the most often and the one that has better control and coordination.

One final result worth discussing here is that, in general, infants actually used their preferred hand to execute all of their reaches regardless of an objects’ location in space. The use of the preferred hand, over the use of the non-preferred hand or use of both hands, provides additional evidence for the stability of hand-use preferences in infancy, and converges with findings from the handedness assessment. Even more interesting is that 8-month olds, but not 16-month olds, made more reaches with their preferred hand when A was on the non-preferred side than when it was on the preferred side. That is, 8-month olds with a right-hand preference reached with their right hand more often when A was location on the left side. This finding indicates that perhaps younger infants rely on motor dominance when reaching (or planning their reach) for objects presented contralaterally. Presenting objects in contralateral space may represent
a more difficult context for younger infants, as witnessed by the poorer search performance on A trials discussed earlier. Consequently, younger infants may rely more heavily on intrinsic motor tendencies when executing a reach in contralateral space. In contrast, older infants may not find presentations in contralateral space as difficult because of a developmental advantage. That is, with experience and age, older infants come to rely on additional factors, such as object location, when planning their reaching action. Accordingly, older infants may choose the hand closest to the object (i.e., the non-preferred hand) more often in more difficult tasks (i.e., when the object is in contralateral space).

Taken together, these findings support the presence of hand-use preferences in infancy. They also demonstrate that when present, hand-use preferences can influence manual search performance on the A-not-B task such that if preference and hiding side are matched, infants will perform better. As a motor constraint on reaching, hand-use preferences are thus another important motor skill to consider when examining what infant do on an object search task.
Chapter 4

General Discussion

Overall, the findings of the current investigation confirm that the presence of various motor constraints on reaching affect manual search performance on the A-not-B task, affording those in the A-not-B field much more information about what infants do when searching for hidden objects. Consistent with the primary hypotheses, both 8- and 16-month olds’ manual search performance on A trials was facilitated by having no barrier present and by hiding the object on the infants’ preferred side. However, only the presence of a barrier influenced B trial performance, and this was only true of 8-month olds.

It is important to discuss why motor constraints on reaching were of interest in this investigation. Motor constraints on reaching were of interest because not many A-not-B studies focus on the motor aspects of reaching that may influence manual search performance. Accordingly, this investigation adds to our knowledge about what infants do on the A-not-B task. Both the presence of a barrier and infants’ hand-use preference are motor constraints that require infants to make repetitive actions with their hands. How the hand functions is very important in supporting cognitive development because hand movements allow for interactions with objects that in turn support the development of knowledge about objects, particularly where they are hidden and how to retrieve them. Motor constraints can thus directly affect infants’ manual search performance on the A-not-B task and consequently, the formation of motor memories for reaching.

As shown here, motor memories for reaching can be difficult to create in younger children, especially when certain motor constraints of reaching are used, namely an
opaque barrier. Hand-use preference is a much more influential motor constraint that shapes the creation of motor memories for reaching. The present data demonstrate that instead of facilitating the creation of a motor memory for reaching, the presence of a barrier may have actually prevented infants from developing a motor history for successful search on A trials, or created an alternative motor memory. Hiding an object on the preferred side however, was a motor constraint that created stronger motor memories for reaching, with infants building up motor memories for reaching to A location better when hand-use preference and hiding side were congruent during the A trials.

Even with barriers being the more difficult motor constraint to affect infant reaching and motor memory formation than hand-use preferences, the current findings indicate that overall, the presence of various motor constraints significantly affects infants’ manual search performance on the A-not-B task, and that their effects are depended upon age. In summary, 8-month old infants were affected by extrinsic motor constraints that changed the nature of the motor movements required for successful search (i.e., the presence of a barrier) but not by intrinsic motor constraints (i.e., having the A location on the preferred side). In contrast, 16-month olds were not affected by either extrinsic or intrinsic motor constraints. Similar to the factors of age, or time of delay between hiding and searching events, which are two common factors known to influence the production of the A-not-B error, motor constraints that affect infants’ reaching should be thought of as important factors that are also influential to infants’ A-not-B performance, more generally.
There are several reasons why extrinsic motor constraints on reaching were more
difficult than intrinsic motor constraints. It is possible that extrinsic motor changes may
have been more difficult for younger infants because of their relatively novice ability to
interact with barriers such as screens (Piaget, 1954). Consequently, on the B trial,
younger infants explored their motor possibilities when manually searching and selected
the most appropriate motor action (i.e., a new motor action), as suggested by Thelen
(1995). B trial performance may not have been facilitated by intrinsic factors such as
preferred side, for either age group, simply because such intrinsic factors may play a
more influential role on the development of creating motor memory for reaching to the A
location. This was, in fact, true in the present investigation, with preferred side
facilitating A trial search performance across both 8- and 16-month olds. Alternatively,
perhaps changes to intrinsic factors (i.e., varying the hiding side location to be congruent
or incongruent with the preferred side) did not affect either age group because
preferences for reaching to a particular side were not strong after the switch trial. This
was not the case however, as infants in this sample had consistent hand-use preferences
for reaching. Clearly, some motor constraints on reaching are more influential than
others when it comes to creating motor memories for reaching on the A-not-B task.

The ability to create motor memories for reaching by way of these two motor
constraints was important because these experiments were both designed to test the
theoretical notion that infants make the A-not-B error because of a motor memory for
reaching to the A location (Smith et al., 1999). The main idea behind this theory is that
when no changes in motor movements are made across trials, infants should be more
likely to use previous motor memories for reaching to A if such memories are the cause
of the error. Since the A-not-B search task is fundamentally a reaching task, motor constraints on infants’ reaching behaviours, such as barriers that blocked the path of the hands and infants’ hand-use preferences for reaching were believed to be the most logical way to test this motor memory account. The results from the Experiment 1 provided clear support for the theory that motor memories are the cause of the A-not-B error because when changes in the motor movement requirements between trials were made, search performance increased in the younger age group only. This result suggests that these infants could not be using previously established motor memories when searching on the B trial. Support for this theoretical position is not as clear when hand-use preferences, as represented by presentation side of the A location, were used as the motor constraint on reaching (Experiment 2). Having the A location on the infants’ preferred reaching side certainly created stronger motor memories for reaching compared to having the A location of the infants’ non-preferred side; however, no effects were seen with respect to the production of the A-not-B error. One would expect that infants who created stronger motor memories for A because the A location was ipsilateral to their preferred reaching hand would have then made more perseverative errors on B because their motor memories for reaching are firmly established. More research is needed, however, to confirm the role of this highly influential motor constraint on perseveration in this context. Nevertheless, there is some novel evidence from this investigation that motor memories are definitely present on the A-not-B task, and that they are one of the reasons for why infants make the A-not-B error.

The implications from this investigation are similar to those that have been reported in previous studies in this field (Diedrich et al., 1999; Smith et al., 1999). Smith
et al. found that shifts in posture between A and B trials, such that infants sat for A but stood for B, also led to less perseveration on the B trial. Likewise, changing the motor movements between A and B trials in the present investigation, also led to less perseveration, at least in the case of Experiment 1. Both sets of findings suggest that postural shifts and/or motor movement shifts changes the internal activity infants use to direct their reaching. Specifically, on the B trial, the internal activity for reaching is reset due to the postural change or motor movement differences, and so infants tend to use the immediate input rather than the past motor memory. The results of Smith et al. and the findings with the barrier in Experiment 1 are thus similar because changing the motor actions between A and B trials changed the reaching trajectories needed to get the toy. Together these studies all demonstrate that motor movements associated with reaching are important factors contributing to A-not-B performance.

Moreover, the present investigation was the first to change the motor actions from A to B trials using actual motor constraints that affect infants’ reach execution. The presence of both of these motor constraints on the task could not be easily ignored by the infant. The only other motor constraint on reaching that has been implemented on the A-not-B task is the addition of weights on the arm, which changed the ‘feel’ of the arms on the B trial, and which also reduced perseveration (Diedrich et al. 1999). Like these previous studies, the present investigation therefore provides evidence for the theoretical position that motor memories contribute to infants’ decisions to reach to A or to B.

**Limitations and Directions for Future Research**

This investigation is not without its limitations, and future research examining the motor memory account for the occurrence of the A-not-B error should consider the
following issues. First, the type of barrier used in Experiment 1 may have been too
difficult for the younger infants. Although previous studies have shown that 8-month
olds can retrieve an object hidden by an opaque screen (Piaget, 1952; Ugris & Hunt,
1975), this age group did not do as well as the 16-month olds when a barrier was
blocking the path of the A location. Furthermore, the fact that a second, unblocked
location was available during A trials could have led infants to search at that second
location instead. One solution to this limitation could be to perhaps use a barrier that is
not rigid, but one that is still opaque. With a non-rigid opaque barrier, such as a hanging
cloth, in front of the A location infants could still approach the barrier, push through it,
and search for the hidden object rather than give up, and search incorrectly at the second
location. Using this type of barrier would be valuable for future studies to show if the
properties of the barrier influence the development of motor memories in the A-not-B
context.

Second, it is reasonable that infants in the barrier condition of Experiment 1
developed some type of motor memory for reaching but that these motor memories were
of a different type. Recall that our measure of correct search, like others in the field (for
example, Bell & Adams, 1999; Dunst et al., 1982) was the first location touched by the
infant. However, this measure could have underestimated infants true search
performance on A in this context. That is, other search behaviours such as touching the
barrier first could have been considered as a correct search attempt on A. In fact, 8-
month olds touched the barrier significantly more often on their first reach than did 16-
month olds. Moreover, when 8-month olds infants did not successfully move the barrier
out of the way or if they failed to touch the A location, they would then search at the B
location. Thus, it is possible that the infants developed strong motor habits for reaching to the B location on the A trials. As a result, performance on B trials in the barrier condition could represent that infants were making perseverative errors back to the B location as that is where they initially searched on A trials. In this case, the presence of a motor habit for reaching related to the presence of a barrier would have played no role in infants B trial search performance. However, given that the majority of the younger infants touched the barrier on their first reach it is more likely that their motor memories for reaching did include the barrier and thus, any motor movements associated with touching the barrier.

Third, pointing is another manual action that may contribute to our understanding of to what infants do (or even know) when searching for hidden objects (and even to the development of hand-use preference), yet it was not measured in the present investigation. Pointing is considered a communicative gesture that appears around 11-months of age and is related to language (Butterworth & Morissette, 1996). Interestingly, laterality of pointing has also been found to correlate with handedness for object manipulation (Vauclair & Imbault, 2009). Right handers, for instance, tend to gesture (or point) most often with their right hand. As a communicative gesture, pointing is thus a motor action that older infants may do more often in the context of manual search tasks. Perhaps infants with a manual preference point more often on the A-not-B task, or perhaps they use pointing in conjunction with other communicative gestures (e.g., baby sign language) to convey that they know where the hidden object is location. In a similar vein, perhaps when presented with a physical barrier infants would use more pointing
behaviours rather than direct searches. Such questions were not answered by the present investigation, but they should be examined by future investigations to find out whether communicative hand gestures are also influential motor constraints on reaching in the A-not-B task.

**Conclusion**

In summary, the current findings provide some strong evidence for the theoretical notion that motor memories for reaching are one reason for the occurrence of the A-not-B error. The results clearly demonstrate that when certain motor constraints are placed upon reaching behaviour, infants can develop motor memories for reaching to location A, as was the case for the presence of a barrier or having the A location congruent with hand-use preference. The production of the A-not-B error seems to be reduced, at least for 8-month olds, when the motor actions required for reaching and searching are changed between A and B trials, as was the case when barriers were used as the motor constraint affecting infants’ reaching. Thus, studies on what infants do on the A-not-B task provide some much needed information about the influence of motor processes on object search and about the role of motor memories for reaching. The use of our hands to reach and manipulate objects and/or to make gestures is, unmistakably, a valuable motor skill that not only allows for execution of action but also for communication, and so it is unreasonable to overlook motor aspects of reaching when examining object search. Future works should further examine these, and other, motor constraints of reaching to better understand how motor processes affect infants’ search for hidden objects.
Appendix A

Hand-preference questionnaire

This list contains questions regarding the different aspects of left- and right-handedness. Please answer as accurately and completely as possible.

Writing hand

Which hand do you use to write?  left / right / forced to use the right hand in school

Hand-preference

Below, a number of activities are mentioned that one can perform with either the left or right hand. Please indicate which hand you normally use for each of these activities. If you do not know the answer, imagine performing the task. Only if you have no preference, tick ‘both’.

1. Which hand do you use to draw?  left / right / both
2. Which hand do you use to brush your teeth?  left / right / both
3. Which hand do you use to hold a bottle opener?  left / right / both
4. Which hand do you use to throw a ball far away?  left / right / both
5. Which hand do you use to hammer a nail?  left / right / both
6. Which hand do you use to hold a racket (for example, when playing tennis)?  left / right / both
7. Which hand do you use to hold a knife when cutting a rope?  left / right / both
8. Which hand do you use to stir with a spoon?  left / right / both
9. Which hand do you use to hold an eraser when rubbing out something?  left / right / both
10. Which hand do you use to hold a match while striking it?  left / right / both
References


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