HAND CHOICE AND REACHING

THE EFFECT OF PLANNING AND HAND POSITION ON HAND CHOICE WHEN REACHING

By DANIEL BRYAN LEDDA GARCIA, H.B.SC.KIN

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AUTHOR: Daniel Bryan Ledda Garcia, H.B.Sc.Kin

SUPERVISOR: Dr. James L. Lyons, PhD.

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Abstract

A fundamental decision when interacting with objects in our environment involves hand selection. Two major factors that influence this choice include handedness (the proficiency of one hand over the other) and the spatial relationships perceived between the object and both effectors (Gabbard & Rabb, 2000). Previous studies have altered the location of an object in space and the complexity of a task as it relates to hand choice decisions (Bryden et al., 2003; Gabbard et al., 2003; Mamalo et al., 2006). This thesis investigates the idea of reaching toward a series of predictable target locations and its effect on the frequency of hand use when compared to unpredictable reaches. Predictable reaches allow participants to assign hand use prior to movement initiation. Participants reached to a series of 3-target sequences in one of two groups: unpredictable reaches, selecting a hand to reach each target as it appeared; and predictable reaches, where the target sequence was presented prior to initiating a reach. Unpredictable reaches at different hand positions in space demonstrate that object proximity often mediates hand choice by promoting use of the effector that affords the shortest reaching amplitude. Further, predictive reaches demonstrate a preference to complete larger reaching amplitudes earlier in the sequence in order to place both hands in a position where object proximity mediates hand choice later in the sequence. Overall, predictable reaches seem to resemble the end-state comfort effect (Rosenbaum, 1992), where participants change their approach to executing reaches when they know the sequence of targets that follows.

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Daniel

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Introduction

Decisions are part of our daily lives, whether it’s choosing what to eat for breakfast, what clothes to wear for the day, or what to watch on television. We are also faced with many hand choice decisions, although this may not be as obvious. Everyday we must interact with our environment by opening doors, turning on a light switches, or grabbing our groceries, and this requires decisions about what hand to use in order to handle these objects. Some hand choice decisions require more deliberation such as which hand should reach for the salt shaker depending on its location on the table, and others occur without conscious thought such as deciding what hand to use when brushing your teeth. Where most people think of unimanual tasks when making hand choice decisions, decisions are made with bimanual tasks as well. For example, when getting dressed in the morning, you fastened a button or zipper with both hands. These tasks require decisions about the division of labor between effectors. Most of the world’s population is right-handed, however our non-dominant hand does not go unused. Several factors influence our hand choice decisions for unimanual and bimanual tasks, and studying hand choice begins to uncover the complexity of our ability to process multiple sources of information when making those decisions.

Handedness

The traditional idea of handedness suggests that if an individual truly preferred the use of one hand, it would be used to carry out all unimanual tasks regardless of the awkward hand or body positions that might result (Bryden. Singh, Steenhuis, & Clarkson, 1994). Furthermore, handedness was initially thought of as an invariant biologically based trait (Gabbard & Helbig, 2004; Gabbard, Tapia, & Helbig, 2003). Klar (1999, 2003) went so far as to propose a single-gene model as evidence supporting the role of genetics in determining handedness.

Although 90 percent of the world's population is right-handed (Annett, 1985; Bryden, 1977), "handedness" is not the only factor that determines hand use, however. For example, right-handed individuals will, depending on the situation, use their left hand to grasp a glass when filling it with liquid, suggesting that hand choice decisions are a result of the interaction between the task, environment, *and* handedness (Gabbard & Helbig, 2004; Gabbard & Rabb, 2000; Helbig & Gabbard, 2004).

Before investigating how these factors interact, it is important to explain how researchers determine a direction of handedness (i.e. right-handed vs. left-handed). Early researchers used crude behavioural measures and simple questions to determine a participant's handedness. For example, Bryden, Pryde, & Roy (2000) note early investigators asking individuals which hand they preferred to write with and used their responses as an evaluative tool. Gross behavioural measures provided a quick and efficient means of identifying handedness, however its simplicity served as its major downfall. In other words, it is difficult to generalize the idea of handedness on very few questions without further insight into how the individual chooses to use their hands in other scenarios. More precise, thorough, and systematic investigation was necessary for more accurate evaluations of handedness.

Questionnaires and surveys were the next available tools used to assess handedness (i.e. the Edinburgh Handedness Inventory or Waterloo Handedness Inventory). Rather than relying on gross behavioural measures, they consisted of a series of questions asking individuals to rate how often either hand was used for different unimanual tasks, such as holding a toothbrush, throwing a ball, using a spoon, or turning on a light switch (Oldfield, 1971; Steenhuis & Bryden, 1989). Although questionnaires and surveys were more thorough than early estimative measures of handedness, these newer methods were difficult for participants to complete successfully for several reasons: they required participants to subjectively recall previous experiences, and asked them to discern between when they "always" and "usually" used a given hand. Further, it was difficult for researchers to rely confidently on the inventory because they weighed each item of the survey equally, where some tasks required more skill, accuracy, and control over others (Stins, Kadar, & Costall, 2001). Despite the difficulty in answering the questionnaires and surveys, this assessment was more thorough and successful at identifying directions of handedness. They also provided insight into a new measure, qualitative degrees of handedness (i.e. strongly right-handed versus ambidextrous; Bryden, 1977). Overall, surveys and questionnaires were better than early measures in determining directions of handedness, but because of their subjectivity and need for recall, more quantitative and objective measures were needed.

The introduction of performance measures served as an objective measure of handedness. This type of assessment had participants complete unimanual tasks with both hands and compared the relative performance between effectors. For example, Annett (1970, 1976) compared the speed of movement between hands using a peg-moving task. Participants were presented with two boards separated by fixed distance, with a row of holes in each board. The task tested both speed and accuracy having participants transfer pegs from one row to another row as quickly as possible, once using their preferred hand and then the other. The results of Annett revealed a linear relationship between degrees of handedness and the relative manual skill demonstrated between effectors. Another comparison of hand performance was the Tapley & Bryden dot-marking task (Tapley & Bryden, 1985). In this task, participants drew dots in a series of circles placed in a pattern as quickly and as accurately as possible, again switching between their preferred and non-preferred hand. The number of circles properly filled were counted and compared between effectors, suggesting a relationship between performance and handedness, similar to Annett (1970, 1976). In comparison to gross behavioural measures, questionnaires, and surveys, the introduction of performance measures as an evaluative tool for handedness led to more refined and objective measure of this trait.

Overall, these measures serve to provide a more robust operational definition of handedness: The hand with which an individual is most *proficient* when evaluating a series of unimanual tasks; where the degree of handedness refers to the proficiency of said hand in comparison to the other.

Workspace

In addition to handedness, our environment or workspace also serves to significantly mediate hand choice decisions. Therefore, it is important to operationalize areas of space in relation to the individual. Personal space refers to the space immediately surrounding an individual that can vary in size due on variables such as culture, feel states, and personality (Dosey & Meisels, 1969; Sommer, 1967). Personal space can then be divided into two hemispaces using the body's midline. The ipsilateral hemispace refers to the same side of a given hand, where the right space is ipsilateral to the right hand, and the left space is ipsilateral to the left hand. In contrast, the contralateral hemispace refers to the opposite side of a given hand, where the left space is contralateral to the right hand, and the right space is contralateral to the left hand. From this point forward, this thesis will refer to workspaces with respect to a right-handed individual.

Theoretical Background of Hand Choice Decisions

In terms of how handedness and workspace interact, research suggests that attentional information is one factor that plays a major role in hand choice decisions (Gabbard and Helbig, 2004; Gabbard, Iteya & Rabb, 1997; Gabbard, Rabb, & Gentry, 1998; Gabbard, Tapia, & Helbig, 2003). The definition of 'attention' is often very broad, if not ambiguous. The earliest descriptions often define attention in predominantly phenomological terms such as "the narrowness of consciousness", where a limited number of available sensory inputs are able to reach the individual (James, 1890). In the 100 plus years since James, researchers have sought to more precisely define both the construct of attention as well as the mechanisms that drive it. Whereas a comprehensive review of this literature is beyond the scope of this thesis, some more recent work is very relevant. Welsh and Weeks (2010), for example, identify three characteristics of attention as it relates to our ability to process information. The first, similar to James' conceptualization, states that humans are limited in the amount of information we can process at any given time (i.e. the limited capacity model). The second is that we can change our focus of attention, both intentionally and unintentionally. For example, we can change our gaze from one visual point to another or shift between sensory systems. The third characteristic is that we can divide our attention to act on more than one piece of sensory information at a time, often relating to the concept of "multi-tasking".

The term 'attention' is often mentioned in the hand choice literature, more specifically with respect to 'attentional information'. Although several researchers have addressed 'attentional information', it has never been operationally defined.

Therefore, for the purposes of this thesis, attentional information will refer to the visual perception of spatial relationships between objects. With reaching tasks, attentional information is associated with the perceived location of the target with respect to the position of both hands.

Gabbard et al. (1997) used attentional information in the form of object location to investigate its effect on hand choice decisions. The experimenters seated participants at a table, blindfolded them, and placed a cube at one of nine locations spaced 20 degrees apart (Figure 1). Once the experimenter removed the blindfold, participants were instructed to reach toward and grasp the cube, then place it at their midline.

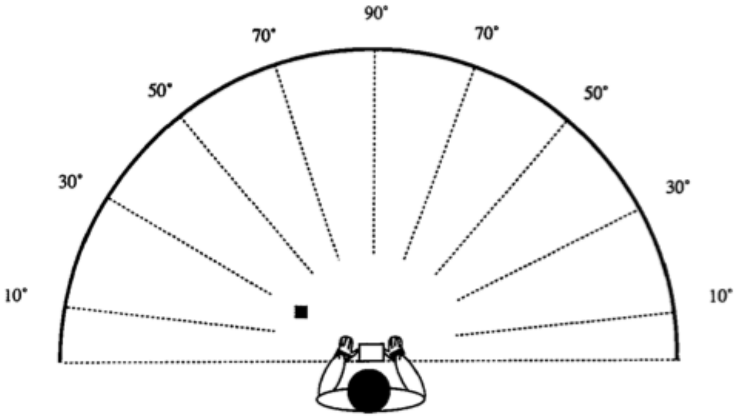


Figure 1: Experimental setup for Gabbard et al. (1997) where right-handed participants reach more frequently with their right into right space and the midline, and less frequently deeper into left space.

The results of Gabbard et al. (1997) reveal that right-handers frequently use their right hand to reach for the cube in both ipsilateral space and at the midline. Gabbard & Rabb (2000) elaborate on these findings (Gabbard et al., 1997), suggesting that handedness is a strong mediator of hand choice when reaching for objects located in ipsilateral hemispace and at the midline. In contrast, right-handers reach more frequently with their left hand to reach objects located in contralateral hemispace, showing that individuals can “override” the idea of handedness mediating hand use. Importantly, the hand use patterns of Gabbard et al. (1997) suggest that an object's location (i.e. the spatial relationship between the object and effectors) can influence hand use in conjunction with handedness.

Individuals have the ability to use both hands, and handedness does not limit us to using a single effector for all unimanual tasks. Given that our left hand does not go unused, how can we explain a right-hander's ability to “override” the idea handedness mediating hand use when reaching for objects in contralateral space? Theoretically, Gabbard & Rabb (2000) propose two hypotheses explaining hand use: (1) the kinesthetic hypothesis, and (2) hemispheric bias.

Kinesthetic Hypothesis

The kinesthetic hypothesis is based on the idea that individuals prefer movements that maximize reaching efficiency and comfort. Before addressing how the efficiency and comfort relate to the hand use, it is important to highlight one problem with all reaching tasks: there are many possible solutions to complete a reaching movement. More specifically, an infinite number of joint angles and hand trajectories can be used to complete a movement. The infinite number of solutions for a single task is known as the degrees of freedom problem (Bernstein, 1967).

Individuals eliminate many of the infinite reaching possibilities by selecting the hand that involves the shortest reaching amplitude. The kinesthetic hypothesis suggests that individuals use spatial cues to observe a specific target location and evaluate the shortest distance between each hand and the object (Gabbard & Helbig, 2004; Helbig & Gabbard, 2004). This concept can also be summed up by the term 'object proximity' where participants use the effector closest to the object or target location (Gabbard & Rabb, 2000). Therefore, the kinesthetic hypothesis mediates hand use on the basis of minimizing reaching amplitudes and optimizing reaching efficiency (e.g. it is easy to visualize that an object located further in left hemispace is closer to the left hand than the right).

The concept of reaching "efficiency" has been studied in other contexts as well. For instance, with goal-directed aiming tasks oriented horizontally, reaches that hit or initially undershoot a target result in faster movement times than reaches that overshoot the target. Undershooting the target allows the limb to travel a shorter distance that can easily be re-accelerated to achieve the target position (Elliott, Helson, & Chua, 2001), where overshooting the target results in the limb travelling further which must decelerate and overcome the inertia at the point of reversal. These observations support the idea that individuals prefer to complete movements that optimize energy expenditure.

Additional support that individuals prefer efficient movements involve reaching tasks that take into account gravitational forces. For example, Lyons, Hansen, Hurding, & Elliott (2006) manipulated the orientation of their targets in a reaching task by placing them vertically, asking participants to reach targets locations above or below a home position. The results of Lyons et al. (2006) demonstrate that downward aiming movements favor undershooting the target because corrections are aided with the downward force gravity and overshoots must work against it. In contrast, undershoots in the upward direction are less prevalent since the cost of an overshoot in upward aiming movements are not as great. Reversal corrections for overshoots in the upward direction take advantage of gravity pulling the hand toward to the target and reacceleration corrections must work against the force of gravity. Overall, these results investigating the idea of energy optimization suggest that individuals organize movements to minimize energy expenditure and maximize reaching efficiency, consistent with the kinesthetic hypothesis.

Lastly, individuals prefer more comfortable reaches. For example, Mark, Nemeth, Gardner, Dainoff, Paasche, Duffy & Grandt (1997) suggest that individuals choose reaching positions based on the perceived comfort associated with different postures. More specifically, reaches that require additional degrees of freedom (i.e. additional use of the shoulder or torso to reach across the midline) are perceived as less comfortable than reaches involving fewer degrees of freedom. Further, Kim, Gabbard, Buchanan, & Ryu (2007) identify changes in elbow and shoulder contributions for reaching tasks, showing that reaches using the left hand further in left space restrict motion at the shoulder, reducing the degrees of freedom needed. Overall, fewer degrees of freedom are perceived as more comfortable and relate to movement efficiency since coordinating fewer joints simplifies the action.

In summary, the kinesthetic hypothesis encompasses the ideas of object proximity, energy optimization, and comfort mediating hand choice in order to maximize overall movement efficiency.

Hemispheric Bias

A second theory used to explain hand use is known as the hemispheric bias, which states that participants tend to favor the hand on the same side of the stimulus (i.e. right hand use for targets on the ipsilateral side and left hand for targets on the contralateral side; Simon, 1969). Hemispheric bias relates to the idea of stimulus-response (S-R) compatibility and its effects on movement performance as a result of pairing arrangements between the stimulus and the appropriate response (e.g., Fitts & Seeger, 1953). Attention-based models of S-R compatibility focus on the idea that visual stimuli direct our gaze to certain locations, resulting in minimized cognitive involvement in response choice processes, enhancing overall movement efficiency (i.e. shorter RTs). Simply, compatible S-R pairings (i.e. using the hand on the same side of the stimulus) result in greater movement performance compared to incompatible S-R pairings (i.e. using the hand contralateral to the side of the stimulus).

More specifically, attentional models of S-R compatibility rely on the relationship between each cerebral hemisphere and the location of stimuli in the contralateral workspace (i.e. the left cerebral hemisphere and right space or right hemisphere and left space). When a stimulus is present in one hemispace (i.e. the right side), the contralateral hemisphere (i.e. left hemisphere) is activated, resulting in a direction of the visual gaze toward that side of space (i.e. right space). Since the activated hemisphere also controls the hand located in the same hemispace as the stimulus (i.e. the left hemisphere directs gaze to a stimulus in the right hemispace and controls the right hand), this hand will be favored to reach toward the target (Verfaille, Bowers, & Heilman, 1990). Further, each hemisphere favors stimuli located deeper in each hemispace, consistent with the idea that participants have an "innate" tendency to respond in the direction of the source of the stimulus.

A series of experiments conducted by Wallace (1971) also support the idea of attention-based S-R compatibility models. Participants positioned both hands on either side of their midline and were required to press a button located beneath each hand in response to light stimuli for each target (Figure 2). In the compatible S-R condition, the left light signaled the left button to be pressed by the left hand, and the right light signaled the right button to be pressed by the right hand (Figure 2A). In the incompatible S-R condition, the right light signaled the left button press with the left hand and the left light signaled the right button press with the right hand (Figure 2B). Wallace demonstrated that participants are quicker to respond in the compatible condition when compared to the incompatible condition showing a bias for the hand on the same side as the stimulus.

A second experiment by Wallace challenges the attention-based models of S-R compatibility, however. Participants performed the same experiment, but were asked to cross their arms so the left button was pressed by the right hand and right button was pressed by the left hand. Once again, participants responded to both the compatible (right light signaled the right button to be pressed by the left hand; Figure 2C) and incompatible (right light signaled the left button to be pressed by the right hand; Figure 2D) S-R conditions. Interestingly, with their arms crossed, participants responded more quickly in the compatible condition, challenging the relationship between each cerebral hemisphere and the effector it controls.

Wallace's second experiment supports the idea of coding-based models of S-R compatibility rather than attention-based models. Coding explanations suggest that cognitive representations of the workspace are formed and then used to execute the appropriate response, where compatibility effects are a result of an efficient translation between the stimulus (i.e. location of the light) and the appropriate response (i.e. effector located near the stimulus). It is not the physical relationship between the stimulus and response that results in enhanced movement performance, but rather the correspondence between mental codes of the stimulus and the response.

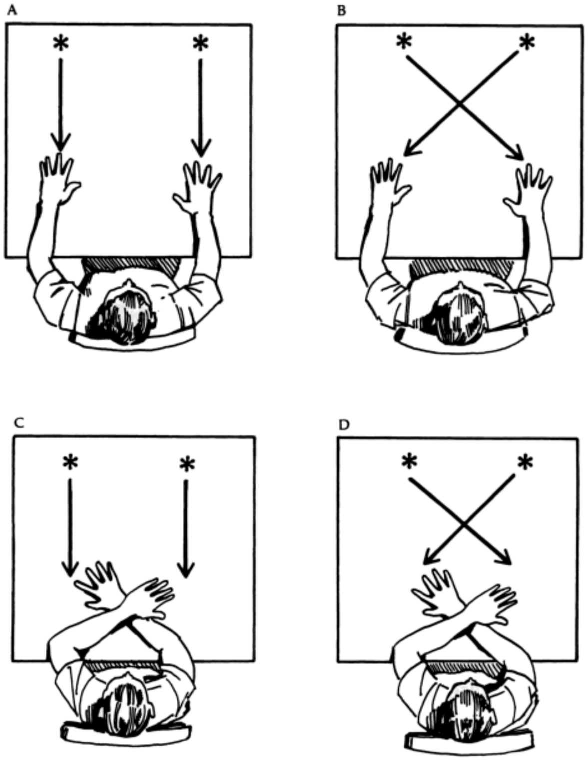


Figure 2: Four stimulus-response arrangements from Wallace (1971). (A) Compatible mapping between stimulus, button, and hand; (B) incompatible mapping between stimulus, button, and hand; (C) compatible mapping between stimulus and button, but not hand; (D) incompatible mapping between stimulus and button, but not hand. Responses are faster in (A) and (C) than in conditions (B) and (D) (Rosenbaum, 1992).

Despite two different models used to explain S-R compatibility effects (i.e. coding- and attention-based models), both can be applied to the hemispheric bias model of hand choice. With both hands placed in their respective hemispaces, hand selection on the same side of the stimulus is consistent with compatible spatial locations (coding-based models) and the relationship between each cerebral hemisphere and the effector it controls (attention-based models).

Task Complexity

Beyond object location, researchers have investigated the effect of task complexity on hand use. An experiment by Mamalo, Roy, Rohr, and Bryden (2006) placed tools in an array of 5 positions at 45-degree intervals (Figure 3) and asked participants to perform three different actions with each tool: lift, pantomime, or use each tool. The assumption was that using the tool is more difficult than pantomiming, and pantomiming is more difficult than lifting the tool.

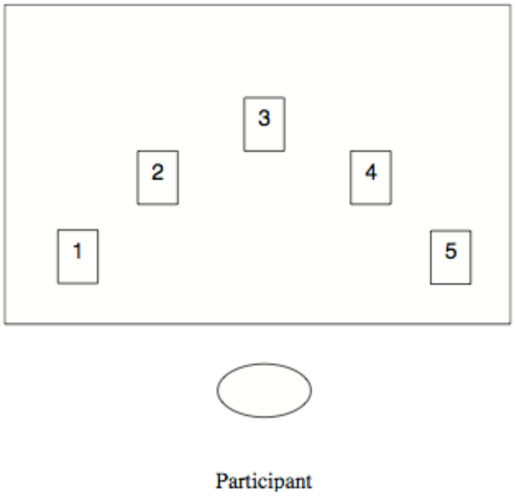


Figure 3: Experimental setup for Mamalo et al. (2006). Participants use their right hand more frequently in left space with increasing task complexity (i.e. lifting vs. pantomiming with an object)

The results of Mamalo et al. (2006) demonstrate that information about the task complexity influences hand use, especially for reaches into contralateral space. When presented with more complex tasks of using or pantomiming with the tool, right-handed individuals use their right hand deeper into contralateral space. However, when completing the simpler task of lifting an object in left-space, right-handed individuals more often use their left hand. Individuals perceive the constraints associated with task demands and factor complexity into their hand use. Participants opt to use their preferred hand further in contralateral space when the task demands more accuracy, control, or precision.

Others have also investigated the effect of task complexity. Rezaee, Shojaei, Ghasemi, & Moghadam (2010) conducted an experiment similar to Mamalo et al. (2006), asking participants to lift, pantomime, or use an object as quickly and accurately as possible. Rezaee et al. (2010) report observations similar to Mamalo et al. (2006), supporting the idea that increased task demands result in greater right hand use deeper in contralateral space. Stins, Kadar, & Costall (2001) altered task complexity by introducing control demands, asking participants to lift an empty glass or one filled with liquid. Stins et al. (2001) revealed that right-handers continue to use their right hand more often in contralateral space when the control demands of the task are greater (i.e. when the glass is filled with liquid).

Overall, studying the effect of task complexity on hand choice shows that right hand use varies according to the constraints, demands, and requirements of the task, showing that hand choice decisions are truly a complex interaction between the task, environment, and handedness.

Hand Choice Distribution, Points of Subjective Equality, & Kinematic Measures

As observed with varying task complexities, right-handed individuals alter the point in space where they switch between using their right and left hand. Recall, right-handers use their right hand deeper into contralateral space more often with complex tasks than simple tasks. Furthermore, the specific transition point between hands differs between individuals since the perception of task complexity is subjective. Although the specific location for this switch in hand use can vary between individuals, the distribution of right hand use for right-handers remains consistent at approximately 60% of the workspace (Gabbard & Helbig 2004; Helbig and Gabbard, 2003).

More recently, Oliveira, Diedrichsen, Verstynen, Duque, & Ivry (2010) identified a more specific location for transition between hands. They termed it the point of subjectively equality (PSE), the virtual point in space where an individual has an equal probability of using the right hand or left hand. They calculated the PSE by plotting the frequency of right hand use for a series of 10 targets arranged in a semi-circle in a participant's workspace (Figure 4; represented by the solid squares). Oliveira et al. (2010) then generated a logistic regression for the probability of right hand use at the different target locations and matched a sigmoidal pattern to the curve. From there, they extrapolated the point in space where the probability of right hand use is 50% (the PSE) and plotted the PSE of each participant (Figure 4; open circles). The average PSE among all participants is calculated at 15.2 degrees left of the midline (solid vertical line; Figure 4).

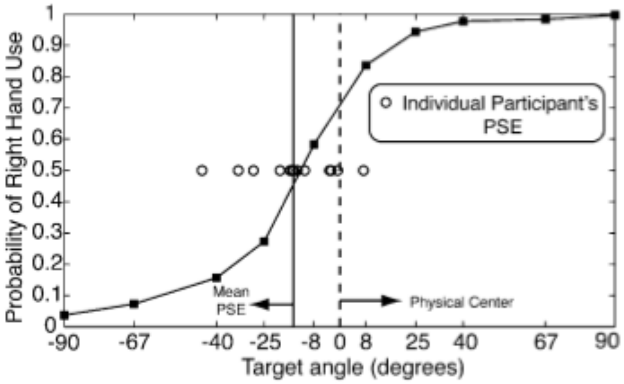


Figure 4: Mean PSE (point of subjective equality) as illustrated by the solid vertical line, the point in space where the probability of choosing either hand is equal. The dashed vertical line represents the participant's midline. Open circles represent individual participant's PSE (Oliveira et al., 2010).

Values different than 15.2 degrees left of the midline (Oliveira et al., 2010) have been suggested as the transition point for hand use. Gabbard & Helbig (2004) identify 20 degrees left of the midline, and Kim et al. (2011) report a smaller value of 10 degrees left of the midline. The differences in these values can be attributed to the fact that both experiments observed the frequency of right hand use for each target and identified the target location that showed a drop in right hand use below 50%. This is in contrast to Oliveira et al. (2010) who extrapolated their point from a generated curve. Despite the differences in the exact location, it is more important to note that individuals typically switch between using the right and left hand in left hemispace at approximately 10-20 degrees left of the midline.

Beyond observing changes in the frequency of hand use and calculating PSE, Stins et al. (2001) relied on kinematic measures to reveal underlying mechanisms behind hand use. Stins et al. (2001) recorded the trajectories of reaches using 3D positional markers and found that the transition point between hands occurs left of the midline where the deceleration times for reaches are identical between hands. Kim et al. (2011) elaborate on Stins et al. (2001), stating the hand that executes the most accurate reach spends less time decelerating the limb. Therefore, shorter deceleration times by the non-preferred hand are associated with more accurate reaches deeper in left space. It seems that more recent studies using kinematic measures have given more insight into why the non-preferred hand might be chosen over the preferred hand to reach into contralateral space.

Bimanual Coordination: Moving Both Hands at Once

To this point, hand choice decisions have required selecting one effector for unimanual tasks, however there are several opportunities where both limbs are needed. Mention of bimanual coordination in the field of motor control is typically associated with oscillating movements between effectors, using symmetrical and asymmetrical movements between hands and fingers. The field of cyclical bimanual coordination has been extensively studied and is of great value to researchers interested in the planning and control of human movement (Obhi, 2004).

A classic finding by Kelso (1984) reports that high frequency bimanual finger movements tend to favor stable symmetrical or in-phase coordination (i.e. moving both index fingers together and apart simultaneously). A series of experiments done by Kelso, Southard, & Goodman (1979) present observations that relate the bimanual coordination findings of Kelso (1984) with the kinesthetic hypothesis. Recall, one aspect of the kinesthetic hypothesis states that individuals favor movements that optimize movement efficiency in response to the degrees of freedom problem. Kelso et al. (1979) presented individuals with bimanual reaching tasks, varying the degree of difficulty between effectors by manipulating the amplitude of the reaches, size of the targets, and the movement trajectories with the use of barriers of different heights between the home positions and targets. The results of their experiments demonstrate that regardless of the disparity in task difficulty between hands, both effectors display similar movement times, path trajectories, and kinematics of the more difficult task (further amplitude, smaller target location, or taller barrier). Therefore, when the motor system is faced with controlling multiple degrees of freedom, movement synergies provide a solution by constraining both limbs to act as a single unit. The observed constraints in the system support the idea that individuals prefer to optimizing movement efficiency when performing reaching tasks, as consistent with the kinesthetic hypothesis.

It is important to note that Obhi (2004) highlights a current imbalance in the field of bimanual coordination research despite the extensive literature currently available. Obhi (2004) suggests a paucity of studies investigating object-oriented and goal-directed bimanual tasks, where more focus should be spent on non-cyclical, discrete movements. Using multiple limbs in this sense is an important skill when completing tasks such as buttoning a shirt or opening a jar. Bimanual object-oriented and goal-directed tasks can be grouped into one of two categories: Two effectors can be bound together with each hand producing different motor outputs (i.e. playing the guitar), or both effectors can produce similar motor outputs in a specific temporal order (i.e. typing). This thesis aims to provide more insight into non-cyclic, discrete movements to help remedy the current imbalance in bimanual coordination research. More specifically, the methodology of this thesis uses reaching tasks that involve both hands, each producing similar motor outputs in a specific temporal order.

Hand Use: A Decision-Making Process

It is important to discuss the processes involved in hand use decisions, whether it is selecting one hand for unimanual tasks or assigning roles to each hand in bimanual coordination tasks. The Diffusion Decision Model by Ratcliff (1978) describes the cognitive process involved in simple two-choice decisions (i.e. selecting the right hand versus the left hand). The ability to make decisions resembles a race between the two-choice options, in this case, either hand. From a starting point (A in Figure 5), both hands accumulate viable information based on the stimulus (i.e. object location, task complexity, accuracy demands of the task), where the rate of accumulation varies depending on quality of information extracted from the stimulus (i.e. whether one hand is closer to the object than the other, or which hand provides greater control based on the degree of handedness). Labels 1-4 in Figure 5 represent different rates of information accumulation from quickest to slowest. When either hand accumulates enough information to reach the response criteria boundaries or "finish line" (B in Figure 5), that choice (or hand) is selected over the other to complete the task. For example, when a target is located in right space, both hands have the opportunity to complete the reach. If the right hand results in a shorter reach, fewer coordinated degrees of freedom, or greater control, more viable information is accumulated at a quicker rate. When the right hand accumulates enough information to reach the boundary threshold, it is chosen to complete the reach over the left.

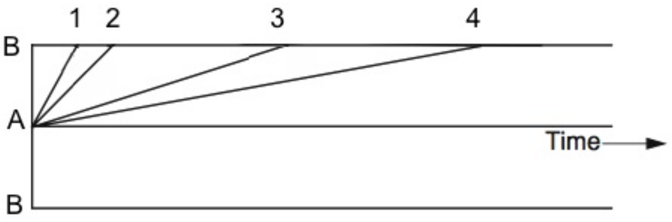


Figure 5: The Diffusion Decision Model: Examples of different rates of information accumulation from quickest (1) to slowest (4) moving from the start point (A) toward the response criteria boundary threshold for either hand (B) (i.e. right hand on top, left hand on the bottom). Adapted from Ratcliff & McKoon, 2008.

Oliveira et al. (2010) adds to the idea that decisions resemble a competition between hands by using reaction time (RT) as a dependent measure. Simple RTs are associated with one signal and only one possible response, where choice RTs are associated with more than one signal and more than one possible response (Rosenbaum, 2001). RTs used by Oliveira et al. (2010) are an example of choice RT, representing a measure of the participants' information accumulation when selecting either hand to reach a target. Oliveira et al. (2010) demonstrates that RTs are longer when participants reach toward a target located near their PSE (the point in space where there is an equal probability of selecting either hand). In contrast, RTs are significantly faster when participants select a hand to reach targets located further in left or right workspace. Oliveira et al. (2010) suggests that longer RTs for targets at a participant's PSE are associated with greater levels of uncertainty due to the equal probability of selecting either hand, resulting in slower rates of information accumulation.

Oliveira et al. (2010) have also manipulated the distribution of hand choice decisions during reaching tasks. The posterior parietal cortex (PPC) is highlighted to play a critical role in planning reaching movements, with greater levels of activity seen in the hemisphere contralateral to the selected hand (e.g. greater levels in the left hemisphere PPC with right hand use). Oliveira et al. (2010) used transcranial magnetic stimulation (TMS) to "knock out" the PPC by interrupting the information accumulated when preparing a reach using the contralateral hand. Their results demonstrate that with TMS to the left hemisphere, participants are less likely to select the right hand and more likely to use their left hand when completing reaches. The same cannot be said for TMS to the right PPC, suggesting an asymmetrical representation in preparing reaches, however this may a result of using right-handed participants in their study.

Purpose

Different Hand Positions

Early research has investigated attentional information in the form of object location and its influence on hand choice decisions, where this thesis aims to alter the reference point that individuals extract information when observing a target location. More specifically, several studies mention the importance of hand position with respect to the target location (Bryden & Huszcynski, 2011; Gabbard et al., 1997; Oliveira et al., 2010), however there is a relative shortage of studies that investigate different hand positions and its effect on hand choice decisions.

Therefore, the first purpose of investigate the effect of different hand positions on hand use and test the hypothesis that participants will adhere to the idea of object proximity (as part of the kinesthetic hypothesis) mediating hand use. It is predicted that participants will use the hand closest to the target to ensure shorter reaching amplitudes and optimize movement efficiency as part of the kinesthetic hypothesis.

Predictable Reaches to Multiple Targets

Information available to an actor during reaching tasks is not limited to the spatial cues of an object's location since the perceived complexity, accuracy requirements, and control demands of the task are also taken into account when making hand choice decisions. Several studies demonstrate changes in the frequency of hand use as a function of task complexity (Mamalo et al., 2006; Rezaee et al., 2010; Stins et al., 2001), where the right hand is used for a larger proportion of the workspace when presented with more complex tasks.

Therefore, the second purpose of this thesis is to investigate the concept of planning or knowledge of future targets as another source of information available to the actor when making hand choice decisions. Participants were provided with a target sequence prior to movement initiation allowing them to assign hand use when completing a series of reaches to multiple targets. This type of bimanual coordination differs from cyclical and oscillating movements, and contributes to the area of coordination focused on discrete, temporally linked goal-oriented tasks.

Gabbard, Tapia, and Helbig (2003) provide early insight into the effect of planning for reaches to multiple target locations. Participants were asked to use one hand to move a cube from one position to another, where they knew the location of the initial reach and where the cube needed to be placed. Gabbard et al. (2003) report an interesting finding, observing greater use of the left hand in right space to place an object initially grabbed in left space. In this case, planning for a series of reaches and knowledge of future target locations challenges the idea of handedness mediating hand use in ipsilateral space. For this thesis, it is hypothesized that planning for multiple reaches will result in changes in the frequency of hand use when compared to unpredictable reaches to single targets. The results of Gabbard et al. (2003) warrant this thesis' purpose to further investigate the effect of planning on hand choice decisions.

Although Gabbard et al. (2003) shed light into the effect of planning for multiple reaches on hand use, differences in the methodologies used by Gabbard et al. (2003) and the current thesis should be noted. First, Gabbard et al. (2003) asked participants to select one hand to complete both reaches, where this thesis gives participants the opportunity to use either hand to reach a given target. Second, target pairs used by Gabbard et al. (2003) had participants move between locations equidistant from the midline (i.e. from 30 degrees on the left to

30 degrees on the right). This thesis presents targets at varying positions in left and right hemispace, with some targets appearing on the same side of the midline.

Experimental Design

The general experimental design was as follows (specific details are included in the Methods section). Twenty participants were presented with 4 targets placed in a semi-circular array and 2 home positions below on either side of the midline (Figure 6). From left to right, the four targets were identified as the far left, near left, near right, and far right; and 2 home positions as the left home position and right home position for the left and right hand, respectively (Figure 6). Participants were randomly assigned to two groups of 10, each defined by the types of reaches they were asked to perform: Unpredictable Reaches (Experiment 1) and Predictable Reaches (Experiment 2). For both groups, each participant was asked to reach to a series of 3-target sequences using their index fingers. With unpredictable reaches, participants were unaware of the target sequence, but were asked to select a hand to reach each target as it appeaeds. With predictable reaches, participants were presented with the 3-target sequence prior to executing the reaches, allowing them to assign hand use for each target. We calculated the frequency of right hand use for each target as a dependent variable, used different hand positions in the workspace as a within-participant independent variable, and used predictable versus unpredictable reaches as the between participants independent variable.

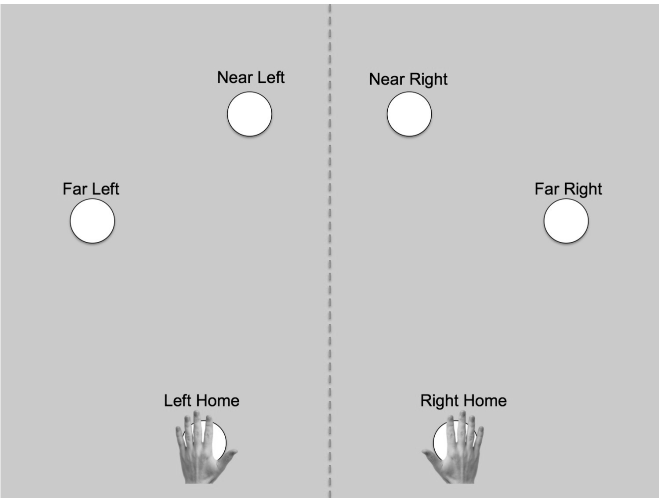


Figure 6: Target display with 4 targets named relative to the participant's midline (dotted line): far left, near left, near right, and far right; and 2 home positions: left home position and right home position for the left and right hand, respectively.

Hypotheses

Far Left and Far Right Target

The far left and far right targets are located furthest in their respective hemispaces, 40 degrees on either side of the midline. Gabbard & Rabb (2000) showed that their participants used their right hand for 100% of the reaches to targets located at 50 and 30 degrees right of the midline, and less than 20% for reaches to targets located at 50 and 30 degrees left of the midline. Therefore, it is predicted that during both unpredictable and predictable reaches, the right hand will be used to reach the far right target (40 degrees right of the midline) and left hand for the far left target (40 degrees left of the midline) for a large proportion (80-100%) of the reaches because of their location between targets used by Gabbard & Rabb (2000). In line with both the kinesthetic hypothesis and hemispheric bias, this hypothesis is consistent with the idea that reaches across the midline compromise the efficiency of the travel amplitude, the comfort of the reach (Mark et al., 1997), introduce more degrees of freedom at the torso and shoulder (Kim et al., 2007), and do not comply with S-R compatibility (Verfaille et al., 1990; Wallace, 1971). It is predicted that any changes in the frequency of hand use will be seen at the near left and near right target, each located at 10 degrees on either side of the midline.

Unpredictable Reaches to Single Targets at Different Hand Positions

The unpredictable reaches condition provides the frequency of hand use for each target (i.e. far left, near left, near right, and far right) at different hand positions. It serves as the baseline measure to compare with the predictable reaches condition.

In 2004, Helbig & Gabbard attempted to determine whether object proximity (as part of the kinesthetic hypothesis) or hemispheric bias is a better predictor of hand choice decisions by switching the home positions of both hands. They introduced an arms-crossed condition to identify whether: (1) participants selected a hand based on its relative position to the target, keeping both arms crossed to complete reaches in contralateral space (consistent with the idea of object proximity); or (2) uncross the arms to complete reaches using the arm on the same side of the stimulus/target (consistent with the idea of hemispheric bias and attention-based models of S-R compatibility).

Overall, Helbig & Gabbard (2004) demonstrate that participants keep their arms crossed for reaches in both contralateral and ipsilateral space, supporting the idea that object proximity mediates hand choice over hemispheric bias and attention-based models of S-R compatibility. Therefore, with both hands at different positions in the workspace during unpredictable reaches, it is predicted that participants will select the hand closest to a given target to optimize movement efficiency. Different hand positions allow participants to re-evaluate the spatial information of the target's relative position during hand choice decisions.

Predictable Reaches to Multiple Targets at Different Hand Positions

Hand use in the predictable reaches condition is compared to the frequency of hand use during the unpredictable reaches condition at all hand position combinations.

During predictable reaches, participants have the opportunity to assign reaches to either hand for the 3-target sequence. It is hypothesized that participants will continue to exhibit the idea of object proximity when making hand choice decisions, but not in all cases. It is predicted that participants will complete longer and inefficient reaching amplitudes earlier in the movement sequence to ensure that the later reaches are shortened and completed efficiently. This could be considered similar to the phenomenon known as the end-state comfort effect (Rosenbaum, 1992), where participants were asked to lift a horizontal bar using an overhand or underhand grip and place it in different orientations with certain ends of the bar pointing upward. Rosenbaum (1992) showed that each participant switched the strategies of their initial grip depending on which way the bar was to be placed to ensure that participants ended their movement in a comfortable position. Overall, the idea of end-state comfort states that participants are willing to incur the cost of an awkward or uncomfortable posture earlier in a movement to ensure a comfortable end-posture.

A more broadly defined end-state comfort effect can be applied to predictable reaches, wherein participants plan to incur the cost of a larger reaching amplitude earlier target sequence to ensure that object proximity and movement efficiency are maximized for subsequent targets. Therefore, it is hypothesized that during predictable reaches there will be a trade-off with when hand use is mediated by object proximity. Reaches will be completed using the hand positioned further away from a target to ensure that both hand are closer to target locations later in the sequence.

Methods

Participants

A total of 20 participants were involved in two studies, each study using 10 participants (5 males and 5 females). Participants were healthy, right-handed, adults recruited from the McMaster University population (ages 19-25). All participants read and signed consent forms approved by the McMaster Research and Ethics Board, and received monetary compensation of $10.

Apparatus

3D positional data were collected using an Optotrak 3020 Camera System (Northern Digital Inc., Waterloo, ON, Canada), sampled at a rate of 500 Hz. Two infrared markers were fastened to two metal banjo picks, worn on the dorsal side of the 2nd distal phalange (tip of the index finger, above the nail) of each hand (Figure 7). Each hand also held a mechanical trigger (Figure 8) using their 1st (thumb) and 3rd phalange (middle finger) in a pinch grip, placing their 2nd phalange on the trigger so that the infrared marker was inline with the mechanical trigger (Figure 7).

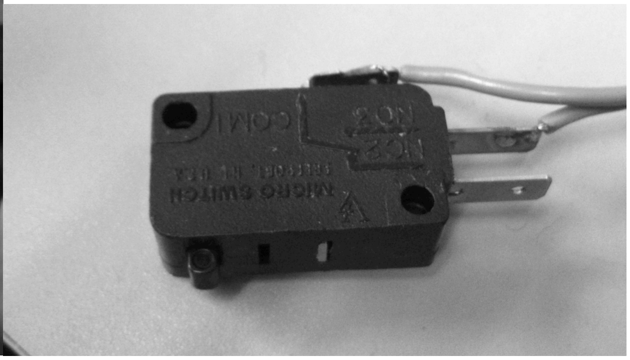
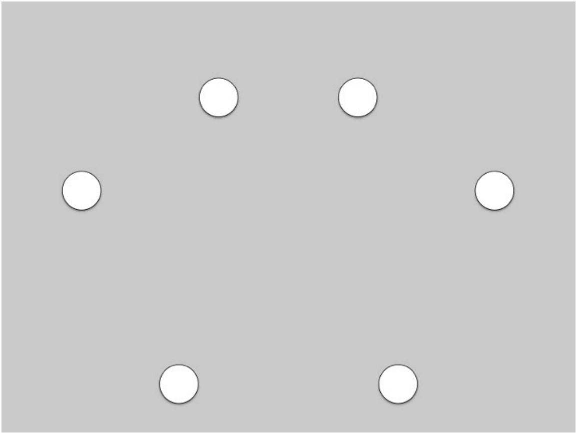


Figure 7 (left): Pinch grip with the infrared marker located above; Figure 8 (right): Mechanical trigger used as an input device for the E-Prime Software.

Participants were seated at a table facing the Optotrak Camera System. In front of the participant was a 21-inch Dell LCD monitor (Dell, Round Rock, TX) lying flat without a stand so that the display faced the ceiling. The computer monitor's default screen displayed 6 targets represented by white circular outlines on a black screen, each target measuring 25mm in diameter (Figure 9). 2 targets representing the home positions for each hand were placed at the bottom of the screen, equidistant from the participant's mid-line. The remaining 4 targets were placed in a semi circle above the home targets at 40 and 10 degrees left of the midline for the far left and near left target, respectively, and 10 and 40 degrees right of the midline for the near right and far right target, respectively (Figure 9). Target illumination patterns were controlled using custom E-Prime software (Psychology Software Tools Inc., Sharpsburg, PA, United States) (Figure 10).



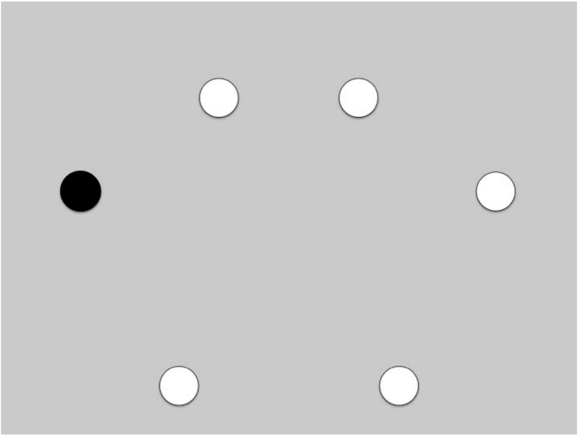


Figure 9 (left): Target display set up; Figure 10 (right): Target display set up with the far left target illuminated

A total of twenty-four 3-target combinations were generated using the 4 target locations. All 24 combinations were randomly presented 3 times for 72 trials per block, and a total of 4 blocks were collected in Experiment 1 (288 trials per participant) and 3 blocks for Experiment 2 (216 trials per participant). Fewer blocks were collected in Experiment 2 in order to complete data collection in the allotted time due to the longer pre-trial set up.

Procedure: Experiment 1

The default screen displaying the 2 home positions and 4 targets was presented to the participants. The word 'READY' appeared on the default screen, prompting participants to place their left and right fingers/triggers on their respective home positions.

Once the participant placed their fingers/triggers on the home positions, a trial began with the experimenter illuminating the first target. Note that neither the participant nor experimenter knew which of the four targets would appear. Participants were required to select a hand to move their finger from the home position to the target. Once they reached the first target, a second target illuminated while keeping the current location of both hands, and the participant selected either hand to reach the second target. Finally, a third target appeared, and the participant selected either hand to reach the last target. Participants were asked to move only one hand at a time.

Optotrak file collection was triggered immediately before the illumination of the first target and automatically stopped after 4 seconds. Participants were asked to complete the 3-target sequence within the allotted time. Further, participants remained still after completing a trial until the 'READY' screen appeared. This minimized excessive movement collected by the Optotrak file and ensured that the Optotrak camera successfully collected the trial. Participants were permitted to take breaks between blocks and at their own discretion.

Movements to target locations in Experiment 1 were referred to as unpredictable reaches (versus predictable reaches in Experiment 2) since participants were unaware of which target would appear on screen.

Procedure: Experiment 2

The same default screen and ‘READY’ prompt from Experiment 1 signaled participants to place both fingers/triggers on their respective home positions. Next, the experimenter triggered the appearance of a 3-target sequence that the participant watched. Next, the word ‘SET’ appeared allowing participants to plan hand use for their movements. Following a variable foreperiod delay (e.g. 1500, 1750, 2000, 2250ms), a ‘GO’ prompt cued participants to complete the 3-target sequence. Once again, participants were asked to move only one hand at a time.

Optotrak file collection was triggered immediately before the ‘GO’ screen and automatically stopped after 4 seconds. Participants were asked to complete the 3-target sequence in the allotted time and remained still after completing a trial. Again, participants were permitted to take breaks between blocks and at their own discretion.

Data Analysis

3D positional data were obtained from the data files created by the Optotrak system. The data collected for each participant were filtered using a 2nd order low-pass Butterworth filter with a cutoff frequency of 8 Hz. Custom LabView Software (Version 8.2, National Instruments, Austin TX) was developed to analyze the 3D positional data of each participant.

Trials were eliminated from the data set if a participant did not finish the movements in the data-recording time window (4 seconds), if a participant started their movements before the Optotrak began recording, or if either infrared marker was not detected by the Optotrak system. 513 trials were removed from Experiment 1, leaving an average of 237 (of 288) trials collected per participant, and 27 trials were removed from Experiment 2, leaving an average of 213 (of 216) trials collected per participant.

To determine which hand a participant used to complete each reach, the travel amplitudes of both hands were compared following the illumination of a target. The chosen hand was identified as the effector travelling the larger amplitude (i.e. one moved toward the target, the other maintained its position). After determining the order of hands used for a given trial, this sequence was matched to the trial number corresponding to the 3-target combination.

Statistical Analysis

Where appropriate, parametric analyses were conducted. Otherwise, non-parametric analyses were used. Two one-way (Hand Position) repeated measures ANOVA were conducted to compare the effect of different hand positions on the frequency of right hand use for the near left and near right target for unpredictable reaches; an independent samples t-test was conducted to compare the number of trials collected between experiments; 12 Pearson's chi-square analyses were conducted to compare the effect of predictable reaches versus unpredictable reaches on the frequency of right hand use; and 2 two-way univariate ANOVA (4 [Hand Positions] × 4 [Next Target] for Target 2; 5 [Hand

Position] × 4 [Next Target] for Target 3) were performed to compare hand use between predictable reaches and unpredictable reaches by looking at specific targets that followed in the sequence. All tests were conducted with a priori significance set at $p = .05$.

Results

Unpredictable Reaches to Single Targets at Different Hand Positions

This condition provides the frequency of hand use for each target (i.e. far left, near left, near right, and far right) at different hand positions. It serves as the baseline measure to compare with the predictable reaches condition.

Repeated Measures ANOVA

The left hand reaches toward the far left target and the right hand reaches toward the far right target in 100% of the trials in Experiment 1. Therefore, changes in the frequency of hand use at different hand positions are evaluated for the near left and near right target only. A one-factor (Current Hand Position) repeated measures ANOVA on the near left target data reveals a main effect for different hand positions on the frequency of right hand use F (5, 45) = 8.330, $p <$ 0.05. A Tukey's HSD *post-hoc* reveals that the frequencies of right hand use for the near left target are not different with both hands at the home positions, and with the right hand at the far right target and left hand at the left home position. In comparison to the previously mentioned hand positions, the frequency of right hand use for the near left target is significantly greater when the right hand is at the near right target and left hand is at the left home position, when the left hand is at the far left target and the right hand is at the right home position, and when the left hand is at the far left target and right hand at the far right target. The frequency of right hand use for the near left target is significantly greater when the right hand is at the far right target and left hand is at the far left target when compared to both hands at the home positions, but is not different than with the right hand at the far right target and left hand at the home position (Figure 11).

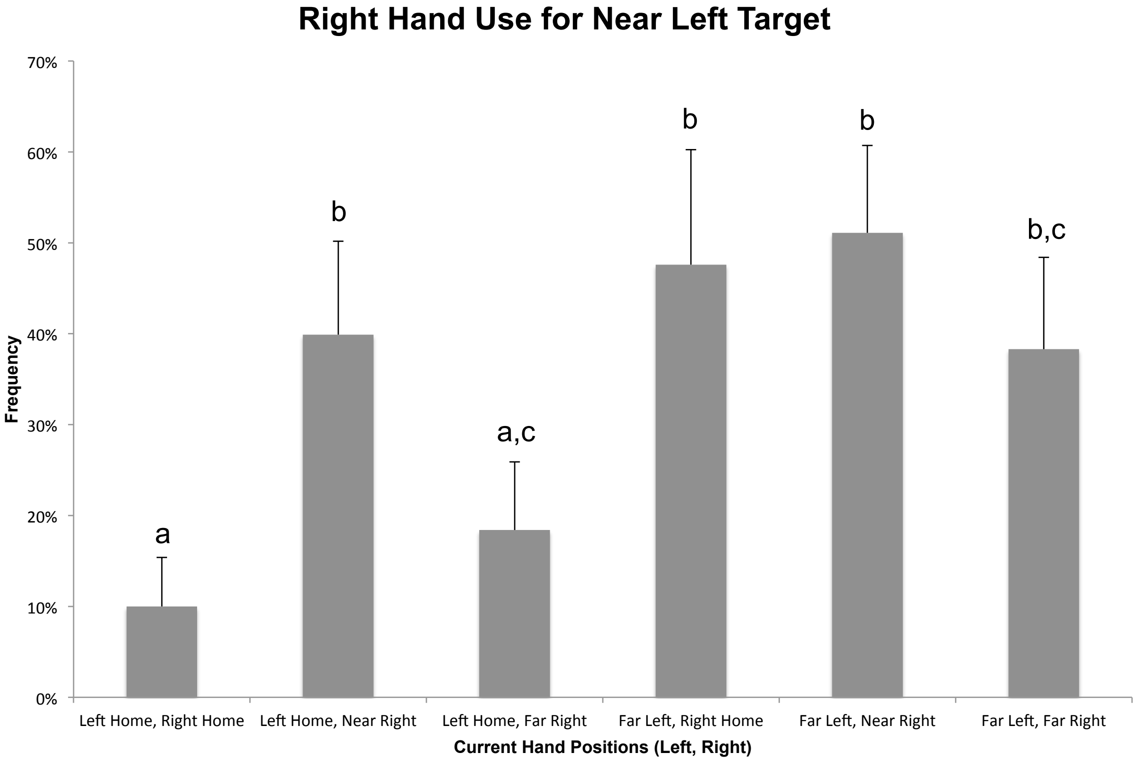


Figure 11: Frequency of right hand use for the near left target during unpredictable reaches where different letters represent a significant difference. Error bar values represent standard error.

A one-factor (Current Hand Position) repeated measures ANOVA conducted on the near right target data reveals a main effect for different hand positions on the frequency of right hand use F (4, 36) = 8.820, $p < 0.01$. A

Tukey's HSD *post-hoc* reveals that frequency of right hand use for the near right target is significantly lower when the left hand is located at the near left target and right hand is at the right home position compared to when the left hand is positioned at the far left target and right hand at the right home position, when both hands are on their respective home positions, and with the right hand at the near left target and left hand at the left home position (Figure 12).

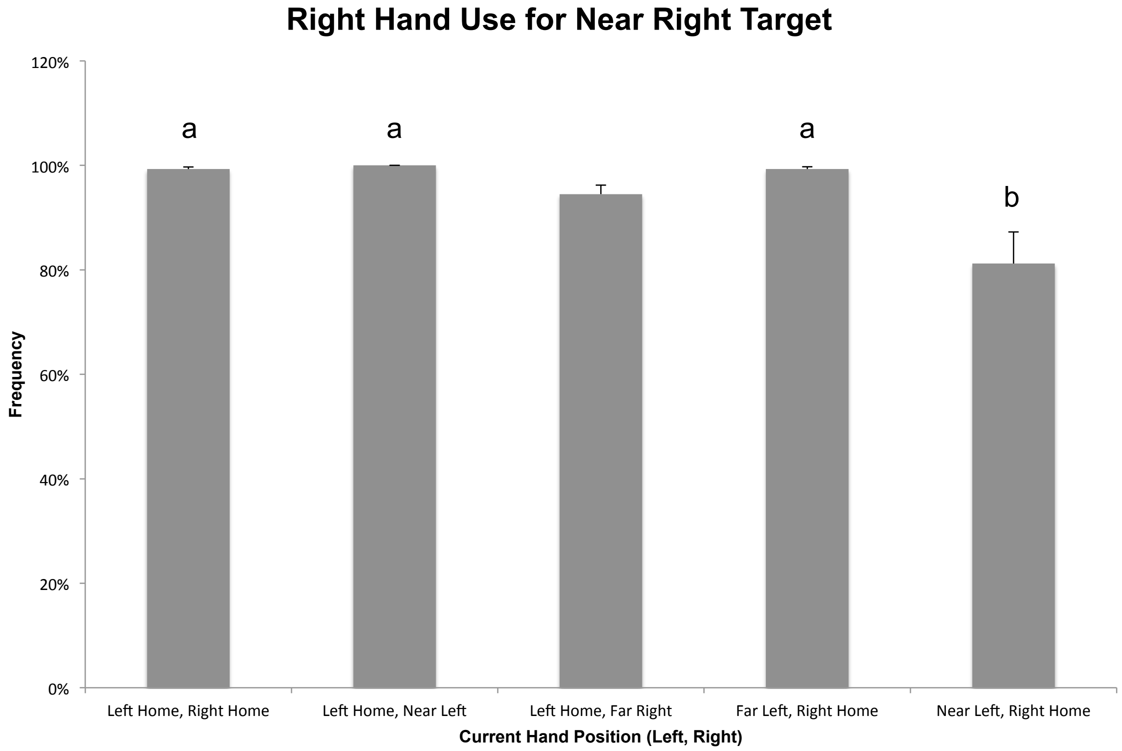


Figure 12: Frequency of right hand use for the near right target during unpredictable reaches where different letters represent a significant difference. Error bar values represent standard error.

Number of Trials in Experiments 1 & 2

Independent Measures t-test

2367 (82.3%) trials from Experiment 1 and 2135 (99.4%) trials from Experiment 2 were available for analysis. An independent t-test reveals no difference in the number of trials collected between experiments, t (18) = 1.801, p > .05.

Predictable Reaches vs. Unpredictable Reaches at Different Hand Positions

Recall, the frequency of hand use in the predictable reaches condition is compared to the frequency of hand use during the unpredictable reaches at the different hand positions.

Chi-Square Analyses

Far Left and Far Right Target

Comparing unpredictable and predictable reaches reveals that the left hand reaches toward the far left target and the right hand reaches toward the far right target in 100% of the trials. Therefore, a chi-square analysis cannot be conducted because there are zero instances of right hand use for the far left target, and left hand use in the far right target, resulting in an expected value less than 5 when generating a cross-tabulation. This violates an assumption of the chi-square test.

Near Left Target

Analyses of the near left target data (Figure 13) reveals a significant association between predictable reaches and unpredictable reaches on the frequency of right hand use at different hand positions. Specifically, with the left hand at the left home position and right hand at the near right target χ^2 (1) = 15.399, $p < .001$, the proportion of left hand use is 1.28 times greater during predictable reaches versus unpredictable reaches; with the left hand at the left home position and right hand at the far right target χ^2 (1) = 12.618, $p < .001$, the proportion of left hand use is 1.32 times greater during predictable reaches versus unpredictable reaches; and with the left hand at the far left target and right hand at the far right target χ^2 (1) = 14.759, $p < .001$, the proportion of left hand use is 1.29 times greater during predictable reaches versus unpredictable reaches.

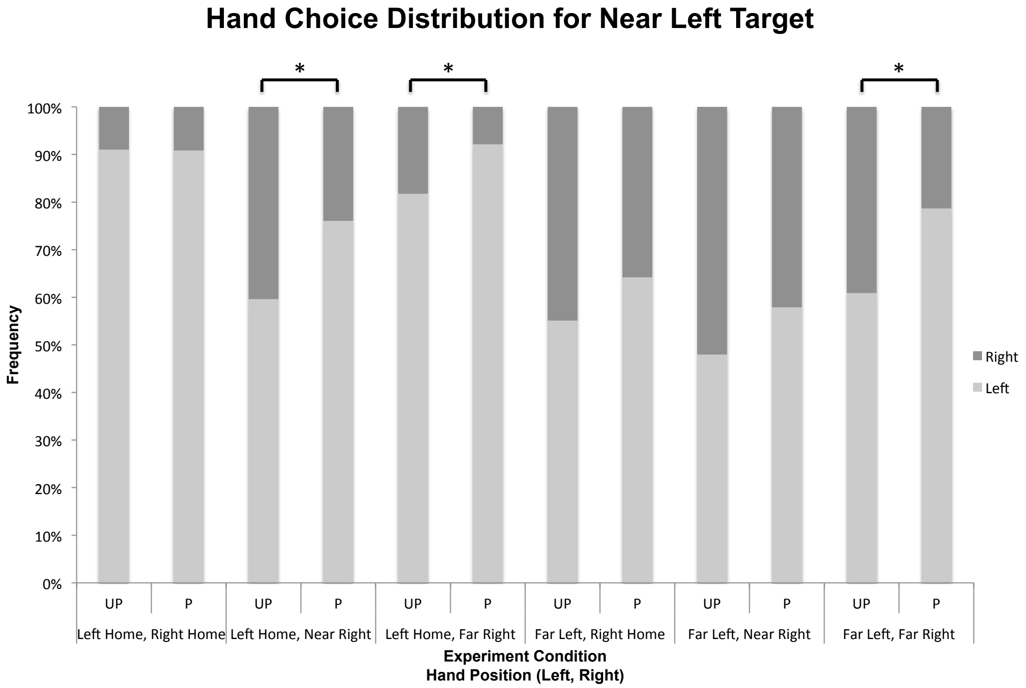


Figure 13: Hand use frequency distribution for near left target for predictable (P) and unpredictable (UP) reaches. An asterisk (*) indicates a significant association between frequency of right hand use and predictable reaches.

Analyses of the near left target data (Figure 13) did not reveal a significant association between predictable reaches and unpredictable reaches on the frequency of right hand use at different hand positions. Specifically, with the left hand at the left home position and right hand at the right home position χ^2 (1) = 0.017, *p* = .917; with the left hand at the far left target and right hand at the right home position χ^2 (1) = 3.080, *p* = .087; and with the left hand at the far left target and right hand at the near right target χ^2 (1) = 3.618, *p* = .061.

Near Right Target

Analyses of the near right target data (Figure 14) reveals a significant association predictable reaches and unpredictable reaches on the frequency of right hand use at different hand positions. Specifically, with the left hand at the left home position and right hand at the right home position χ^2 (1) = 25.588, $p < .001$, the proportion of left hand use is 15.27 times greater during predictable reaches versus unpredictable reaches; with the left hand at the left home position and right hand at the far right target χ^2 (1) = 4.981, $p < .05$, the proportion of left hand use is 1.77 times greater during predictable reaches versus unpredictable reaches; and with the left hand at the far left target and right hand at the right home position χ^2 (1) = 5.877, $p < .05$, the likelihood of using the left hand is 5.33 times greater during predictable reaches versus unpredictable reaches.

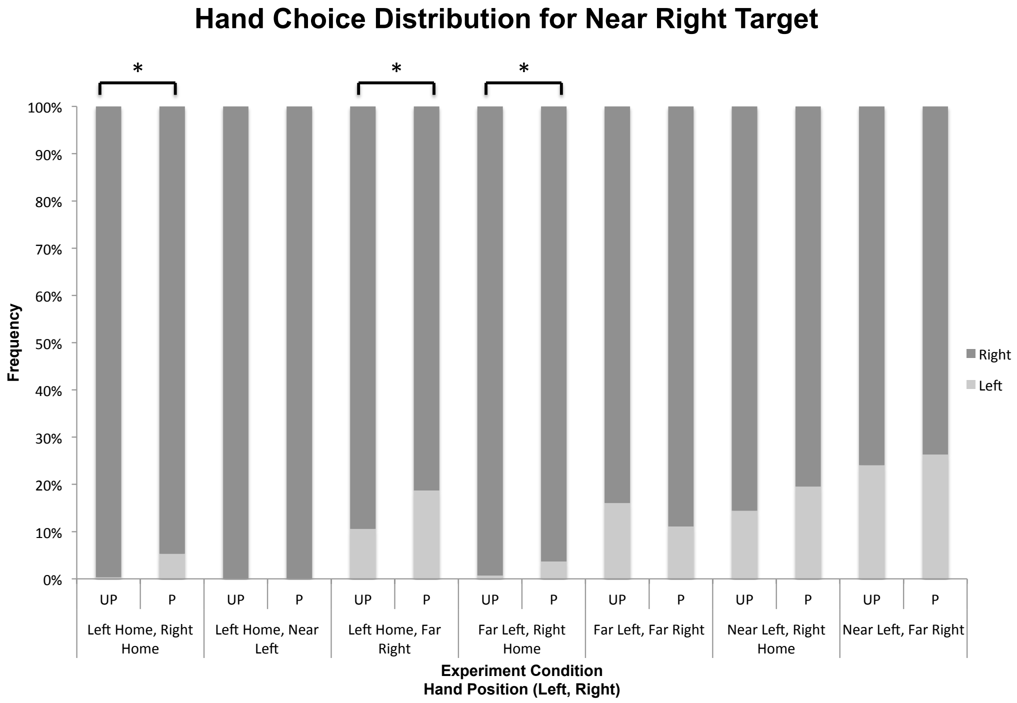


Figure 14: Hand use frequency distribution for near right target for predictable and unpredictable reaches. An asterisk (*) indicates a significant association between frequency of right hand use and predictable reaches.

Analyses of the near right target data (Figure 14) did not reveal a significant association predictable reaches versus unpredictable reaches on the frequency of right hand use at different hand positions. Specifically, with the left hand at the far left target and right hand at the far right target χ^2 (1) = 2.023, *p* = .189; with the left hand at the near left target and right hand at the right home position χ^2 (1) = 2.006, *p* = .161; and with the left hand at the near left target and right hand at the far right target χ^2 (1) = .242, *p* = .626.

A chi-square analysis was not used to investigate the association between predictable reaches versus reacted reaches on the frequency of right hand use for the near right target location with the left hand at the left home position and right hand at the near left position (although frequency distribution is illustrated on Figure 14). There were zero instances of left hand use for the near right target, resulting in an expected frequency less than 5, violating an assumption of a chi-square test.

Predictable Reaches for Specific Targets that Follow vs. Unpredictable Reaches at Different Hand Positions

Two-Way ANOVA

Left hand use for the far left target and right hand use for the far right target occurred in 100% of the cases, regardless of the experiment condition (unpredictable vs. predictable reaches) and hand position. Therefore, an ANOVA investigating the effect of predictable reaches for specific targets that followed versus unpredictable reaches at different hand positions was conducted only on the near left and near right targets.

Near Left Target

Near left target data (Figure 15) did not reveal a significant effect between predictable reaches to specific targets and unpredictable reaches on the frequency of right hand use F (3, 117) = 1.893, p = .135. There is a significant main effect for the different hand positions on the frequency of right hand use, F

(3, 117) = 7.171, *p* < 0.001. There is no interaction between predictable reaches to specific targets and unpredictable reaches on the frequency of right hand use at different hand positions, *F* (6, 117) = .552, *p* = .768.

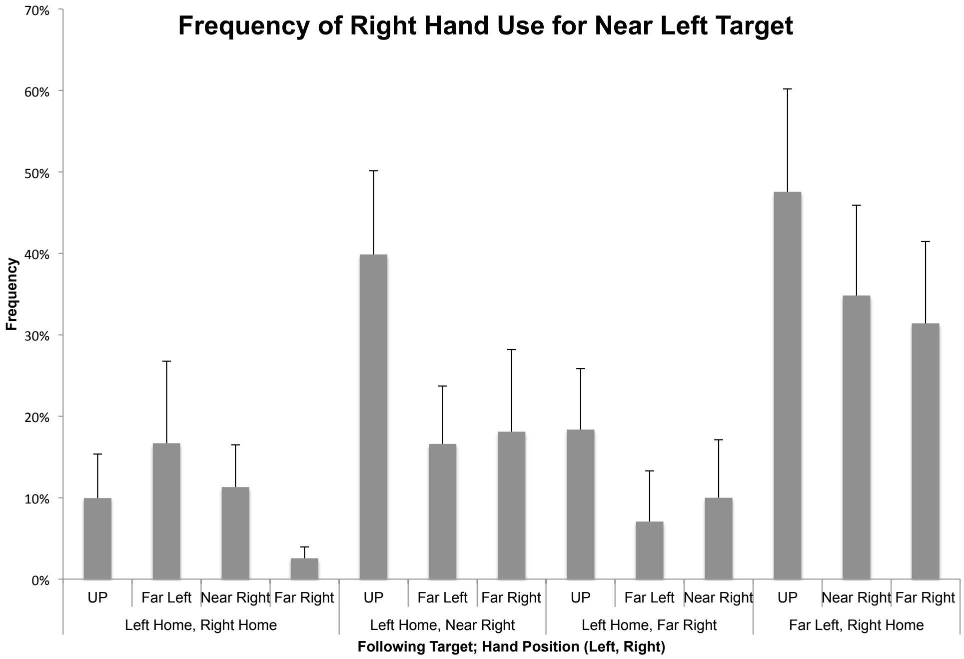


Figure 15: Two-way ANOVA comparing predictable reaches to specific targets (Far Left, Near Right, and Far Right) and unpredictable reaches (UP) at different hand positions for the near left target.

Near Right Target

Near right target data (Figure 16) did not reveal a significant effect between predictable reaches to specific targets and unpredictable reaches on the frequency of right hand use *F* (3, 144) = .928, *p* = .428. There is a significant main effect for different hand positions on the frequency of right hand use, *F* (4, 144) = 4.310, *p* = .003. There is no interaction between predictable reaches to specific targets and unpredictable reaches on the frequency of right hand use at different hand positions, *F* (8, 144) = .647, *p* = .737.

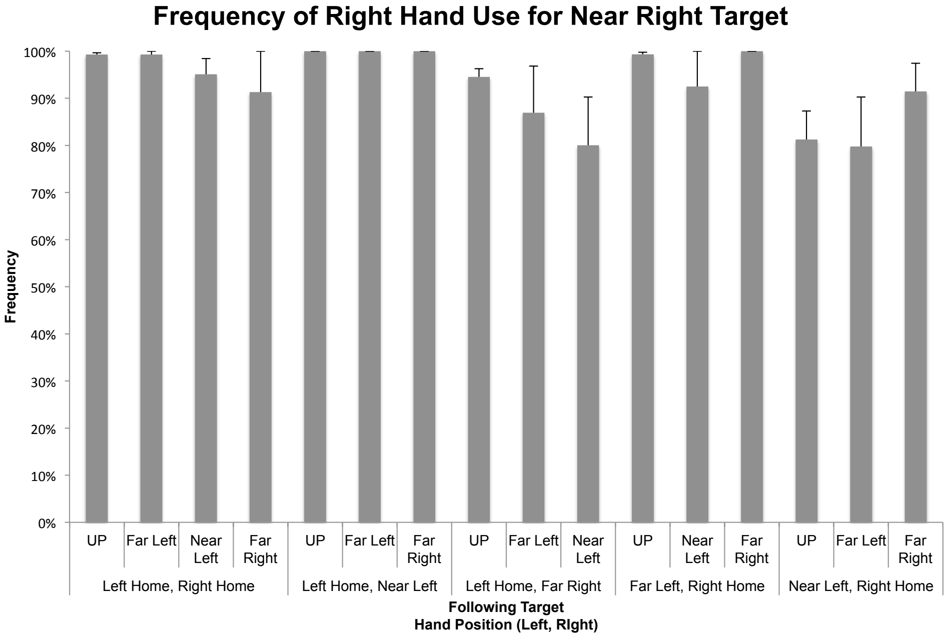


Figure 16: Two-way ANOVA comparing predictable reaches to specific targets (Far Left, Near Left, and Far Right) and unpredictable reaches (UP) at different hand positions for the near left target

Discussion

Far Left and Far Right Target

This thesis compares the effect of predictable reaches to multiple targets and unpredictable reaches to single targets on the frequency of hand use at different hand positions. Earlier studies on hand choice have focused on reaches to single target locations from the same starting home positions (i.e. Gabbard et al., 1997, 2000; Bryden et al., 2000; Gabbard & Helbig, 2004; Helbig & Gabbard, 2004; Mamalo et al., 2006), where this thesis allows participants to reach to targets during unpredictable and predictable reaches from different hand positions relative to a given target location.

One finding consistent between both experimental conditions (i.e. unpredictable vs. predictable reaches) and all hand positions is that the right hand reaches for the far right target (40 degrees right of the midline) and the left hand reaches for the far left target (40 degrees left of the midline) in 100% of the trials. This observation is consistent with our initial hypothesis of using the hand on the same side of a stimulus for target locations deeper in the workspace. Further, this hand choice pattern falls in line with the previous findings reporting that right-handers use their right hand 100% of the time for reaches at 50 and 30 degrees right of the midline and decreases for target locations at 50 and 30 degrees left of the midline, where left hand use is near 80% (Gabbard & Rabb, 2000). It is difficult to determine whether the observed hand use data support the kinesthetic hypothesis or hemispheric bias, however. If the kinesthetic hypothesis is supported, reaches would be completed to shorten reach amplitudes (Gabbard & Rabb, 2000), involve fewer degrees of freedom, and result in more comfortable reaching postures (Mark et al. 1997); whereas, if the hemispheric bias is supported, hand choice decisions would reflect stimulus-response compatibility (Wallace, 1971).

Unpredictable Reaches to Single Targets at Different Hand Positions

Near Left Target

Near left target data reveals that the frequency of right hand use is 10% with both hands at the home positions (Figure 11). Greater right hand use is expected (i.e. closer to 50%) because of the target's location near the average PSE of 15.2 degrees left of the midline (see Oliveira et al., 2010), where the probability of using either hand is equal. This target location also falls within the values others have observed as the transition between using their preferred and non-preferred hand (see Gabbard & Helbig, 2004; & Kim et al., 2011).

The frequency of right hand remains low (<20%; Figure 11) when participants position their right hand further into right space (i.e. right hand at the far right target and left hand at the left home position). Lower values of right hand use are expected because this hand position places the right hand further away from the near left target. It is difficult to attribute left hand use to the kinesthetic hypothesis (because of the left hand's proximity to the target), or the hemispheric bias, where S-R compatibility is maintained (Gabbard & Rabb, 2000).

Support for object proximity (and kinesthetic hypothesis) over hemispheric bias is evident with greater right hand use for the near left target at different hand positions (40-45% vs. 10-20%; Figure 11). Specifically, when the right hand is positioned closer to the near left target (i.e. right hand at the near right target and left hand at the left home position, and left hand at the far left target and right hand at the near right target), this promotes participants to cross their midline into left space rather than continuing to use their left hand.

Therefore, near left target data for unpredictable reaches at different hand positions reveals increases in the frequency of left hand use consistent with our hypothesis that individuals comply with the idea of object proximity driving hand choice over hemispheric bias. Our results also confirm the hypothesis of Helbig & Gabbard (2004) that object proximity (as part of the kinesthetic hypothesis) influences hand choice decisions more than hemispheric bias. At different hand positions during unpredictable reaches, individuals maximize movement efficiency by completing reaches using the hand with the shortest reaching amplitude to the target.

Near Right Target

Right hand use for the near right target remains quite high with both hands at the home positions (99%; Figure 12). This is consistent with the idea of movement efficiency, hemispheric bias, S-R compatibility, and hand preference mediating hand use on the ipsilateral side (Gabbard & Rabb, 2000), making it is difficult to attribute one explanation to hand use decisions. Further, right hand use for the near right target remains consistently high when the right hand is positioned in left space (100%; Figure 12) (i.e. right hand at the near left target and left hand at left home position) and when the left hand is placed further from the target (99%; Figure12) (i.e. left hand at the far left target and right hand at the right home position). At these hand positions, the right hand is best located for a short and efficient travel distance to the near right target. Although object proximity is maximized for the right hand, it is once again difficult to determine whether right hand use conforms with the idea of object proximity or hemispheric bias since the target location remains ipsilateral to the right hand.

There are instances when individuals display hand use behaviour that supports object proximity over hemispheric bias. Specifically, individuals use their left hand to reach toward the near right target when it is placed closer to the target than the right hand (i.e. left hand at the near left target and right hand at the right home position). At these hand positions, hemispheric bias suggests that the right hand will reach toward the near right target because of its location on the same side of the stimulus regardless of the left hand’s proximity to the target. Therefore, using the left hand to cross the midline into right space when positioned closer to the target supports the idea of object proximity having a greater influence on hand choice decisions over hemispheric bias.

Our observation of left hand use in right space is consistent with other hand choice reaching studies. For instance, Helbig & Gabbard (2004) attempted to distinguish between object proximity and hemispheric bias influencing hand use by introducing a hands-crossed condition placing the left hand in right space and right hand in left space. Participants kept their arms crossed and used their left hand to reach for targets in right space, supporting the idea of object proximity drives hand use over hemispheric bias. In this thesis, positioning the left hand at the near left target and right hand at the right home position does not cross both arms, but places the left hand closer to the near right target than the right.

Overall, the frequency of hand use during unpredictable reaches to single targets at different hand positions is consistent with our hypothesis object proximity mediating hand choice over hemispheric bias. Evidence supporting this is seen when both hands complete reaches across their midline. Object proximity, as part of the kinesthetic hypothesis, ensures that movement efficiency is maximized with shorter reaching amplitudes, and challenges the idea of hemispheric bias since participants did not always use the hand on the same side of the stimulus.

Predictable Reaches to Multiple Targets at Different Hand Positions

In contrast to unpredictable reaches to single target locations, participants placed in the "predictable reaches" group were shown the 3-target sequence prior to movement execution. This allowed participants to assign hand use when reaching toward each target location. The purpose of this condition was to compare the effect of planning for future reaches and unpredictable reaches to single targets on hand use at different hand positions.

Near Left Target

Near left target data reveals that predictable reaches show greater use of the left hand over unpredictable reaches when the right hand is positioned in right space, specifically when the right hand is at the far right target and left hand at the left home position (90% predictable vs. 80% unpredictable; Figure 13), and with the right hand at the near right target and left hand at the left home position (75% predictable vs. 57% unpredictable; Figure 13). Greater left hand use during predictable versus unpredictable reaches is also seen with both hands deep in their workspace. Specifically, with the right hand at the far right target and left hand at the far left target (80% predictable vs. 60% unpredictable; Figure 13).

When the right hand is positioned at the far right target and left hand at the left home position, unpredictable reaches with the left hand toward the near left target support the idea of object proximity driving hand choice. Further, greater use of the left hand during predictable reaches (90% predictable vs. 80% unpredictable; Figure 13) suggests that participants recognize the location of targets that will appear later in the sequence. More specifically, participants plan to better position both effectors in the work environment (i.e. right hand at the far right and left hand at the near left), both subsequently closer to future targets (i.e. the far left and near right targets).

Predictable reaches that better position the left hand for future reaches is more evident with the right hand located at the near right target and left hand at the left home position. Although the right hand is positioned closer to the near left target, where object proximity predicts its use, predictable reaches demonstrate greater use of the left hand instead. This hand choice pattern suggests that participants plan reaches to prepare and accommodate larger reaching amplitudes with the left hand to reach the near left target in order to place both hands closer to future target locations (i.e. far left target or far right). It seems that participants incur the cost of larger reaching amplitudes earlier in a movement sequence to ensure that reaches later in the sequence are short and efficient. Consistent with our hypothesis of predictable reaches resembling the end-state comfort effect, participants change their approach to executing reaches depending on the targets that follow.

Lastly, predictable reaches also show a greater use of the left hand for the near left target compared to unpredictable reaches when both hands are placed at the far target locations (i.e. left hand at the far left target and right hand at the far right target). Using the left hand to reach the near left target is consistent with the idea of object proximity, however its greater use with predictable reaches is less obvious. Specifically, with both hands off the home positions, the near left target represents the last target in the 3-target sequence. Therefore, planning to maximize movement efficiency for future reaches is not an option. It is possible, however, that the greater use of the left hand can be attributed to the fact that participants are better prepared to use their non-dominant left hand rather than relying on the more accurate right hand as seen in unpredictable reaches (Vaughan, 2012).

Hand choice decisions based on the idea of object proximity occur for reaches found later in the predictable reaches condition, rather than at the start of a sequence. Greater use of the left hand is consistent with our hypothesis of hand choice decisions resembling the idea of end-state comfort, where individuals use the left hand to travel further earlier in the sequence to shorten reaching amplitudes for later reaches. Further, it is possible that predictable reaches allow participants to better prepare the non-preferred left hand over the right (Vaughan, 2012).

Near Right Target

Participants use their left hand more often for the near right target during predictable reaches despite the target’s location in right space (10 degrees right of the midline). This occurs with both hands at their home positions (5% predictable vs. 0% unpredictable; Figure 14); and when one hand is at its far target location while the other is at its home position, specifically, with the left hand at the far left target and right at the right home position (4% predictable vs. 0% unpredictable; Figure 14), and left hand at the left home position and right at the far right target (20% predictable vs. 10% unpredictable; Figure 14).

When both hands are at the home positions, participants use their left hand more often to reach toward the near right target during predictable reaches than unpredictable reaches (5% predictable vs. 0% unpredictable; Figure 14). Initially, this challenges idea of hemispheric bias, hand preference, and object proximity mediating hand use on the ipsilateral side as seen consistently throughout this thesis. Using the left hand to reach the near right target results in larger reaching amplitudes, however it places the left hand in a better position for future reaches appearing in left space. Predictable reaches toward the near right target with both hands at their home positions also resemble the end-state comfort effect.

More specifically, predictable reaches to the near right target show a bias for hand use based on the terminal target position. In other words, participants use the hand on the same side of the stimulus that appears last in the target sequence. Gabbard et al. (2003) report a contrasting finding suggesting a bias for hand choice based on the initial positions of a target sequence, where participants use the hand on the same side of the stimulus that appears first in the target sequence and continue its use for future reaches. According to Gabbard et al. (2003), participants use their right hand more often for reaches that start in right space and end in left space because of the right hand's proximity and location in ipsilateral space at the start of the movement. A possible explanation for the discrepancy in target location biases (terminal vs. initial) relates to the methodological approaches between this thesis and the experiment of Gabbard et al. (2003). Gabbard et al. (2003) required participants to select one hand to complete a series of multiple reaches, where this thesis allowed participants to select either hand for each reach. Our results demonstrating a preference for the terminal hand location more closely resembles idea end-state comfort effect (Rosenbaum, 1992), a consistent finding throughout this thesis.

A terminal target position bias on hand choice is also evident with greater left hand use for the near right target when the right hand is positioned at the far right and left hand at the left home position (20% predictable vs. 10% unpredictable; Figure 14). Individuals bias their hand use according to the terminal location of the targets later in the sequence (i.e. using the left hand because the target sequence will end in left space). For example, with the right hand at the far right target and left hand at the left home position, using the left hand to reach to the near right target suggests that the last target in the sequence will appear in left space. Examples of this sequence include: far right, near right, far left; or far right, near right, near left. Although the left hand travels further to reach the near right target, participants are consistent with the idea of optimizing object proximity for reaches later in the movement sequence showing a bias for terminal target positions.

There is one instance, however, where our results demonstrate reaches that favor initial target locations. In other words, participants continue to use the hand ipsilateral to the first target in the sequence. For example, having the left hand positioned at far left target and right hand at the right home position suggests that the left hand is used to complete the first reach in the sequence, and that participants continue to use their left hand more often for the near right target during predictable reaches (4% predictable vs. 0% unpredictable; Figure 14). This result is similar to Gabbard et al. (2003), where participants cross their midline using their left hand when grabbing an object in left space and placing it into right space. In this thesis, participants are more willing to reach toward the near right target with their left hand when the target sequence begins in left space and moves to right space.

Although near right target data presents conflicting evidence supporting a hand selection bias based on the initial or terminal position of a target sequence, it is more important to note that predictable reaches to multiple targets are associated with different hand use frequencies when compared to unpredictable reaches to single targets at different hand positions.

Conclusion

Consistent with our initial hypotheses, predictable reaches do not conform to the idea of object proximity for initial reaches in the sequence. Rather, our data are more in line with an expanded interpretation of an end-state comfort effect. For example, the left hand is used to travel larger amplitudes toward the near right target earlier in a target sequence to optimize object proximity future reaches for both hands. This maximizes overall movement efficiency and is consistent with the kinesthetic hypothesis.

We see evidence supporting a hand choice bias towards initial *and* terminal target locations, neither of which is addressed in our initial hypotheses. It is difficult to distinguish which bias is more influential, however both demonstrate the fact that individuals use their left hand more during predictable reaches versus unpredictable reaches to enhance movement efficiency for future target locations.

Predictable Reaches for Specific Targets that Follow at Different Hand Locations

The data was re-analyzed further by sorting trials from the "predictable reaches" group based on the specific targets that followed the near left and near right target location. The aim was to determine whether changes in the frequency of hand use when comparing predictable reaches and unpredictable reaches are related to the specific target locations the follow the near left or near right at the end of a sequence.

Near Left Target

The results of this analysis provide intriguing insight into the effect of specific target locations appearing next in a sequence. Perhaps the most interesting observed changes are seen in the frequency of right hand use that occurs at the near left target with both hands placed at their home positions (far left panel of Figure 15). Despite the lack of an interaction between planning for specific targets to follow and unpredictable reaches on hand use at different hand positions, there is trend for participants to shift their hand use to the effector not needed for the next target location. For example, with both hands at the home positions, the *right* hand is used more often to reach toward the near left target when the far left target follows. This ensures that the left hand available to reach the far left target and places the right hand closer to targets appearing next in right space. In contrast, if the far right target follows the near left target (again, with both hands starting at the home positions), participants use their *left* hand more often to reach the near left target so that the right hand is available to reach into right space. It seems that individuals prefer to alternate hands, an observation consistent with the hand and finger use of typists. Typists alternate between hands and fingers to optimize movement times during a sequence of key presses (Rabbitt & Vyass, 1970). Although participants only moved one hand at a time, the use of alternating hands is the next best approach to moving both hands simultaneously. Assigning separate reaches for each hand rather than using the same hand for multiple reaches also minimizes the amount of programming for each effector, reducing the cognitive effort required and enhancing overall movement efficiency.

At other hand positions (see the near left, near right, and far right panels of Figure 15), predictable reaches continue to show greater use of the left hand when reaching for the near left target. These results are consistent with the idea that predictable reaches to multiple targets accommodate larger reaching amplitudes with the left hand earlier in the target sequence to position both hands closer to future target locations.

Near Right Target

Near right target data does not reveal an interactioon between planning for specific targets to follow and unpredictable reaches on hand use at different hand positions, however some trends are evident. For example, with both hands at the home positions (far left panel of Figure 16), the left hand is used slightly more to complete larger reaching amplitudes to the near right target when the near left target follows, placing the left hand closer to the near left target. This pattern of hand use is consistent with the idea of hand choice resembling the of end-state comfort effect. However, left hand use also increases for the near right target when the far right target follows. Use of the left hand in this case frees the right hand to reach the far right target, supporting the idea that participants also use alternating hands for multiple reaches.

Left hand use for the near right target also increases when the left hand is positioned at the left home position and right hand is at the far right target (middle panel of Figure 16). The left hand is used more often during predictable reaches to reach toward the near right target if the far left or near left target follows. Once again, this pattern of hand use supports the idea of individuals planning longer reaches with the non-preferred left hand to shorten reaches to future targets, therefore maximizing movement efficiency as consistent with the kinesthetic hypothesis.

Overall, it seems that participants continue to demonstrate the concept of end-state comfort (although it may be best referred to as an end-state efficiency effect in this case) by accommodating inefficient reaches early in the sequence and alternating hand use similar to typists. It is difficult on the basis of our data, however, to categorically determine when and why participants choose to display one hand use pattern over the other, which serves as an area that warrants further investigation.

Considerations for the Interpretation of the Data

As mentioned above, there is no interaction between predictable reaches to multiple targets and unpredictable reaches to single targets when looking at the specific target locations to follow. Statistically, this makes it difficult to identify and suggest trends for hand use patterns.

This thesis did not use RT as a dependent measure during unpredictable or predictable reaches when initiating movement. This thesis focused on providing participants with the opportunity to select either hand during reaches rather than on the speed of their movements. RT can serve as a measure of the amount of planning that occurs when participants are shown the target sequence prior to movement execution. Further, RT data can suggest whether greater levels of planning occur with more complex sequences and if certain targets and hand positions create greater levels of uncertainty when selecting a hand.

Participants were presented with 4 targets locations in the workspace, each located at 10 and 40 degrees to the left and right of the midline. Introducing a target at the participant's midline along with more targets at smaller degree intervals should provide the opportunity to identify a more specific location in space that participants are willing to cross their midline when executing predictable movement sequences. Further, additional targets should allow the opportunity to calculate an average PSE across participants in order to compare any differences in PSE values with reaches to target sequences when compared to single targets.

Lastly, Mamalo et al. (2006) correlate the frequency of reaches in contralateral space for right-handed individuals with handedness surveys and questionnaires. Therefore, the use of handedness questionnaires, surveys, and/or performance measures can be used to relate degrees and directions of handedness to specific locations that participants are willing to cross the midline (i.e. depth in each hemispace).

Conclusion

This thesis investigates the effect of predictable reaches to multiple targets versus unpredictable reaches to single targets on the frequency of hand use at different hand positions. Earlier studies on hand choice have focused on reaches to single target locations starting from a home position (i.e. Gabbard et al., 1997, 2000; Bryden et al., 2000; Gabbard & Helbig, 2004; Helbig & Gabbard, 2004; Mamalo et al., 2006) and reveal that changes in an object’s location and variances in the task demands/complexities are associated with shifts in the frequency of hand use. For example, the hand used to reach an object located in ipsilateral space is often mediated by handedness, whereas the non-dominant hand is often used to reach for objects located in contralateral space. Further, complex tasks promote greater use of the preferred hand further in contralateral space to accommodate accuracy or control constraints. In this thesis, predictable reaches and unpredictable reaches to target sequences provide insight into situations that require more complex processes of motor planning. Participants reached to 3-target sequences after being placed in one of two groups: the Unpredictable Reaches group, where participants selected a hand in response to individual target stimuli; or the Predictable Reaches group, where participants assigned hand use after being shown the target sequence prior to movement initiation.

The frequency of hand use served as the main dependent variable, where we first investigated the effect of different hand positions on hand use in unpredictable reaches to single targets. Multiple chi-square analyses compared hand use between predictable and unpredictable reaches at different hand locations. Finally, we compared hand use between predictable reaches to specific targets and unpredictable reaches to single targets at different hand locations.

In all cases, participants are consistent with their hand use for targets in far left and far right space located 40 degrees on either side of the midline. The right hand is used for the far right target and left hand is used for the far left target for 100% of the trials, consistent with previous studies investigating hand choice use in deep workspace (Gabbard et al., 1997; Gabbard & Rabb, 2000; Mamalo et al., 2006). Changes in hand use frequency occur for the near left and near right targets, found at 10 degrees on either side of the midline.

During unpredictable reaches to single targets, object proximity mediates hand choice at different hand positions. For example, participants use their non-preferred left hand in right space when the left is positioned closer to the target, minimizing its reaching amplitude. This supports the kinesthetic hypothesis where individuals prefer comfortable and efficient movements, challenging the idea of hand preference, hemispheric bias, and compatible S-R pairings mediating hand use in ipsilateral space.

Predictable reaches to multiple targets display greater use of the left hand over unpredictable reaches for the near left and near right target. Our observations demonstrate that predictable reaches use their left hand more frequently, placing it closer to future target locations appearing next in the sequence. Further, it seems the idea of object proximity mediating hand choice is compromised during predictable reaches, however using the left hand to travel larger amplitudes earlier in the movement sequence ensures that object proximity is optimized for future target locations. The accommodation of larger reaching amplitudes resembles the phenomenon of end-state comfort, where participants take on uncomfortable positions at the start of movements to end in more comfortable positions (Rosenbaum, 1992). In this thesis, participants change their approach to executing reaches depending on the targets that follow. It is also possible that predictable reaches better prepare the non-preferred left hand, rather than relying on the more accurate right hand used in unpredictable reaches (Vaughan, 2012). Near right target data reveal an uncertainty in whether predictable reaches display a hand choice bias accommodating the initial or terminal positions in a target sequence (Gabbard et al., 2003), serving as a potential area for future research to tease apart both explanations mediating hand choice decisions. More importantly, near right target data demonstrates that the frequency of hand use during predictable reaches to multiple targets are different from unpredictable reaches to single targets, where participants change their approach to executing reaches depending on the targets that follow.

Despite the lack of a significant effect when comparing predictable reaches to specific targets and unpredictable reaches to single targets, the data tells an interesting story. Near left target data reveals that individuals shift their hand use to the effector not needed for the future target locations. This allows participants to alternate hand use for targets in the sequence, similar to typists who alternate between hands and fingers to minimize movement times needed to complete key presses (Rabbitt & Vyas, 1970).

Near right target data reveal that right hand use remains quite high, consistently above 80%, with slight increases in left hand use during predictable reaches. These increases in left hand use continue to support the idea that predictable reaches incur the cost of inefficient amplitudes early in the movement sequence, similar to the end-state comfort phenomenon (Rosenbaum, 1992). Further, reaching the near right target with the left hand also promotes the use of alternating hands for subsequent targets in right space.

It is difficult on the basis of our data, however, to categorically determine when and why participants choose to alternate hand use or comply with the idea of object proximity. Both assist to maximize movement efficiency, and also serves as an area that warrants further investigation.

Overall, our data suggest that during unpredictable reaches to single targets, different hand positions reveal changes in hand use frequency where object proximity mediates hand choice decisions. Further, there is a trade-off for object proximity is optimized during predictable reaches, occurring later in a reaching sequence rather than at the start. Participants incur the cost of larger reaching amplitudes to ensure that movements found at the end of the sequence are more efficient, as consistent with the kinesthetic hypothesis.

Implications

The current thesis has several important implications for the hand choice literature. Notably, this study demonstrates that planning for multiple reaches at different hand positions provide individuals with enough information to change their hand use when compared to unpredictable reaches to single targets. At different hand positions, individuals perceive spatial information about the location of the target and use this to influence their hand choice decisions differently than if both hands were at their home positions.

Furthermore, planning for multiple movements reveals that individuals have the ability to assess a task in its entirety and can work backwards to ensure that reaches and movements found at the end of a sequence are completed efficiently. Overall, it is apparent that planning for multiple reaches and different hand positions contribute to the complex interaction between the task, environment, and handedness of the actor when reaching.

These results also have workplace implications, where hand choice decisions made daily in factories such as automotive assembly lines. In an effort to reduce repetitive injuries in the workplace, ergonomists can analyze a worker's hand positions between successive tasks when assessing the safety of a job.

More specifically, understanding a worker's hand position after installing a pipe or bumper should influence the where location of subsequent tools or parts used next should arrive or be placed with respect to the individual. Further, knowledge of parts arriving down the line can influence how a worker plans to finish their current task to better position themselves for the next. With planning, participants can minimize reaching amplitudes, maximize comfort, and improve the speed and safety of the workplace.

Future Directions

This thesis sheds light into the effect of planning for multiple reaches on hand choice when compared to unpredictable reaches to single targets at different hand positions. One unanswered question is whether participants choose to complete a series of movements showing a hand choice bias for the initial or terminal target locations in a sequence of reaches. The results of this thesis provide support for both initial and terminal locations, where future studies should aim to tease apart these two possible explanations of hand choice decisions.

This thesis also involves a 3-target sequence, where previous studies use a maximum of 2 target locations in hand choice studies (i.e. Gabbard et al., 2003). A third target introduces a greater level of processing during predictable reaches, however future studies should go one step further by using longer and more meaningful sequences. For instance, when typing a sentence on a smart phone, individuals have a message word order in mind when completing reaches to each key using their thumbs. Future studies can use sequences of letters or strings of words to create sentences to investigate how far in advance participants are willing to plan their movements.

Lastly, it seems that kinematic measures are being used more recently when collecting hand choice studies (see Kim et al., 2007, 2011). The use of 3D positional markers (i.e. Optotrak, Vicon, or Motion Capture) to collect the trajectories, velocities, and acceleration profiles at the hand, wrist, elbow, and shoulder while completing predictable reaches can be used to help identify any underlying mechanisms behind hand choice decisions not seen with observational data.

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Appendix A

1. Informed Consent Form Experiment 1
2. Informed Consent Form Experiment 2
3. Recruitment Poster

LETTER OF INFORMATION / CONSENT
Choice reactions to serial target locations

Principal Investigator:
Daniel Garcia
Department of Kinesiology
McMaster University
Hamilton, Ontario, Canada
905-525-9140
E-mail: garcid4@mcmaster.ca

Faculty Supervisor: Dr. Jim Lyons
Department of Kinesiology
McMaster University
Hamilton, Ontario, Canada
(905) 525-9140 ext. 27899
E-mail: lyonsjl@mcmaster.ca

Funding Agency: Natural Sciences and Engineering Research Council of Canada (NSERC)

Purpose of the Study
We are hoping to explore the ways in which we use environmental information to plan movements. Fitts' Law (1967) describes the "speed-accuracy" trade-off, where faster movements are made to closer targets than further targets. Overall, closer targets and faster movements can minimize total movement time when reaching several targets. The study we are asking you to participate in will be part of a Master's thesis in motor behaviour. We will attempt to determine whether hand location with respect to a given target influences hand choice when moving a target location in order to minimize total movement time.

Procedures involved in the Research
Once reading through this consent form and given the opportunity to ask questions, you will be seated in front of a computer monitor displaying a series of circles. The two central circles are the 'home' position, and the four circles above are 'targets'.

A trigger switch will be placed underneath both index fingers to record movement time and reaction time. Your task is to use either index finger to move from the home positions to any of your target locations when they flash. When one index finger moves, the other must remain in the same location until the completion of the movement.

The experiment is split into 4 blocks, each consisting of 72 trials.

Participation in this experiment will require a time commitment of approximately 60 minutes. When the experiment is finished, you will be fully debriefed. You will also receive $10.00 for your time.

Potential Harms, Risks or Discomforts:
There are very minor risks involved in this study. As you will be moving to targets repeatedly, you may experience some fatigue in your arm or hand. Further, you may experience boredom. To minimize fatigue or boredom, a 1-minute rest period will be provided following each block of 48 movements. If at any time you feel the need to stop the procedure or take a break, you are free to do so. You may withdraw from the study at any time, and will still be paid in full for your time. The procedure for withdrawal is outlined below. Moreover, if at any time during the study you experience pain, discomfort or extreme fatigue please inform the researchers.

Potential Benefits
Aside from your honorarium, the proposed study will allow us to garner a greater understanding of hand choice and the way we use environmental information to plan movements to benefit society's understanding of motor behaviour.

Payment or Reimbursement
You will be awarded a $10 honorarium for participation in the study, and will be paid in full for your time should you withdraw from the study

Confidentiality
Confidentiality is respected. There will be no link between your name and your data. All data will be used solely for experimental purposes. Individual data will only be identified by your participant number. The data will be stored in a password-protected computer, and on a USB key that only the experimenter and their supervisors have access to.

Participation and Withdrawal
Your participation in this study is voluntary. You may withdraw at any time, even after signing the consent form, or during the study. The procedure to withdraw is to simply tell the experimenter you wish to terminate the experiment. There will be no consequences and you will be paid in full. Any data you have provided will be destroyed. You will then go through the same process at the end of the experiment as all other participants. That is, we will debrief you, and give you $10.

The data analysis will be performed as of January 1, 2013. Once that date has arrived, we will no longer be able to be remove your data from the data set.

Information about the Study Results

This study is expected to reach completion near January 2013. If you would like to know the results of the experiment, please tell us how you would like it sent to you.

Copy of Consent Form

You will be given a copy of the consent form for your records. You can choose to take a hard copy of the form with you. Otherwise, if you would like a copy of the consent form emailed to you, please include your email:____________________.

Questions about the Study

If you have questions or require more information about the study itself, feel free to contact me.

This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance. If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat
Telephone: (905) 525-9140 ext. 23142
c/o Office of Research Services
E-mail: ethicsoffice@mcmaster.ca

CONSENT

I have read the information presented in the information letter about a study being conducted by Daniel Garcia and Dr. Jim Lyons, of McMaster University. I have had the opportunity to ask questions about my involvement in this study and to receive additional details I requested. I understand that if I agree to participate in this study, I may withdraw from the study at any time. I have been given a copy of this form. I agree to participate in the study.

Signature: ____________________________ Date: _____________________

Name of Participant (Printed) ___________________________________

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Choice reactions to serial target locations

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Procedures involved in the Research

Once reading through this consent form and given the opportunity to ask questions, you will be seated in front of a computer monitor displaying a series of circles. The two central circles are the 'home' position, and the four circles above are 'targets'.

A trigger switch will be placed underneath both index fingers to record movement time and reaction time. Your task is to use either index finger to move from the home positions to the combination of 3 target locations after their order has been given to you. When one index finger moves, the other must remain in the same location until the completion of the movement.

The experiment is split into 3 blocks, each consisting of 72 trials.

Participation in this experiment will require a time commitment of approximately 60 minutes. When the experiment is finished, you will be fully debriefed. You will also receive $10.00 for your time.

Potential Harms, Risks or Discomforts:
There are very minor risks involved in this study. As you will be moving to targets repeatedly, you may experience some fatigue in your arm or hand. Further, you may experience boredom. To minimize fatigue or boredom, a 1-minute rest period will be provided following each block of 48 movements. If at any time you feel the need to stop the procedure or take a break, you are free to do so. You may withdraw from the study at any time, and will still be paid in full for your time. The procedure for withdrawal is outlined below. Moreover, if at any time during the study you experience pain, discomfort or extreme fatigue please inform the researchers.

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The data analysis will be performed as of February 1, 2013. Once that date has arrived, we will no longer be able to be remove your data from the data set.

Information about the Study Results

This study is expected to reach completion near February 2013. If you would like to know the results of the experiment, please tell us how you would like it sent to you.

Copy of Consent Form

You will be given a copy of the consent form for your records. You can choose to take a hard copy of the form with you. Otherwise, if you would like a copy of the consent form emailed to you, please include your email:___________________.

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Signature: ____________________________ Date: _____________________

Name of Participant (Printed) ___________________________________

McMaster University

PARTICIPANTS NEEDED FOR RESEARCH IN MOTOR BEHAVIOUR

We are looking for volunteers to take part in a study of choice reactions to a series of targets

You will be asked to reach a series of targets on a computer monitor while collecting kinematic data through video markers

Your participation involves 1 session, about 60 minutes long. In appreciation for your time, you will receive a $10 honorarium.

For more information about this study, or volunteer to participate, please contact:

Daniel Garcia
Department of Kinesiology
905-525-9140
Email: garcid4@mcmaster.ca

This study has been reviewed by, and received ethics clearance by the McMaster Research Ethics Board.

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