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Reach-to-Grasp Actions Under Direct and Indirect Viewing Conditions

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REACH-TO-GRASP ACTIONS UNDER DIRECT AND INDIRECT VIEWING CONDITIONS

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Abstract

The purpose of this study was to determine whether indirectly viewing an object through a mirror causes reach-to-grasp kinematics to differ from those performed under normal conditions, when participants directly observe the object to be grasped. Participants, in a supine position, reached for objects placed on a presentation platform (workspace) resting above their thighs. In the indirect viewing condition, a two-mirror viewing system was placed above the head that allowed participants to view the workspace. In the direct viewing condition, participants' heads were elevated and tilted forward such that they could directly view the workspace. Three infrared markers were attached to participants' right index fingertip, the tip of the right thumb and the knuckle of the right index-finger. Hand movements were captured using an OPTOTRAK 3020 camera system and kinematics were calculated offline following the experiment. It was found that reaches made under the indirect viewing condition were performed at a slower speed, and overall took longer than reaches made under the direct viewing condition. Hand shaping was effected by viewing condition and object size interaction. The results from this study reveal that reach-to-grasp movements performed under different viewing conditions are quantifiably different and may suggest that different neural substrates and/or different computational loads are present during these two viewing conditions. These results suggest that there may be experimental confounds in several of the previously published reach-to-grasp neuroimaging studies, specifically those that have used optical manipulations to view the hand and workspace within the fMRI scanning environment.

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Introduction

We use a mirror for everyday activities without the need to think about the visuomotor transformations needed to perform these activities normally. As an example, when one looks into a mirror when brushing their teeth, one is rarely conscious of the fact that their image has been reversed left to right. In fact, we are so accustomed to using mirrors, that we hardly think they hinder our performance with most tasks. However, when multiple mirrors interact, such as in fitting room mirrors or in a “funhouse”, we can readily see that it becomes progressively more difficult to perform motor acts accurately.

There is a vast wealth of literature that has investigated visually-guided control of motor movements, using techniques that quantify how we move our body segments during goal-directed behaviours, such as when reaching out to grasp an object. Jeannerod (1986) describes the typical reach-to-grasp movement, in which an individual reaches away from the body and towards an external target object, as being composed of two distinct components. The first of these is the transport component (as shown by the red arrow in Figure 1), which is composed of the arm movement that transports the grasping hand toward a target object. The second component is grip (as shown by the green circle in Figure 1), which is the accurate shaping of the hand to securely grasp an intended object.

Extrinsic object information, such as position, is critical to the transport component. Changes related to extrinsic object properties, such as increased object distance, cause an increase in the reach velocity (a transport component measure), but leaves the grip component unaffected (Jeannerod, 1986). Interestingly, the grip

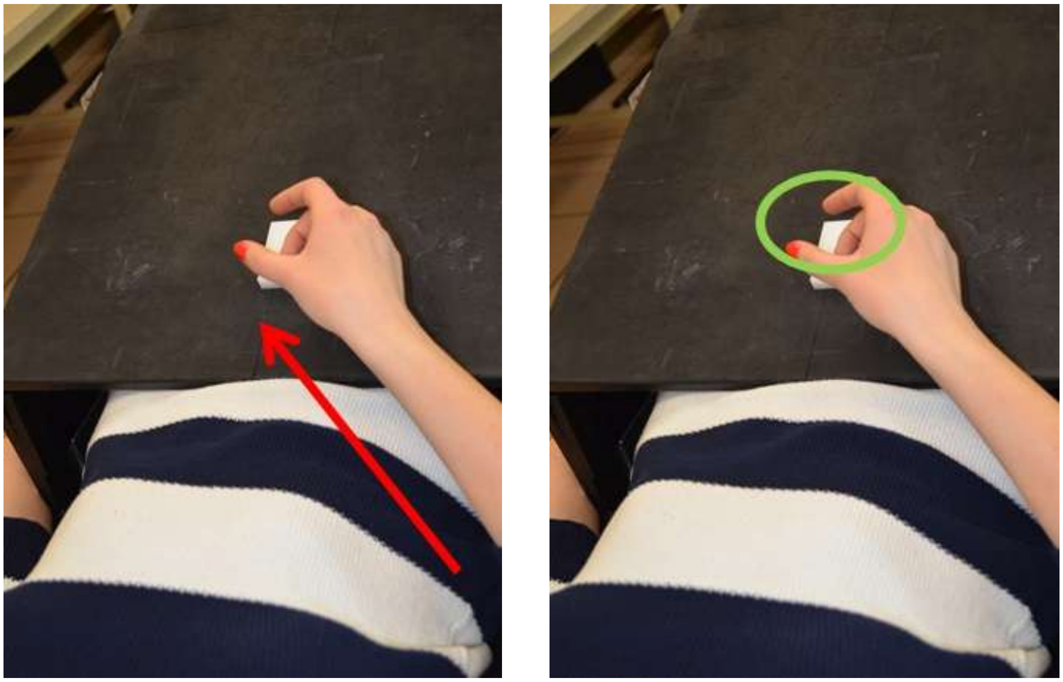


Figure 1. The Transport (red arrow) and grip (green circle) components discussed in the reach-to-grasp literature.

component uses intrinsic object information such as size or shape. When these features were manipulated, maximum grip aperture measures (a grip component measure) were affected, but did not cause any such change to the transport component. These two components work synchronously, and Jeannerod (1986) suggested that the two channels are independent and are likely under the control of some higher-level timing mechanism. More recent work with perturbation studies (Wing, Turton & Fraser, 1986; Paulignan., Jeannerod, MacKenzie & Marteniuk, 1991) has described the process as an interdependent model coordinating between the transport and grip components. It is possible that the two processes are regulated by different neural substrates and thusly can be manipulated independently of one another.

The basic movement characteristics (transport and grip components) of reach-to-grasp actions have been defined by behavioural measures. Known as kinematics, these measures have been an invaluable tool to quantifying how we move our body during a reach-to-grasp action under normal conditions and under experimental manipulations. Likewise, these tools have also been crucial to investigating how the varying of sensory inputs can affect the planning, guiding, and execution of typical reach-to-grasp movements.

During a typical reach-to-grasp action, the grasping hand will usually start in a closed position, quickly opening to a maximum aperture value that is larger than the target object, then reduce the grasp aperture to match the size of the target object as the reach is completed. Customarily, researchers report the size of maximum grip aperture, which usually occurs approximately 70 % of the way through a normal reaching movement. As well, an oversizing measure is typically reported. Aperture oversizing is calculated by subtracting the final grip aperture (i.e. the target object size) from the maximum grip aperture (Jeannerod 1984). Figure 2 is a graphical representation of how the grip aperture is expressed in the literature.

Likewise, the transport component is associated with typical measures as well, which include Total Movement Time and Peak Reach Velocity. Total Movement Time is typically reported in either milliseconds or number of recorded frames, and is the mean time it takes participants to complete the reach-to-grasp action in a given condition. Since the movement of interest is recorded with a high speed infrared camera which samples the positions of the infrared emitting diodes 100 times per minute (i.e. also known as the frame rate), the duration measure can be expressed in terms of how many frames in which the behaviour of interest was performed. Peak Reach Velocity tends to be a bell-shaped curve that peaks approximately halfway through the reaching movement (Jeannerod, 1984). Figure 3 is a graphical representation of how the transport component is expressed in the literature.

Theoretical models of neural mechanisms that control these movements have been developed based on these kinematic studies. Previous studies of macaque neurophysiology and human neuropsychology has indicated that the parietal cortex plays a crucial role in numerous cognitive functions, particularly in the processes linking sensation to action (Clower et al., 1996; Beis, Andre, Barre & Paysant., 2001; Culham, Cavina-Pratesi & Singhal, 2006, for example). The temporal cortex forms part of the ventral visual pathway and is involved with object recognition. This is contrasted with the parietal cortex forms part of a dorsal visual pathway that encodes spatial location (i.e.

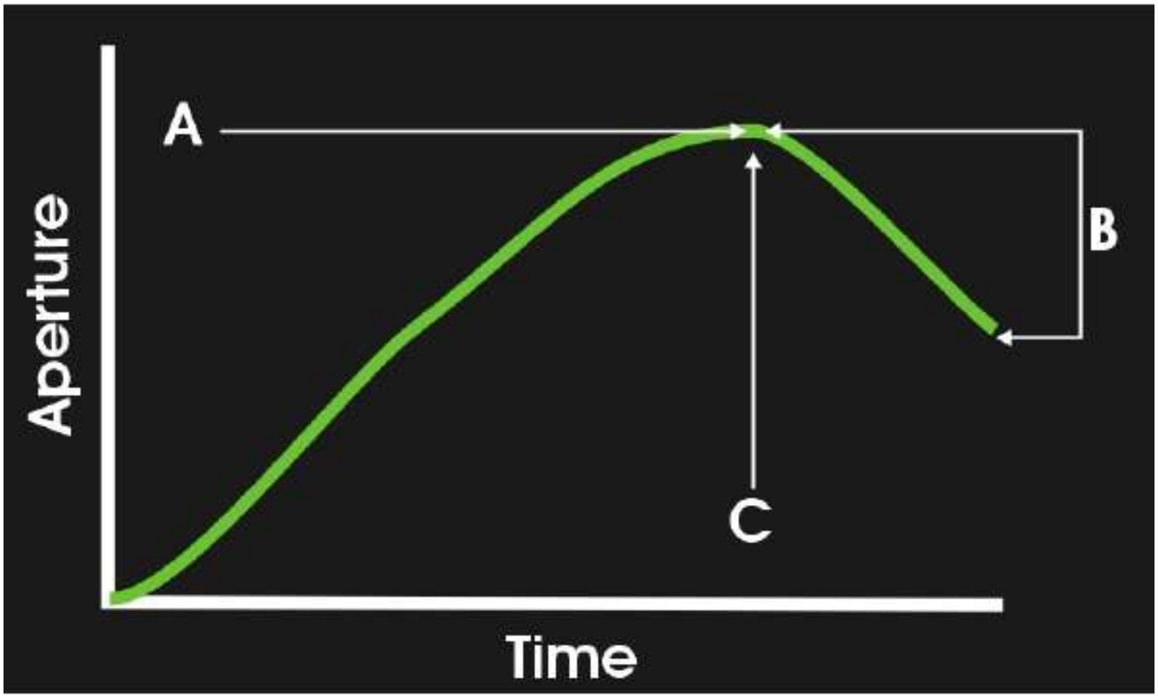


Figure 2. Grip Component Measures. This graph represents the typical way in which grip aperture is presented in the reach-to-grasp literature. The green line indicates aperture size, usually in millimeters, as it changes as a function of time: (A) the maximum value that the aperture attains is referred to as the Maximum Grip Aperture measure; (B) is the difference between the Maximum Grip Aperture and the object size (typically the last measurement of the green aperture profile) and is referred to as the Oversizing measure; (C) is the time at which Maximum Grip Aperture is attained and is referred to as the Time of Maximum Grip Aperture (Quinlan, 2009, p. 7. Reprinted with permission).

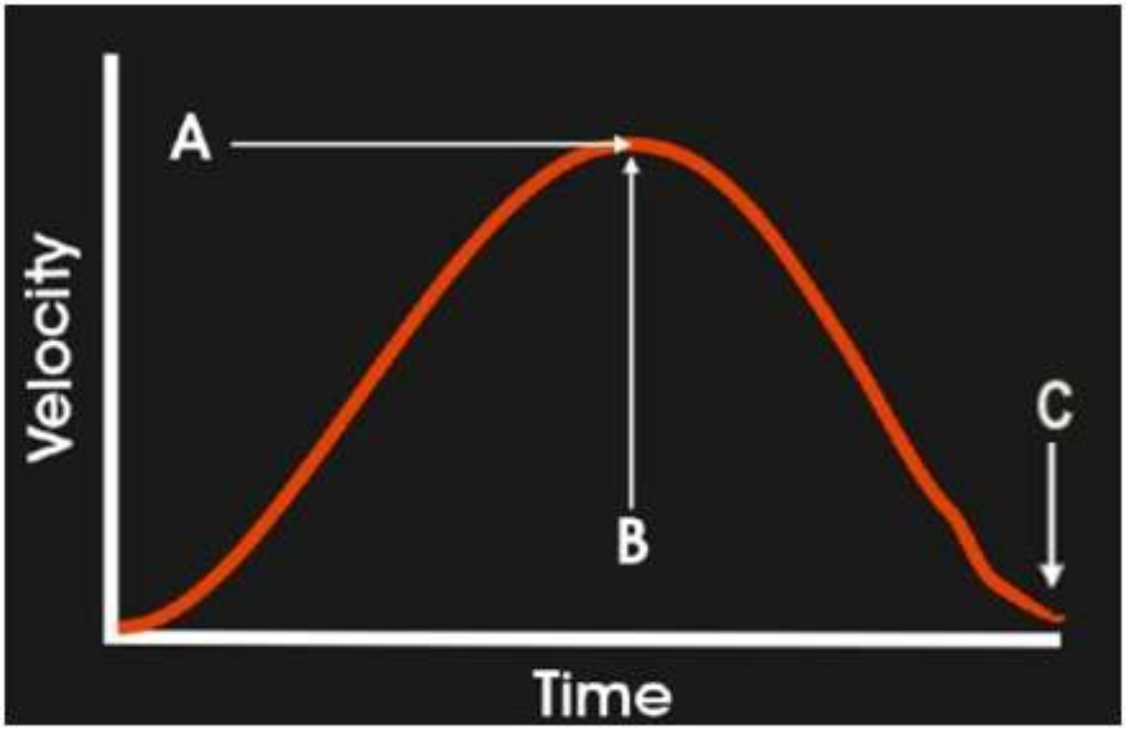


Figure 3. Transport Component Measures. This graph represents how reach velocity changes over time during a reach-to-graph action. The measures of interest typically calculated from these movement profiles are: (A) the Peak Reach Velocity, (B) the Time of Peak Reach Velocity and (C) Total Duration of the Movement (Quinlan, 2009, p. 9. Adapted with permission).

“where” an object is) and guides visually directed action (i.e. determining “how” to interact with an object) (Ungerleider & Mishkin, 1982; Goodale & Milner, 1992). The dorsal pathway and the parietal lobe have been shown to be an especially important aspect of the neural substrates subserving reach-to-grasp movements.

An fMRI study conducted by Cavina-Pratesi et al. (2010) explored the neural substrates required for the control of the arm transport component and the grip component in reach-to-grasp actions in humans. The superior parieto-occipital cortex and the rostral superior parietal lobule were identified as key regions related to the transport component when participants reached towards three-dimensional objects. When participants grasped the target object with a pincher grip, activity was observed in bilateral anterior intraparietal sulcus and left ventral premotor cortex. This activation was not observed when participants merely touched the object with the knuckles of the right hand or when participants passively viewed the object. This suggests that the observed activation in these neural regions are related to the grasping behaviours and not just simply interacting with the object or exposure the object. Cavina-Pratesi et al. (2010) also proposed that in order for the reach and grasp movements to coordinate, the integration of the transport and grip components occurs in dorsal premotor cortex and supplementary motor areas.

Their work is further supported by evidence of human patients with parietal damage that show visuomotor dysfunction, such as visuomotor ataxia or ideomotor and ideational apraxia with significant disturbance of spatial temporal relationships. Ataxia disorders refer to the inability to coordinate movements and apraxia refers to disordered motor planning. Lesions in the parietofrontal systems tend to disturb reaching and grasping movements, while lesions in the frontostriatal system tend to affect sequential motor events (Leiguarda & Marsden, 1999). The disturbance of sensorimotor transformations can be quite specific when discrete regions of the parietal lobe are damaged.

Various technical challenges make it difficult to study reach-to-grasp arm movements with neuroimaging, such as the restricted confines of the imaging scanners which make reaching movements problematic. One such problem is the difficulty related to rotating one’s head (i.e. chin to chest rotation) such that a direct view of reach-to-grasp movements is possible. While the aforementioned (Cavina-Pratesi et al., 2010) study had participants lay supine within the fMRI scanner with the head tilted to permit direct viewing of the stimuli, many studies conducted investigating similar research topics employ the use of a system of mirrors in order to view the workspace.

Due the restricted confines of the fMRI scanner, previous studies have used optical manipulations, such as the use of mirrors, in order to view the hand and workspace. It has been previously assumed that indirect viewing conditions such as these do not alter activation in the neural regions subserving reaching and grasping actions. Research by Ramachandran et al. (1997) and Binkofski et al. (1999) revealed that patients with certain brain injuries tend to interpret objects in mirrors differently than directly viewed objects.

Ramachandran et al. (1997) reported that four right-hemisphere stroke patients seemed to be indifferent to objects in their left visual field. When a mirror on the right side of the patient was positioned to provide an indirect way to perceive their left side, participants attempted to reach into the mirror or claimed that the target object was behind the mirror (i.e. the object was behind a pane of glass). Ramachandran et al.'s (1997) patients could not understand the concept of the mirror's use. In a similar way, Binkofski et al. (1999) described patients with mirror agnosia who were unable to distinguish between a real object and a mirror image. These patients believed the object was located inside or behind the mirror and directed their reaches towards the image, often hitting their hand on the mirror. In contrast to Ramachandran et al. (1997), Binkofski et al. (1999) concluded that neither hemi-neglect, nor right parietal lesions, were necessary conditions for mirror agnosia. Additionally, Goebel et al.'s (1998) BOLD imaging study showed that the superior parietal lobule, the cortex lining the intraparietal sulcus, and the laterooccipital area were activated in mirror and inverse reading activities. These areas have been implemented in object recognition and spatial transformations studies.

With this in mind, it seems that mirrors present evidence that a specific cognitive load, or recruiting of additional neural systems is required order to correct for the optical manipulation. It is apparent that there are neural substrates that deal explicitly with the spatial transformations and object recognition that need to occur when viewing objects through a mirror. However, it is not clear to what extent this activation impacts the reach-to-grasp movements of healthy individuals. The current project will investigate the kinematic differences that result from performing reach-to-grasp movements under different viewing conditions (i.e. direct vs indirect viewing). Such kinematic differences would suggest that the neural processes underlying these movements may vary and are dependent upon how the viewing problem in imaging studies is resolved.

As the evidence above suggests, the choice of viewing method (i.e direct vs. indirect) in reach-to-grasp neuroimaging studies, may act as an experimental confound, possibly skewing the results of interest. Surprisingly, no studies have yet to assess the effect of viewing method and as such, indirect-viewing methods have been the standard in many fMRI studies involving reach-to-grasp actions. However, the additional visuomotor transformations required to perform reach-to-grasp movements using a mirror to plan and guide the movement, likely require the altering of neural activity which can be inferred through kinematic measures.

The present study measured reach-to-grasp kinematics that resulted from reaching and grasping objects under varying viewing conditions (i.e. direct vs. indirect viewing). If it is the case that participants are using different neural substrates under the different viewing conditions (i.e. direct-viewing or through a mirror), it is expected that this neural recruitment difference would be reflected in the kinematic variables measured. It is expected that peak reach velocity will be slower, the time of peak reach velocity will occur later in the movement and that the total duration of the movement would take longer in the indirect viewing condition. As well, it is expected that maximum grip aperture will be larger, more aperture oversizing will occur, and that the time of maximum grip aperture will occur earlier in the movement during the indirect viewing condition. This pattern of responses would be expected, as the additional computational load and increased possibility of error exists due to the visuomotor transformations needed to perform mirror grasps. Other kinematic measures, such as time to maximum grip aperture and reach duration, will also be investigated.

Methods

Participants

Thirteen right-handed participants (nine males, four females; mean age= 23.62 years, *SD* = 8.90) with normal or corrected-to-normal vision participated in this experiment. Participants were self-identified as being right-handed and as having normal vision.

Kinematic Data Collection

The transport and grip data were recorded using a three-camera opto-electronic recording system (i.e. the OPTOTRAK 3020 system). The camera system calculates the three-dimensional (3-D) position of Infrared-Emitting Diodes (IREDs) as they move through space over time. By attaching these IREDs to specific locations on a participant's body, kinematic measures such as grip aperture and reach velocity can be recorded as the participant performs the required reach-to-grasp actions. The camera system was elevated and positioned to the left of the participant such that all IREDs were visible to the camera system throughout the duration of the reach-to-grasp movements. This allowed for continual positional information to be collected throughout the entire movement, with very few trials being lost due to unseen IREDs. Using in-house software (OTCollect, programmed by Haitao Yang), the 3-D position of each IRED was recorded at 100 Hz, the coordinates of which were used to calculate kinematic measures of transport and grip. Each movement trial was recorded for a period of 5 seconds, enough time to perform the entire reach-to-grasp movement.

IRED positioning

Participants were fitted with IREDs on their right hands (as shown in Figure 4). IREDs used for calculating hand grip aperture were placed on the side of the distal thumb and index finger. When the thumb and finger were brought together to form a “pinching” action, these IREDs were immediately adjacent one another. To measure reach velocity, an IRED was also placed on the side of the index finger knuckle, where the finger meets the hand. IREDs were fastened to the hand using cloth medical tape that did not perceptibly alter normal hand movements. As this tape was present in both testing conditions, it should not systematically alter kinematics in any way to create confounds.

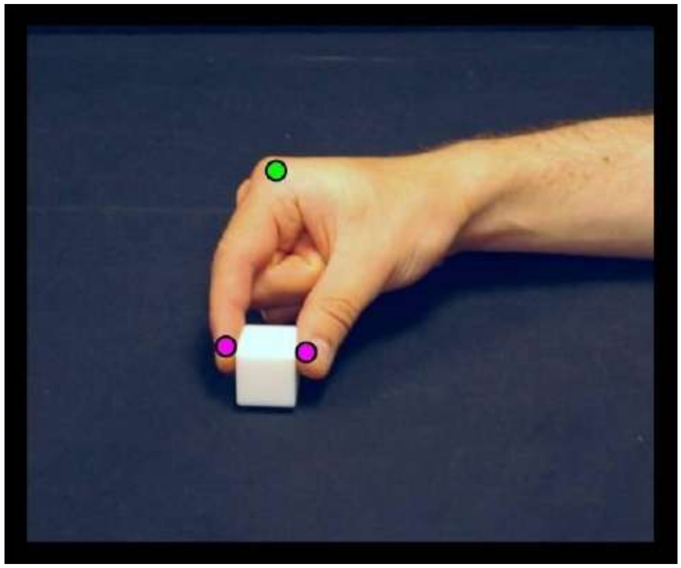
Liquid Crystal Goggles

Participants wore liquid crystal goggles which can become clear or opaque and were under computer control (PLATO Goggles, Translucent Technologies). A weak electric current is passed through the occlusion goggles to make the lenses transparent during the planning and movement phase of the experiment, then becoming opaque when the experimenter handled the blocks between data collection trials.

Mirror Apparatus

The mirror apparatus consisted of a frame that could be placed above the participants’ head (Figure 5a&b) while they lie in a supine position. The apparatus consisted of a two mirror (~2inch x ~8 inch, each) system, the angles of which could be adjusted prior to testing to bring the participant’s hand and workspace into view. The participants’ lay supine with their necks’ in a neutral position, with their gaze directed upwards and through the mirrors.

a)



b)

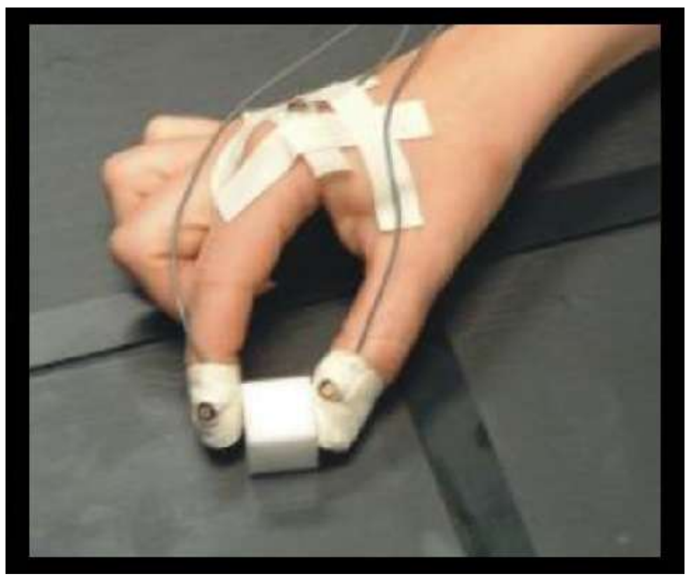
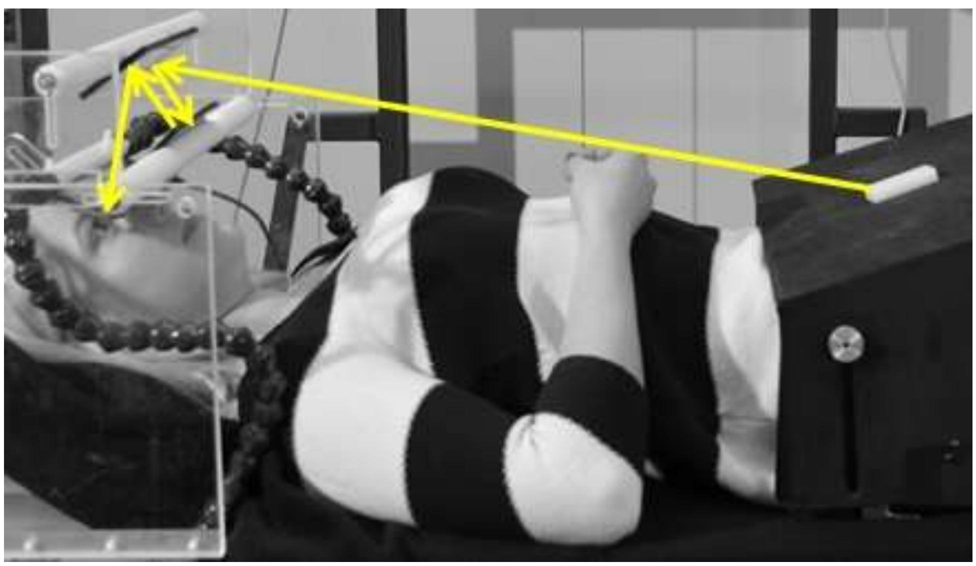


Figure 4. Infrared emitting diode (IRED) placement: (a) IREDs for calculating hand grip aperture were placed on the side of the distal phalanx of the thumb and index finger (Purple dots). The IRED for recording reach velocity was placed on the side of the index finger knuckle (index metacarpophalangeal joint; Green dot). IREDs and wires were secured with medical tape in such a fashion that they would not hinder natural pinching motions (Quinlan, 2009, p. 13, 31. Reprinted with permission).

a)



b)

Figure 5. Mirror apparatus setup: (a) Close up of the dual-mirror set up. The angles of the mirrors were adjustable. Occlusion goggles were placed above the eyes. (b) The light path of the mirrors that allows participants to view the workspace.

Procedure

Prior to data collection trials, participants were given 15 practice trials and asked to perform their reach-to-grasp movements as naturally as possible. Participants were instructed to begin each trial in an "initial position" with their right-hand thumb and forefinger in a closed “pinch” position, with their hand resting on their chest. The liquid crystal goggles were occluding the participants view at this time. A white plastic cuboid (i.e. a 3-D rectangular block) of varying size (40 mm, 50 mm, 60 mm or 70 mm length by 20 mm width by 10 mm height) was placed in the centre of a black presentation platform which rested above the participants’ thighs (as seen in Figure 6 - a). On randomized trials, a flanker cuboid (40 mm, 50 mm, 60 mm or 70 mm) was positioned ~ 10cm to the left of the target cuboid (see Figure 6 – b). Participants were instructed to only reach for and lift the target cuboid.

An auditory beep was played to inform the participant that a new trial was about to commence. After a randomized amount of time (range of 0 - 4000 msec., mean = 2000 msec.) a second auditory beep sounded coinciding with the moment the occlusion goggles became transparent. At this point, participants were then to reach out with their right hand, pick up the target cuboid with the thumb and forefinger using a precision grip, raise the cuboid a few centimeters off the platform, lower the cuboid back to its starting position, release the cuboid and then bring their hand back to the “initial position” on their chest (see Figure 6 a-d).

Participant's movements were recorded beginning with the first auditory cue with enough time to perform the required actions (5000 msecs.). The four cuboid sizes, the

Figure 6. Participant’s actions in the reach-to-grasp movement. 1) Initial position; 2) outward reach; 3) securing target object with pinch grip. a) Participant’s view as they made their reach-to-grasp movement during the no-flanker condition. b) Participant’s view during flanker condition. The participant was instructed to always reach towards the right-most object. c) The experimental set-up for the Direct Viewing condition. The participant’s head was propped up and they were able to directly view the workspace. Occlusion goggles were placed in front of the eyes so the participants did not see the workspace between trials. d) The experimental set up for the Indirect Viewing condition. The participant remained in a supine position and used the dual-mirror set-up to view the workspace. Occlusion goggles were placed above the eyes to prevent the participant from viewing the workspace between trials.

flanker sizes, and the presence or absence of flanker objects were presented in a randomized order, for a total of 70 trials per viewing condition.

Parsing Data

Custom in-house software (Opto Pipeline, programmed by Kevin Stubbs) was used to parse the reach-to-grasp movement out of the 5000 msec. recordings. A reach velocity threshold of 20 mm/sec of the knuckle and index finger IREDs was used to capture the onset and offset of the outward reaches. This is typical of reach-to-grasp kinematic studies and has been shown that this threshold will capture the entirety of the reach-to-grasp action. In instances where reach velocity did not pass below the 20mm/sec threshold between the end of the reach-to-grasp movement and lifting movement, the local minima was used as the offset of the outward reach.

Data Processing

Calculating measures

Grip aperture, the distance between the thumb and forefinger, was calculated from the vector distance between the thumb and index finger IRED coordinates. This is an acceptable means of determining grip aperture because the IREDs placed on the thumb and index finger are very close to the grasping surfaces during a "pinching" grip. To account for initial offset of these markers, the average distance between these IREDs during a closed pinch was subtracted from the open aperture measures.

Reach velocity, observed during the reach-to-grasp movement, was calculated from the velocity of the IRED on the index-finger knuckle.

The object size condition had two levels: smaller target object (50 mm) and larger target object (60mm). The levels consisted of three types of trials: target object presented alone, target object presented with a smaller flanker object and target object presented with a larger flanker object. For example, the smaller object condition included averaged data from the 50 mm target object presented alone, the 50 mm target object presented with a 40 mm flanker and the 50 mm target object presented with a 60 mm flanker. The 60 mm target had either a 50 mm flanker or a 70 mm flanker, or no flanker.

Two other sizes of target objects, 40 mm and 70 mm, were presented for the participant to reach for to add variety to their hand positions, but this data was not analyzed. These trials were conducted to prevent participants from shaping only two different hand sizes. The concern was that participants may only form two motor-plans and execute them automatically. As well, the flanker objects were included on some trials, but not others, to add variety and keep the participant engaged with novel stimuli.

Data Analysis

As each movement took a different length of time to complete (even within the same condition), duration of movement, peak grasp aperture size, grasping oversizing, time to peak velocity, time to peak aperture in each of the experimental conditions needed to be averaged for each participant. To achieve these averaged profiles, the average number of frames captured while a given participant completed the movement of a given condition was calculated.

To reduce noise and preserve the shape of the movement profiles, all the movement profiles for each participant in a particular condition were then resampled to 1000 time points. Resampling allows the value of a peak measure, as well as the time at which that peak value occurred, to be preserved. This allows for comparisons across different profiles which may have different time durations. Each participant’s movement profile was resampled into 1000 time points and then all movement profiles within a given condition were averaged to create the participant's typical movement for that condition.

Once this was completed, peak reach velocity, the time of peak reach velocity, aperture oversizing, and the time of peak aperture were observed from the resampled movement profiles. This data was then analyzed using a repeated-measures ANOVA, followed by post hoc, paired-sample t tests where appropriate.

Results

Summary

The kinematic profiles show that during direct viewing and indirect viewing, the grip component measures differed in some aspects. In both viewing conditions, maximum grip aperture presented at the same time within the movement profile regardless of Object Size. The peak grip aperture size differed by Object Size, in that a larger peak aperture was created when reaching for the larger Object. There was also an interaction effect, with maximum grip aperture affected by Object Size and Viewing Condition. In that the largest maximum grip aperture was observed for Indirect Viewing of the Large Object, and the smallest maximum grip aperture was observed for the Direct Viewing of the Small Object. However, the Object aperture oversizing (i.e. the difference between peak aperture and final aperture) adjusted with Object Size, but was not affected by Viewing Condition.

The transport component of the movements were also analyzed and revealed Viewing Condition effects. First, the reach movements that were performed during the Indirect Viewing Conditions took longer to perform than those performed while the target objects were Directly Viewed (i.e. indirect viewing = longer duration). The time of peak reach velocity occurred at the same percentage time of the movement for Indirect Viewing and Direct Viewing of the target objects. Lastly, peak reach velocity was higher for Direct Viewing of the target objects, than for Indirect Viewing.

Time of Peak Aperture

Maximum grip aperture presented at the same time within the movement profile regardless of Object Size or Viewing Condition, as shown in Figure 7. These observations were supported by a 2 x 2 repeated-measures ANOVA which resulted in no significant main effect for the Viewing Condition (Direct vs. Indirect; $F(1, 11) = 1.19$, *n.s.*) or for Object Size ($F(1, 11) = 0.34$, *n.s.*). The interaction between Viewing Condition and Object Size was also not significant ($F(1, 11) = 1.51$, *n.s.*).

Maximum Grip Aperture

There was a main effect Object Size, and an Object Size x Viewing Condition interaction, as seen in Figure 8. Specifically, the 2x2 repeated-measures ANOVA analysis of maximum grip aperture showed a significant main effect for Object Size, ($F(1, 11) = 15.07$, $p = 0.003$), with the Large Object producing a larger maximum grip aperture, as expected.

As well, the interaction between Object Size and Viewing Condition was significant ($F(1, 11) = 4.97$, $p = 0.048$). Dependent samples t-tests were conducted to further explore the nature of this interaction. A larger grip aperture was formed when viewing Large Objects in the Indirect Viewing condition ($M = 99.50$ mm, $SD = 2.78$) than when viewing Small Objects in the Direct Viewing condition ($M = 94.28$, $SD = 6.44$), $t(11) = -2.743$, $p < 0.05$. A larger grip aperture was formed when viewing in the

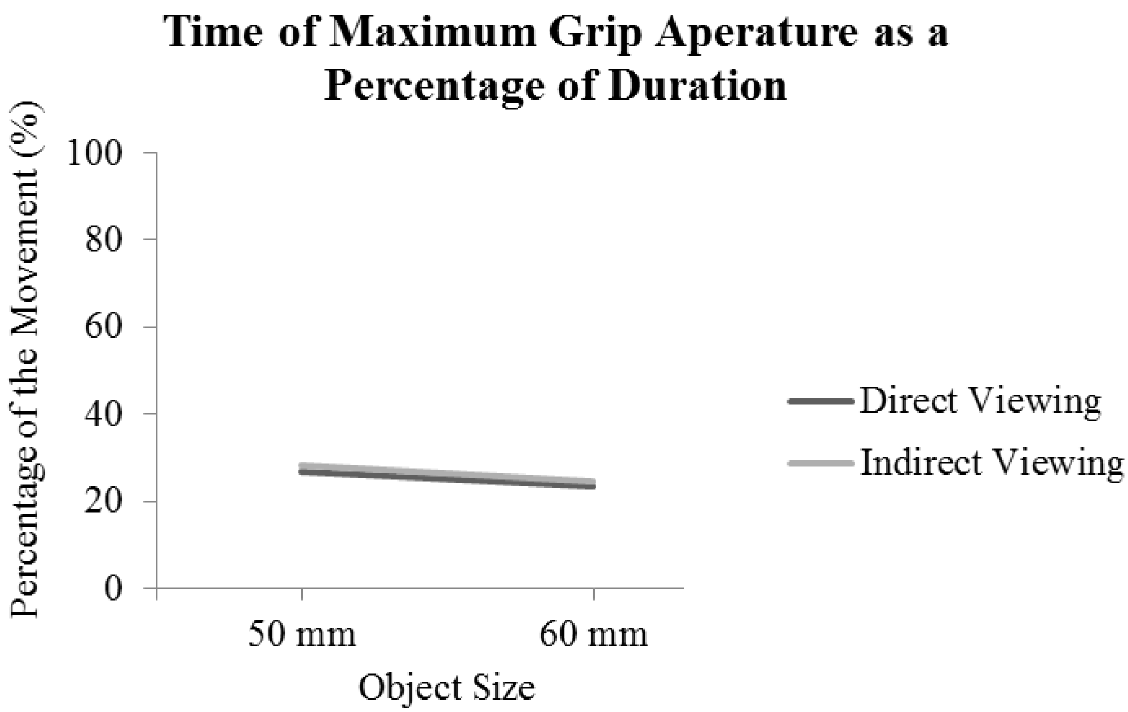


Figure 7. Comparing the percentage of the reach-to-grasp movement at which the maximum grip aperture occurred for Object Size and Viewing Condition.

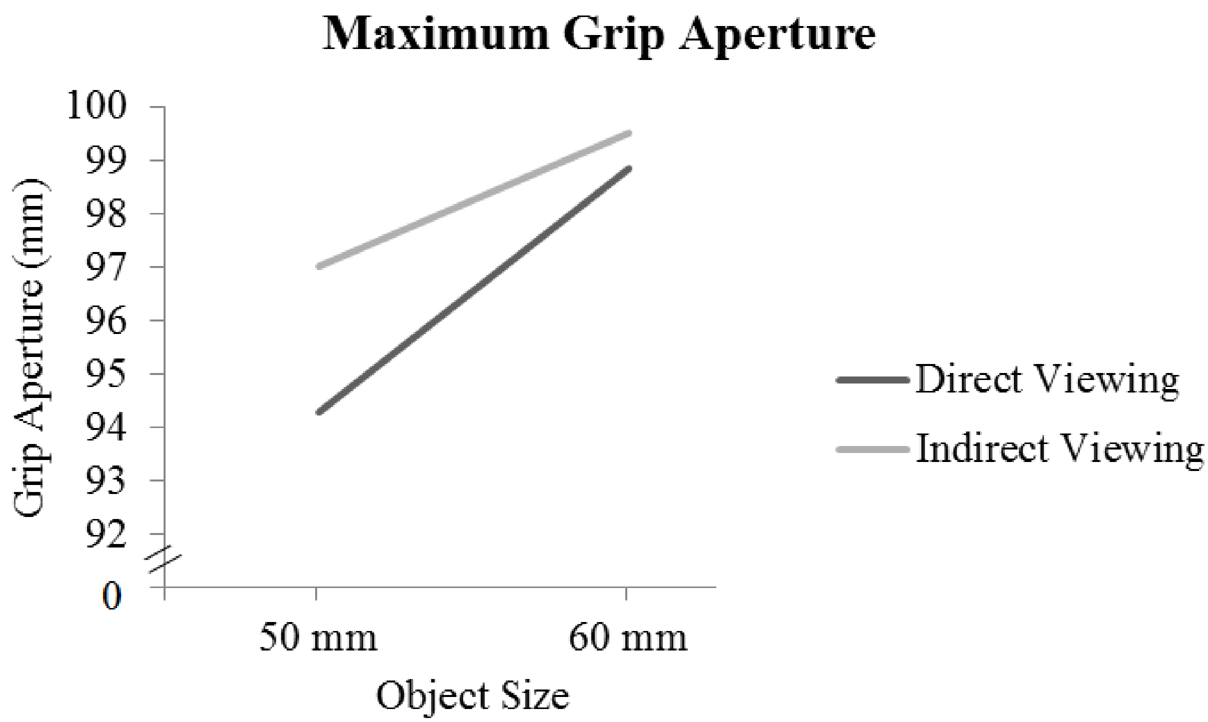


Figure 8. Comparing the maximum grip aperture formed during reach-to-grasp movements for Object Size and Viewing Condition.

Large Object in the Direct Viewing (*M* = 98.86, *SD* = 5.49) than when viewing the Small Object in the Direct Viewing (*M* = 94.28, *SD* = 6.44), $t(11) = -5.54$, $p < 0.001$. It appears that the large difference in maximum grip aperture for the Small Object, as well as the insignificant difference in maximum grip aperture for the Large Object between Viewing Conditions is determining the interaction. No significant main effect for Viewing Condition, ($F(1, 11) = 1.04$, *n.s.*) was found.

Aperture Oversizing

Aperture oversizing, or the difference between the peak aperture and the final aperture (i.e. Object Size), had a main effect of Object Size, but not Viewing Condition (as shown in Figure 9). In particular, the grip became more oversized for smaller objects than for larger objects. The 2 x2 repeated-measures ANOVA analysis of aperture oversizing showed a significant main effect of Object Size ($F(1, 11) = 16.71$, $p = 0.002$), but did not find a main effect for Viewing Condition ($F(1, 11) = 0.58$, *n.s.*). There was also no significant interaction between Viewing Condition and Object Size for grip aperture oversizing, ($F(1, 11) = 0.48$, *n.s.*).

Total Movement Time

Total movement time (i.e. duration) appeared to be longer for reach-to-grasp movements performed under indirect viewing than those performed under direct viewing (as shown in Figure 10). These effects were verified in the repeated measures ANOVA that showed a significant main effect of viewing condition ($F(1, 11) = 16.33$, p = 0.002) but not for Object Size ($F(1, 11) = 1.65$, *n.s.*) or the interaction between the two ($F(1, 11) = 0.81$, *n.s.*).

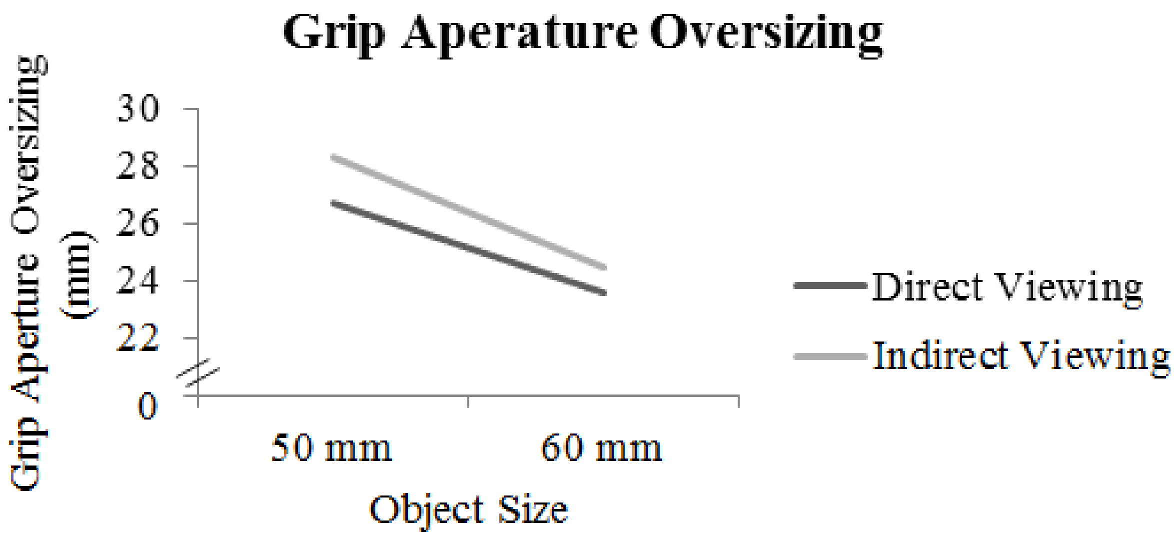


Figure 9. Comparing the grip aperture oversizing produced during reach-to-grasp movements for Object Size and Viewing Condition.

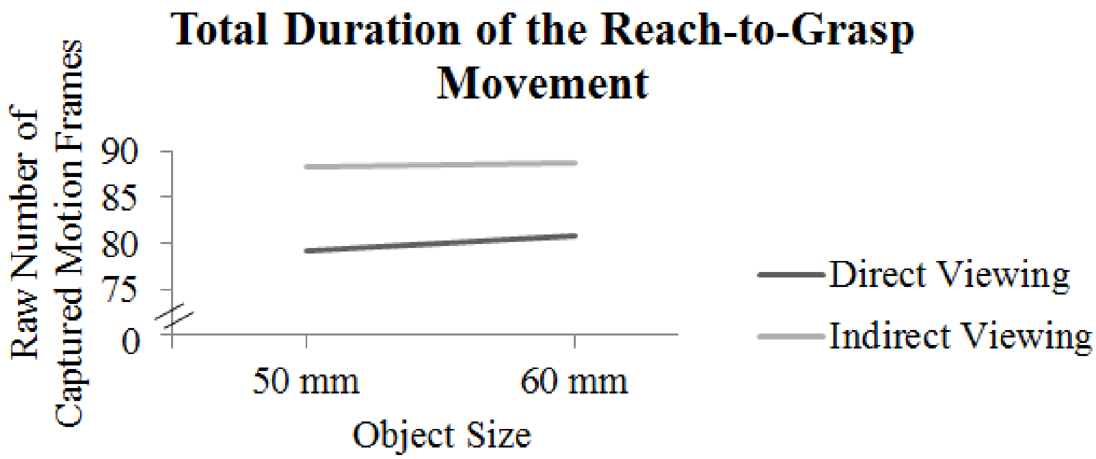


Figure 10. Comparing the total duration of the reach-to-grasp movements for Object Size and Viewing Condition.

Time of Peak Reach Velocity

Examination of the reach velocity movement profiles shows that the time of peak reach velocity was similar for all conditions (as shown in Figure 11). There was no significant main effects for Object Size ($F(1, 11) = 0.34$, *n.s.*), nor for Viewing Condition ($F(1, 11) = 1.19$, *n.s.*). Additionally, there was no interaction between for Object Size by Viewing Condition on time of peak reach velocity ($F(1, 11) = 1.51$, *n.s.*).

Peak Reach Velocity

The reach velocity profiles show that the reach-to-grasp movements are unaffected by Object Size. However, during the Direct Viewing conditions, reach-to-grasp movements were faster than those performed when indirectly viewing the target objects (as shown in Figure 12 & Figure 13). The velocities of reach-to-grasp movements toward objects of differing size were not found to be different ($F(1, 11) = 0.01$, *n.s.*). However, a significant main effect of viewing condition was found ($F(1, 11) = 17.99$, $p = 0.001$), with direct viewing producing higher velocities than indirect viewing. There was no interaction between Object Size and Viewing Condition ($F(1, 11) = 0.28$, *n.s.*).

Discussion

The results of this study support the hypothesis that there would likely be kinematic differences in the transport component of reach-to-grasp actions as a result of viewing target objects through a mirror. The results of the current study show some evidence of kinematic differences in the grip component of the reach-to-grasp movements. A further discussion of the various hypotheses and their findings are discussed in the following sections.

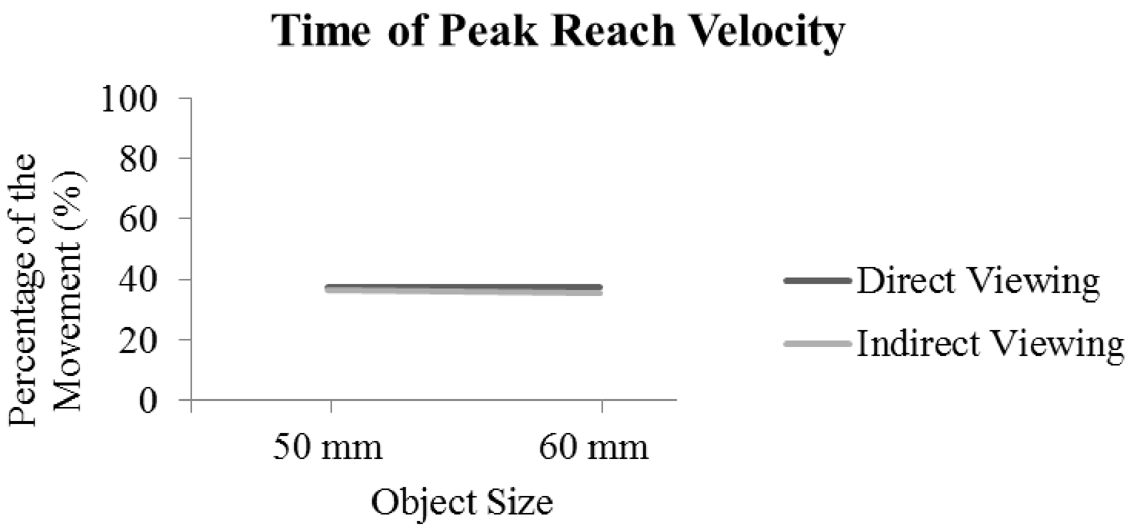


Figure 11. Comparing the percentage of the reach-to-grasp movement at which the peak reach velocity occurred for Object Size and Viewing Condition.

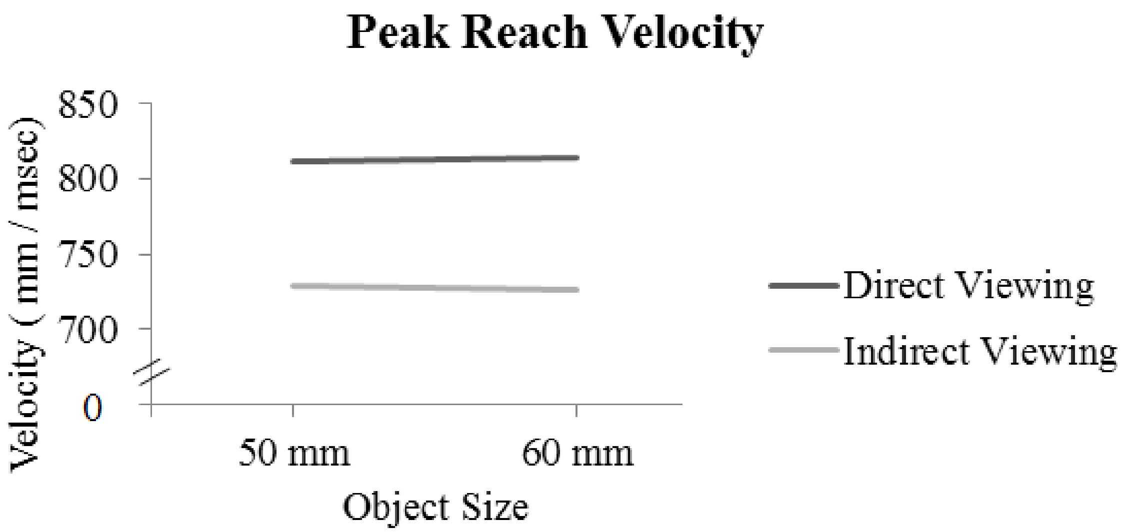


Figure 12. Comparing the peak reach velocity of the reach-to-grasp movement for Object Size and Viewing Condition**.**

Transport Component

It was hypothesized that the total duration of movement would be longer for the indirect viewing condition than for the direct viewing condition. It was postulated that this would be due to the reaches made during the indirect viewing condition performed slower, because there is more uncertainty in this viewing condition. It was found that the raw number of motion frames recorded (total duration of movement) was longer for the indirect viewing condition. As well, the peak velocity of the arm was faster for the direct viewing condition than for the indirect viewing condition.

It was originally hypothesized that the timing of maximum reach velocity would differ between the two viewing conditions, and that object size might be a mediating factor. However, upon examination, the time of peak reach velocity was similar for all conditions. Figure 13 displays the mean reach velocity curve of a single participant for all experimental conditions.

The results show that the transport component of the reach is quantifiably different between viewing conditions. The indirect viewing condition consisted of slower arm movements and took longer to complete the entire reach-to-grasp action. A possible explanation for this difference is that subjects felt unsure of their movements during this unnatural indirect viewing condition. Possible sources of uncertainty include the mismatch of seeing (visual cues) versus feeling their body in space (proprioceptive cues) and the mismatch of seeing versus feeling the workspace in space (extroperceptive cues). Figure 14 shows a visualization of what the participant sees and feels. Additionally, this slowing could be due to the visuomotor transformations that are required during the indirect viewing conditions. Participants must reconcile the conflicting visual and

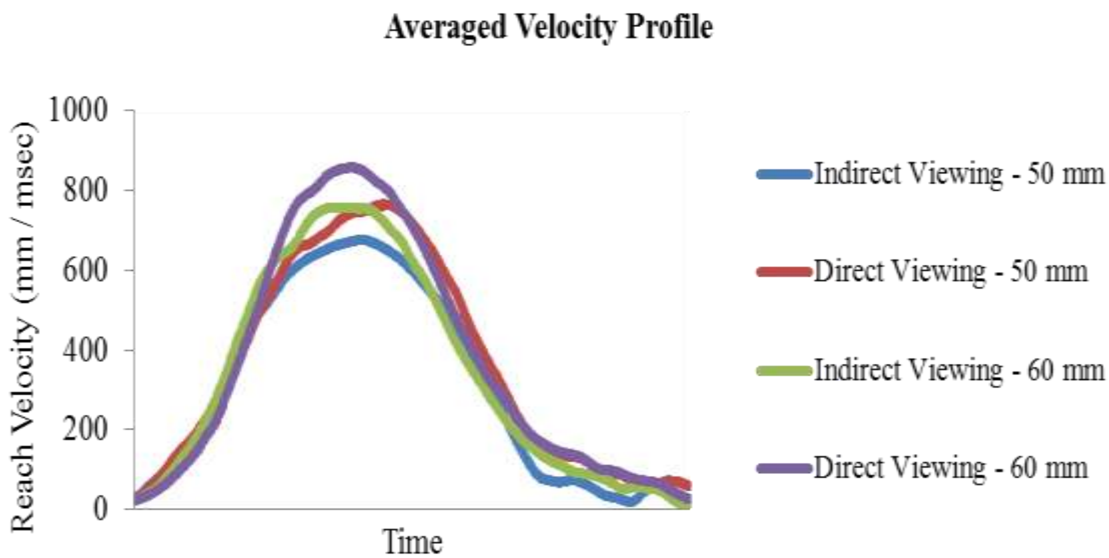


Figure 13. Average reach velocity curve of a single participant for all experimental conditions (Viewing Conditions and Object Size).

Figure 14. Due to the use of the mirror system used by many researchers participant receives conflicting visual cues and proprioceptive cues as to where their body exists in space during the indirect viewing condition. The participant sees their body as extending vertically but feels their body lying horizontal.

proprioceptive cues in order to make the reach-to-grasp movement accurate. Possible readjustments to the reach trajectory could be occurring as the arm moves towards the object, which would slow down the overall movement.

This feeling of uncertainty, as well as the cognitive loads of the aforementioned factors would motivate participants to slow their movements to ensure accuracy in directing their arm toward the target object. It is clear from the differences observed that the movements made while looking through the mirrors differ from movements made when directly viewing the object, despite practice within the indirect viewing condition. Thus, from this difference in kinematics, it can be inferred that there is a difference in neural activation related to the transport component performed during the different viewing conditions.

It was found that the transport component was similar no matter the size of the target object that the participant was reaching towards. Because of the similar placement of the objects and similar shapes of the objects, the motor plan of the arm did not have to differ much between the object sizes within the same viewing condition. Only the motor plan of the hand (to form the pinch grip) had to be altered and this will be discussed further in the grip component of the discussion. The position of the target object was deliberately placed in the same location for all trials to mimic fMRI paradigms. Within the fMRI scanner, the upper arm must be secured in order to ensure it is not eliciting head movements, for the head must be motionless for detailed images to be produced.

The background literature supports the differences found in the transport component of the reaching and grasping movement. It states that when reaching towards a target, visual input for both target and grasping hand position are necessary to perform an accurate reach (example: Gordon et al., 1994). However, in situations in which the hand position cannot be seen, proprioceptive information can be used. Studies have shown that both proprioception and visual input are used to determine hand position when planning reaching and grasping movements. But, we tend to rely more on the system with higher acuity (van Beers et al., 1996). Vision would be the dominant sense as the visual system has a higher resolution for body position, as determined by the eye.

The proprioceptive sense during movement differs in its usefulness between the viewing conditions. During the direct viewing condition, both visual and proprioceptive cues work harmoniously to provide information about body position. During the indirect viewing condition, there is conflicting information between the visual and proprioceptive systems. When vision and proprioception do not agree, we tend to follow the higher acuity visual system and ignore proprioception. Thus, it can be concluded that the proprioceptive information may be less useful in the indirect viewing condition as participants most likely rely on visual information.

This sensory conflict would introduce error to participants' movements, which could result in the slowing of the reaching motion to correct error in movement. Differences were observed in the peak arm velocity and the raw duration of the execution of the movement between the viewing conditions. This suggests that sensory weighting differences between the viewing conditions may be occurring.

Grip Component

It was hypothesized that the maximum grip aperture would occur earlier in the movement profile for indirect viewing condition versus the direct viewing condition in order to compensate for possible error. As well, it was thought that object size would be a mediating factor, in that peak grip aperture would tend to occur later in movement profile for the larger object size. However, the movement profiles were similar in both viewing conditions, in that the time of maximum grip aperture occurred within the similar location of the movement graphs.

It was found that maximum grip aperture is affected by object size, in that participants create a larger grip when they are reaching towards the larger object, as to be expected. Additionally, viewing condition had an interactive affect with maximum grip aperture. It was found that maximum grip aperture was largest when the participant reached towards the largest object during the indirect viewing condition. Inversely, the maximum grip aperture was smallest when the participant was reaching towards the smaller object in the direct viewing condition. This means that participants were able to grasp with more accuracy for the smaller objects in the direct viewing condition. Additionally, participants performed the movements with the least amount of accuracy when reaching to grasp the larger object in the indirect viewing condition than for the indirect viewing condition.

However, it is interesting to note that grip aperture oversizing did not show a significant interaction between the viewing conditions and object size. It was found that more oversizing occurred when the participants reached towards the smaller object over the larger object, but this oversizing was not affected by viewing condition. It is possible that the larger object (60mm) was pushing the limits of some participants' maximum grip aperture due to differences in individual anatomy. If this is the case then this would mean that there would be no expected differences of oversizing or maximum grip aperture between the viewing conditions because the participants' are opening their fingers as wide as they can in both conditions.

Overall, the grip component was quantifiably different between the object sizes but viewing conditions had mixed results. Grip aperture oversizing was most prominent for the smallest object and least apparent for the largest object. There is no difference in oversizing between viewing conditions. The different viewing conditions seemed to affect the motor plan of the hand within the total movement profile as it shapes to pinch the object, in that the maximum grip aperture was affected by an interaction by viewing condition and object size, but was not found to be significant factor in grip aperture oversizing.

It was expected that grip aperture oversizing differences would occur between viewing conditions. In particular, it was expected that the indirect viewing conditions would produce more grip aperture oversizing, as the background literature suggests. It has been shown previously that increases of reach uncertainty result in increased oversizing (Wing et al., 1986; Athénes and Wing, 1988). Possible sources of uncertainty include the mismatch of visual cues and proprioceptive and extroperceptive cues within the indirect viewing condition. As well, the viewing window for the area of interest (i.e. the hand and the workspace) was smaller in the indirect viewing condition than the direct viewing condition. This provided fewer useful environmental cues than in the direct viewing condition. While the transport component of the movement seemed to be affected by uncertainty (slowing down to ensure accuracy), it is unclear that the grip component was similarly affected.

Limitations and Future Directions

It is possible that the kinematic differences shown between the viewing conditions were not caused the condition itself (directly versus indirectly looking upon the object), but instead by the amount of visual information. The viewing window for the area of interest (i.e. the hand and the workspace) was significantly smaller during the indirect viewing condition than when the subject directly looked upon the object. The subject looked through occlusion googles and a system of small mirrors in the indirect viewing condition, thus their field of view was smaller during this viewing condition.

The purpose of this study was to recreate similar paradigms used in fMRI scanners. Ideally it would be better to use bigger mirrors however, due to the space constraints of the scanner, this is not possible. This experiment sought to replicate the viewing conditions used at many labs which employ indirect viewing methods in their reach-to-grasp neural imaging studies and compare those kinematics results to those collected during a direct viewing paradigm much like that employed by the Culham Lab at the Brain and Mind Institute. Other labs likely do not use the direct viewing condition because it requires additional custom equipment to tilt the head coil and the participant's head. Additionally, if the head is titled to far the image quality can be compromised. This study sought to determine if the hypothesized confounds have an impact on the reach-to-grasp movement and if these adjustments are necessary. This study purposely included the same methodological issues that are present in the typical indirect viewing paradigm and highlighted that these movements are altered because of them.

Researchers that use indirect viewing conditions in fMRI settings have worked under the assumption that the reach-to-grasp movements made during indirect viewing conditions are the same as the reach-to-grasp movements made during direct viewing. However, it can be argued that there is a higher cognitive demand in indirect viewing setups due to the visuomotor transformations that have to occur in order to perform the reach-to-grasp movements accurately. If there is a higher demand in the indirect viewing conditions, then it can be expected to be reflected in brain activity. There could be observable differences in the activity maps (location of activity within the brain), because the brain must recruit additional neural circuitry to reconcile the conflicting visual and proprioceptive cues. The differences in activity maps could also be due to greater activation observed in the neural areas that are typically activated during reach-to-grasp movements. Finally, the differences could be a combination of additional neural system recruitment and greater activation in existing areas.

It was observed that participants performed their reach-to-grasp movement significantly slowly in the indirect viewing condition. It may be that there is a cognitive need to slow down within the indirect viewing condition in order to give oneself more time to make an accurate reach-to-grasp movement. It is because of this slowing that it can be concluded that the movements made in the indirect viewing condition were different than the reach-to-grasp movements performed in the direct viewing condition. Thus, it could be expected to see larger responses in neural areas that normally function during the movement or extra areas being brought online.

Ideally, this same experiment would be conducted in an fMRI, but due to analysis confounds related to MRI physics, this sort of comparison of head positions and neural activation cannot be conducted. The magnetic field, in which fMRI data is collected, must be identical in the direct and indirect conditions in order for valid comparisons to be made. This means that the magnetic force lines, strength and direction, must be the same between viewing conditions, or else confounds between data sets will result and any findings will be highly suspect. In the direct viewing condition, the participant's head is positioned partially out of the homogenous magnetic field (i.e. magnet isocenter). It would then be unclear if the observed difference in brain activation was due to true differences of neural recruitment or simply the result of differences in the magnetic field.

Future directions include further kinematic studies of flanker objects to the target object that one reaches toward. In other reach-to-grasp studies, in which flanker objects were employed, flanker objects affected both the grip and transport component of the movement. In that, if flanker objects are placed closer to the target object, grip apertures become smaller and, reach velocity slows and movement duration becomes longer. It is thought that these changes are made in order to avoid possible collision with the flanker object. Even when flanker objects are not positioned in the direct path of the target, their presence still affects these kinematic measures (Gangitano, Daprati & Gentilucci, 1998).

Additionally, this study did not require drastic alternations of the hand motor plan within viewing conditions, as the objects were similarly shaped. Both target objects had the same width and depth and only the length dimension differed (50mm versus 60mm). Participants were required to place their fingers on the vertical axis of the rectangular object in both cases. However, would requiring the hand shape to adjust to irregular shaped objects take longer in indirect viewing conditions? It is possible that it would take longer to recalculate/form motor plans for objects of varying shapes because of the constant mismatch of visual and proprioceptive cues.

As well, it may be interesting to measure accuracy levels of the grasp, in that how accurately fingers are placed so that they are directly through the centre of mass. This would be measured by comparing a vector distance between the index and thumb when the object is grasped. It can be hypothesized that while the grip aperture oversizing may be similar between viewing conditions, contact with the object is not as accurate. Such that the participants are picking the object up by holding on to its edges instead of making a firm grasp at the centre of mass.

The present study manipulated the viewing condition of the stimulus and measured the reaching and grasping kinematics. The indirect-viewing methodology has been the standard in many contemporary fMRI studies of reaching and grasping. However, the additional visuomotor transformations required to perform reach and grasp movements through a mirror have now shown to result in key differences in kinematic measures of these reach-to-grasp movements. While participants can perform the movement required of them in this paradigm, the mirror system alters both the grip and transport components of the movement. Inferred by differences found in the measured kinematics, it can be suggested that there may be confounds in previous reach-to-grasp neuroimaging studies that have used optical manipulations to view the hand and workspace. Further research needs to be conducted to precisely determine the extent of the effect the mirror system imposes on reach-to-grasp movements.

References

Athénes, S., Wing, A.M. (1988). Knowledge-directed coordination in reaching for objects in the environment. In: Perspectives on the coordination of movement. Wallace S (ed). Elsevier, Amsterdam.

Beis, J. M., Andre, J. M., Barre, A., & Paysant, J. (2001). Mirror images and unilateral spatial neglect. *Neuropsychologia*, *39*, 144-1450.

Binkofski, F., Buccino, G., Dohle, C., Seitz, R. J., & Freund, H. -J. (1999). Mirror agnosia and mirror ataxia constitute different parietal lobe disorders. *Annals of Neurology*, *46*, 51-61.

Cavina-Pratesi, C., Monaco, S., Fattori, P., Galletti, C., McAdam, T. D., Quinlan, D. J., Goodale, M. A., Culham, J. C. (2010). Functional Magnetic Resonance Imaging Reveals the Neural Substrates of Arm Transport and Grip Formation in Reach-to-Grasp Actions in Humans. *The Journal of Neuroscience*,*30*, 10306-10323.

Clower, D., Hoffman, J., Votaw, J., Faber, T., Woods, R., & Alexander, G. (1996). Role of posterior parietal cortex in the recalibration of visually guided reaching. *Nature*, *383*, 618-621.

Culham, J. C., Cavina-Pratesi, C., & Singhal, A. (2006). The role of parietal cortex in visuomotor control: What have we learned from neuroimaging? *Neuropsychologia*, *44*, 2668–2684.

Gangitano, M., Daprati, E., & Gentilucci, M. (1998). Visual distractors differentially interfere with the reaching and grasping components of prehension movements. *Exp Brain Res.*, *122*, 441-452.

Goebel, R., Linden, D. E. J., Langermann, H., Zenella, F. E., & Singer, W. (1998). Functional imaging of mirror and inverse reading reveals separate coactivated networks for oculomotion and spatial transformation. *NeuroReport*, *9,* 713-719.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. Trends in Neurosciences,15(1), 20–25.

Gordon, J., Ghilardi, M. F., & Ghez, C. (1994). Accuracy of planar reaching movements. I. independence of direction and extent variability. *Exp Brain Res*, *99*, 97-111.

Holmes, S. A., & Heath, M. (2013). Goal-directed grasping: The dimensional properties of an object influence the nature of the visual information mediating aperture shaping. *Brain and Cognition*, *82*, 18-24.

Leiguarda, R. C., & Marsden, C. D. (1999). Limb apraxias: Higher-order disorders of sensorimotor integration. *Brain*, 123 (5), 860-879.

Massing, W., Kenklies, M., & Kalus, H. (2001). Virtual image grasping in patients with alzheimer-type dementia. *Neuroscience Letters*, *299*, 101-104.

Paulignan, Y., Jeannerod, M., MacKenzie, C., & Marteniuk, R. (1991). Selective perturbation of visual input during prehension movements the effects of changing object size. *Exp Brain Res, 87*, 407-20.

Priftis, K., Rusconi, E., Umilta, C., & Zorzi, M. (2003). Pure agnosia for mirror stimuli after inferior parietal lesion. *Brain*, *126*, 908-919.

Quinlan, D. (2009). *The kinematics of reach and grasp actions involving the mouth vs. external targets*. Ottawa: Library and Archives Canada = Bibliothèque et Archives Canada.

Ramachandran, V., Altschuler, E., & Hillyer, S. (1997). Mirror agnosia. *Proceedings of the Royal Society Biological Sciences*, *264*, 645-647.

Snow, J. C., Pettypiece, C. E., McAdam, T. D., McLean, A. D., Stroman, P. W., Goodale, M. A., et al. (2011). Bringing the real world into the fMRI scanner: Repetition effects for pictures versus real objects. Scientific Reports, 1, 130.

Jeannerod, M. (1984). The timing of natural prehension movements. *J Mot Behav, 16*, 235-54.

Jeannerod, M. (1986). The formation of finger grip during prehension. A cortically mediated visuomotor pattern. *Behav Brain Res*, *19*, 99-116.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), Analysis of visual behavior (pp. 549–586). Cambridge, MA: MIT Press

van Beers, R.J., Sittig, A.C., van der Gon, J.J. (1996). How humans combine simultaneous proprioceptive and visual position information. *Experimental Brain Research*, 111, 253-261.

Wing, A. M., Turton, A., & Fraser, C. (1986). Grasp size and accuracy of approach in reaching. Journal of Motor Behavior, 18, 245–260.

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