CHILDREN'S USE OF VISUAL INFORMATION IN ACTION PLANNING

A Dissertation

by

ALBERTO CORDOVA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2008

Major Subject: Kinesiology

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Approved by:

Chair of Committee,	Carl Gabbard
Committee Members,	John Buchanan
	David Wright
	Teresa Wilcox
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ABSTRACT

Children's Use of Visual Information in Action Planning.

(December 2008)

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Chair of Advisory Committee: Dr. Carl P. Gabbard

The primary intent of this study was to gain insight into children's ability to use visual information in planning reaching movements. More specifically, the work presented here examined, from a developmental perspective, the use of visual information to use a) egocentric cues, b) allocentric cues, and c) the combination, in the form of visual background around a target. Children representing the age groups 5-, 7-, 9-, 11 years and adults participated in three experiments. All experiments were conducted using an immediate (visually-guided) and response-delay (memory-guided) paradigm. Experiment 1 examined the ability of participants to use an egocentric frame of reference to estimate reach via motor imagery. Results indicated that introducing a ≥ 2s delay affected responses in all age groups, especially the younger age groups (5- and 7-year-olds). As delay increased, children as a group tended to overestimate, while adults underestimated. Experiment 2 investigated how participants used allocentric cues to estimate the location of objects in a perceptual estimate paradigm. Results revealed that introducing a delay affected the estimation of distance among all age groups, with greater effect on the younger age groups. Experiment 3 examined how a visual background surrounding a target would affect estimation of reach. Results revealed that there were no differences when targets were surrounded with or without a background. Results also showed that the 5- and 7-year-olds were most affected on their perception of reach and estimates by longer delays.

Considered together, these results hint that: (1) there is a significant temporal constraint on the representation of movement through the visoumotor stream, especially with children 7 years and younger, and (2) children as a whole tend to operate and rely more on an egocentric frame of reference; therefore, responses of reachability and distance estimates were susceptible to greater error when performed after a 2s delay.

DEDICATION

To my wife, Yvette, for her unconditional love and support in this journey

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I would like to thank God for the endless and unconditional love He has given me and for the strength and blessings He has given me to accomplish my endeavors. I would also like to express my deep and sincere gratitude to my supervisor, Dr. Carl Gabbard, who has shared his knowledge, experience, prayers, and friendship throughout this journey. I would also like to thank the members of my committee, Dr. John Buchanan, Dr. David Wright, and Dr. Teresa Wilcox, for their guidance and support throughout my educational career.

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CHAPTER I

INTRODUCTION

Understanding the perception to action developmental dynamics involved in reaching and grasping an object constitutes one of the most mystifying issues in motor behavior research. It is assumed that one of the initial steps in programming such movements is to derive a perceptual *estimate* of the object's distance and location relative to the body. This means that an individual must be able to perceive critical reach distances beyond which a particular reach action is no longer afforded and to which a transition to another reach mode must occur. For example, the individual must ascertain whether the object is close enough to reach while seated, or should they stand up? From a Gibsonian view (1979), the detection of the affordance for a particular mode of reaching entails perceiving whether the reach action will fit in the existing layout of the environment. Obviously, visual information and an action representation are critical factors in planning reach movements.

Part of the motivation for this project derived from recent work in our laboratory showing that there are differences between children and young adults in estimates of reach (Gabbard, Cordova, & Ammar 2007a). More specifically, when viewing reaching space as peripersonal (within grasp) and extrapersonal (beyond reach), children display a distinct ‘body-scaling’ problem in extrapersonal space; a problem not shown in adults. It has been our contention and the view of some reviewers of our work that part of the problem is age-related differences in the use of visual information – which includes the

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This dissertation follows the style of *Research Quarterly for Exercise and Sport*.

ability to represent and predict actions.

The primary purpose of this project was to gain insight into children's ability to use visual information in planning reaching movements. To this end, three experiments examined the use of visual information in action processing via estimating reach among children ages 5- to 12 years, and a sample of young adults. More specific, our plan aimed to determine the age-related ability to use a) egocentric cues, b) allocentric cues, and c) the combination of both cues, in the form of visual background around a target.

Often linked to the use of visual information in the form of visual representations are egocentric and allocentric visual frames of reference. It is generally well-accepted that visual information is used to code specific characteristics of objects and its surroundings with respect to particular references. One form involves reference relative to the actor's body or body parts, labled as an *egocentric frame of reference*. For example, the visual mapping of the actor's effector (hand) and reaching object. The other, referred to as an *allocentric frame of reference*, is a representation relative to the object and background independent of the actor; such as recognition of object shape and general location. Furthermore, it has been proposed that egocentric cues associated with intended action are processed in the dorsal pathways thru the brain, whereas allocentric representations that help to recognize (for example) object shape and location are found mainly along the ventral pathways in the brain (Goodale et al., 2005; Goodale & Westwood, 2004). Moreover, specific propositions of the two-visual-system hypothesis [vision-for-perception and vision-for-action; Goodale et al., 2005] and behavioral data support the idea that for *estimation judgments* (as with reach), the dorsal stream (via egocentric reference) is ‘metrically’ more accurate than the ventral stream (allocentric reference) (Bradshaw et al., 2004; Goodale & Humphrey, 1998).

Moreover (and of specific relevance to this work), the perception and action streams are speculated to operate under very different temporal constraints. That is, real-time (visually-guided) movements depend on pathways from the early visual areas via relatively encapsulated visuomotor mechanisms in the dorsal stream. These dedicated visuomotor mechanisms, together with motor centers in the premotor cortex and brainstem, compute the absolute metrics of the target object and its position in the *egocentric* coordinates of the effector used to perform the action. In contrast, it is suggested that memory-driven actions make use of a perceptual representation of the target object generated by the ventral stream. Unlike the real-time visuomotor mechanisms, perception-based movement planning makes use of scene-based coordinates to establish an *allocentric* frame of reference. Research testing the temporal aspects of the visual systems is supportive of how the two visual frame of references operate (Goodale et al., 1994; Graham et al., 1998; Hu et al., 1999).

Although the consensus of research leads to the notion that the two visual pathways have a distinct (and independent) role, the ‘interactive’ complementary function of the processes has drawn considerable attention in updated discussions (Goodale et al., 2005; Goodale & Westwood, 2004; Guillery, 2005). For example, research has demonstrated that allocentric and egocentric references interact to influence the trajectory and accuracy of a movement (Bradshaw et al., 2004; Diedrichsen et al., 2004; Krigolson & Heath, 2004; Stevens, 2005). In addition, Goodale et al. (2005) has stated, “Of course, the two systems are not hermetically sealed from one another - perception and action are intimately linked. After all, many actions, which are mediated by mechanisms in the dorsal stream, are conditional upon the presence of complex stimuli that can be interpreted only by mechanisms in the ventral perceptual stream” (p. 274). From a developmental perspective, this observation may be described as a ‘coupling’ of perception to action processes.

Although little has been reported about motor cognition per se for reaching in children, contemporary studies have found significant age-related change in mastery of the visuomotor system between 5 and 11 years (e.g., Bourgeois & Hay, 2003; Lambert & Bard, 2005). Common observations include age-related improvements in general information processing abilities - for example, changes in the ability to effectively integrate visual feedback with the motor system. However, of closer relevance to the present question is the body of information concerning specific use of visual information in action processing. Using a visual (Ebbinghaus) illusion task with grasping, Hanisch et al. (2001) provided evidence for nonspecific use of an allocentric (ventral stream) and/or egocentric (dorsal stream) frame of reference while making perceptual judgments or planning motor acts during childhood. That is, children were relying on both visual streams during perceptual and visuomotor activities; therefore suggesting that these pathways <u>are not</u> functionally segregated during childhood. The researchers did note that the reliance on visual feedback decreased with increasing age (5- to 12 years).

In a later paper, using the Duncker illusion with a pointing task, Rival et al. (2004) found that the different type of spatial information (location versus distance) encoded by the participants to program their motor responses matures early during childhood. Their data suggested that before 7 years of age, children use mainly egocentric object representations when performing motor tasks. On the other hand, when making only perceptual judgments, children preferentially use allocentric cues. Furthermore, the researchers contend that by 7 years, children use the same attentional strategy as adults. It was noted that the difference between their results and those of Hanisch and colleagues might lie in the task used.

In essence, these findings beg the question and need for further study considering the developmental status of the visual pathways in children. The reports are somewhat conflicting –one notes that these pathways ‘are not’ functionally segregated (by age 12). The other concluded that the systems are relatively mature and segregated by 7 years of age.

An interesting approach to investigate the nature of visual representation in action control is to introduce a temporal delay between stimulus presentation and response. This paradigm has been used in pointing tasks (Bradshaw et al., 2004; Bradshaw & Watt, 2002; Elliot & Madalena, 1987; Heath et al., 2004, Westwood et al., 2003) and prehension tasks (e.g., Hu et al., 1999). Experimentally, the use of a temporal delay has been shown to modify the features of visuomotor responses. For example, Bradshaw & Watt (2002) found that a 2s delay was sufficient to significantly disturb prehensile movement. They found that when presented with a delay, subjects exhibited reaches with lower peak velocities and lower peak apertures. Moreover, they used a perceptual-matching condition and found that accuracy, as well as variance, of a pointing task remained unaffected after imposing a temporal delay. Other researchers report similar results ranging from a decrement in movement behavior at 1s (Graham et al., 1998) and 5s (Hu et al., 1999). Those findings support the notion that the visuomotor (dorsal) pathway has limited memory and that response after a temporal delay may be sustained by representation stored in memory through the perceptual stream (ventral).

As mentioned before, perceptual tasks (e.g. recognizing the color of a target) have been separated from action-based tasks (e.g. reaching for an object) and differences in performance have been explained by functional dissociations of two independent streams, the ventral and the dorsal stream located in the temporal and parietal lobes, respectively. Several behavioral experiments have demonstrated that some patients can perform perceptual tasks but not visually- guided behavioral tasks (see, Goodale et al, 1994); on the other hand, others are capable of performing normally on visuomotor tasks, but not perceptual tasks (see Goodale et al, 1991).

In regard to studies of children, Bradshaw and colleagues (2004) examined the effects of a pre-movement delay on the kinematics of prehension in middle childhood (5 to 11 years of age). The participants performed visually open-loop reaches to two different sized objects at two different distances along the midline. Reaches took place either immediately, or 2s after the occlusion of the stimulus. With all age groups, reaches following the pre-movement delay were characterized by longer movement durations, lower peak velocities, larger peak grip apertures and longer time spent in the final slow phase of the movement. The results suggested that the representations that control the transport and grasp component are affected similarly by delay, and is consistent with the results previously reported for adults. The researchers concluded that such representations appear to develop before the age of 5.

In regard to visual background (VB) information in the form of allocentric cues, research has shown that it facilitates visually-guided actions (Coello & Greally, 1997; Velay & Beaubaton, 1986) and enhances the kinematics of reach movements (e.g., peak velocity) to a memory-guided target (Carrozzo et al., 2002; Lemay et al., 2004). In essence, egocentric and allocentric visual frames can be integrated to facilitate the accuracy of goal-directed reach movements. One limitation of the studies cited is that none addressed whether or not VB facilitates or impedes the accuracy of visually-guided and memory-guided actions performed across different delay intervals. Diedrichsen et al. (2004) used a delay paradigm to address this issue in part by investigating the effect of scene-based (allocentric) information on memory-guided pointing actions. The researchers concluded that “non-target landmarks” played an important role in the encoding of target position, resulting in better performance. However, this study did not examine the affect of allocentric cues on visually-guided (i.e., real-time) actions. Krigolson and Heath (2004) addressed this problem by examining the kinematics and the endpoint accuracy in visually-guided *and* memory-guided reaching conditions (i.e., with delay) with and without background cues. Their results indicated that VB cues provide allocentric information about the target location that can be used in conjunction with egocentric limb, visual background, and visible or stored target information to facilitate online control processes. In 2005, Obhi and Goodale reported similar results after examining the effects of non-target landmarks on accuracy of immediate and delayed target-directed pointing movements. Unique to this study was that the allocentric cues were present just prior to and during presentation of the target, never during movement execution. Results indicated that participants displayed significantly less error when landmarks were available during target presentation in delayed and immediate action conditions. In regard to the precision of movements, landmarks improved performance in the delayed, but not in the immediate condition. The researchers concluded that the landmark effect appeared to be in the encoding of target position and that when available, this information is used to improve accuracy of the *estimation* of target location; a point that has direct implications for the present study. Moreover, it appears that dependence on landmark information becomes more critical as the movement is delayed. In a more current study involving reach actions, one that touched on the intent of the experiment presented here, Coello and Iwanow (2006) found that textured background influenced cognitive (distance estimation) and sensorimotor coding of target information. For distance estimation, responses were closer to actual reach in the textured, compared to darkness condition. The authors went on to conclude that visual processing for perception and action cannot be dissociated from contextual influence. However, that study did not include a delay condition. To our knowledge, no experiments with children have been reported.

Motor imagery is used with each of the three experiments described in this paper; a paradigm that we have tested and published using adults and children (see subsequent section). Our specific interest is the usefulness of imagery in understanding the programming of reach actions. As noted earlier, one of the initial steps in programming reach is to derive a perceptual *estimate* of the object's distance and location relative to the body. Motor imagery also known as kinesthetic imagery, has been described as an active cognitive process during which the representation of a specific action is internally reproduced in working memory without any overt motor output (Decety & Grezes, 1999).

Jeannerod (1997, 2001) contends that *MI provides a window into the process of action representation*; that is, it reflects an unconscious internal action representation, or internal model of volitional movements. And, perhaps more important, MI is therefore a conscious equivalent to a prediction and consequence for that action (e.g., Johnson, 2001; Kosslyn et al., 2001). These representations, that are associated with forward models, are hypothesized to be an integral part of action planning (Choudhury et al., 2007; Miall & Wolpert, 1996). Furthermore, Steenbergen et al. (2007) suggests that MI may be a necessary prerequisite for motor planning. From another view, MI represents a form of motor cognition. That is, the cognitive level of action processing. Motor cognition takes into account recognizing, anticipating, predicting and producing actions.

In addition to the reasonable case that MI is a reflection of action representation and motor planning, justifying the use of this technique are several reports suggesting that there is a high correlation between real and imaged movements (e.g., Gonzalez et al., 2005; Michelon et al., 2006; Sabate et al., 2004). Furthermore, evidence has been reported showing that MI follows the basic tenets of Fitts' Law (Solodkin et al., 2004; Steven, 2005). Stevens (2005) contends that MI represents the kinesthetic and biomechanical constraints connected with action, associated with the dorsal stream. The notion that MI elicits corticomotor excitability associated with action was supported by recent work of Filimon et al. (2007), Neuper et al. (2005), and Stinear et al. (2006). Furthermore, Holmes and Sholl (2005) and Milner & Goodale (2004) report that egocentric frames for visually guided action are coded within the dorsal stream.

A form of MI is *estimating (perceived) reachability*, which involves the perceptual / cognitive judgment of whether an object is within or out of our grasp. Partial support for use of this tactic in understanding action representation and planning is found in an excellent treatise on the issue by Coello et al. (2007). Although considerable research has involved children in reaching studies, few reports have addressed action processing in the context of verbally estimating reachability. Several reports using infants hint at the suggestion of perceived reachability, however, *the obvious inherent limitation of such studies is the problem with determining the level of cognitive processing involved in estimation of reachability*. Arguably, the use of reaching contacts, forward lean, and gaze, are not ideal for addressing the issue of motor cognition. A review of work involving older children and adults reveals a common finding that both groups tend to *overestimate* their reaching abilities; that is, individuals tend to perceive that objects are within reach, when actually they are out of grasp (children: Gabbard et al., 2007a; Rochat, 1995; Schwebel & Plumert, 1999; adults: Coello & Iwanow, 2006; Fischer, 2000; Gabbard et al., 2005b, c; Robinovitch, 1998; Rochat & Wraga, 1997). Furthermore, there is evidence that this overestimation bias is greater in children (Gabbard et al., 2007a).

Purpose of the Study

The primary intent of the present study was to gain insight into children's ability to use visual information in planning reaching movements. To this end, the study explored, from a developmental perspective, the use of visual information in action processing via estimating reachability among children ages 5- to 12 years and young adults. More specifically, the experiments addressed the following objectives:

To determine the age-related ability to use allocentric and egocentric cues with action planning (estimating reach).

To ascertain the effects of visual background (non-target landmarks) on estimation of reachability (combination of allocentric and egocentric cues).

To address these objectives, three experiments were designed using an immediate (visually-guided) and delayed (memory-guided) paradigm.

Experiments 1 and 2 explored the perception and action dynamics involved in action processing via estimating reach using egocentric and allocentric frames of reference. Although our attention focuses on the age-related ability to use allocentric and egocentric information in motor planning, we are also interested in the distinctiveness of each and perhaps most important, their *interactive role* in action processing. Research questions addressed were: How well do children (compared to adults) use allocentric cues to estimate the location of objects in a reaching paradigm? Is there a difference between immediate (visually-guided) and delayed (memory-based) responses? Can children use target information to establish egocentric coordinates in estimating reachability? From these questions, some speculation may be established in regard to ventral and dorsal visual stream processing in motor (action) planning.

Experiment 3 examined the effect of visual background cues (non-target landmarks) on estimates of reach. In other words, we wanted to determine if additional allocentric information around a target improves visually-guided and memory-guided estimation accuracy. From another perspective, can egocentric and allocentric visual frames of reference be integrated to facilitate the accuracy of reachability [distance] estimation? Past work with adults in an actual movement paradigm has shown that introducing a visual structure around a target enhances the accuracy of goal-oriented actions. Research questions addressed were: Does visual background surrounding a target effect estimation of reach in children compared to adults? Is there a difference between visually-guided and memory-guided responses?

General Method

Participants

A total of 83 participants were used for all experiments (1-3) representing age groups of 5- (n=17), 7- (n = 14), 9- (n = 18), 11- (n = 17) year-olds and a group of adults (n = 17). The mean ages for each group were 5.61, 7.72, 9.47, 11.36, and 21.53 respectively. All data collection took place at the Texas A&M University Motor Development Laboratory. Participants were recruited from Texas A&M University and the surrounding residential communities of Bryan / College Station TX via advertisements and personal communication with schools, guardians and summer camps held at the University. All participants were screened using a questionnaire (filled out by the parent) to ensure normal vision and that none have a history of past or present sensorimotor impairment. For the purposes of this study, only participants identified as strong right-handers via manual performance were selected. That is, those for whom all items scored in the lateral direction using the Lateral Preference Inventory (Coren, 1993) were included in the investigation. All participants (and / or parent) signed the informed consent forms approved by our Institutional Review Board before beginning the experiment and were naïve to the hypotheses under investigation.

General Procedures (Experiments 1-3)

Testing for Experiments 1-3 required three approximate 30-minute sessions on separate days within a 3-week period. The experiment order was counterbalanced between participants and conditions were counterbalanced within experiments.

During the first session, hand preference and anthropometric measures were taken. Explanation of procedures was given at the beginning of each session along with a familiarization phase, which included either motor imagery or perceptual estimate training and practice trials. Prior to this study, pilot-testing was conducted to determine that the methodology used for each experiment was appropriate for the youngest children (5-year-olds). Testing was conducted during the spring and summer months.

CHAPTER II

EXPERIMENT 1: ESTIMATION OF REACH VIA EGOCENTRIC CUES

Introduction

In Experiment 1, we examined the ability of children to use an egocentric frame of reference to plan reaching movements via estimation of reach. This process was explored using an immediate (visually-guided) and response-delay (memory-guided) paradigm. Response-delay refers to the delay between stimulus presentation (visual information) and a cue to respond. This tactic involved the manipulation of temporal (time) constraints on estimation of reach using motor imagery. More specifically, this experiment aimed to examine the influence of visually-guided and response-delay on estimation of reach.

Our research question addressed the ability of children to use target information to establish egocentric coordinates in estimating reach using an immediate (visually-guided) and response-delay paradigm? According to Goodale et al. (2004), visuomotor processes responsible for action control (via egocentric cues as used in MI) seem to only retain information in real-time about the target. Therefore, our assumption was that at some point, delay should have an adverse affect on the perception of reach.

Method

Apparatus

A general illustration of the testing apparatus used to solicit perceived and actual reaching behavior is shown in Figure 1 and has been reported elsewhere with adults (Gabbard et al., 2007b; Gabbard et al., 2006; Gabbard et al., 2005a, b, c) and children

(Gabbard et al., 2008, 2007a). Actual maximum reach (used as the comparison) and imaged reach responses were collected via a projection system linked to a PC programmed with *Visual Basic*. Visual images were systematically projected onto a table surface at midline (90^o).

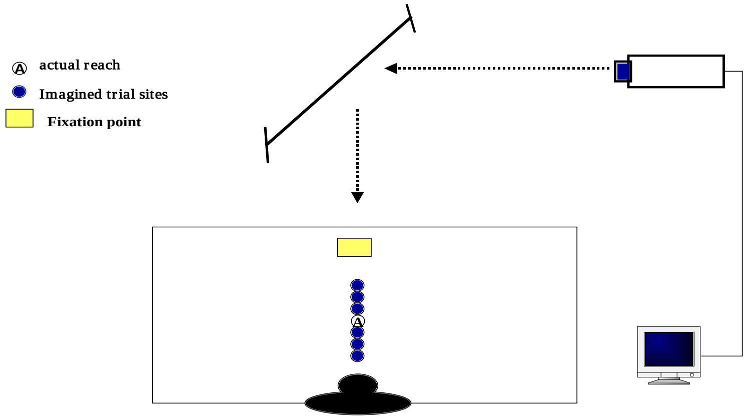


Figure 1. View of experimental set-up for Experiment 1.

The table was constructed on a sliding bracket frame, allowing it be moved back and forward for adjustment to the participant. Participants sat in an adjustable ergonomics chair fixed to the floor, aligned with the midline of the projected image. Seatpan height (surface is metal and nondepressive) was set to 105% of participant's popliteal height. Popliteal height was the distance from the underside of the foot to the underside of the thigh at the knees. Table height was then adjusted to the midpoint between seatpan height and seated eye height. Table and seatpan positioning were modified from Carello et al. (1989) and Choi and Mark (2004). To aid in establishing actual reach limitations for a 1-*df* action (described in the next section), a commercial seatbelt system was modified and secured to the back of the chair. The room was darkened with the exception of light from the computer monitor and visual images (color varies with experiment and condition) projected onto the table programmed with a gray background surface. The fixation point was projected onto a rectangular box (with a 45 degree angle surface) placed at midline approximately 45 cm from the most distal target.

Procedure

To begin, participants were systematically positioned in the chair and introduced to the task for determining 'actual' maximum reach - full extension of the right limb and middle finger to slide a penny forward using a 1-*df* reach (Carello et al., 1989). A 1-*df* reach involved a comfortable effort of the hand, forearm, and upper arm acting as a single functional skeletal unit. Based on maximum reach, seven imagery targets (2 cm diameter-penny size) were randomly programmed with '4' representing actual reach complemented with three image sites farther and three sites closer touching at the rims (Figure 1). In essence, actual reach is 'scaled' to individual arm lengths, therefore allowing acceptable comparison.

Participants were asked to focus while kinesthetically 'feeling' themselves executing the movement with the right limb – therefore being more sensitive to the biomechanical constraints of the task (MI) (Johnson et al., 2001; Sirigu & Duhamel, 2001; Stevens, 2005). The dominant (right) hand was placed within a drawn box on the table close to the torso at midline, while the nondominant limb rests on the participant's upper left thigh under the table. Prior to final data collection, participants were trained in the use of imagery techniques that we have reported in the literature (cited earlier for adults and children).

Four blocks of trials (conditions) were administered: no-delay with MI (M0), 1s delay with MI (M1), 2s delay with MI (M2), 4s delay with MI (M4). Conditions were counterbalanced between participants and each condition began with three practice trials. Data collection started with a 5s verbal “Ready!” signal – immediately followed by a central fixation point lasting 3s, at the end of which the participant hears a tone. In the no-delay conditions, participants were instructed to respond immediately.

Three trials at each of the seven target sites were presented randomly. No feedback was available to participants about the accuracy of performance. *As a precaution for general and especially eye fatigue due to fixation, the experimenter provided breaks between trials* (for all experiments). A second experimenter served to reinforce instructions regarding imagery technique and refocusing to the central fixation point with each trial (this procedure was also followed for all experiments). Testing required one approximate 30-minute session; four conditions. Each participant completed 84 trials in Experiment 1 (4 conditions X 21 trials = 84 trials).

Data Analysis

The focus of analysis was to determine each participant’s accuracy in estimating reachability (MI) at each of the randomly presented targets. The accuracy was based on their responses as to whether the target was reachable or not; as noted by a “Yes” or “No” response. The basis for being reachable was derived from the participant’s actual reach measurement. Given that the responses (yes or no) were categorical, frequency data analysis and chi-square procedures were used to compare the four conditions in regard to total and distribution of error across targets. Total error is described as the percentage (proportion rounded to the nearest whole number) of wrong responses in relation to total trials for each condition. That is, when the participants responded "no" when actually, the target was within reach, or "yes" when in fact, the target was out of reach. The reader should keep in mind that there were seven target sites with target '4' representing the participant's actual maximum reach. Incorrect responses at the three targets above (distal to) actual reach (5 – 7) indicate an overestimation, while incorrect responses at any of the lower (proximal) targets (1 – 4) was an underestimation. For example, if a participant notes that target 5 was reachable ('yes') when in fact it was not, it is an overestimation.

To determine the general direction of error in terms of mean bias (i.e., over- or underestimation), descriptive statistics and analysis of variance (ANOVA) procedures with Duncan's post hoc tests ($p < .05$) were employed to determine estimates of error. That is, data was given a positive or negative sign and then summed to provide a signed mean. Zero on the y- axis represents no error, whereas a minus value corresponds to an underestimation and above zero an overestimation.

Results

Total Error (Within Group)

The first step in the analysis was to look within each age group across conditions comparing total error. Chi-square analyses indicated a significant difference with the 5- and 7-year-olds (Figure 2). With 5-year-olds, the difference was between the M0 (20%), M2 (36%), and M4 (43%) conditions; values were $\chi^2_{(1)} = 5.58$, $p < .01$ and $\chi^2_{(1)} = 11.22$, $p < .001$ respectively. The 5-year-olds were also different between M1 (24%) and M4 (43%), with $\chi^2_{(1)} = 7.27$, $p < .01$. With 7-year-olds, the only difference was between M0 (19%) and M4 (36%), $\chi^2_{(1)} = 6.42$, $p < .05$.

There were no significant differences with the 9-year-olds, 11-year-olds and adults on any of the conditions. The values (%) ranged from 16 to 25 for the 9-year-olds, 15 to 23 for 11-year-olds, and 14 to 20 for the adults (Figure 2).

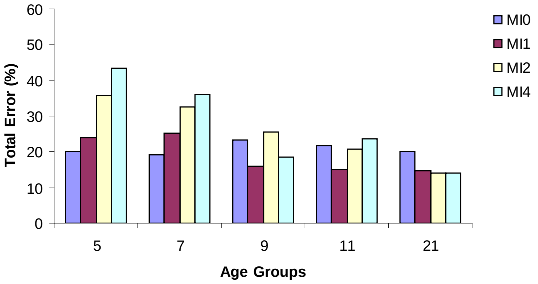


Figure 2. Percentage of total error for egocentric task. M0 = no-delay, M1 = 1s delay, M2 = 2s delay, M4 = 4s delay.

Distribution of Error (Within Group)

To determine where the errors occurred, we analyzed the distribution of errors across targets within each condition. Profiles of the error distributions in Figure 3 show that most of the error occurred at target 5 for children. With adults, the highest frequency of error occurred at target 4 except in the M2 condition. A more detailed list of distribution values can be seen in Appendix A.

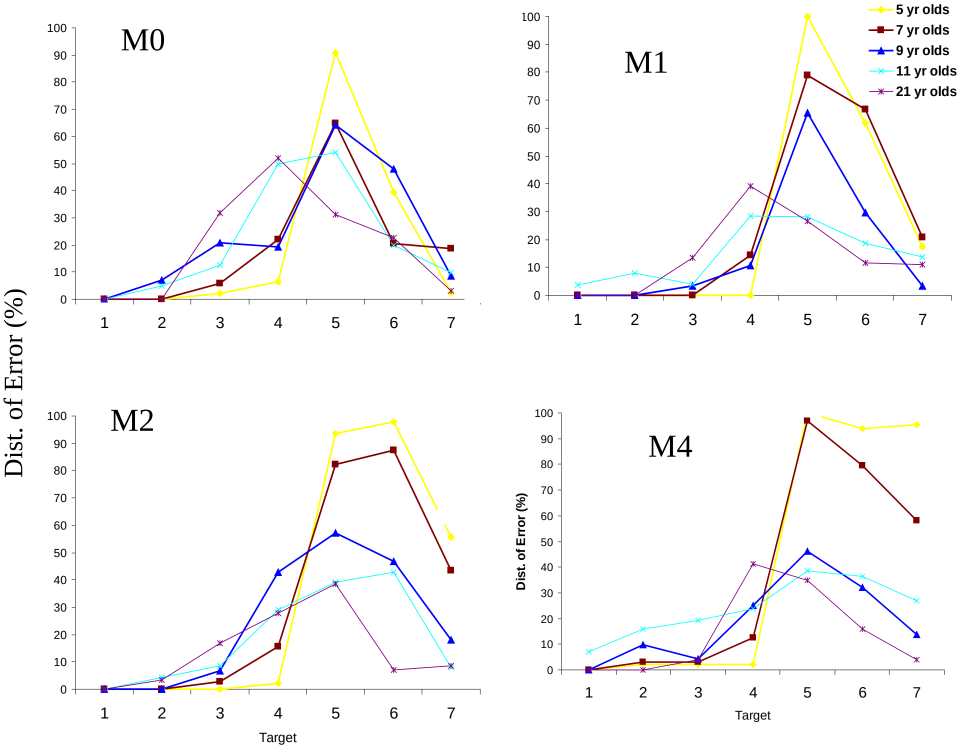


Figure 3. Percentage of distribution error for egocentric task. M0 = no-delay, M1 = 1s delay, M2 = 2s delay, M4 = 4s delay.

Mean Bias (Within Group)

In regard to the general direction of error (mean bias in cm) within each of the conditions, the one-way ANOVAs indicated a significant main effect of age (M0, $F_{(4,78)} = 2.98$, $p <= .05$; M1, $F_{(4,78)} = 8.91$, $p < .0001$; M2, $F_{(4,78)} = 16.64$, $p < .0001$; M4, $F_{(4,78)} = 20.77$, $p < .0001$) (Figure 4). Post hoc analysis indicated that within the M0 condition, the 5- ($M = 0.54$; $SD = 1.08$) and 7-year-olds ($M = 0.36$, $SD = 1.04$) were different from the adults ($M = -0.08$; $SD = 1.20$). In M1, 5-year-olds ($M = 0.81$; $SD = 1.5$) were different from 9-year-olds ($M = 0.40$; $SD = 1.07$), 11-year-olds ($M = 0.25$; $SD = 1.31$) and adults ($M = 0.06$; $SD = 1.06$). Also within M1, analysis revealed that 7- ($M = 0.66$;

SD = 1.43) and 9-year-olds (*M* = 0.40; *SD* = 1.07) were different than 11-year-olds (*M* = 0.25; *SD* = 1.31) and adults (*M* = 0.06; *SD* = 1.06).

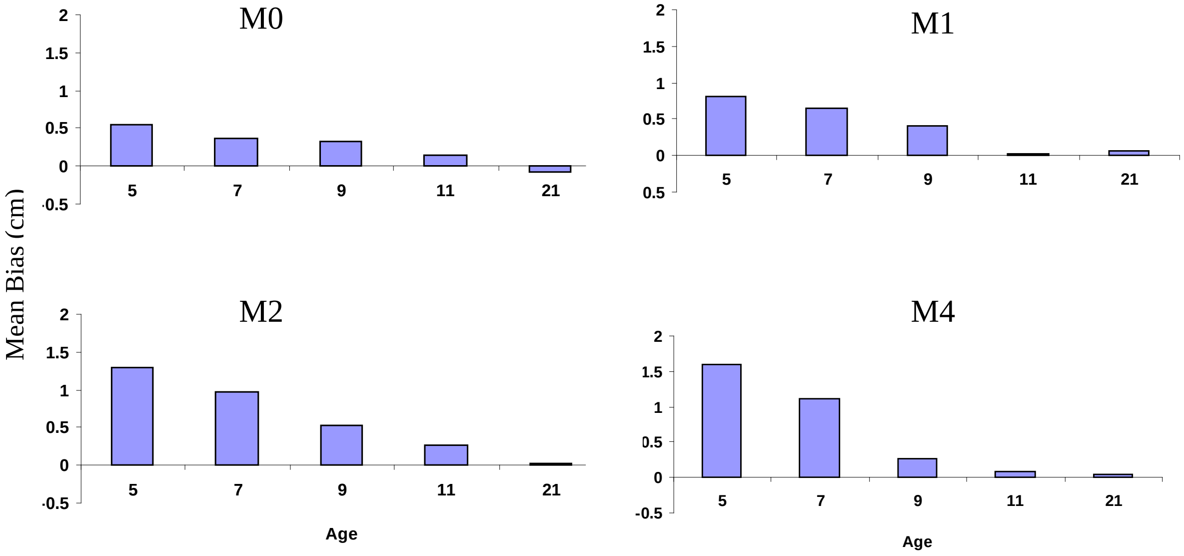


Figure 4. Mean bias by condition for egocentric task. M0 = no-delay, M1 = 1s delay, M2 = 2s delay, M4 = 4s delay.

With the M2 condition, analysis revealed that 5- (*M* = 1.29; *SD* = 1.79) and 7-year-olds (*M* = 0.97; *SD* = 1.72) were different from 9-year-olds (*M* = 0.54; *SD* = 1.53), 11-year-olds (*M* = 0.26; *SD* = 1.13) and adults (*M* = 0.02; *SD* = 1.05). Also with the M2 condition, 9-year-olds (*M* = 0.54; *SD* = 1.53) were different from adults (*M* = 0.02; *SD* = 1.05) (Figure 4).

In the M4 condition, results showed that 5- (*M* = 1.60; *SD* = 2.25) and 7-year-olds (*M* = 1.11; *SD* =1.91) were different from each other and each were different from the older groups (9-year-olds, *M* = 0.26; *SD* = 1.48, 11-year-olds, *M* = 0.08; *SD* = 2.01, and adults *M* = 0.05; *SD* = .91; (Figure 4)).

Space (Within Group)

Now our attention shifts to peripersonal (target 1-4, within reach) and extrapersonal (target 5-7, beyond reach) space within conditions. Chi-square analysis revealed that with the M0 and M1 conditions, 5-, 7-, and 9-year-olds had differences between peripersonal and extrapersonal space (Figure 5). The differences ($\chi^2_{(1)}$ with *ps* < .01) for space in the M0 condition were as follow: 5-year-olds (peri- = 2%, extra- = 44%) = 47.46; 7-year-olds (peri- = 7%, extra- = 35%) = 21.97; and 9-year-olds (peri- = 12%, extra- = 40%) = 18.95. In the M1 condition, the differences ($\chi^2_{(1)}$ with *ps* < .01) for space within age groups were: 5-year-olds (peri- = 0%, extra- = 60) = 82.88; 7-year-olds (peri- = 4%, extra- = 55%) = 60.10; and 9-year-olds (peri- = 4%, extra- = 33%) = 26.00.

Analyses also showed that children were significantly different in the M2 and M4 conditions between peripersonal and extrapersonal space: M2 values were ($\chi^2_{(1)}$ with *ps* < .01); 5-year-olds (peri- = 1%, extra- = 82%) = 131.81; 7-year-olds (peri- = 5%, extra- = 71%) = 89.67; 9-year-olds (peri- = 12%, extra- = 41%) = 20.13; and 11-year-olds (peri- = 11%, extra- = 30%) = 9.94. In the M4 condition, the chi-square values were ($\chi^2_{(1)}$ with *ps* < .01): 5-year-olds (peri- = 2%, extra- = 96%) = 173.05; 7-year-olds (peri- = 5%, extra- = 78%) = 106.77; 9-year-olds (peri- = 10%, extra- = 34%) = 12.27; and 11-year-olds (peri- = 17%, extra- = 34%) = 6.74.

Chi-square analysis revealed that there was no significant difference between conditions in peripersonal space. However, when viewing extrapersonal space, differences emerged (Figure 6). The differences between conditions for 5-year-olds were ($\chi^2_{(1)}$ with *ps* < .01): M0 from M1 = 4.51, M2 = 29.37, and M4 = 61.93; M1 from M2 = 10.71, and M4 = 35.69; and M2 from M4 = 8.63. For 7-year-olds, analysis revealed differences which were ($\chi^2_{(1)}$ with *ps* < .01): M0 from M1 = 7.29; M0 from M2 = 24.59; M0 from M4 = 35.89; M1 from M2 = 4.83, and M1 from M4 = 10.86.

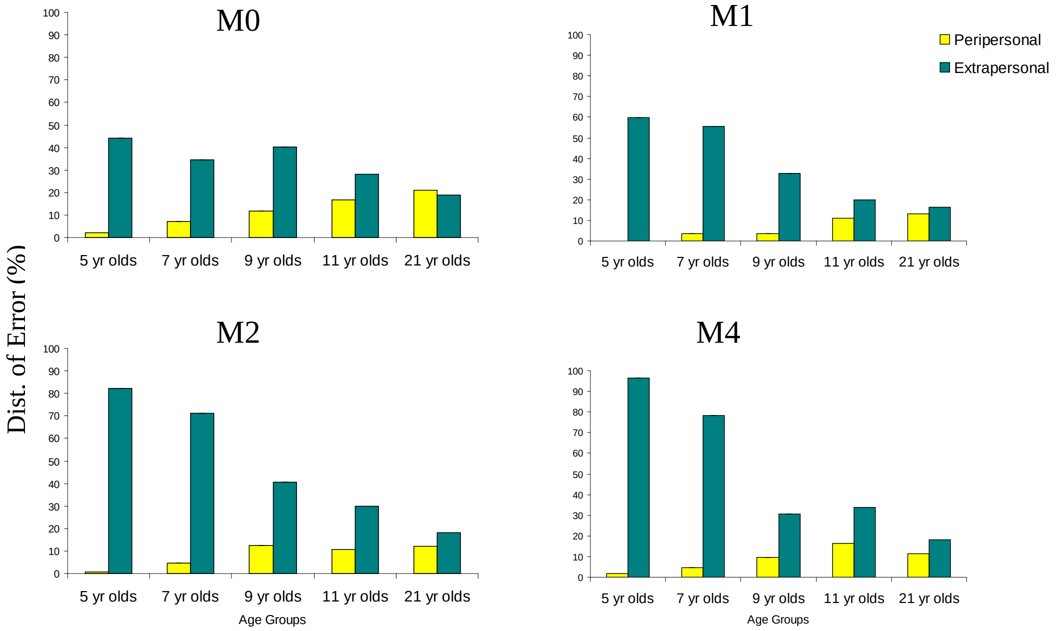


Figure 5. Percentage of mean error by space for egocentric task. M0 = no-delay, M1 = 1s delay, M2 = 2s delay, M4 = 4s delay.

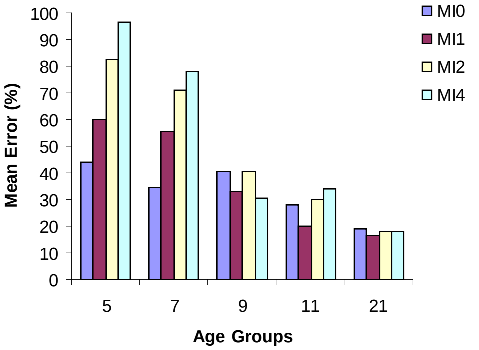


Figure 6. Percentage of mean error by extrapersonal space for egocentric task. M0 = no-delay, M1 = 1s delay, M2 = 2s delay, M4 = 4s delay.

Total Error (Between Group)

Regarding total error between groups, there were no differences between the M0 (ranging from 19% to 23%) and M1 (ranging from 15% to 25%) conditions as shown in Figure 2. In other words, 5-year-olds were not different from the other age groups between the conditions just mentioned.

In reference to total error between groups in the M2 condition, chi-square analysis revealed differences between 5-year-olds (36%), 11-year-olds (21%) and adults (14%); $\chi^2_{(1)} = 3.85$, $p <. 05$; $\chi^2_{(1)} = 11.76$, $p < .001$ respectively. Also, 7-year-olds (32%) were different from adults, ($\chi^2_{(1)}= 8.16$, $p < .01$) (Figure 2). The analysis also showed differences between groups in the M4 condition; 5-year-olds (43%) were different from 9-year-olds (19%), 11-year-olds (23%) and adults (14%). The comparative results for 5-year-olds to the age groups just mentioned were ($\chi^2_{(1)}$ with *ps* < .01): 12.37, 8.16 and 19.24 respectively. The analysis also revealed that 7-year-olds (36%) were different from 9-year-olds ($\chi^2_{(1)} = 6.42$, $p < .05$) and adults ($\chi^2_{(1)} = 14.04$, $p < .001$).

Distribution of Error (Between Group)

Concerning distribution of error, only targets 4 (actual maximum reach) and 5 will be addressed; at these targets most of the errors occurred with all groups. From another perspective, this area represents the commonly observed ‘critical boundary’ in regard to the perception of maximum reach. The distribution of error across age groups in the M0 condition showed that 5-year-olds were different from the rest of the age groups at target 4. The chi-square values for 5-year-olds and the other age groups were ($\chi^2_{(1)}$ with *ps* $< .01$): 7-year-olds = 7.91, 9-year-olds = 5.35, 11-year-olds = 43.28, and adults = 46.54.

Also with target 4, 7-year-olds were different from 11-year-olds $\chi^2_{(1)} = 15.82$, $p < .0001$ and adults $\chi^2_{(1)} = 18.04$, $p < .0001$. The results for the 9-year-olds showed that they were different from 11-year-olds ($\chi^2_{(1)} = 19.91$, $p < .0001$) and adults ($\chi^2_{(1)} = 22.36$, $p < .0001$). Examining target 5, analysis showed that 5-year-olds were different from all other groups; values were ($\chi^2_{(1)}$ with *ps* $< .01$): 7-year-olds = 18.21; 9-year-olds = 19.38; 11-year-olds = 32.50; and adults = 73.16. Finally in the M0 condition, results showed that 7-year-olds were significantly different from adults ($\chi^2_{(1)} = 21.82$, $p < .0001$).

The distribution of error across age groups in the M1 condition showed that at target 4, 5-year-olds were different from the rest of the age groups; values were ($\chi^2_{(1)}$ with *ps* $< .01$): 7-year-olds = 12.98; 9-year-olds = 9.62; 11-year-olds = 31.62; and adults = 446.00. Also with target 4, 7-year-olds were different from 11-year-olds $\chi^2_{(1)} =$

5.81, $p < .05$ and adults $\chi^2_{(1)} = 14.79$, $p < .0001$. The 9-year-olds were also different from 11-year-olds $\chi^2_{(1)} = 9.03$, $p < .01$ and adults $\chi^2_{(1)} = 19.44$, $p < .0001$.

Examining target 5, the results showed that 5-year-olds were different from the other groups; values were ($\chi^2_{(1)}$ with $ps < .01$): 7-year-olds = 21.28; 9-year-olds = 38.59; 11-year-olds = 109.40; and adults = 111.83. Also for target 5, results revealed that 7-year-olds were different from 11-year-olds ($\chi^2_{(1)} = 50.25$, $p < .0001$) and adults ($\chi^2_{(1)} = 52.21$, $p < .0001$). The results also showed that 9-year-olds were different from 11-year olds and adults ($\chi^2_{(1)} = 27.48$, $p < .0001$; $\chi^2_{(1)} = 29.02$, $p < .0001$ respectively).

Concerning target 4 in M2, results showed that 5-year-olds were different from the rest of the age groups; values were ($\chi^2_{(1)}$ with $ps < .01$): 7-year-olds = 10.32 , 9-year-olds = 45.88; 11-year-olds = 25.81; and adults = 24.51. The 7-year-olds were also different from 9-year-olds $\chi^2_{(1)} = 16.25$, $p < .05$ and 11-year-olds $\chi^2_{(1)} = 4.13$, $p < .05$ at target 4. With 9-year-olds, the difference was with 11-year-olds $\chi^2_{(1)} = 4.28$, $p < .05$.

Examining target 5 in M2, the analysis revealed that 5-year-olds were different from all age groups; values were ($\chi^2_{(1)}$ with $ps < .0001$ unless otherwise noted): 7-year-olds = 4.57, $ps < .05$; 9-year-olds = 32.67; 11-year-olds = 62.59; and adults = 64.52. Also for target 5, results showed 7-year-olds to be different ($\chi^2_{(1)}$ with $ps < .0001$) from 9-year-olds, 11-year-olds, and adults, values were: 9-year-olds = 13.59; 11-year-olds = 36.91; and adults = 38.52. The 9-year-olds were also different from 11-year-olds and adults ($\chi^2_{(1)} = 5.79$, $p < .05$; $\chi^2_{(1)} = 6.50$, $p < .05$ respectively).

For the last condition, M4, the results showed 5-year-olds to be different from the other groups, values were ($\chi^2_{(1)}$ with $ps < .01$): 7-year-olds = 7.21; 9-year-olds = 20.72;

11-year-olds = 19.50; and adults = 42.78 concerning target 4. The 7-year-olds were also different from 9-year-olds $\chi^2_{(1)} = 3.93$, $p < .05$ and adults $\chi^2_{(1)} = 18.49$, $p < .0001$. The 9- and 11-year-olds were different from adults $\chi^2_{(1)} = 5.09$, $p <. 05$ and $\chi^2_{(1)} = 5.84$, $p < .05$ respectively.

Examining target 5 in M4, analysis revealed that 5-year-olds were different from all age groups except for 7-year-olds; values were ($\chi^2_{(1)}$ with *ps* < .0001): 9-year-olds = 71.26; 11-year-olds = 86.98; and adults = 93.36. Also results for target 5 showed 7-year-olds were different ($\chi^2_{(1)}$ with *ps* < .0001) from 9-year-olds, 11-year-olds, and adults, values were: 61.34; 76.67; and 82.91 respectively.

Mean Bias (Between Group)

In regard to mean bias (cm), the 4 x 5 (Condition [M0, M1, M2, M4]) x Age groups [5-, 7-, 9-, 11-year-olds, and adults]) ANOVA results revealed a main effect for Condition by Age groups ($F_{(19, 309)} = 12.19$, $p < 0.0001$). Post hoc analysis showed that within the 5-year-olds, condition M4 and M2 were different from the M0 and M1 (Figure 7). Concerning 7-year-olds, the M0 condition was different from M2 and M4.

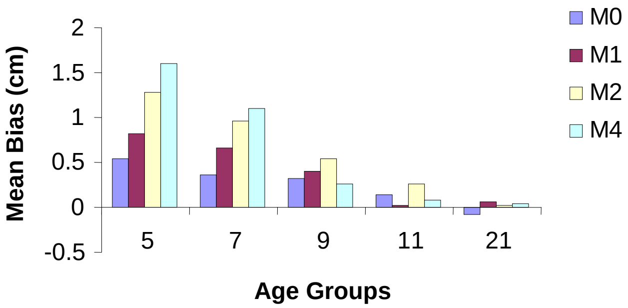


Figure 7. Mean bias between groups for egocentric task. M0 = no-delay, M1 = 1s delay, M2 = 2s delay, M4 = 4s delay.

Discussion

Our intent with Experiment 1 was to investigate the ability of children to use an egocentric frame of reference to plan reaching movements via estimation of reach. Stated differently, how well do children use target information to establish egocentric coordinates in estimating reach in real-time (visually-guided) and response-delay (memory-guided) conditions? Our assumption was that at some point, delay should have an adverse affect on the perception of what is within reach based on work from Goodale et al. (2004) and Bradshaw et al. (2002, 2004).

Our findings support the notion that delay affects the perception of what is within or out of reach. *The first key finding showed clearly that introducing a response-delay* (M2 and M4) *affected estimation of reach* (total error) *among the two younger age groups* (5- and 7-year-olds) *concerning total error* (Figure 2). Our second key finding revealed that children overall, displayed the most error at target 5, and as delay increased (M2 and M4), error increased, while with adults, most error occurred at target 4 (Figure 3).

In regards to what amount of delay hinders performance, our data indicated that a 2s delay (M2) was sufficient for decrements to be seen for 5- and 7-year-olds but not for the older children (9- and 11-year-olds) and adults with total error. The older children and adults had similar percentage of total error with the ≥ 2s. With the shorter delays (no-delay and 1s delay) there were no differences among age groups, indicating that children and adults have similar estimation responses in real-time and when target information was relatively still available, via egocentric frame (dorsal stream).

As regards to the first finding, our data supports previous studies (Goodale et al., 2004; Bradshaw et al., 2002, 2004) that indicated a delay affects visuomotor responses. Although previous studies used an actual reaching paradigm and our study used a motor imagery (MI) paradigm, literature indicates that there is a high correlation between motor imagery and movement execution. Therefore, similarities between MI and actual movement execution were evident. Our results support previous data showing that delays have an affect on movement execution (Bradshaw et al., 2002, 2004) and confirm the high correlation between MI and actual movement execution.

In Bradshaw and colleagues study, children (5- 11 years) made visually open-loop reaches either immediately or after a 2s occlusion, to two different sized objects at two varying distances along the midline. The study concluded that the visuo-motor system performance was affected by a 2s delay, just as our MI data showed for the younger children (5- and 7-year-olds). *However, our older age group data (9- and 11-year-olds and adults) did not support Bradshaw's findings (not an expectation)*. Why were there no differences for the older age groups as response-delay increased? The answer maybe that the results just mentioned are overall error, a more in-depth look is needed to illustrate where the errors are occurring (second key finding).

In regard to the second key finding, children had considerably more error at target 5, supporting previous studies showing that children in general overestimate in real-time (visually-guided responses) (Gabbard et al., 2007a; Rochat & Wraga, 1997; Schwebel et al., 1997). Previous studies with adults revealed an overestimation in visually-guided estimates; however, our adult data revealed an underestimation as delay increased (Fischer, 2005; Gabbard et al., 2005a, c). One possible explanation for what appears to be conflicting results with previous reports is that our adults may have used a more conservative strategy resulting in under- rather than over-estimation in the planning phase. Keep in mind that motor imagery is thought to be in the planning aspects of movement execution (pre-reflective). It has been suggested that individuals will underestimate in the planning phase and compensate as movement execution takes place (Coello et al., 2007; Lemay et al., 2004).

Mean bias data was supportive to the general observation that children were more likely to overestimate than adults. Why were there differences in the estimates of children and adults? One possibility may be explained by the visual information processing. It appeared that children were more accurate in ‘real time’ (egocentric frame) referencing as opposed to response-delay (allocentric frame) referencing. This finding suggests that children were unable to hold target information. There seems to be a developmental difference in the use of visual information via egocentric reference associated with dorsal stream processing.

In regards to space (peripersonal and extrapersonal), the adult data did not reach any level of significance across conditions. However, the childrens’ data revealed differences with space in each of the conditions. Children had considerably more error in extrapersonal space compared to peripersonal space as delay increased and as delay increased, the younger age groups (5- and 7-year-olds) became significantly different from the older age groups (9-year-olds, 11-year-olds and adults). These results suggest that younger children had difficulty in perceiving reachability after target information was no longer affordable.

In conclusion, these data indicate that children rely on an egocentric frame of reference for making estimates of reach and therefore are more susceptible to delay (Bradshaw et al., 2002, 2004; Rival et al., 2004). Speculatively, children as young as 5 years of age were capable of using egocentric cues via dorsal stream to make functional judgments of reachability in peripersonal space with minimal delay (M0 and M1), but as delay increased, differences emerged. One key explanation for the difference may lie in the fact that the perceptual system of children is not as mature for body scaling estimates in extrapersonal space, compared to adults (Hanisch et al., 2001; Rival et al., 2004). Another possible reason for the errors in extrapersonal space may be level of experience, confidence and spatial movement awareness (Coello et al., 2007). It appears from our data that children relied more on an egocentric frame of referencing and therefore after a 2s delay, there was a major temporal constraint on the representation of movement through the visouomotor stream (Goodale et al., 2004). Are children limited to only using egocentric frame of referencing? Can children use another form of referencing? Experiments 2 and 3 addressed these questions?

CHAPTER III

EXPERIMENT 2: PERCEPTUAL TASK

Introduction

In Experiment 2(abc) we examined the perceptual (object and location) properties associated with estimation of distances. These properties were explored via allocentric (perceptual) cues in real-time (visually-guided) and response-delay (memory-guided) conditions (as in Experiment 1). As mentioned earlier, theory suggests that the vision-for-perception and the vision-for-action processing streams operate under very different temporal constraints. The perceptual representation of the target and its surroundings are predominately memory-based and derived from allocentric cues. In other words, allocentric representation relates to targets coded as a function of the surrounding visual cues that are presumed to be independent from the participant's position (Blouin et al., 1993; Lemay & Porteau, 2003). This frame of referencing allows target location to be represented as a function of the surrounding visual cues and not to the relatively transient position of the body. In this respect, as long as the relation between the target and the context remains the same, the position of the observer may be changed because body position relative to the target is not important.

Some studies that have investigated the features of the allocentric frame of reference have used visual illusion paradigms. In these illusion studies, a target was embedded within a visual illusion like the Roeloff effect (Bridgemand, 1991) or the Müeller-Lyer effect (Gentilucci et al., 1996; Westwood, et al., 2000). In these illusion studies, participants are asked to remember the target position for a few seconds and subsequently point or grasp it. If target information is encoded in an egocentric frame of reference, the surrounding context and pointing accuracy should not be affected by the visual illusion. However, if the target is encoded with the surrounding context, allocentric frame of reference, a biased response should be observed (Rival et al., 2004; Hanisch, et al., 2001; Bridgemand et al., 2000; Gentilucci et al., 1996). It has been proposed by some that short recall delays (< 1s) are not (or is less) affected by visual illusions (Bridgemand, et al., 1997; Gentilucci et al., 1996) because target information is still available for an egocentric frame of reference (Glover & Dixon, 2001, 2002). However, for longer recall delays (> 2s), a context-dependent representation is remembered and possibly used to control movement (Bridgemnad et al., 1997) and the visual illusion emerges.

We intended to answer the following questions: How do children (compared to adults) use allocentric cues to estimate the location of objects in a perceptual estimation paradigm? Is there a difference between immediate (visually-guided) and delay (memory-based) responses? Based on the idea that the perceptual stream (via allocentric cues) has a memory component, we predicted performance after a delay would be constant for some period. In other words, there should be no differences after a 2s delay.

Method

Apparatus

The apparatus for this experiment was identical to the apparatus in Experiment 1 with the exception of the visual presentation (to be explained in the procedure section of this experiment) (Figure 2).

Procedure

In these experiments (abc), the use of visual imagery (VI) was required. In order to facilitate the use of VI, the participant’s limbs rested on their laps under the table. This position minimizes engagement of the effector (hand) when instructing the participant to give a ‘visual estimate’ of whether the target was reachable or not. That is, a visual estimate based on general location rather than in reference to the effector (hand). We hypothesized that thinking about one's own hand prompts motor simulation (MI) and an egocentric reference (mapping) to the target (wanted to disengage MI). Conversely, visual estimation with hands placed under the table will more likely activate ventral pathways via allocentric reference (the objective) and hence be less sensitive to biomechanical considerations (adopted from Sirigu & Duhamel, 2001; Stinear et al., 2006). We wish to emphasize that in contrast to MI, VI is linked with the spatial component of the perceived environment via the ventral stream. Furthermore, theory suggests that MI operates in real-time, whereas VI has a memory component; which is relevant to our delay paradigm.

With these experiments (abc), participants were asked to identify the location of the projected target (red) in reference to a cue target (blue target). For example, after the designated delay or no-delay, the participant would state “+2,” which is two targets above the cued target (see Figure 8 for this example). More specifically, in experiment 2a, three targets were presented distally (above) to the cued target (out of reach) and three were projected proximally (below) to the cued target (within reach). Experiment 2b had the same possible distances from blue target to red, but all target positions were within reach (peripersonal) whereas in experiment 2c, all target positions were out of reach (extrapersonal space).

Four blocks of trials (conditions) were administered in each of the variations of Experiment 2(abc) with the following delays: no-delay with PT (P0), 1s delay with PT (P1), 2s delay with PT (P2), and 4s delay with PT (P4). Conditions were counterbalanced between participants and each condition began with three practice trials. In general, data collection was similar to Experiment 1.

The participant’s responses were an estimate of the remembered location to a target; for example, -2 or +2 from cue target-blue. To begin, the blue target (max reach) appeared for 1s, then according to the specified delay (or no delay) a red target appeared for 1s, after which the participant responded. Three trials at each of the seven target sites were presented randomly. No feedback was available to the participants about the accuracy of performance as with the previous experiment. Testing required three approximate 30-minute sessions on separate days within a 2-week period; four conditions per session. Each participant completed 252 trials (12 conditions X 21 trials = 252 trials).

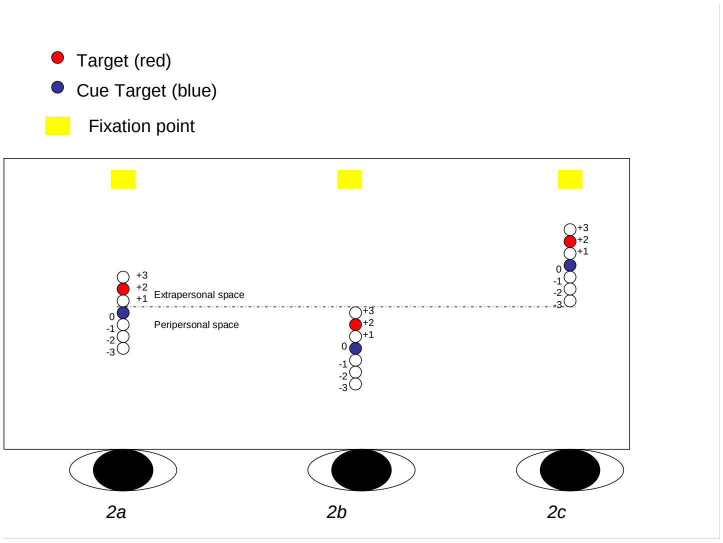


Figure 8. View of experimental set-up for Experiment 2. There were three variations, 2a represents four targets within reach and three out of reach; 2b represents all targets within reach; and 2c represents targets all out of reach.

Data Analysis

The focus of analysis was to determine each participant’s accuracy in estimating remembered location at each of the randomly presented targets. Responses corresponded to the numbered value ranging from –3 to +3. For comparative purposes with Experiment 1, total mean error was computed, that is, frequency data of wrong estimates (responses) for each of the target presentations. Also, chi-square procedures were used to compare the twelve conditions in regard to total error and distribution of error across targets.

As with the data analysis of Experiment 1, descriptive statistics and analysis of variance (ANOVA) procedures were employed. These values were derived from mean error (cm) - from actual distance (cue target-target). As appropriate, post hoc analyses using Duncan's Multiple Range tests were performed ($p < .05$).

Results

The results for each of the variations (abc) in Experiment 2 were not different from each other; therefore, for simplicity of presentation, the variations were combined. For example, the no-delay conditions in each of the variations were combined into one no-delay condition, and the same for the other conditions.

Total Error (Within Group)

As in the previous experiment, the first step of the analyses was to look within each age group across conditions comparing total error. Chi-square analyses indicated differences within all age groups (Figure 9). The difference ($\chi^2_{(1)}$ with $ps < .001$ unless otherwise noted) within the age groups were between the shorter delays (no-delay and 1s delay) to the longer delays (2s and 4s delays). For 5-year-olds, P0 (9%) was different from P2 (52%) and P4 (64%); values were: 41.61 and 62.91 respectively. Also with 5-year-olds, P1 (7%) was different from P2 and P4, values were: 46.54 and 68.48 respectively. With 7-year-olds the results showed that P0 (6%) was different from P2 (56%) and P4 (64%); values were 56.12 and 71.41 respectively. The 7-year-olds also showed differences between P1 (10%), P2 and P4; values were 45.79 and 60.25 respectively. The 9-year-olds, 11- year-olds and adults had similar results as the younger age groups. The results for 9-year-olds were: P0 (9%) from P2 (39%) 24.33 and P4 (54%) 44.86; and P1 (12%) from P2 17.79 and P4 38.01. The results for 11-year-olds were: P0 (7%) from P2 (40%) 28.48 and P4 (45%) 35.58; and P1 (7%) from P2 28.48

and P4 35.58. The results for adults values were: P0 (4%) from P2 (20%) 10.65 (*p* <. 01) and P4 (29%) 20.90; and P1 (7%) from P2 6.17 (*p* <.01) and P4 14.94.

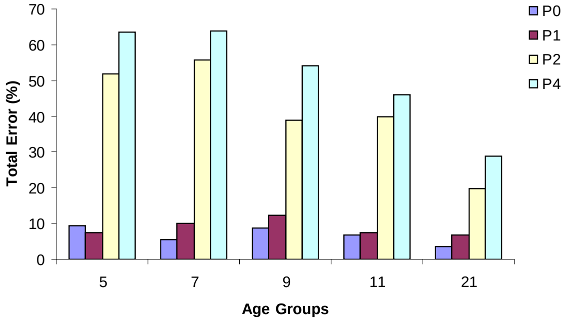


Figure 9. Percentage of total error for the perceptual task. P0 = no-delay, P1 = 1s delay, P2 = 2s delay, P4 = 4s delay).

Distribution of Error (Within Group)

The distribution of error across targets as evident in Figure 10 shows that most error occurred at the most distal targets from the cued target (target 4) in the two conditions with the longest delays (P2 and P4). There were no significant differences with age groups in the P0 and P1 conditions except for the 9-year-olds in the P0 and P1 condition ($\chi^2_{(1)} = 5.50$, $p < .05$). Table 1 shows the chi-square with the significance values within age groups across P2 and P4. A more detailed list of distribution values can be seen in Appendix B.

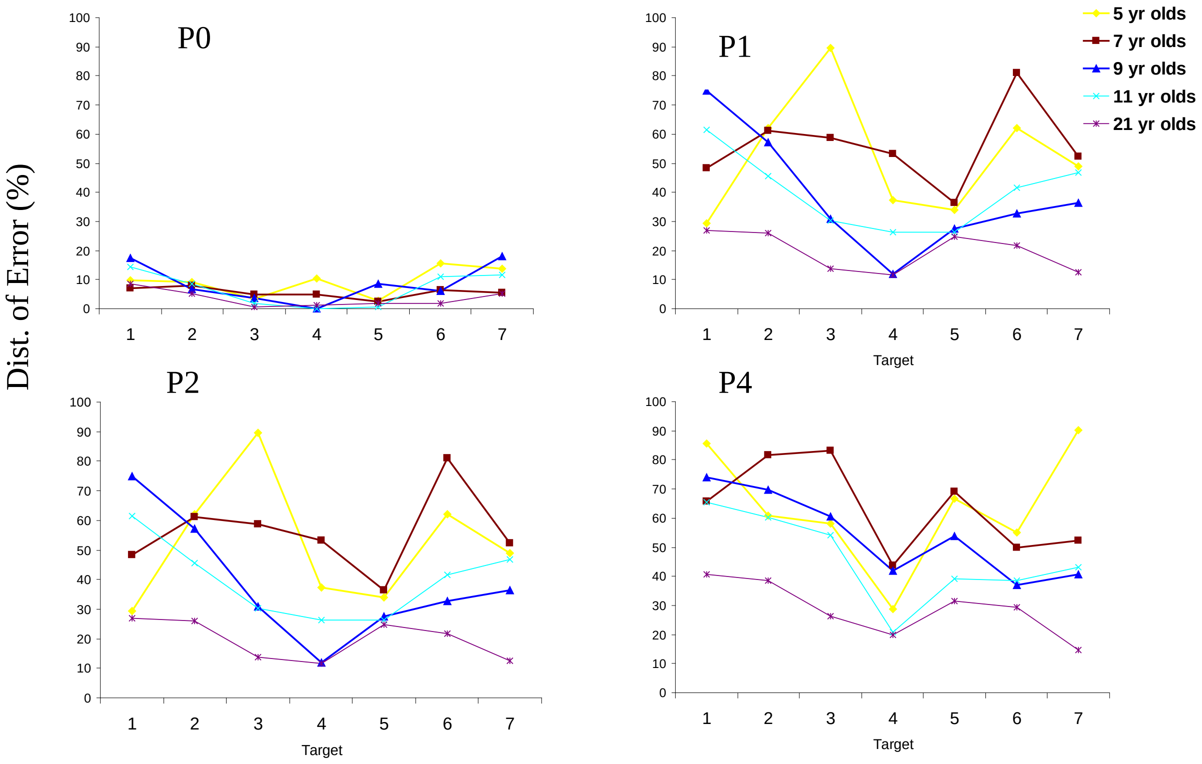


Figure 10. Percentage of distribution error for the perceptual task. P0 = no-delay, P1 = 1s delay, P2 = 2s delay, P4 = 4s delay.

Table 1. Chi-square values within age groups across targets for P2 and P4.

		Targets						
		1	2	3	4	5	6	7
Age	5	64.46 ***		24.97 ***		20.48 ***		37.74 ***
	7	5.896 *	9.82 *	12.85 **		19.3 ***	11.48 **	
	9			16.93 ***	21.33 ***	12.92 **		
	11			10.86 **				
	Adults							

*$p < .01$
**$p < .001$
***$p < .0001$

Mean Bias (Within Group)

In regards to the general direction of error (mean bias in cm), the one-way ANOVAs indicated a significant main effect of age within each of the following conditions (P0, $F_{(4,78)} = 3.70$, $p <= .01$; P2, $F_{(4,78)} = 42.31$, $p < .0001$; P4, $F_{(4,78)} = 20.82$, $p < .0001$) (Figure 11). Post hoc analysis indicated that within the P0 condition, 5-year-olds (*M* = 0.07; *SD* = 0.36) were different from 9- (*M* = -0.05, *SD* = 0.33) and 11-year olds (*M* = -0.03, *SD* = 0.37) and adults (*M* = -0.04; *SD* = 0.31). In the P1 condition, 7-year-olds (*M* = 0.05; *SD* = 0.38) were different from adults (*M* = -0.05; *SD* = 0.52).

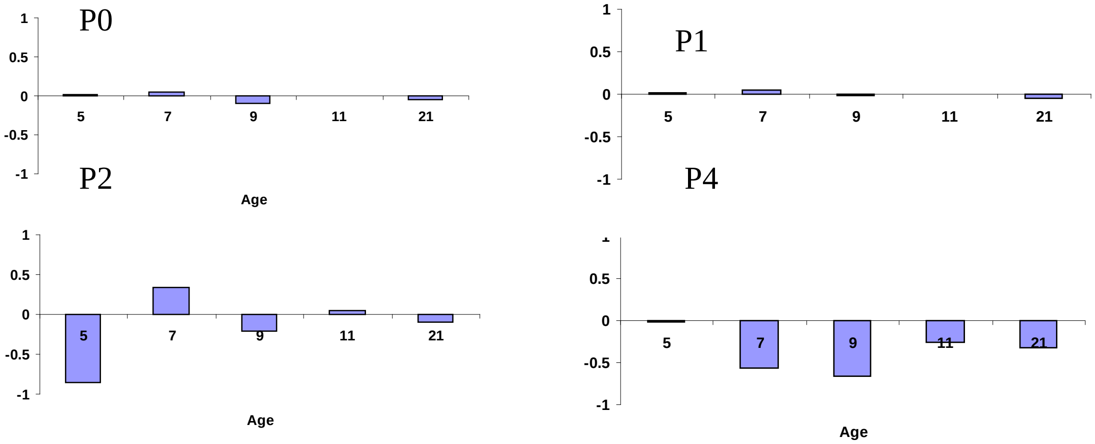


Figure 11. Mean bias by condition for the perceptual task. P0 = no-delay, P1 = 1s delay, P2 = 2s delay, P4 = 4s delay.

Within the P2 condition, post hoc analysis revealed that 5-year-olds (*M* = -0.82; *SD* = 0.95) were different from 7-year-olds (*M* = 0.33; *SD* = 1.38), 9-year-olds (*M* = -0.20; *SD* = 1.01), 11-year-olds (*M* = 0.05; *SD* = 0.94) and adults (*M* = -0.09; *SD* = 0.57). Also with the P2 condition, 7-year-olds (*M* = 0.54; *SD* = 1.53) were different from the rest of the age groups. The 9-year-olds were also different from 11-year-olds (*M* = 0.05; *SD* = 0.94) (Figure 11).

With the P4 condition, results showed that 5-year-olds (*M* = -0.02; *SD* = 1.43) were different from 7-year-olds (*M* = -0.57; *SD* =1.68), 9-year-olds (*M* = -0.66; *SD* = 1.02), 11-year-olds (*M* = -0.26; *SD* = 1.06), and adults (*M* = -0.33; *SD* = 0.63). The results also showed that 7- and 9-year-olds were different from 11-year-olds and adults (Figure 11).

Total Error (*Between Group)*

Regarding total error between groups, there were no differences in the P0 (ranging from 4% to 9%) and P1 (ranging from 7% to 12%) conditions as shown in Figure 9. In other words, the 5-year-olds were not different from the other groups in the PO and P1 conditions.

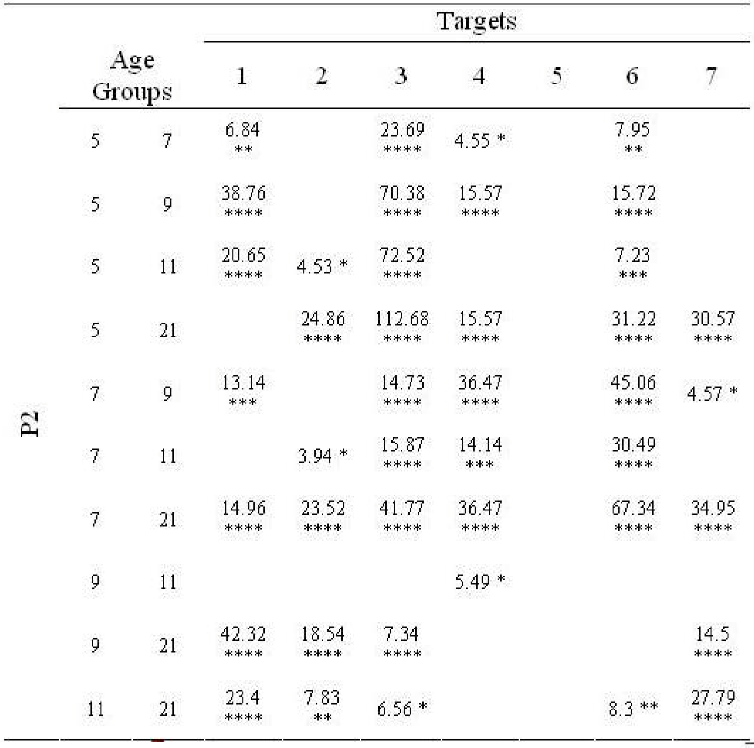
Concerning total error between age groups in the P2 condition, chi-square analysis revealed differences between 5-year-olds (52%) and adults (20%); $\chi^2_{(1)} = 20.86$, $p <. 0001$. Also, the 7-year-olds (56%) were different from 9-year-olds (39%); 11-year-olds (40%) and adults (20%); with chi-square values 5.13; 4.507; and 26.00 respectively (Figure 9). There were differences between the 9- and 11-year-olds and adults; values were 7.789 and 8.60 respectively. The analysis also showed differences between age groups in the P4 condition; 5- and 7-year-olds (64%, similar percentage) were different from 11-year-olds (46%) ($\chi^2_{(1)} = 5.84$, $p <.05$) and adults (29%) ($\chi^2_{(1)} = 23.23$, $p <$

.0001). The analysis also revealed that 9-year-olds (54%) and 11-year-olds (46%) were significantly different from adults; values were 11.86 and 5.46 respectively.

Distribution of Error (Between Group)

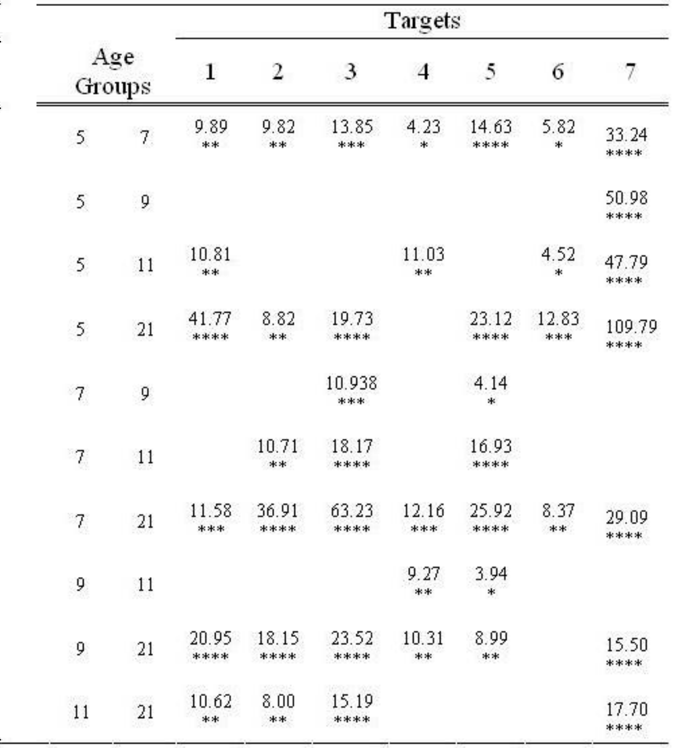
In reference to the distribution of error between groups across targets, the difference ($\chi^2_{(1)}$ with *ps* $< .05$ unless otherwise noted) in the P0 condition was between 5-year-olds and 7-, 9-year-olds and adults; values were 4.14, 4.14, and 10.32 ($p < .01$) respectively at target 6 (Figure 10). At target 7 in the P0 condition, the differences were between 7-year-olds ($\chi^2_{(1)} = 5.73$, $p < .05$) and adults ($\chi^2_{(1)} = 7.07$, $p < .05$). In P1, the differences between age groups were the 9-year-olds to 5- ($\chi^2_{(1)} = 12.78$, $p < .001$), and 11-year-olds ($\chi^2_{(1)} = 10.96$, $p < .001$) and adults ($\chi^2_{(1)} = 7.91$, $p < .01$). For simplicity of presentation, Table 2 provides the age groups that were different in the P2 and P4 conditions.

Table 2. Chi-square values between age groups for P2 and P4.



P2

Age Groups		Targets						
		1	2	3	4	5	6	7
5	7	6.84 **		23.69 ****	4.55 *		7.95 **	
5	9	38.76 ****		70.38 ****	15.57 ****		15.72 ****	
5	11	20.65 ****	4.53 *	72.52 ****			7.23 ***	
5	21		24.86 ****	112.68 ****	15.57 ****		31.22 ****	30.57 ****
7	9	13.14 ***		14.73 ****	36.47 ****		45.06 ****	4.57 *
7	11		3.94 *	15.87 ****	14.14 ***		30.49 ****	
7	21	14.96 ****	23.52 ****	41.77 ****	36.47 ****		67.34 ****	34.95 ****
9	11				5.49 *			
9	21	42.32 ****	18.54 ****	7.34 ****				14.5 ****
11	21	23.4 ****	7.83 **	6.56 *			8.3 **	27.79 ****



Age Groups		Targets						
		1	2	3	4	5	6	7
5	7	9.89 **	9.82 **	13.85 ***	4.23 *	14.63 ****	5.82 *	33.24 ****
5	9							50.98 ****
5	11	10.81 **			11.03 **		4.52 *	47.79 ****
5	21	41.77 ****	8.82 **	19.73 ****		23.12 ****	12.83 ***	109.79 ****
7	9			10.938 ***		4.14 *		
7	11		10.71 **	18.17 ****		16.93 ****		
7	21	11.58 ***	36.91 ****	63.23 ****	12.16 ***	25.92 ****	8.37 **	29.09 ****
9	11				9.27 **	3.94 *		
9	21	20.95 ****	18.15 ****	23.52 ****	10.31 **	8.99 **		15.50 ****
11	21	10.62 **	8.00 **	15.19 ****				17.70 ****

**p* < .05 ****p* < .001
***p* < .01 *****p* < .0001

Mean Bias (Between Group)

In regard to mean bias (cm), the 4 x 5 (Condition [M0, M1, M2, M4]) x Age groups [5-, 7-, 9-, 11-year-olds, and adults]) ANOVA results revealed a significant main effect for Condition by Age group ($F_{(19, 1896)} = 31.79$, $p < 0.0001$). Post hoc analysis showed that with P0 and P1, there were no differences with the age groups (Figure 12). The 11-year-olds and adults performed similarly in the P2 and P4 condition with the other age groups in the P1 and P0 conditions. The 5- and 7-year-olds in the P2 condition were different from all other age groups across conditions. The 11-year-olds and adults in P4 performed similarly to the 9-year-olds in the P2 condition. The 7- and 9-year-olds performed similarly in the P4 condition.

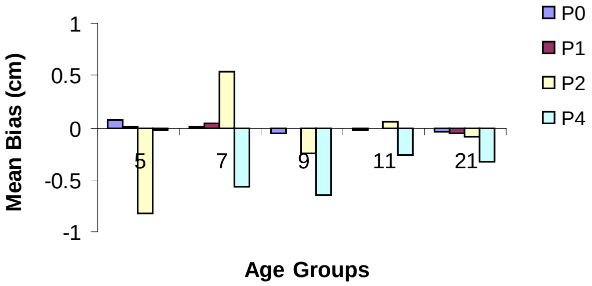


Figure 12. Mean bias between groups for the perceptual task. P0 = no-delay, P1 = 1s delay, P2 = 2s delay, P4 = 4s delay).

Discussion

Our intent with Experiment 2 was to investigate the ability of children to use allocentric cues to estimate the location of objects in a perceptual estimation paradigm using a response-delay. Our assumption was that since the perceptual stream (allocentric cues) has a memory component, performance after a delay would be constant.

Contrary to our assumption that performance would be constant after a delay, the findings clearly showed that introducing a response-delay (M2 and M4) affected the estimation of distance (total error) among all age groups (Figure 9) and more specifically affected the 5-year-olds.

Previous work by Lemay et al., (2004) suggested that when participants pointed to a remembered target, they had a more stable retention of target information due to the memory component associated with the frame of reference. Others have stated that if information is coded in an egocentric frame, the information is prone to decay over time (Vindras, et al., 1998; Wann & Ibrahim, 1992; Desmurget, et al., 2000). In comparison of the two types of referencing, when target information is maintained in an egocentric frame of reference, information might decay more rapidly than when information is kept in an allocentric frame of reference.

Our assumption was that if participants were to give perceptual estimates of how far one target was from another, estimates would be similar in increased delays. Our data contradicts this line of thought. Our data revealed that all age groups were affected by the longer delays (Figure 9 and 10). One possible explanation for the result is that participants were operating in an egocentric frame even though the task required a perceptual estimate. The task required participants to estimate distances from a cued target to another target. The experiment was set-up in a way that removed any referencing back to the individual (Carrozzo et al., 1999; McIntyre et al., 1998;

Soechting & Flanders, 1989a, 1989b; Vindras & Viviani, 1998). One can conclude that the task was indeed set-up for object to object (allocentric frame) comparisons. Another possible and likely explanation for the differences was that the task asked individuals to estimate distances, which according to the literature, operates in the dorsal stream (egocentric frame of reference). This might account for our data seeming to be contradictory to previous work. If this is the case and if children primarily operate in an egocentric frame (see previous experiment), it is understandable for the memory trace to be weak and/or decaying in longer delays. However, to our knowledge, no study comparing the decay of allocentric and/or egocentric information in children has been conducted to date.

Our distribution results indicated that more error was displayed with targets farthest away from the reference point. In other words, estimates for targets near the reference point were more accurate than the targets located farther from the reference point. It is reasonable that participants had a harder time determining the distance of a target that was farther away than one that was closer to the reference point. In addition, our distribution data showed that children as young as 5 years of age are capable of estimating distances as accurate as adults in real (no-delay) and 1s-delay. Previous work has shown that if a movement was initiated quickly following target extinction (< 2s), movement accuracy was less affected than when longer recall delays were used. It was likely that accuracy was not affected by the short delays because target information remained available in memory (Elliot & Calvert, 1990; Elliott & Madalena, 1987; Lemay & Poteau, 2002).

Our mean bias data also revealed that as delay increased, most participants underestimated the distance from targets to the cue target. More specifically, the results showed that as delay increased, the 5-year-olds became significantly different from the other age groups. It seems that they had the hardest time holding target information to make perceptual estimates of distances. Keep in mind that we only recorded estimates of distance from target to target, no actual reaching took place. It has been proposed by some (Glover & Dixon, 2001, 2002) that movement planning is based on a context-dependent visual representation. In other words, our task involved the planning phase and therefore it is reasonable that participants underestimated distances, a strategy that emerged in Experiment 1.

In conclusion, it appears that our major assumption was incorrect. Children and adults were susceptible to decay of memory in a perceptual task that asks participants to estimate distances. Children as young as 5 years of age, like adults, displayed similar error in minimal delays when giving verbal estimates. However, more research is needed to compare the decay of allocentric and egocentric information in children and adults (Experiment 3).

CHAPTER IV

EXPERIMENT 3: VISUAL BACKGROUND

Introduction

The aim of Experiment 3 was to test whether a visual background (VB) surrounding a target affected the estimation of reach in children. In other words, will combining egocentric and allocentric visual frames of reference facilitate the accuracy of goal-directed reaching movements - in our case, accuracy in estimating reach. As noted in the review of literature, with actual movement tasks, VB information (allocentric cues) facilitated memory-guided actions. The study presented here builds on this work by examining the effects of non-target landmarks on estimation of reach via motor imagery. More specific, our intent was to examine whether or not VB information can facilitate visually-guided and memory-guided estimations of reach. Is there a difference between visually guided and memory-guided responses? For the delay conditions, we predicted that participants would perform better (less error) with a VB compared to no VB (Experiment1). That is, by providing additional allocentric information about target location, overall motor performance would be enhanced. In the real-time (visually-guided) conditions, we expected that the presence of VB would have minimal effect. That is, participants would be able to estimate reach effectively using an egocentric reference.

Method

Apparatus

In addition to the basic apparatus and stimulus presentation as in Experiment 1, a background was displayed, modified from Krigolson & Heath (2004). In this experiment, the target (2cm circle) was presented within an illuminated 20 x 20cm square composed of four 4cm red circles. An important note is that the VB frame always moved with the target – keeping it in the center. The focal point was projected onto a rectangular box (with a 45 degree angle surface) placed at midline approximately 15cm from most distal target (Figure 13).

Procedure

Actual and simulated reach (MI) was determined as described in Experiment 1. Participants completed four blocks of trials (delay conditions): no-delay, 1s, 2s and 4s delay and conditions were counterbalanced between participants and each condition began with three practice trials. Each block of trials began with a 5s “Ready!” signal – immediately followed by a central fixation point lasting 3s, at the end of which the participant heard a tone. The image appeared immediately thereafter and lasted for 1s (adopted from Bradshaw & Watt, 2002). All targets were presented in a random order. A second tone then provided the signal for the participant to respond. In the no-delay condition, participants were instructed to respond immediately with a “yes” or “no” in reference to whether the stimulus was “reachable” or not. More specific, participants were instructed (and trained) to ‘hold’ the location of the target for the duration of the delay and then use imagery to respond at the second tone, using MI. A second experimenter served to reinforce instructions regarding MI and refocused the attention of participants to the central fixation point with each trial (as in the previous experiments). Testing required a single session, approximately 30-minutes. Each participant completed 84 trials (4 conditions X 21 trials = 84 trials).

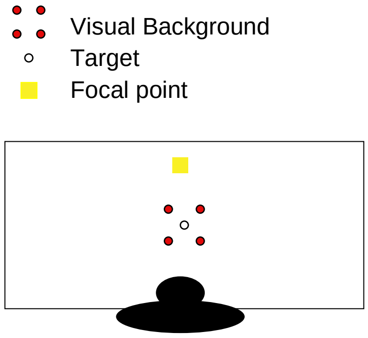


Figure 13. View of experimental set-up for Experiment 3.

Data Analysis

See Experiment 1 data analysis. Briefly, chi-square and ANOVA procedures were used to compare the four conditions in regards to total error, distribution of error, mean bias, and age.

Results

Total Error (Within Group)

As in the previous experiments, the analysis was to look first within each age group across all conditions comparing total error. Chi-square analyses indicated a significant difference with 5- and 7-year-olds (Figure 14). For the 5-year-olds, the differences were between the V0 (24%) condition and the V2 (40%) and V4 (39%) conditions; values were $\chi^2_{(1)} = 5.17$ $p < .01$ and $\chi^2_{(1)} = 4.54$, $p < .05$ respectively. With 7-year-olds, differences were between V0 (16%) and V2 (32%) and V4 (34%) condition; values were $\chi^2_{(1)} = 5.30$, $p < .05$ and $\chi^2_{(1)} = 6.74$, $p < .01$ respectively.

There were no significant differences found in the 9-year-olds, 11-year-olds and adults concerning total error. The values (%) ranged from 19 to 23 for 9-year-olds, 18 to 24 for 11-year-olds, and 16 to 22 for adults (Figure 2).

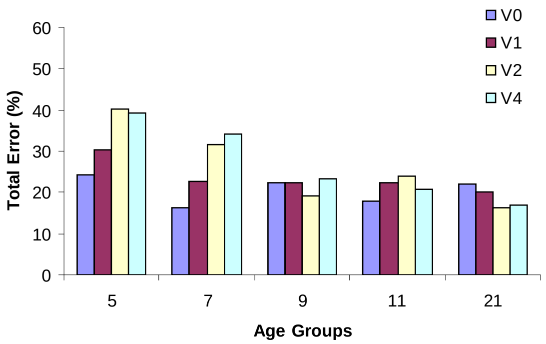


Figure 14. Percentage of total error for visual background task. V0 = no-delay, V1 = 1s delay, V2 = 2s delay, V4 = 4s delay.

Distribution of Error (Within Group)

To determine where the errors occurred, we analyzed the distribution of error across targets within each condition. Figure 15 shows the profiles of the distribution. As evident, most error occurred at target 5 for the children, whereas with adults, the highest frequency occurred at target 4. A more detailed list of distribution values can be seen in Appendix C.

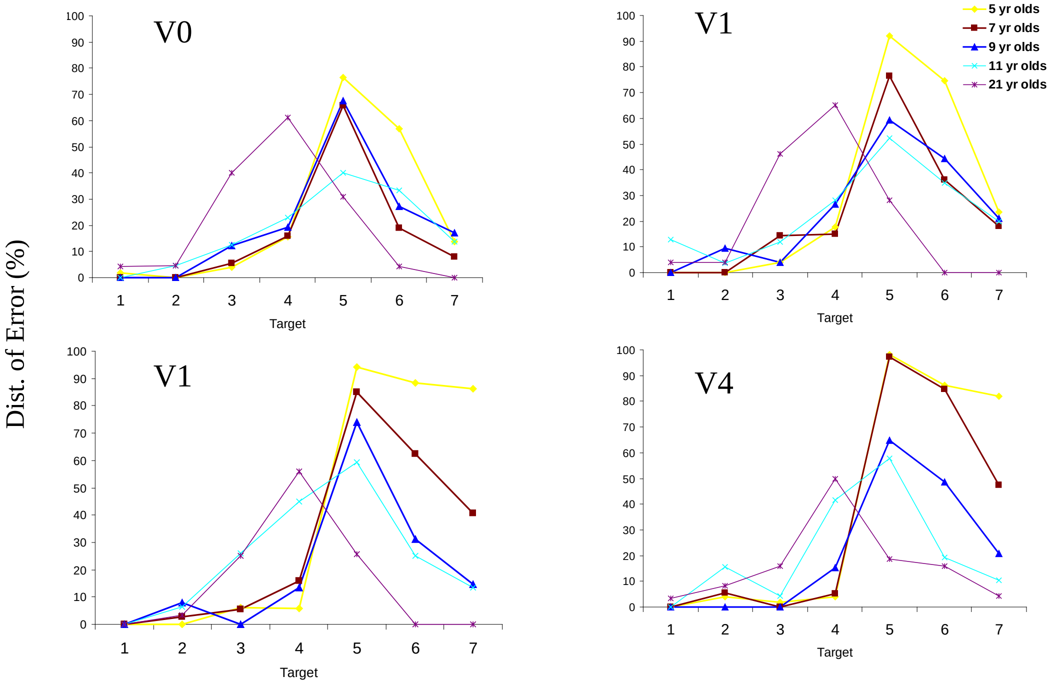


Figure 15. Percentage of distribution of error for visual background task. V0 = no-delay, V1 = 1s delay, V2 = 2s delay, V4 = 4s delay.

Mean Bias (Within Group)

In regard to the general direction of error (mean bias in cm) the one-way ANOVAs indicated a significant main effect of age (V0, $F_{(4,78)} = 6.18$, $p <= .001$; V1, $F_{(4,78)} = 9.67$, $p < .0001$; V2, $F_{(4,78)} = 20.17$, $p < .0001$; V4, $F_{(4,78)} = 18.63$, $p < .0001$). Post hoc analysis indicated that within the V0 condition, all children age groups were different from adults, adults underestimated while children overestimated (Figure 16). In the V1 condition, 5- (*M* = 0.82; *SD* = 1.45) and 7-year-olds (*M* = 0.46; *SD* = 1.31) were different from adults (*M* =-0.44 ; *SD* = 1.19). Also, 5-year-olds were different from 9- (*M* = 0.35; *SD* = 1.54) and 11-year-olds (*M* = 0.19; *SD* = 1.65).

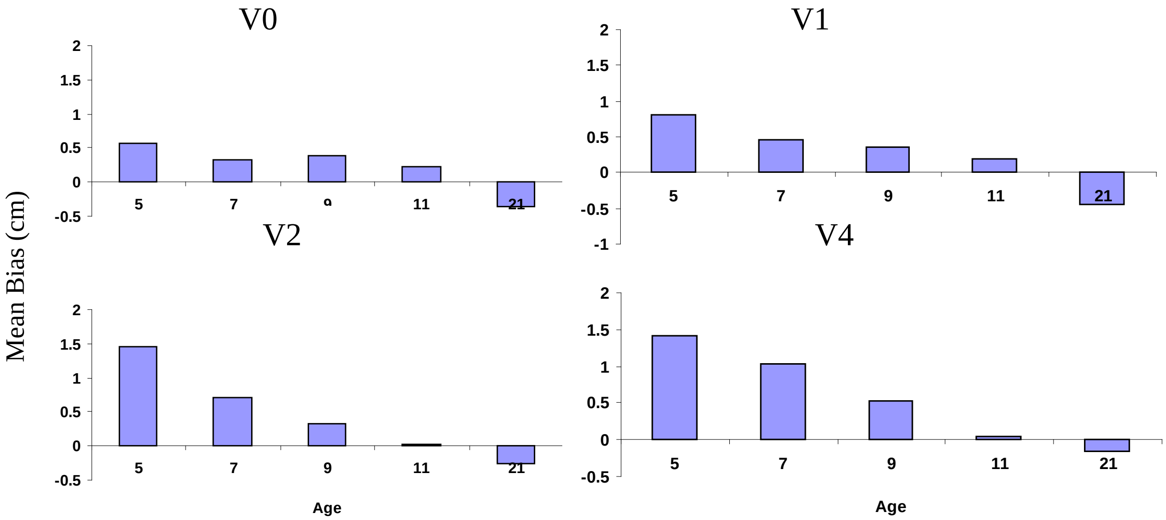


Figure 16. Mean bias by condition for visual background task. V0 = no-delay, V1 = 1s delay, V2 = 2s delay, V4 = 4s delay.

Within the V2 condition, post hoc analysis revealed that 5-year-olds (*M* = 1.46; *SD* = 2.13) were different from the other age groups (7-year-olds *M* = 0.72; *SD* = 1.88; 9-year-olds *M* = 0.32; *SD* = 1.39; 11-year-olds *M* = 0.02; *SD* = 1.43; and adults *M* = -0.26; *SD* = 1.02). Also with the V2 condition, 7-year-olds were different from 11-year-olds and adults. The results also revealed that 9-year-olds were also different from adults in the V2 condition (Figure 16).

In the V4 condition, 5-year-olds (*M* = 1.42; *SD* = 2.12) and 7-year-olds (*M* = 1.04; *SD* =1.82) were different from the older groups (9-year-olds, *M* = 0.53; *SD* = 1.31, 11-year-olds, *M* = 0.04; *SD* = 1.34, and adults *M* = -0.16; *SD* = 1.31; (Figure 16). Furthermore, 9-year-olds were different from all age groups in the V4 condition.

Space (Within Group)

Our attention now shifts to peripersonal (target 1-4, within reach) and extrapersonal (target 5-7, beyond reach) space within conditions. Analysis revealed that in the V0, V1, and V2 conditions, there were differences between peripersonal and extrapersonal space in all age groups (Figure 17). In the V4 condition, the difference in space was not found for the adults, but was found for all other age groups.

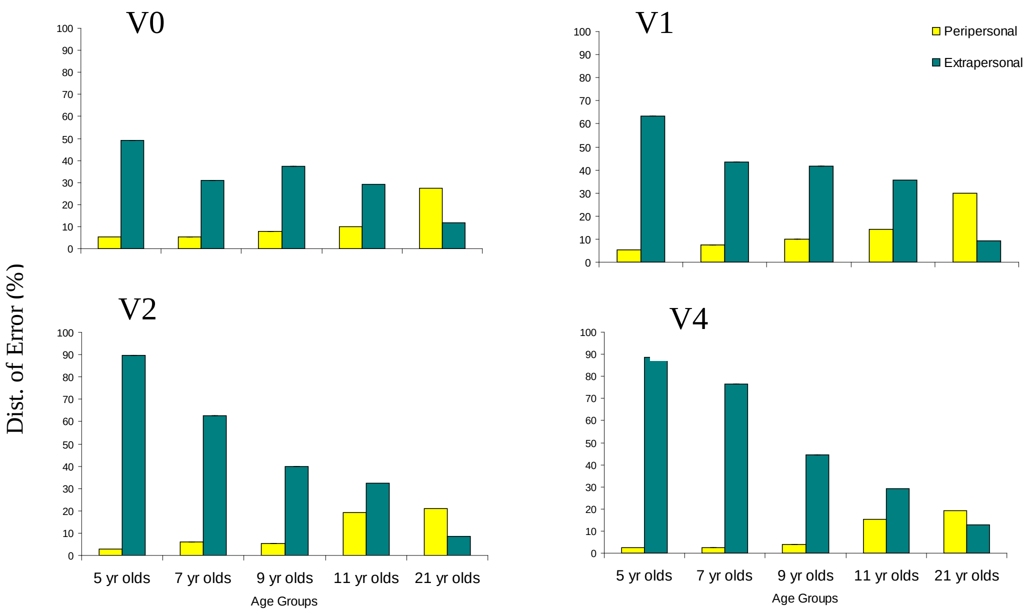


Figure 17. Percentage of distribution error by space for visual background task. V0 = no-delay,V1 = 1s delay, V2 = 2s delay, V4 = 4s delay.

Total Error (Between Groups)

There were no differences between age groups in the V0 (ranging from 16% to 24%) and V1 (ranging from 20% to 30%) conditions illustrated by Figure 14. In other words, 5-year-olds were not different from the other groups in the V0 and V1 conditions concerning total error.

However concerning total error between age groups in the V2 condition, analysis revealed differences between 5-year-olds (40%) and 9-year-olds $\chi^2_{(1)} = 9.62$, $p < .01$; 11-year-olds (24%) $\chi^2_{(1)} = 5.17$, $p < .05$; and adults (16%); $\chi^2_{(1)} = 13.12$, $p < .001$ (Figure 14). The analysis also revealed differences between age groups in the V4 condition. The analysis showed that 5-year-olds (39%) were again different from 9-year-olds (23%) $\chi^2_{(1)} = 5.26$, $p < .05$; 11- year-olds (21%) $\chi^2_{(1)} = 4.29$, $p < .05$; and adults (17%) $\chi^2_{(1)} = 6.74$, $p < .01$. Also, in the V4 condition, 7-year-olds were different from 11-year-olds $\chi^2_{(1)} = 4.29$, $p < .05$ and adults $\chi^2_{(1)} = 6.74$, $p < .05$.

Distribution of Error (Between Groups)

As in Experiment 1, only targets 4 (actual maximum reach) and 5 will be addressed in this section. The distribution of error across age groups in the V0 condition showed that adults were significantly different from the rest of the age groups at target 4. The chi-square ($\chi^2_{(1)}$ with *ps* < .01) values for adults compared to the other age groups were: 5-year-olds = 40.88; 7-year-olds = 40.88; 9-year-olds = 35.02; and 11-year-olds = 28.10.

In regards to target 5, analysis showed that 11-year-olds were different from the other children groups; values were ($\chi^2_{(1)}$ with *ps* < .01): 5-year-olds = 25.14; 7-year-olds

= 12.55; and 9-year-olds = 13.59. Also, in the V0 condition, adults were different from 5-year-olds = 38.91; 7-year-olds = 23.14; and 9-year-olds = 24.51.

The distribution of error across age groups in the V1 condition showed that at target 4, adults were different from the rest of the age groups; values were ($\chi^2_{(1)}$ with *ps* < .01): 5-year-olds = 43.58; 7-year-olds = 50.02; 9-year-olds = 29.12; and 11-year-olds = 26.05. Also with target 4, 7-year-olds were different from 11-year-olds $\chi^2_{(1)} = 4.27$, $p < .05$.

Results of target 5 revealed that 5-year-olds were different from all age groups; values were ($\chi^2_{(1)}$ with *ps* < .01): 7-year-olds = 8.37; 9-year-olds = 27.68; 11-year-olds = 37.72; and adults = 82.69. Also for target 5, 7-year-olds were different to 9-year-olds ($\chi^2_{(1)} = 5.84$, $p < .05$); 11-year-olds ($\chi^2_{(1)} = 11.48$, $p < .001$); and adults ($\chi^2_{(1)} = 44.25$, $p < .0001$). The results also revealed that adults were different from 9-year-olds, ($\chi^2_{(1)} = 18.31$, $p < .0001$ and 11-year-olds $\chi^2_{(1)} = 11.02$, $p < .001$.

In reference to target 4 in the V2 condition, 5-year-olds were different ($\chi^2_{(1)}$ with *ps* < .01) from 7-year-olds = 4.14; 11-year-olds = 38.01; and adults = 56.12. The 7-year-olds were also different from 11-year-olds $\chi^2_{(1)} = 18.49$, $p < .0001$ and adults $\chi^2_{(1)} = 39.03$, $p < .0001$ at target 4.

Results at target 5 in the V2 condition, 5-year-olds were different ($\chi^2_{(1)}$ with *ps* < .0001) from 9-year-olds = 13.43; 11-year-olds = 32.15; and adults = 93.52. Also for target 5, 7-year-olds were different ($\chi^2_{(1)}$ with *ps* < .0001) from 11-year-olds, and adults, values were: 11-year-olds = 15.50 and adults = 68.10. The 9-year-olds were also different from 11-year-olds and adults ($\chi^2_{(1)} = 4.40$, $p < .05$; $\chi^2_{(1)} = 44.18$, $p < .0001$

respectively*)*. The results also revealed that 11-year-olds were different from adults; $\chi^2_{(1)}$ = 20.95, $p < .0001$.

In regards to the distribution of error for the last condition, V4, 5-year-olds were different ($\chi^2_{(1)}$ with *ps* < .01) from 9-year-olds = 5.82; 11-year-olds = 38.65; and adults = 51.37 at target 4. The 7-year-olds were also different from 9-year-olds $\chi^2_{(1)} = 4.50$, $p < .05$; 11-year olds $\chi^2_{(1)} = 36.05$, $p < .0001$; and adults $\chi^2_{(1)} = 48.55$, $p < .0001$. While the 9-year-olds were different from adults $\chi^2_{(1)} = 26.35$, $p < .001$ and 11-year-olds were different from adults $\chi^2_{(1)} = 16.59$, $p < .0001$.

Concerning target 5 in the V4 condition results revealed that 5-year-olds were different ($\chi^2_{(1)}$ with *ps* < .0001) from 9-year-olds = 33.96; 11-year-olds = 44.32; and adults = 125.31. Also for target 5, the 7-year-olds were different ($\chi^2_{(1)}$ with *ps* < .0001) from 9-year-olds, 11-year-olds, and adults, values were: 31.22; 41.41; and 121.70 respectively. The adults were also different from 9-year-olds ($\chi^2_{(1)} = 39.87$, $p < .0001$) and 11-year-olds ($\chi^2_{(1)} = 30.49$, $p < .0001$)

Mean Bias (Between Groups)

In regard to mean bias results of the 4 x 5 (Condition [V0, V1, V2, V4]) x Age groups [5-, 7-, 9-, 11-year-olds, and adults]) ANOVA, results revealed a significant main effect for Condition by Age Groups ($F_{(19, 310)} = 13.19$, $p < .0001$). Post hoc analysis showed that within the 5-year-olds, condition V0 and V1 were different from the V2 and V4 (Figure 18). Concerning 7-year-olds, the V0 condition was different from V2 and V4.

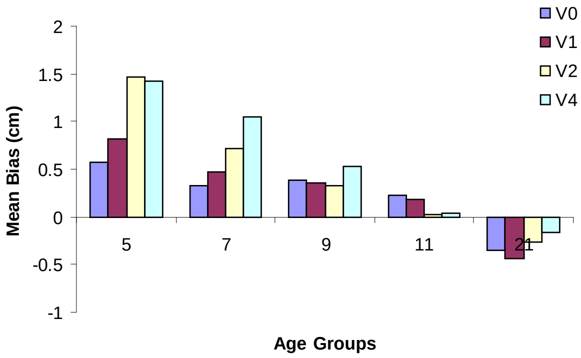


Figure 18. Mean bias between groups for visual background task. V0=no-delay, V1 = 1s delay, V2 = 2s delay, V4 = 4s delay.

Space (Between Groups)

Results for peripersonal space showed no differences between conditions. However, when viewing extrapersonal space, differences emerged (Figure 19). The differences between conditions for the 5-year-olds were as follows ($\chi^2_{(1)}$ with *ps* < .0001): V0 from V2 = 37.74 and V4 = 35.55; V1 from V2 = 18.80, and V4 = 17.13. For 7-year-olds, chi-square analysis revealed differences as following ($\chi^2_{(1)}$ with *ps* < .01): V0 from V2 = 19.29, and V4 = 38.91; V1 from V4 = 8.85.

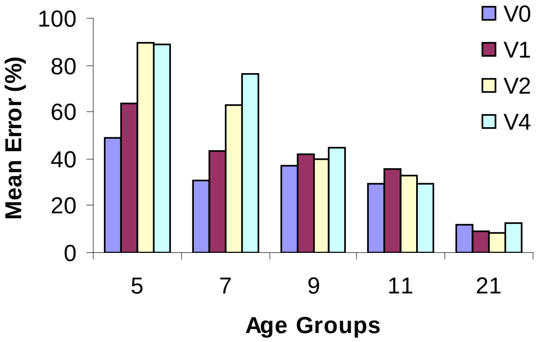


Figure 19. Mean error by extrapersonal space for visual background task. V0 = no-delay, V1 = 1s delay, V2 = 2s delay, V4 = 4s delay.

Motor Imagery Without and With Background

Comparing motor imagery without background (Exp 1) to motor imagery with background (Exp 3), the ANOVAs analyses revealed differences only for mean bias. For the 5-year-olds ($F_{(7, 816)} = 6.27$, $p < .0001$), 7-year-olds ($F_{(7, 666)} = 4.51$, $p < .0001$), and adults ($F_{(7, 810)} = 4.30$, $p < .0001$). For the 5-year-olds, the 2s and 4s delays (M2, M4, V2, and V4) were different from the no-delay and 1s delay (M0, M1, V0, and V1). For 7-year-olds, M1, V1, M0 and V0 were different from M2, M4 and V4. Also with 7-year-olds, the post hoc analysis revealed that M4 V4, and M2 were different from V1, M0 and V0. For the adults, the differences were between M4 to V4, V2, V0, and V1. Also, the M2 condition was found different to V0 and V1, while the V1 condition was different from M1, M0, V4, V2, and V0.

Discussion

The aim of Experiment 3 was to test whether a visual background (VB) surrounding a target affected the estimation of reach in children. In other words, would combing egocentric and allocentric visual frames of reference facilitate the accuracy of goal-directed reaching movements - in our case the accuracy in estimating reaching distances. Our assumption was that having additional cues (allocentric information in the form of a VB) would enhance judgments of estimates of reach. In addition, our intent was also to investigate if there would be differences between visually guided and memory-guided responses (response-delays). We had predicted that delays would not have an effect on estimating reach when targets have a VB.

The first key finding was that VB did not facilitate estimations of reach. It appears from our data that children had similar judgments of what is within and out of reach when no VB was provided and when VB was provided. Our second key finding was that delay did have an effect on judgments of estimation of reach even in the presences of a VB and younger children (5- and 7-year-olds) were most affected by the longer delays.

To address the first significant outcome we compared Experiment 1 and 3. In regards to the visually-guided conditions (no-delays, M0 and V0), results indicated that responses for M0 and V0 were not different. In addition, when viewing the response-delay in both experiments, the results indicated no differences between M1, M2, M4 and V1, V2, and V4 among total error. An interesting and relevant finding was the differences seen in regards to mean bias. It appears that for the younger children (5- and 7-year-olds), there is an enhanced judgment with a VB of what was within reach in the shorter delays (no- and 1-s delays) compared to the longer delays (2- and 4-s delays). The adults with a VB slightly underestimate more than when no background (MI) was provided. It appears that our adult data seemed to contradict previous findings. Previous studies had shown that a VB improved accuracy of responses in movement execution (e.g. Krigolson & Heath, 2004; Lemay et al., 2004; Obhi & Goodale, 2005). However, in the context here, estimates of reach, adults with a VB change their strategy, and adopted a more conservative strategy by saying ‘no’ to targets that are indeed within reach (Figure 16, 17 and 18).

Concerning our second finding, it appears that the influencing factor was the response-delay introduced and not the VB. Previous studies of actual movement had suggested that with a VB, accuracy of responses improved because the additional (allocentric) information strengthened the egocentric representation (e.g. Carrozzo et al., 2002; Krigolson & Heath, 2004). However, based on the childrens' data, those previous results were not replicated. This is contrary to work by Bradshaw and Watt (2002, 2004) that found that with a perceptual-matching task, pointing performance remained relatively unaffected after imposing a delay for adults and children. The key difference between Bradshaw and Watt's work to ours is that their work involved actual movement execution (grasping) where cues could be used to update movement execution as it takes place (on-line). In our task, no feedback was provided to aid in the estimation of reachability, therefore perceptual judgments could not be updated and corrected. Could it be that children cannot use additional cues (allocentric) to aid their egocentric frame of reference? Illusion studies (Hanisch et al., 2001; Rival et al., 2004) have concluded that both visual systems are intact in young children; however, different explanations of use were given. Hanisch and colleagues found that children rely on both visual streams during perceptual and visuomotor activities; therefore suggesting that these pathways 'are not' functionally segregated. Complementing this finding is the notion that children exhibit nonspecific use of an allocentric and/or egocentric frames of reference, which were linked to ventral and dorsal streams, respectively. On the other hand, Rival and colleagues concluded that these systems are relatively mature and segregated by 7 years of age. Their data suggested that children use mainly egocentric object representations when performing motor tasks and allocentric cues when making only perceptual judgments. Our results seem to fit better with the Rival et al. work in that children favored using egocentric representation when both cues were provided. Our work also adds to Rival and colleagues work in that children even with a VB primarily rely on egocentric representation. It is as if children disregard or are unable to use the additional cues provided for planning reachability.

Studies with adults have shown that a VB facilitated visually-guided actions (Coello & Greally, 1997; Velay & Beaubaton, 1986) and enhanced the kinematics of reaching movements to a memory-guided target (Carrozzo et al., 2002; Lemay et al., 2004). Others have shown that VB cues provided allocentric information about the target location that can be used to facilitate online control processes (Krigolson & Heath, 2004; Obhi & Goodale, 2005). An interesting note is that our adults had a slight tendency to have more error in peri- compared to extra-personal space (difference from Experiment 1). It appears that as more cues were provided, adults tended to be influenced by them and underestimated. Speculatively, adults adopted a more conservative strategy (Figures 16 and 17).

In conclusion, it appears that adults changed their estimation of reach slightly when cues were provided, while children did not. The influencing factor for the estimation of reach was a response-delay, specifically after a 2s delay. The work presented here adds to previous work suggesting that children primarily rely on egocentric representations when planning a reach (Rival et al., 2004).

CHAPTER V

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

General Discussion

The primary purpose of this study was to gain insight into children's ability to use visual information in planning reaching movements. More specifically, we examined the use of visual information in regard to the age-related ability to use a) egocentric cues, b) allocentric cues, and c) a combination of cues, in the form of a visual background around a target.

Three experiments were designed to address the aims of this study. Experiment 1 examined the ability of children to use an egocentric frame of reference to plan reaching movements via estimation of reach. In other words, how well do children use target information to establish egocentric coordinates in estimating reach in an immediate (visually-guided) and response-delay (memory-guided) paradigm using a motor imagery. Our assumption was that at some point, delay should have an adverse affect on the perception of what is within or out of reach (Goodale et al. 2004; Bradshaw et al. 2002, 2004). With Experiment 2, we investigated the ability of children to use perceptual properties via allocentric cues in visually-guided and response-delay conditions. As theory suggests, allocentric memory representation relates to targets coded as a function of the surrounding visual cues, which are independent from the participant's position (Blouin et al., 1993; Lemay & Porteau, 2003; and Lemay et al., 2004). Therefore, our assumption was that performance after a delay would be constant. The aim of

Experiment 3 was to examine whether a visual background, VB, surrounding a target would affect the estimation of reach in children. Stated differently, will combining egocentric and allocentric referencing facilitate the estimation of reach? Our assumption was that participants would perform better with additional cues than when only one type of referencing was available.

In regard to our aim in Experiment 1, can children use an egocentric frame of reference to plan reaching movements in visually-guided and response-delay paradigm, our results showed that children and adults had similar estimates in real-time (visually-guided) and in minimal delay (1s). Results are supportive of previous studies in that they suggest children operate in an egocentric frame of reference (Rival et al., 2004; Hanisch et al., 2001; Gabbard et al., 2007a). In this type of referencing, children were able to have target information represented in relationship to them while operating in real-time and presumably, having target information processed in the dorsal stream (Bradshaw et al., 2004; Goodale & Humphrey, 1998; Goodale et al., 1997; Graham et a., 1998; Hu et al., 1999). Previous studies had shown that a delay, specifically a 2s delay, produced an adverse affect on the movement performance (Goodale et al., 2004 and Bradshaw et al., 2002, 2004). In our data, when a response-delay of 2s was introduced, the two younger age groups were most affected in their estimation of reach. In addition, as delay increased to 4s, the 5-year-olds became significantly different from the other age groups. However, our older children and adults did not show any delay effect with total error. To view why there seems to be some conflicting results of our data to previous data, we needed a more in-depth view of where the errors occurred. When viewing the distribution of where errors occurred, results showed that children overestimated significantly, as delay increased. Adults on the other hand, underestimated as delay increased. It seems that the perception of reach was affected by delay, but the children and adults handled it differently. Adults were more cautious in their responses as to what was within reach as target information decayed. Adults tended to say ‘no’ to targets that were indeed within reach, children on the other hand, tended to respond less conservatively. Children perceived targets that were indeed out of reach to be within reach; perception of reach had expanded into extrapersonal space. Our results were consistent with our assumption, that delay would affect estimation of reach.

In regards to Experiment 2, our intent was to compare how children and adults use allocentric cues to estimate the location of objects in a perceptual estimate paradigm. We examined the perceptual properties associated with estimation of distance in real-time (visually-guided) and response-delay (memory-guided) conditions. Contrary to our assumption, our findings showed that when a response-delay of ≥ 2s was presented, the delay affected the estimation of distance among all groups, with 5-year-olds being most affected. Our assumption, delay at a certain point (2s) should not have an effect on estimates of distance, was based primarily on the work from Lemay and colleagues (2004). Lemay and colleagues stated that when an allocentric frame of reference is presented, a more stable representation of the information is encoded and is less likely to decay because of the memory component of the ventral stream. In visually-guided and minimal delay conditions (1s) our results revealed that children and adults performed similarly in estimates of target distances. Keep in mind that participants were to estimate the distance of targets to a cued target. Our other finding in Experiment 2 showed that most of the errors occurred at the most distal targets from the cued target. Estimates of distance for targets near the reference point were more accurate than targets that appeared farther away from the reference point. It appears from our data that children and adults are susceptible to decay of memory in a perceptual estimation task.

The aim of Experiment 3 was to investigate if adding a visual background (VB) to a target would affect the estimation of reach. Stated differently, would combining egocentric and allocentric visual frames of reference facilitate the accuracy of estimates of reachable distances? We tested our hypotheses with a visually-guided and response-delay paradigm and compared the results from Experiment 1 to Experiment 3. We compare the results of both experiments because both were similar except for the addition of a VB (Experiment 3). The results comparing Experiment 1 (egocentric cues only) to Experiment 3 (egocentric and allocentric cues) showed that having additional allocentric cues around a target did not change the perception of what was reachable with children concerning total error. In regard to mean bias, results showed that with a VB, younger children (5- and 7-year-olds) had more accurate judgments in shorter delays than when longer delays (2s and 4s) were used. The adults tended to slightly underestimate more with the additional cues (VB) as delay increased. Unlike our study, previous studies with adults had shown that a VB improved the accuracy of movement execution (Krigolson & Heath, 2004; Lemay et al., 2004; Obhi & Goodale, 2005). Speculatively, our adults adopted a conservative strategy in their planning phase. Our results from Experiment 3 indicated that a VB did not facilitate visually-guided and memory-guided estimations of reach for children. It seems that children did not attend to the additional cues. Could it be that children could not use the additional cues to estimate reach? It has been proposed by some that information held in memory using both an egocentric and an allocentric representation is not the easiest way to hold target information. Holding the information in both frames requires more processing, since two concomitant representations have to be created and possibly compared (Clounin et al., 1993; Carrozzo et al., 2002). Perhaps, children are unable to hold both representations and use them accordingly. Therefore, children (as a default) relied on an egocentric representation. Our comparative results from Experiment 1 and 3 seem to hint that children could not use the additional cues to aid in their estimation of reach.

Taken together, these results show that children and adults were affected by a ≥ 2s delay in their judgments of reach and estimates of distances. Our results reaffirm what theory has suggested, that the vision-for-perception and the vision-for-action visual processing streams operate under very different temporal delays. It appears that when motor imagery was used (Experiment 1 and 3) it was affected by an egocentric frame of reference. Our results collectively showed that children tend to operate primarily in an egocentric frame, reaffirming what others have proposed with illusion paradigms (Rival et al., 2004, Hanisch et al., 2001).

Providing information in an egocentric, allocentric or a combination thereof might not be the simplest way of holding target information to make pre-reflective estimates of reach. It would appear that there is a vision-for-perception and vision-for-action, (two-visual-system hypothesis; Goodale et al., 2005). It would be advantages to present object information in the mode the stream of reference operates. In other words, if estimates are desired, then it would be advantages to present information in real-time rather than having information stored in memory. In addition, it seems from our results that it would be advantages to present object information in an egocentric frame to children.

Conclusions

Based on the collective results and limitations of this investigation, the following conclusions seem warranted.

1. *Children as young as 5 years of age seem to have the same responses of estimation of reach as adults do in real-time (visually-guided) and in minimal delay (1s) but are most affected by ≥ 2s delay*. Our results showed that with longer delay (≥ 2s); target information was susceptible to decay in the planning phase of reaching. It appears that based on this decay of information in memory, children and adults change their strategy on responding to estimates of reach. Children tended to overestimate, while adults tended to underestimate. These results reaffirm movement execution studies and the correlation between motor imagery and movement execution.
2. *There seems to be a major temporal constraint on the representation of movement through the visoumotor stream for children and adults* (Goodale et al., 2004). Children and adults seem to be susceptible to information decay that is held in memory. Children's responses hint that their perception of reach and estimation of distances tend to increase as information is stored for ≥ 2s in memory. Adults on the

other hand, were more conservative in their estimates of reach and distances. The results seem to indicate that while in the planning phase, information is susceptible to time.

3. *Children as young as 5 years of age relied on an egocentric frame of reference for making perceptual estimates of reach and distances regardless if additional cues via visual background were provided.* Our comparative results from Experiment 1 and 3 clearly showed that providing additional cues in the form of a visual background did not enhance the judgments of reach for children. It seems that children were unable to process the additional cues perhaps because they could not or perhaps because they decided not to. The results do confirm previous work that suggest children primarily rely on an egocentric frame of reference. However, more research is needed to compare the decay of allocentric and egocentric information in children and adults.

4. Overall, our attempts to gain insight into children's ability to use visual information in planning reaching movements revealed that children primarily use an egocentric frame of reference in the planning phase of movement. We also were able to conclude speculatively that information stored in memory is vulnerable to decay, especially if it is encoded with an egocentric frame of reference. Finally, our data suggest that having a visual background around a target did not enhance the estimation of reach for all our participants.

Limitations and Recommendations

Although the present study addressed significant objectives, our conclusions were limited on some aspects. There remains a slim possibility that participants in every trial did not follow protocol (i.e. used egocentric in Experiment 1, used allocentric in Experiment 2 and used ego- and allo-centric frame of reference for Experiment 3). This study was also limited in the context that perceived reach rather than actual reach and its kinematic parameters were not analyzed. Finally, our paradigm, due to its behavioral nature, could not depict the areas of the brain involved in each experiment.

In regard to the extension of this work, future studies should investigate the extent to which visual structures (different backgrounds) around a target might affect perceived reach. More developmental work is needed to investigate the roles of egocentric and allocentric frames of referencing have in the planning of movements.

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APPENDIX A

		Target						
		1	**2**	**3**	**4**	**5**	**6**	**7**
M0	**5**	0	0	2	7	91	40	2
	7	0	0	6	22	65	21	19
	9	0	7	21	19	64	48	9
	11	0	5	13	50	54	20	10
	21	0	0	32	52	31	23	3
M1	**5**	0	0	0	0	100	62	17
	7	0	0	0	14	79	67	21
	9	0	0	3	11	66	30	3
	11	4	8	4	29	28	19	14
	21	0	0	13	39	27	12	11
M2	**5**	0	0	0	2	93	98	56
	7	0	0	3	16	82	88	43
	9	0	0	7	43	57	47	18
	11	0	4	9	29	39	43	8
	21	0	3	17	28	38	7	9
M4	**5**	0	2	2	2	100	94	95
	7	0	3	3	13	97	79	58
	9	0	10	4	25	46	32	14
	11	7	16	19	24	38	36	27
	21	0	0	4	41	35	16	4

Appendix A. Distribution of error given in percent: Motor imagery (M0=no-delay, M1=1s delay, M2=2s delay, M4=4s delay)

APPENDIX B

		Target						
		1	**2**	**3**	**4**	**5**	**6**	**7**
P0	**5**	10	9	3	10	3	16	14
	7	7	8	5	5	2	6	6
	9	17	7	4	0	9	6	18
	11	14	9	2	0	1	11	12
	21	9	5	1	1	2	2	5
P1	**5**	11	10	6	10	4	4	8
	7	9	12	8	9	11	11	10
	9	9	11	11	5	22	13	14
	11	9	9	8	3	5	8	12
	21	11	8	6	8	7	5	4
P2	**5**	29	62	90	37	34	62	49
	7	48	61	59	53	37	81	52
	9	74	57	31	12	28	33	36
	11	62	46	30	26	26	42	47
	21	27	26	14	12	25	22	12
P4	**5**	86	61	58	29	67	55	90
	7	66	82	83	44	69	50	52
	9	74	70	61	42	54	37	41
	11	65	60	54	21	39	39	43
	21	41	39	26	20	32	29	15

Appendix B. Distribution of error given in percent: Perceptual task (P0=no-delay, P1=1s delay, P2=2s delay, P4=4s delay)

APPENDIX C

		Target						
		1	**2**	**3**	**4**	**5**	**6**	**7**
V0	**5**	2	0	4	16	76	57	14
	7	0	0	5	16	66	19	8
	9	0	0	12	19	68	27	17
	11	0	5	13	23	40	33	14
	21	4	5	40	61	31	4	0
V1	**5**	0	0	4	18	92	75	24
	7	0	0	14	15	76	36	18
	9	0	9	4	27	59	44	21
	11	13	4	12	28	52	35	20
	21	4	4	46	65	28	0	0
V2	**5**	0	0	6	6	94	88	86
	7	0	3	6	16	85	63	41
	9	0	8	0	13	74	31	15
	11	0	6	26	45	59	25	13
	21	0	3	25	56	26	0	0
V4	**5**	0	3	2	4	98	86	82
	7	0	5	0	5	97	85	47
	9	0	0	0	15	65	48	21
	11	0	16	4	42	58	19	10
	21	3	8	16	50	19	16	4

Appendix C. Distribution of error given in percent: Visual background (V0=no-delay, V1=1s delay, V2=2s delay, V4=4s delay)

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