

INTERFERENCE IN SEQUENTIAL GRASPING: EFFECTS OF ACTION AND
PERCEPTION

by

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ABSTRACT

Past research has shown strong evidence supporting the notion that the visual control of action and the visual perception of objects are mediated by two functionally and anatomically distinct visual systems (Milner & Goodale, 2008). Little is known about how each visual system interferes with the other when performing a sequential task. However, it is known that the kinematics of an action can be affected by a subsidiary attention task (Castiello, 1996). In the current study participants (N =23) were presented with two rectangular objects placed one in front of the other. Participants were instructed to grasp the first object and place it on a specified target area and then either grasp, make a perceptual judgment about, or ignore the second object. The results revealed that preparing an action to the second object does not produce interference to the first action, but attending to its size for verbal judgment does.

LIST OF ABBREVIATIONS AND SYMBOLS USED

V1	Primary Visual Cortex
M1	Primary Motor Cortex
fMRI	Functional Magnetic Resonance Imaging
aIPS	Anterior Intraparietal Sulcus
PMd	Dorsal Premotor Cortex
SMA	Supplementary Motor Area
LOC	Lateral Occipital Complex
TMS	Transcranial Magnetic Stimulation
EEG	Electroencephalography
ERP	Event Related Potential
LCD	Liquid Crystal Display
ANOVA	Analysis of Variance
M	Mean
SD	Standard Deviation
MSE	Mean Squared Error
η_p^2	Partial Eta Squared

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CHAPTER 1 INTRODUCTION

In 1992, Milner and Goodale proposed a two-streams hypothesis of visual processing, in which the visual information projecting out of the primary visual cortex (V1) follows two distinct streams. The ventral stream projects to regions in the inferotemporal cortex and the dorsal stream projects to the posterior parietal cortex. In addition, the dorsal stream also receives visual input from the superior colliculus (via the pulvinar). Based on converging evidence, the ventral stream is thought to be the stream responsible for vision-for-perception, whereas the dorsal stream is responsible for vision-for action (Westwood & Goodale, 2011). Thus, the ventral stream provides us with the perception (recognition/identification) of the visual world, whereas the dorsal stream is responsible for transforming incoming visual information to guide skilled motor behavior.

Although it is well established that vision-for-perception occurs in the ventral stream and vision-for-action occurs in the dorsal stream, there are cases where the dorsal stream needs to interact with the ventral stream in order to perform a successful action (Westwood & Goodale, 2003). It has been shown that when we perform a memory-guided action, performing an action without the visual input of the object, the dorsal stream alone cannot successfully produce the correct action. Specifically, when performing a memory-guided action the dorsal stream relies on the re-activation of ventral stream (Singhal, Monaco, Kaufman & Culham, 2011). The re-activation of the ventral stream is necessary in order to access the memory of the object features. By accessing the memory of what the object looks like (via the ventral stream) the visuomotor mechanisms of the dorsal stream can then correctly perform the memory-

guided action. Therefore, although each stream has distinct functional properties, they do not necessarily work in isolation in all circumstances.

Not only can the ventral stream influence the workings of the dorsal stream but the interaction can also work in both ways. Specifically, it has been shown that within a priming paradigm, participants' initial dorsal stream response to a priming stimulus (video clip showing the performance of action, but without the object being visually present) activated their ventral stream areas prior to the presentation of the target objects (Sim, Helbig, Graf & Kiefer, 2014). In return, participants were faster and more accurate at recognizing the target object when it afforded a similar action to the priming stimulus. Therefore, once again it is shown how each stream can interact with the other, despite having different functions.

Although we know that each stream can interact with the other, little research has been done to investigate how each stream could possibly interfere with, or disrupt the operation of, the other. Moreover, a current gap in the literature is the fact that most experiments only incorporate performing one task at a time with one object. Thus, it remains unclear how the perceptual and visuomotor systems work to selectively process the appropriate object for the appropriate purpose. In essence, this is an issue of attention, which relates to the selective processing of sensory (or motor) information.

It has been established that action systems can be affected by distracting information, which suggests that attention and selective processing are relevant issues for the control of movement like they are for perception and awareness. In one of the first studies of motor attention, it was shown that participants' are slower at producing a pointing movement towards a target when a distractor is present on or near the hand trajectory (Tipper, Lortie & Baylis, 1992). Unlike distractor interference in tasks

requiring a perceptual judgment about a target stimulus, the interference seen for reaching varied with the starting position of the hand which implies an action-centered frame of reference. This suggests that although we can selectively attend to a target stimulus for the purpose of reaching to the appropriate object, the distractor stimulus nevertheless leaks into the associated motor response implying an incomplete suppression of the non-target stimulus.

Interference from non-target objects is not unique to reaching movements. It has been demonstrated that diverting attention to a distracting visual stimulus can affect the grasp component of manual prehension (Castiello, 1996). Participants were asked to reach out and grasp a piece of fruit while simultaneously counting how many times a light flickered on a second piece of fruit placed to the side of the target object. Results showed that the size of the fruit on which the light flickered affected the size of the grip aperture used to grasp the target object. For example, if the central fruit was a cherry, the amplitude of peak grip aperture was greater when the distracting fruit was an apple compared to when it was a mandarin. It was also found that participants' movement time, time to peak grip aperture and speed of movement were slower when the spotlighting of the non-target fruit began before movement onset. These results suggest that the grasping movement was affected the most when they had to focus their attention to the non-target fruit during the movement planning period. The author of this study concluded that drawing attention to the non-target stimulus engaged perceptual processing of the object including an activation of motor patterns suitable for interacting with the fruit. Presumably this unintentional motor processing interfered with the preparation of the action to the target stimulus even though there was no explicit instruction to perform any task whatsoever with non-target fruit.

Although Castiello (1996) explicitly suggested that the interference arising from the distracting fruit arose from involuntary processing of motor associations, presumably because this would explain an effect operating within a motor response, this was in fact never tested. It could be that participants were merely drawn to implicitly perceive the visual characteristics of the distracting stimulus, and this was sufficient to interfere with the preparation of grasping. In terms of dorsal and ventral stream processing, Castiello was implicitly suggesting that a dorsal stream task (grasping a target stimulus) can be interfered with by another dorsal stream task (implicitly preparing a grasping movement to a non-target stimulus). As mentioned above, however, it remains possible that Castiello's result arises from a dorsal stream task being interfered with by a ventral stream task (implicitly perceiving a non-target stimulus without necessarily preparing an action). Many studies have provided evidence that selection-for-perception (ventral) and selection-for-action (dorsal) share a common attentional mechanism (Deubel, Schneider, & Paprotta, 1998; Hesse & Deubel, 2011; Hesse, Deubel, & Schenk, 2012), hence making it possible that a ventral stream task could in fact interfere with a dorsal stream task.

1.1 Purpose

The primary purpose of this thesis is to determine whether the interference seen in a grasping movement indeed arises from the obligatory processing of motor associations for an attended object that is not the current target of an action. In order to investigate this question a sequential task was used. It has been shown that when completing a sequential task each movement is processed as one whole sequence (Henry & Rogers, 1960; Hesse & Deubel, 2010). Therefore, the sequential task will allow to test whether the nature of a task to be performed later (action vs. perception) affects a current action task. This study

design will permit systematic control over what the second task is via explicit instructions. Specifically, before grasping the first of two visible objects, participants will be told what they are required to do for the second object (either grasp, make a perceptual judgment about, or ignore it). The first object will remain the same throughout the experiment, however the size of the second object will be randomized.

For the perception condition, half of the participants will perform a verbal judgment (estimate the length of the second object in cm) and the other half will perform a manual estimation (estimate the length of the second object with index finger and thumb, but without physically touching the object). The reason behind including two types of perceptual tasks is to determine if there is a difference between the two modes of responding as suggested by previous studies (Franz, 2003; Franz, Gegenfurtner, Bühlhoff, & Fahle, 2000). Specifically, early studies (Aglioti, DeSouza & Goodale, 1995) were criticized because traditional measures of perception do not require the use of the hands, whereas measurements of grasping behavior are necessarily obtained from hand and finger movements. Consequently, most recent studies (Ganel, Tazner, & Goodale, 2008; Haffenden and Goodale, 1998; Westwood & Goodale, 2003) in this field have used manual estimation as a measure of perception, since the obtained metrics are more comparable to a grasping movement. However, because the present experiment employs a relatively unique sequential task structure, it is important to test if the mode of perceptual judgment (verbal estimation versus manual estimation) matters for interference.

1.2 Hypotheses

Based on Castiello's (1996) study it is predicted that making a perceptual judgment or a grasping action to the second object will interfere, in a similar manner, with the peak grip aperture towards the first object. Specifically, participants' peak grip

aperture towards the first object should scale positively with the size of the second object; that is, peak grip aperture when grasping the first object should be larger when the second object is larger, as compared to when the second object is smaller. This is because, according to Castiello, merely paying attention to a target stimulus (for any purpose) leads to obligatory motor processing even if no motor response is requested or produced. However, attention is not directed toward the second object, because it is to be ignored (control condition), it is predicted there will be no interference to the peak grip aperture towards the first object. If, however, interference in grasping arises from perceptual, rather than motor, processing of the non-target stimulus then it is possible that effects of the second object may arise in the perception condition but not the action or control conditions.

Castiello (1996) also showed that a movement is more prone to interference when participants' have to deploy their attention to the non-target object during the movement planning period. Because participants will have the extra task of processing the second object within the action and perception condition, it is predicted that the results will show that movement time, time to peak grip aperture, peak hand speed and time to peak hand speed (speed of the movement) will be slower in those conditions relative to the control condition. It is also predicted, based on the sequential movement literature, that the control condition will be associated with faster reaction times to the first object compared to the perception and action condition, since within the control condition no second movement needs to be planned.

In addition, it is expected to find no difference between the verbal estimation perception condition and the manual estimation perception condition since it is presumed that the underlying visual processing is perceptual, rather than visuomotor, in both cases

(Haffenden and Goodale, 1998) and as such the interference produced should be similar in nature. Nevertheless, as suggested by Franz (2003) it is possible that the two tasks utilize distinct forms of visual processing so it is possible that the interference produced could be different.

1.3 The significance of this research

By doing this type of research it will hopefully give us a better understanding of when and how distracting objects interfere with goal-directed movements. Given that disorders of movement-control, such as stroke, impairs independent functioning it would be extremely beneficial to get a better handle on how movements are actually represented in the brain and how they are carried out sequentially. Therefore, the goal of this research is to explore how our motor systems and perceptual mechanisms interact with each other to produce the appropriate set of actions. By exploring this domain of research it will contribute to the scientific advancement of gaining a better understanding of brain and behavior connections, which in return will help to diagnose and treat people suffering from neurological disorders.

CHAPTER 2 LITERATURE REVIEW

Whether we are performing simple actions (e.g., picking up a cup of coffee) or participating in more complex actions (e.g., playing a guitar), we rely on our motor control processes in order to organize and execute these actions successfully. The interaction between the central nervous system and the musculoskeletal system gives rise to successful motor control. Specifically, motor control relies on the integration of sensory information, from our environment and our current body state, to determine the appropriate set of muscles to be activated in order to generate the desired movement/action (Rosenbaum, 1991). One particular motor control process that we engage in multiple times daily is the reaching and grasping of objects with our hands.

2.1 Grasping

When performing a grasping action, the type of object to be grasped influences the type of grasping kinematics used to approach the object. The two main types of grasps are the power grip and the precision grip (Napier, 1960). The power grip is when all the fingers press down on an object with the thumb making counter pressure. The precision grip is when the index finger and the thumb press against each other. It has been shown that subpopulations of neurons in the primary motor cortex (M1) that project to motor neurons that activate hand muscles are active while conducting a precision grip but not during a power grip, despite the fact that the same target muscles are activated in either grasp (Muir & Lemon, 1983). Based on these findings a precision grip engages neural circuits that are different to those engaged during the power grip (Napier, 1980). Thus, in order to produce the correct grasp, the intended activity to be done with the object must be processed prior to activating the appropriate neural circuit (power grip vs. precision grip). For example, a precision grip would be used on a pen when the intended action is to

write with it. However, if the intended action were to hand over the pen to someone, a power grip would be used (Castiello, 2005). Due to the cortical differences between each type of grip, this thesis will be specifically focusing on the precision grip. Thus, each time the term grasping is used within the following text, it is specifically referring to the precision grip.

2.2 Grasping Kinematics

It has been shown that as soon as we initiate a reach-to-grasp movement, our hand already begins to reflect the size, shape and orientation of the target object (Jeannerod, 1984). During a reach-to-grasp movement there is first a progressive opening of the grip, with straightening of the fingers followed by a gradual closure of the grip until it matches the object's size (Jeannerod, 1984). Specifically, within 60-70% of the duration of the reach is the point in time at which the opening of the thumb and index finger is the largest. This identifiable landmark of the movement is known as peak grip aperture, which is highly correlated with the size of the target object (Jackobson & Goodale, 1991). Peak grip aperture can be quantitatively measured by means of 3D motion capture by placing sensors on the tip of the index finger, tip of the thumb and the radial styloid of the wrist while recording a grasping action being performed. When analyzing the output of the 3D motion capture data, the point in which the opening of the thumb and the index finger is the largest is identified as the peak grip aperture. The maximum distance attained between the fingers is a key parameter studied within the grasping literature to assess control of behavior by the brain.

Moreover, when analyzing the full range of the grasping motion, it has been shown that the initial phase of the transport of the hand towards the object is performed in fast-velocity, whereas the final transport phase is performed in low-velocity (Jeannerod,

1986). The low-velocity phase consistently begins at about 75% of the movement time, which is followed by the behavior of closing the fingers and forming a grip onto the object. As mentioned in the paragraph above peak grip aperture is attained at 60-70% of the duration of the movement. Consequently, peak grip aperture is established within the initial fast-velocity phase. The fact that the shape of our hand starts to reflect the nature of the target (i.e., size) object as soon as the movement is initiated suggests that the preparation of a grasping action must depend on the visual information of the object.

2.3 Visual control of grasping (Dorsal and Ventral Stream)

To successfully produce a grasping movement information from the primary motor cortex (M1) is conveyed to cells in the spinal cord via the corticospinal tracts to activate the appropriate set of muscles to generate the desired movement of the fingers (Gibson, Horn & Van Kan, 1994). In addition, the intermediate zone of the cerebellum compares the incoming sensory information (what the muscles are actually doing) to what the muscles are supposed to be doing and making the appropriate corrections to the movement via the rubrospinal and corticospinal tracts (Smith & Boubonnais, 1981). However, in order to generate the appropriate information of the motor sequence to M1, the coding of the intrinsic properties of the object to be grasped must be processed visually (Jeannerod et al., 1995). Thus, it is suggested that grasping is dependent on the neural mechanisms underlying the transformation of visual information about an object in the environment into motor commands that allow the hand to be correctly shaped for the completion of a successful grasping action. Therefore, it is essential to explore to what extent is the visual control of grasping guided by conscious visual perception.

2.3.1 Neuropsychological evidence

In 1992, Milner and Goodale proposed a two-streams hypothesis of visual processing, in which the visual information projecting out of the primary visual cortex (V1) follows two distinct streams. The ventral stream projects to regions in the inferotemporal cortex and the dorsal stream projects to the posterior parietal cortex. In addition, the dorsal stream also receives visual input from the superior colliculus (via the pulvinar). Based on converging evidence, the ventral stream is known to be the stream responsible for vision-for-perception, whereas the dorsal stream is responsible for vision-for-action (Westwood & Goodale, 2011).

One of the earliest pieces of evidence, demonstrating that the visual control of action and the visual perception of objects are mediated by two functionally and anatomically distinct visual systems, came from neuropsychology (Goodale, Milner, Jakobson & Carey, 1991). A patient (identified as D.F.) who had profound visual form agnosia (inability to properly recognize objects), due to brain damage at the junction of the occipital and temporal lobes, was successfully able to post a wooden card into a series of slots placed at different orientations (visuomotor pointing task). Nevertheless, D.F. was unsuccessful when asked to match the orientation of the slots with the wooden card (perceptual matching task). In other words, D.F. could use visual information to guide movements to objects (dorsal stream process), but she could not use visual information to recognize the same objects (ventral stream process). Thus, when presented with an object, patient D.F. is unable to identify the object, but when asked to reach out and grasp the object, she performs the correct action despite not having conscious awareness of the nature of the object. In contrast, patient A.T. who has optic ataxia (an inability to guide the hand toward an object), due to bilateral brain damage to her parietal lobes, is able to

describe an object when presented to her. However, when asked to reach out and grasp the object, she is unable to correctly scale her grasp when reaching to the object. Unlike patient D.F., patient A.T. is consciously aware of the object but fails to correctly scale her grasp when reaching out towards the object that remains visible both before and during the action. Based on these neuropsychological cases, a clear dissociation is seen between the associated functions of the dorsal and ventral stream (Milner and Goodale, 1995).

2.3.2 Psychophysical evidence

Furthermore, data from psychophysical studies using healthy participants have also yielded results that support the two-streams hypothesis of visual processing. In particular, Aglioti, DeSouza and Goodale (1995) used the Ebbinghaus size-contrast illusion as a stimulus to dissociate the dorsal and ventral stream processes. Their results showed that participants misjudged the actual size of a target stimulus when asked to perform a perceptual judgment (ventral stream process). However, when instructed to actually reach out and grasp the same target stimulus, the illusion did not affect participants' grip aperture (dorsal stream process). Many other studies have also reported similar results when using visual illusions to dissociate between vision-for-perception and vision-for-action (Goodale and Haffenden, 1998; Haffenden, Schiff & Goodale, 2001; Westwood, Heath & Roy, 2000).

In addition, Hu and Goodale (2000) have also had similar results as the illusion studies when simply presenting two rectangular blocks of different sizes. Specifically, participants were instructed to estimate, using their index finger and thumb, the width of a rectangular block that was presented alongside a smaller or larger companion block. When a larger block accompanied the target block, participants perceived the target block to be smaller than when it was accompanied by a smaller block. However, when

participants were actually required to grasp the target block, the presence of a companion block had no effect on the scaling of their grip aperture. Once again the evidence from this study suggests that there are separate visual mechanisms mediating object perception and object-directed action.

However, the psychophysical evidence presented thus far have only focused on the dorsal stream process of grasping an object. It is important to explore whether the dissociation still occurs when using a dependent measure for action that is not grip aperture. One other dependent measure that has been studied is the peak grip force, the maximum force applied by the hand to pull on objects, as a way to investigate lifting dynamics. Grandy and Westwood (2006) have shown evidence of a perception-action dissociation in response to a size-weight illusion. Specifically, participants reported that a small-light object felt heavier than a larger-heavy object throughout the experiment. Nevertheless, participants actually used smaller grip forces to lift the small-light object compared to the large-heavy object. Their findings revealed that the sensorimotor (dorsal stream process) and perceptual system (ventral stream process) use distinct mechanisms for determining the mass of an object. Therefore, the literature does not only find ventral and dorsal stream dissociation when estimating the size of an object, but also when estimating the weight of an object.

2.3.3 Neuroimaging evidence

Based on neuropsychological and behavioural evidence, it is suggested that object processing required for grasping relies on different neural substrates than those required for object recognition. As put forward by Milner and Goodale (1992), it is believed that object recognition relies on structures in the ventral stream (occipitotemporal) and that object grasping relies on structures in the dorsal stream (occipitoparietal). Moreover,

Culham et al. (2003) used functional magnetic resonance imaging (fMRI) to see if performing a grasping task would activate the dorsal stream whereas simply viewing an object would activate the ventral stream.

Their results showed greater activity in the anterior intraparietal cortex (part of the dorsal stream) when participants grasped an object, as opposed to reaching towards an object. Their results also showed greater activity in the lateral occipital complex (LOC), part of the ventral stream, when participants' viewed intact objects relative to scrambled object images. Although objects presented in both grasping and reaching trials activated the lateral occipital complex, no greater activity was found between both conditions. Thus, the results suggest that the anterior intraparietal cortex, but not the lateral occipital complex, plays a crucial role in processing object properties during grasping. However, the lateral occipital complex plays a crucial role in object recognition.

Based on this evidence it is suggested that the ventral pathway is activated when we are perceptually aware of the visual information. Whereas, the dorsal pathway could potentially still successfully process the incoming information even when we are not perceptually aware of the visual information. In order to test this hypothesis, Fang and He (2005) used an experimental framework based on binocular rivalry to design their study to explore the neural correlates of conscious and unconscious visual perception.

Participants were placed in the fMRI scanner where dissimilar images were presented to each eye through a mirror situated above their eyes. Low-contrast, low luminance object images were presented to the non-dominant eye that was completely suppressed by high-contrast dynamic (10 Hz) random texture presented to the dominant eye. Therefore, because the image presented to the non-dominant eye cannot be perceived, the object is considered "invisible". This allowed the researchers to measure

the cortical response to the “invisible” object images. In addition, visible objects were also presented to measure the comparison of the activations. Their results showed that the dorsal pathway was strongly activated by the invisible image of tools but not of faces. It was also shown that the ventral pathway was not activated by the invisible image of either the tools or faces. Therefore, based on this finding it is suggested that neurons in the dorsal pathway actively respond to objects that can be manipulated, such as tools (not faces), without being perceptually aware about it. Thus, once again supporting the notion that the ventral stream is responsible for visually recognizing objects and that the dorsal stream is responsible for visually guided grasping behavior.

2.3.4 Processing of object shape: perception versus action

Ganel and Goodale (2003) showed that when participants are asked to make perceptual judgments of the width of different rectangular objects they are unable to ignore the length, despite being instructed to ignore the length. In other words, when participants are shown two objects that are identical in width but not in length, participants do not perceptually judge their length to be equal. However, when asked to grasp the objects, participants are able to completely ignore the length. These findings are due to the fact that the visual perception of object shape depends on holistic processing, meaning that a given dimension cannot be isolated perceptually from the other dimensions of the object. Whereas when grasping an object, our brain only takes into account the most action-relevant dimension of an object, making it possible to ignore the non-relevant object features.

Evidence from the illusion studies demonstrating dissociation between the ventral and dorsal stream is due to the fact that because the ventral stream engages in a holistic processing of the stimulus' shape, the illusion is able to trick the participant to think the

stimulus is either bigger or smaller. However, because the dorsal stream only processes the relevant dimension, the illusion is unable to trick the participant when they are actually reaching out and grasping the stimulus. Thus, the visual control of action, such as grasping an object, is mediated by neural substrates that are independent of those mediating conscious perception (Goodale et al., 1994a). For this reason, most of the studies analyzing the dorsal and ventral stream processes have shown and demonstrated how each stream can act independently from each other.

2.4 Interaction of the two visual streams

Despite the large amount of research demonstrating the independence of each stream and its associated processes, there are cases where each stream is actually interacting with the other in order to perform a desired action goal. One particular example that shows a clear interaction between each stream is when one engages in a memory-guided grasp towards an object.

2.4.1 Neuropsychological evidence

As mentioned earlier, Patient D.F. has profound visual form agnosia as a result of brain damage to her ventral stream areas (at the junction of the occipital and temporal lobes). Therefore, although she is capable of performing the correct size scaling of her grip when reaching out to grasp an object, she is unable to describe/recognize what the object is due to the fact that her vision-for-perception stream is damaged. However, when a two second delay is introduced between the viewing of the target object and initiating the grasp, D.F. demonstrates extremely poor scaling of her grip when reaching out for the object (Goodale et al., 1994b). This finding suggests that D.F. is not able to use a visual memory of the object that was presented earlier to program her delayed grasping movement. Therefore, based on this pattern of results, the visuomotor mechanisms (dorsal

stream) responsible for the control of actions to visible target objects cannot retain the information about the target object features or the required grasping movement in memory. Thus, the visual memory of object features depend on the perceptual mechanisms located within the ventral stream. Because D.F. has damage to her ventral stream she cannot access the memory of the object features and therefore performs poorly when engaging in a memory-guided grasping task.

In contrast, when a patient with optic ataxia performs the same experiment the opposite pattern of results occur. Patient I.G. has damage to her dorsal stream, which despite being able to recognize and describe the object presented to her she is unable to properly scale her grip when reaching out to pick up the object. However, when presented with a two second delay, between the viewing of the target object and initiating the grasp, I.G. shows a paradoxical improvement in performance when reaching to grasp the object (Milner et al., 2001). Specifically, I.G. is better at grasping an object after it has been removed from view, since it forces her to rely on the object features in memory (ventral stream). Therefore, because her ventral stream is intact, she performs better at a memory-guided grasping task relative to a visually-guided grasping task, which would require the use of the visuomotor mechanisms within her damaged dorsal stream.

Based on these neuropsychological results, it is suggested that the dorsal stream operates in real-time, in which the visual information about the target object is needed throughout the programming of the movement. However, the ventral stream is responsible for creating the object representations that are maintained in memory for the control of actions to be performed later in time. Thus, when performing memory-guided actions the streams no longer act independently from each other. As seen with the neuropsychological patients, when performing a memory-guided grasping task, the two

streams are acting in synchrony. In patient D.F.'s case, this interaction impairs her action (due to her damaged ventral stream, but intact dorsal stream) whereas in I.G.'s case, the interaction improves her action (due to her intact ventral stream, but damaged dorsal stream). Although the research has demonstrated the interaction between each stream with neuropsychological patients, it is important to gain insight on whether this interaction also occurs in healthy subjects.

2.4.2 Psychophysical evidence

Previous experiments comparing visually-guided grasping versus memory-guided grasping actions in healthy individuals have shown a difference in grasping kinematics by means of using illusions as the stimuli (Hu and Goodale, 2000; Westwood, Heath and Roy 2000; Milner et al., 2001). The typical findings in these experiments is that peak grip aperture is significantly affected by the illusion when performing a perceptual task but not when performing an action task, as found in the illusion studies mentioned earlier. However, when participants are presented with a delay between the viewing of the target object and initiating of the grasp, peak grip aperture is significantly affected by the illusion in both the perception and the action condition. Therefore, when engaging in a memory-guided grasp, participants must access the memory of the object features, and because the ventral stream processes are susceptible to the illusion, their action becomes affected by it. This demonstrates an interaction between the dorsal stream (performing the action) and the ventral stream (accessing the memory of the object's features).

However, it is important to mention that within these experiments, visually-guided trials and memory-guided trials were presented within separate blocks. Because of this design participants could have attended to different aspects of the target objects in both conditions. Specifically, within the memory condition, participants could have used a

strategy that would have selectively activated the visual mechanisms in the ventral stream (holistic processing strategy), in which these mechanisms would have been sensitive to the illusion. In contrast, within the vision condition, the dorsal stream mechanisms would have been automatically activated as the target object came into view. Therefore, because both conditions were run in separate blocks, different visual systems would be activated as soon as the target was presented. Therefore, it is possible that the results obtained were not due to the interaction of the streams, but just on the selected strategy used.

In order to avoid this problem Westwood and Goodale (2003) performed a study in which the visually-guided and memory-guided trials were interleaved, thus, equating the viewing strategies used for the two-types of conditions. In this experiment, participants were required to reach out and grasp a rectangular target object that was presented beside either a smaller, larger or same-sized companion object (similar to the Hu and Goodale, 2000 study presented earlier). As predicted, when the target was visible between the response cue and the movement onset, the size-contrast illusion did not affect participants' peak grip aperture. Nevertheless, when the target was occluded from view between the response cue and the movement onset, the illusion did in fact affect participants' peak grip aperture. Specifically, participants' peak grip aperture was larger when the companion object was smaller than the target object, and peak grip aperture was smaller when the companion object was larger than the target object (the classic size-contrast illusion effect). Moreover, participants' peak grip aperture was affected by the illusion in both the 2.5 seconds delay condition and also the immediate delay condition. Despite the fact that in the immediate delay condition the target was visible right up until the movement onset, the illusion still persisted in affecting participants' grip scaling towards the object.

Based on this controlled experiment, the results suggest that the real-time visuomotor mechanisms (dorsal stream processes) are activated for the control of the action only once the response is cued, and most importantly only if the target is visible. As mentioned previously, when performing an action that is independently guided by the dorsal stream, only the relevant dimensions of the target is processed. Thus, the illusion does not affect one's grasping kinematics towards the target. In contrast, as soon as the target is not visible, the movement then becomes a memory-guided action based on the perceptual memory of the object. Because the ventral stream engages in a holistic processing of the object the movement is then susceptible to the size-contrast illusion. As seen with the neuropsychological patients, when participants engaged in a memory-guided grasping task their action was guided by both their dorsal stream (the act of reaching towards and grasping the object) and their ventral stream (the perceptual memory of the object's features).

Furthermore, not only has the interaction of the two streams been shown in a task requiring a delay, but also in experiments requiring a dual-task. Creem and Proffitt (2001) instructed participants in a control condition to reach out, grasp a tool placed in front of them, pick it up, and place it on an identified target area. The tools were placed individually in one of three orientations. In the semantic dual-task condition participants were required to do the same as the control condition, but while simultaneously completing a concurrent paired-associates distractor task. The results revealed that when participants performed the control condition, they reached around to pick the tools up by their handles, in a manner appropriate for the use of the object, despite the tool's orientation. However, when performing the semantic dual-task condition, participants were more likely to grasp the tools by their "near" orientation, which was less awkward to

grasp biomechanically (e.g., instead of grasping the spatula by its handle they would grasp it by its plastic blade).

These results indicate that the semantic task interfered with what the participants could semantically process from the tools, making the information limited to guide the visuomotor system about where to grasp the tool. When an object has a functional identity, the semantic information about the object's function must be retrieved before the initiation of an action towards it. The visuomotor mechanisms guiding the action cannot retrieve the semantic information on its own without the visual cognitive mechanisms. Therefore, when grasping tools at their appropriate functional location (e.g., handles), an interaction between the ventral stream (visual cognition) and dorsal stream (visually guided action) is engaged.

2.4.3 Neuroimaging evidence

Based on the findings contrasting the difference between a memory-guided grasping versus a visually-guided grasping action it is highly suggested that immediate actions recruit different neural substrates than delayed action. Singhal, Monaco, Kaufman & Culham (2011) showed using fMRI that when a 18 second delay interval was presented after the presentation of the object there was a reactivation of the lateral occipital complex (ventral stream areas) and early visual cortex at the time participants performed the action. This reactivation was shown despite the fact that participants remained in complete darkness with no visual stimulation at the time of action. Moreover, no reactivation of these areas was seen when grasping without the delay. However, as expected sustained activation within dorsal stream areas was shown in the anterior intraparietal sulcus (aIPS), dorsal premotor cortex (PMd), primary motor cortex (M1) and the supplementary motor area (SMA) during both the delay phase and non-delay phase.

It is proposed that during delayed actions the dorsal stream areas remain active in order to plan and maintain the action goals, but when the action needs to be executed the motor programming requires the reactivation of the ventral stream and early visual areas in order to re-recruit the visual information about the object. Thus, demonstrating that the dorsal stream areas are dependent on the interaction with the ventral stream areas when performing a memory-guided grasping action. This line of reasoning has also been supported by means of transcranial magnetic stimulation (TMS). Specifically Cohen et al. (2009) showed that TMS to aIPS affected the way participants grasped an object under both the immediate and delayed conditions. However, TMS to LOC only affected the way participants grasped an object for only the delayed movement conditions.

From the studies presented thus far, it is evident that sometimes the dorsal stream processes are not sufficient and need support from ventral stream processes to guide/perform a grasping action towards an object. However, little research has been done to investigate how each stream could possibly interfere with, or disrupt the operation of, the other. A current gap in the literature is the fact that most experiments only incorporate performing one task at a time. Therefore, when the streams appear to act independently from each other, it could be due to the fact that participants are only selectively attending to one object. Thus, it remains unclear how the perceptual and visuomotor systems work to selectively process the appropriate object for the appropriate purpose. In essence, this is an issue of attention, which relates to the selective processing of sensory (or motor) information.

2.5 The role of attention in grasping

When performing grasping actions there are usually other non-target objects surrounding the target object (e.g., reaching for a coffee mug on a cluttered desk with

many other objects surrounding the coffee mug). How is it that our nervous system can direct our attention in order to produce the appropriate motor output to the target object despite having multiple other non-target objects in our line of sight? Selective visual attention is the cognitive mechanism that enables us to select specific information within our environment for further processing and visually guided behavior, while simultaneously ignoring other things in the environment (Wolfe, 1994). However, do we really ignore the other non-target objects or could they be potentially processed in parallel to the target object?

Tipper, Lortie & Baylis (1992) showed that participants' response time to touch an illuminated target button was greater on trials in which a distractor (non-target button) was also illuminated on or near the hand trajectory relative to trials in which there was no distractor illuminated. Based on the performance decrements revealed when a distracting stimulus is presented along with the target stimulus, it is suggested that the motor program associated with the distractor is also processed. Although the competing responses from distractors are inhibited in order to execute the correct response to the target, the motor program for the distractor must still be processed for it to interfere with the planning and control mechanisms of the motor program towards the target.

Furthermore, in support of this view, Welsh, Elliott, & Weeks (1999) showed that when participants reach out to touch a target stimulus, in the presence of a distractor stimulus, their hand deviated towards the distractor when reaching out to touch the target.

Therefore, although we can selectively attend to the target stimulus, the non-target stimulus can somehow leak into the motor response to the target stimulus.

It is important to question whether simply processing the perceptual properties (ventral stream) of the distractor is enough to cause it to interfere with the movement

towards the target object; or does the actual processing of the movement associated with the distractor (dorsal stream) have to be processed in order to obtain an interference to the target object. Thus, it is important to further explore how visual attentive processes are influenced by the perceptual properties and the action intention of the distractor stimulus.

It has been demonstrated that a specific action intention can enhance the visual processing of action-relevant features. Bekkering and Neggers, (2002) instructed participants to search for, and saccade (make a rapid eye movement) to a target object presented among distractors in two conditions: 1) a saccade-and-point condition and, 2) a saccade-and-grasp condition. The results revealed that orientation selection, as opposed to color selection, was better in the saccade-and-grasp condition than the other condition. Specifically, in the grasping condition fewer saccades were made to objects with the wrong orientation compared to the pointing condition. However, the number of saccades to an object with the wrong colour was similar in the both conditions. Because object orientation (but not colour discrimination) is relevant for performing a grasping movement, the results support the view that action intentions influence visual attentive processes at a very early stage.

Based on the results mentioned above, it is suggested that selective dorsal and ventral stream processing share a common attentional mechanism. To investigate this particular question Deubel, Schneider and Paprott (1998) designed a dual-task paradigm. The paradigm consisted of preparing a reaching movement to a cued item in a letter string (action performance) while simultaneously discriminating between the symbols “E” and “3” (mirror image of E) presented very briefly alongside distractors (perceptual performance). It was demonstrated that participants’ performance on the perceptual discrimination task was far superior when the stimulus was presented at the same location

as the target for the manual aiming. As the discrimination stimulus was presented farther away from the aiming target, participants' performance declined. The pattern of results suggests that the selection-for-perception (ventral stream) and selection-for-action (dorsal stream) share a common attentional mechanism. Thus, in order to successfully act upon an object, one must shift their attention, the same attention used to perceive the object, towards it.

In support of this view, Wykowska and Schubo (2012) demonstrated that action planning modulates early perceptual processing and attention mechanisms. Participants were required to perform a task involving a combination of a visual search task for size or luminance targets with a movement (grasping or pointing) task, while recording participants' spontaneous brain electrical activity via electroencephalography (EEG). It was shown that participants demonstrated a better performance in congruent trials (e.g., search for size target when performing a grasping movement) relative to incongruent trials (e.g., search for luminance target when performing a grasping movement). The better performance was reflected by a modulation of the P1 component as well as the N2pc (event related potential markers of spatial attention). Therefore, the conclusion of this study suggests that when planning to act in a particular way, we turn our perception to what is action relevant via a shared attentional mechanism between dorsal and ventral stream.

The studies described thus far have shown the potential of the dorsal and ventral stream having a shared attentional mechanism. Nevertheless, none of these studies have actually investigated the effects of a dual-task paradigm on the kinematics of grasping movements. For this reason, Hesse and Deubel (2011) investigated the effects of visuo-spatial attention on the kinematics of grasping movements when performing a dual-task

paradigm. Their paradigm consisted of grasping cylindrical objects (motor task) while simultaneously identifying a target digit, presented within a rapid serial visual presentation, at a different location (perceptual task). When participants were instructed to focus on the perceptual task they displayed a good performance on the perceptual identification task but a decrease in performance for the motor task. Specifically, they were less accurate in scaling their early grip adjustment while approaching the cylindrical objects compared to when they simply performed this task as a single-task. Therefore, when visual attention is allocated to a perceptual task the efficiency of the grasping movement is impaired.

The result of this study demonstrates that visual attention is needed for the effective control of the grasping kinematics. Although these results once again suggest a shared attentional mechanism of the ventral and dorsal stream (when specifically measuring grasping kinematics), the results could also just simply demonstrate that the perceptual attention distracted the motor attention due to their location differences. Thus, the study does not rule out the fact that the dorsal and ventral stream could have separate attentional mechanisms. In order to clarify their results, Hesse, Schenk and Deubel (2012) performed the same study but while presenting the perceptual and motor task at the same spatial location.

To ensure that both tasks were performed simultaneously, the perceptual target was only presented once the participants had started their movement in order to avoid them from adopting a task sequencing strategy. Similar to their previous study, their results revealed that when performing the dual-task, participants showed a delay opening of their hand and also a delayed grip scaling of the objects' size. Therefore, even when both stimuli are presented at the same location the impairments of the grasping

kinematics persisted. These results provide further evidence that attention is required for successfully grasping an object and that the dorsal and ventral stream share the same attentional mechanism.

Furthermore, because the dorsal and ventral stream share the same attentional mechanism it makes it possible that each stream could influence the processing of the other. Sim, Helbig, Graf & Kiefer (2014) used a priming paradigm in order to demonstrate how paying attention to a dorsal stream task can enhance the processing of a following ventral stream task. The task consisted of showing a video clip (priming stimulus) of someone performing an action with an object, but with the object being erased (e.g., someone playing the piano but the piano is not shown in the video), prior to presenting them with a target object (either affording a similar or dissimilar action as the priming stimulus). It was shown that participants were faster and more accurate at recognizing the target object (via picture-matching task) during the congruent trials (prime action similar to what action is required to the target) versus the incongruent trials (prime action dissimilar to what action is required to the target).

Moreover, while participants performed the task they wore an elastic cap with electrodes mounted on it in order to analyze participants brain response to the priming stimulus via event related potentials (ERP). Using effective connectivity analyses the ERP source analyses showed priming-related activity (120-150 ms) in the pre- and post-central cortex as well as inferior parietal cortex (dorsal stream network) and later priming-related activity (380-480 ms) was obtained in occipital and temporal areas (ventral stream network). Thus, demonstrating that initiating processes within the dorsal stream can functionally contribute to visual object recognition by interacting with ventral stream processes. Once again, this study supports the fact that dorsal and ventral stream

share the same attentional mechanisms, to the extent where the dorsal stream can enhance the processing of the ventral stream. Not only, does this study provide more support for the shared attentional mechanisms hypothesis, but it also shows further support for the interaction between each stream.

Because each stream has a distinct function but a shared attentional resource, it is possible that a ventral stream task could directly leak into a dorsal stream task, or vice versa, and cause an interference effect as oppose to an enhancing effect seen in Sim et al (2014). It has been demonstrated that diverting attention to a distracting visual stimulus can affect the grasp component of manual prehension (Castiello, 1996). Specifically, participants were asked to reach out and grasp a centrally placed fruit while simultaneously counting how many light flicks were flashed on another fruit (placed laterally beside the other one). Results showed that the size of the fruit on which the light flickered affected the size of the grip aperture used to grasp the target object. For example, if the central fruit was a cherry, the amplitude of peak grip aperture was greater when the distracting fruit was an apple compared to when it was a mandarin. It was also found that participants' movement time, time to peak grip aperture and speed of movement were slower when the spotlighting of the non-target fruit began before movement onset. These results suggest that the grasping movement was affected the most when they had to focus their attention to the non-target fruit during the movement planning period. The author of this study concluded that drawing attention to the non-target stimulus engaged perceptual processing of the object including an activation of motor patterns suitable for interacting with the fruit. Presumably this unintentional motor processing interfered with the preparation of the action to the target stimulus even though there was no explicit instruction to perform any task whatsoever with non-target fruit. It is

also important to mention that these results were not only demonstrated with vision as the perception task but also with taste. Precisely, peak grip aperture was greater when participants reached out and grasped a small fruit (e.g., strawberry) that was preceded by a sip of a “large” (e.g, orange) than a “small” (e.g., almond) flavor juice (Parma et al., 2011).

Castiello (1996) is implicitly suggesting that a dorsal stream task (grasping a target stimulus) can be interfered with by another dorsal stream task (implicitly preparing a grasping movement to a non-target stimulus). However, it remains possible that Castiello’s result arose from a dorsal stream task being interfered by a ventral stream task (implicitly perceiving a non-target stimulus without necessarily preparing an action). This leads to the role of this thesis, which will be to test how the nature of a task to be performed later (action vs. perception) affects a current action task. However, in order to further explore this domain of research, the use of a sequential task paradigm will be essential. Using a sequential task will permit systematic control over what the second task is (via explicit instructions). Specifically, we will be able to manipulate if participants will be actively attaining to the perceptual properties of the next object, its associated motor patterns, or simply ignoring it. First, it is necessary to properly investigate the literature of how sequential movements are planned and executed.

2.6 Sequential movements

When looking at our daily activities many of our actions are not separate individual events, but a mere combination of multiple events. For example, to drink a glass of juice does not consist of simply grasping the cup. First we must grasp the jug, pour the juice into the cup, then put the jug down, grasp the cup and take a refreshing drink. As shown in this example, one goal does not merely consist of one simple

movement but an array of sequential movements. However, two questions arise: When completing these sequential movements, do we approach each movement independently? Or are sequential movements prepared and executed as one whole movement?

In 1960, Henry and Rogers showed that as the number of segments within a task increased, the reaction time to initiate the first movement also increased. In one condition of their study, participants were required to lift their hand off a key once they heard an auditory tone. Another condition consisted of participants doing the same thing, but once they lifted their hand, they had to grasp a hanging tennis ball. The third condition was similar to the second condition, but instead of grasping the tennis ball, they had to push it away and grasp another tennis ball located to the left of the other ball. Participants were aware prior to the auditory signal what condition they were performing, making it possible for them to prepare their movements before the onset of the signal.

The results of this experiment showed that reaction times for the first movement, lifting their hand off a key, was faster for the first condition relative to the two other conditions. Moreover, the second condition was faster than the third condition. This effect has been coined the one-target advantage. The fact that the time to initiate and execute the first component of the movement is longer than if the movement is performed in isolation, suggests that preparing a sequence of movements is completed as a whole and not independently. If each movement were prepared independently, there would be no one-target advantage effect. Therefore, when preparing a sequence of movement our attention does not process each movement independently but as one whole movement.

In order to uncover the underlying mechanisms of the one-target advantage, Adam et al. (2000) tested multiple hypotheses. One hypothesis that was tested and ruled out was the possibility of overlapping or concurrent control of eye and hand movements.

Specifically, whether there is a presence or absence of eye movements in a one-target relative to a two-target task, it does not play a role in the mechanisms underlying the one-target advantage. Furthermore, it was also shown that the one-target advantage occurs regardless of the distance to be moved from the first to the second target, ruling out the possible effect of movement distance increments.

The last hypothesis that was tested was the movement integration hypothesis. The movement integration hypothesis states that the one-target advantage is a result of a motor control strategy in which the neuromuscular organization of the second movement is partially implemented during the execution of the first movement (Adam et al., 1995). To test this hypothesis, the authors manipulated the stimulus in order to either eliminate the integration process or enhance it. To eliminate it, they used small targets as the stimuli in order to make it harder to tap the stimuli. As predicted, because the movements were harder to achieve, making it less probable to integrate both movements together, the one-target advantage was not found. Moreover, to enhance the integration process they included a reversal movement back to the start location. As predicted, the results showed a reduced one-target advantage relative to if the second movement was not a reversal movement. Based on this experiment, the mechanisms underlying the one-target advantage can be explained by the movement integration hypothesis, in which the implementation of the second movement overlaps with the execution of the first movement.

The one-target advantage has been demonstrated in various tasks. Nevertheless, for the purpose of the experiment being conducted in this thesis, it is important to explore whether the planning and execution of early movement segments within an action sequence are influenced by specific tasks demands of a later movement segments.

Investigating this particular question, Hesse and Deubel (2010) instructed participants to perform a sequence consisting of grasping a cylinder, placing it into a target area, and then grasping and displacing a target bar of a certain orientation. The purpose of the experiment was to see whether the orientation of the target bar, the last movement, influenced the way in which participants grasped the cylinder.

As predicted, the results showed that the selected grip orientations used to grasp the cylinder were affected by the orientation in which the target bar was orientated. Thus, the results suggest that the reach-to-grasp movements were not performed in isolation. Moreover, the whole action sequence was planned in advance, whereby the hand orientation that would be used in the final steps was taken into account during the first steps. However, by making the placing task more difficult, the cylinder had to be placed on a small pin mounted in the center of the target area, the grasping kinematics towards the cylinder was not affected by the orientation of the target bar. As the task was harder, the action had to be treated independently from the upcoming action. The results attained within this experiment are consistent with the movement integration hypothesis. This suggests that when planning the grasping kinematics of an action, the grasping kinematics that is required for the proceeding action is taken into account. Therefore, by using a sequential task, we can explore how a second task (action task, perception task or control task) affects a current action task.

CHAPTER 3 METHODS

3.1 Participants

Twenty-three right-handed undergraduate students with normal or corrected-to-normal vision and no history of neurological deficits participated in the current study. Past research (Castiello, 1996) has demonstrated statistically significant results, peak grip aperture being affected by the size of a distracting object, with a similar number of participants for an experiment of the similar nature as the current one. Of the 23 participants, 11 performed the verbal estimation perception condition and 12 performed the manual estimation perception condition.

3.2 Materials

One white wooden rectangular object (5cm X 5cm) was used throughout the experiment as the stimulus for the first task. One out of a set of five rectangular wooden objects (all white) was used as the stimulus for the second task. Specifically, one object measured the same dimensions as the object used in the first task (5cm X 5cm). The other objects were either larger in width than the first object (6cm X 4.17cm; 7cm X 3.57cm) or smaller in width (4cm X 6.25cm; 3cm X 8.30cm). The dimensions have been arranged in order to keep the surface area of every object the same (25cm^2), see figure 1. This was done to ensure no effects are generated due to objects occupying more/less physical space than others. The objects were placed on a table, which was covered by a black cloth. The table had marked areas for a starting area (for the participant's hand) and two target areas (one for each of the two objects necessary for the task). The first target area was 10cm away from the starting area, and the second target area was 10cm away from the first target area. Thus, as seen in figure 2, a total of 20cm separated the starting area from the

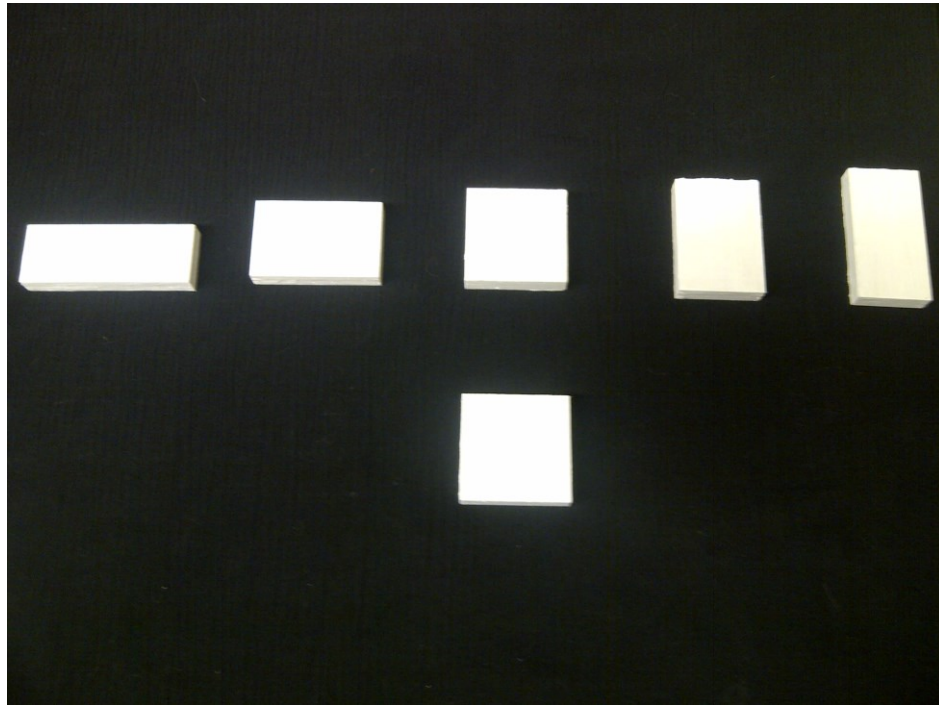


Figure 1. The stimuli used for the experiment. The first object was always the same one, however the second object was one of the five objects shown at the top. Despite the differences in length and width, each object's surface area is equal to 25 cm^2 .

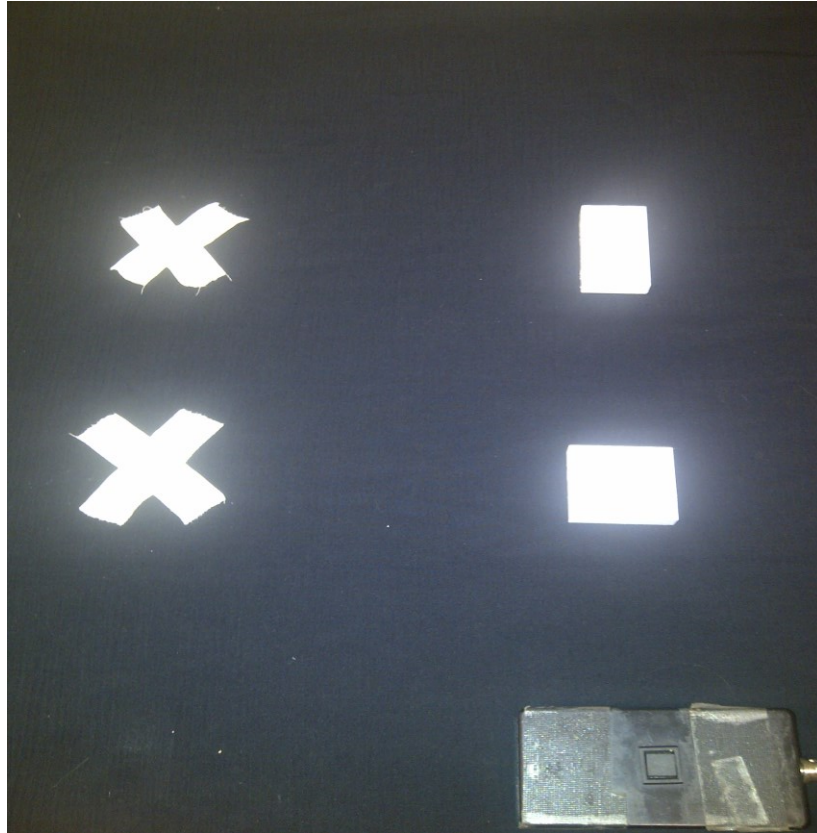


Figure 2. Picture depicting the experimental set up; the starting switch, the two objects and their associated target areas.

second object. An additional placement zone was located 10cm towards the left of each target area, into which participants later moved the target objects.

An Optotrak 3020 (NDI, Waterloo, ON, CANADA) was used to measure kinematic characteristics of the grasping movements. The Optotrak 3020 uses infrared emitting diodes (IREDs) placed on the index finger, thumb, and wrist, which are tracked at 200 Hz by a bank of three infrared detecting cameras and used to compute positions in 3D space, see figure 3.

Participants also wore translucent glasses (PLATO Translucent Technologies, Toronto, ON, Canada), in order to block their vision when needed. The glasses are fitted with a pair of LCD lenses (as seen in figure 4) that can be made opaque or transparent by electronic control, thereby blocking vision without reducing the total amount of ambient light reaching the eyes. When the lenses are clear the participant can see the environment, and when the lenses are opaque the participant sees a homogenous bright grey field.

An auditory tone was used to present the starting signal (Tone of 800Hz; duration of 250ms) to initiate the beginning of each trial. Prior to the beginning of each trial, the experimenter verbally presented the type of task the participants were required to do with the second object.

3.3 Procedure

Participants were seated in front of a table during all experimental trials. The IREDs of the 3D motion capture system were secured using medical tape to the following positions: the tip of the right index finger, the tip of the right thumb and the radial styloid of the right wrist. Participants were then instructed to place their right hand on a button-type switch at the identified starting area of the table before each trial. At the start of each trial the experimenter verbally said which task (perception, action or nothing) was to be



Figure 3. The three infrared detecting cameras of the Optotrak 3020 3D motion capture system.



Figure 4. The PLATO translucent glasses fitted with a pair of LCD lenses that can be made opaque or transparent by the control of a switch.

performed with the second object. The nature of the second task was presented in a randomized order. The liquid-crystal display (LCD) glasses remained opaque until instructions were given; 1.5 seconds later the glasses turned transparent and the auditory start tone was presented at a randomized time later, ranging between 500 and 1500ms (to avoid an expectancy effect).

After the tone, the participants performed the first action (i.e., reaching and grasping the first object, move it to the adjacent placement area) and then the second task (i.e., estimating the size of the second object, grasping the second object, or ignoring the second object). The glasses then returned to opaque after both tasks were completed. Participants performed a total of 120 trials, 50 trials for each condition (perception and action; ten repetitions of each of the five sizes of second object) and 20 control trials (four repetitions of each of the five sizes of second object). The type of task condition was varied randomly on a trial-by-trial basis. Participants were offered to take a small break (~1-2mins) after the 40th and 80th trial. After each trial the experimenter manually changed the second object (randomized order). Once the second object was properly set up the nature of the second task, for the next trial, was verbally presented by the experimenter.

3.3.1 Perception condition

Participants grasped the first object and place it inside its marked target area. Half of the participants were required to make a manual perceptual judgment (using their index finger and thumb to estimate the size without physically touching the object) of the width of the second object. The other half was required to make a verbal judgment by identifying the width of the second object (verbally judging the size of the object in centimeters). The participants performing the verbal estimations were shown a 15 cm

ruler prior to the beginning of the experiment. This allowed them to get familiarized with the measurement they were required to use for their verbal judgment. The perception conditions were identified as PERCEPTION when verbally presented by the experimenter.

3.3.2 Action condition

Participants grasped the first object and placed it inside its marked target area. All participants then grasped the second object and placed it inside its marked target area. The action conditions were identified as ACTION when verbally presented by the experimenter.

3.3.3 Control condition

Participants grasped the first object and placed it inside its marked target area. Neither action nor perceptual judgment was done to the second object. The control conditions were identified as NOTHING when verbally presented by the experimenter.

3.3.4 Data Collection

The 3D kinematics of the action were collected by the Optotrak 3020 system during each trial. Offline, key features of the action such as the peak grip aperture, reaction time, movement time and peak hand speed (i.e., the maximum speed achieved by the hand during action) were extracted by a customized script via the Python software system. Specifically, the algorithms of the script extracted the movement onset (the point in time where the participant started their movement) and the movement offset (the point in time where the participants ended their movement) of the raw data. The movement onset value was then subtracted from the movement offset value, via the script, to obtain movement time. The algorithms of the script also extracted the peak grip aperture value (the point in time where participant's distance between the thumb and index finger was

the greatest), the time it took to reach peak grip aperture, peak hand speed (the point in time where participants' hand moved the fastest), and the time it took to reach peak hand speed from the raw data. In addition, the time elapsed between the start of the trial and the releasing of the start switch was defined as the reaction time value. Each trial was inspected visually, in order to make sure the script was extracting the correct values. If an error was found, the correct values were chosen manually.

CHAPTER 4 RESULTS

The analyses included only trials for which there were no z-scores values greater than three (values that are very different from the majority of data values within the data set) for movement time, reaction time, peak grip aperture, time to peak grip aperture, peak hand speed and time to peak hand speed. Thus, trials in which one of the kinematic measures had a z-score value greater than three were considered outliers and were omitted from the analyses. A total of a 164 trials, 6.1% of the data, were omitted from the analyses.

Each dependent measure was analyzed using an omnibus analysis of variance (ANOVA) with condition (3) and size (5) as factors. The simple effect of size was also analyzed for each task (action, perception, control) regardless of whether the omnibus analysis revealed a significant task x size interaction. In addition to the simple effect of size, separate analyses focused on just the linear component of the size effect for each condition given that Castiello's (1996) original study implied a linear relationship between the size of the distracting stimulus and the observed effect on grasping. Furthermore, the results from the perception condition were analyzed separately for the two groups that performed different types of judgments, manual estimation and verbal estimation, based on Franz's (2003) ideas that the two tasks might possibly utilize distinct forms of visual processing.

4.1 Peak grip aperture

A 3 (perception condition; action condition; control condition) x 5 (size of second object; 3, 4, 5, 6, or 7cm width) repeated measures ANOVA was performed on the mean peak grip aperture for grasping the first object. The results revealed no significant interaction between the type of condition and size of the second object, $F(8, 176) =$

0.844, $p = 0.56$, $MSE = 2.82$, $\eta_p^2 = 0.04$, power = 0.38. A significant difference was found in mean peak grip aperture between the types of conditions, $F(2, 44) = 4.04$, $p = 0.02$, $MSE = 4.03$, $\eta_p^2 = 0.16$, power = 0.69. Specifically, the perception condition showed an overall larger peak grip aperture to the first object ($M = 70.67$, $SD = 6.08$) than the action condition ($M = 70.32$, $SD = 5.81$) and the control condition ($M = 69.96$, $SD = 5.89$). However, no significant difference was found in mean peak grip aperture between the size of the second object, $F(4, 88) = 1.13$, $p = 0.35$, $MSE = 1.9$, $\eta_p^2 = 0.05$, power = 0.34.

Despite no overall interaction between type of condition and size of second object, the data were separated into the three types of conditions in order to perform simple effects analyses. No main effect of size was found for the action condition, $F(4, 88) = 0.11$, $p = 0.98$, $MSE = 1.05$, $\eta_p^2 = 0.01$, power = 0.07; the control condition, $F(4, 88) = 0.67$, $p = 0.60$, $MSE = 4.84$, $\eta_p^2 = 0.03$, power = 0.215; or the perception condition, $F(4, 88) = 2.09$, $p = 0.09$, $MSE = 1.66$, $\eta_p^2 = 0.09$, power = 0.6. Additionally, a subsequent analysis was done to take the main effect of condition and break it into just the linear trend component for analysis. The results revealed that there was no significant linear trend of size for the action condition, $F(1, 22) = 0.01$, $p = 0.93$, $MSE = 1.23$, $\eta_p^2 = 0.001$, power = 0.05 and the control condition $F(1, 22) = 0.18$, $p = 0.9$, $MSE = 5.6$, $\eta_p^2 = 0.001$, power = 0.05. However, a significant linear trend was found for the perception condition $F(1, 22) = 4.36$, $p = 0.05$, $MSE = 1.66$, $\eta_p^2 = 0.17$, power = 0.51. The results for each condition can be seen in figure 5.

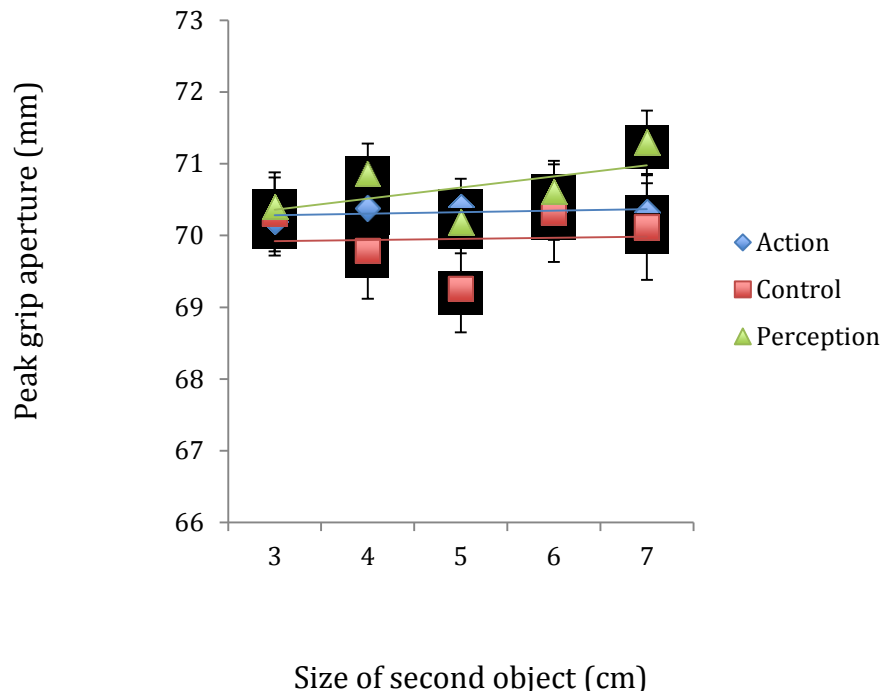


Figure 5. Mean peak grip aperture for each condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

Since half of participants did a manual estimation perception task and the other half did a verbal estimation task we analyzed them separately to determine if the nature of the judgment mattered (Franz, 2003). No significant main effect of size was found for the manual estimation condition, $F(4, 44) = 0.19, p = 0.94, MSE = 1.01, \eta_p^2 = 0.02$, power = 0.09, and there was additionally no significant linear trend of size, $F(1, 11) = 0.1, p = 0.76, MSE = 1, \eta_p^2 = 0.01$, power = 0.06. However, there was a main effect of size for the verbal estimation condition, $F(4, 40) = 2.86, p = 0.04, MSE = 2.24, \eta_p^2 = 0.22$, power = 0.72, and a significant linear trend of size, $F(1, 10) = 6.35, p = 0.03, MSE = 2, \eta_p^2 = 0.39$, power = 0.62. The results of each perception condition can be seen in figure 6.

4.2 Movement time

A 3 (perception condition; action condition; control condition) x 5 (size of second object) repeated measures ANOVA was performed on the mean movement time for grasping the first object. The results revealed no interaction between the type of condition and the size of the second object, $F(8, 176) = 1.23, p = 0.29, MSE = 0.001, \eta_p^2 = 0.05$, power = 0.56. Also, no significant difference was found between each condition, $F(2, 44) = 1.81, p = 0.18, MSE = 0.001, \eta_p^2 = 0.08$, power = 0.36 and between the sizes of the second object, $F(4, 88) = 1.04, p = 0.39, MSE = 0.001, \eta_p^2 = 0.05$, power = 0.32.

The data were separated into the three types of conditions in order to perform simple effects analyses. No main effect of size was found for the action condition, $F(3.19, 70.22) = 0.23, p = 0.89, MSE = 0.001, \eta_p^2 = 0.1$, power = 0.1, and for the control condition, $F(4, 88) = 0.6, p = 0.66, MSE = 0.002, \eta_p^2 = 0.03$, power = 0.19. However, a

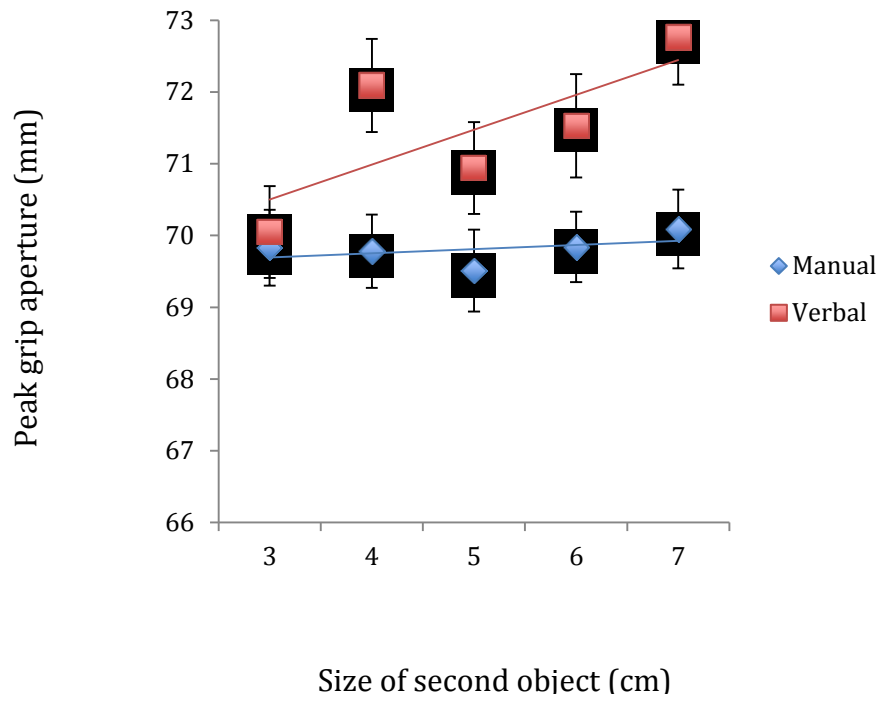


Figure 6. Mean peak grip aperture for each type of perception condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

significant main effect of size was found for the perception condition, $F(4, 88) = 3.76$, $p = 0.01$, $MSE = 0.001$, $\eta_p^2 = 0.15$, power = 0.87. In addition, the linear trend of size was significant for the perception condition, $F(1, 22) = 10.65$, $p = 0.004$, $MSE = 0.01$, $\eta_p^2 = 0.33$, power = 0.88, whereas it was not significant for the action condition, $F(1, 22) = 0.05$, $p = 0.83$, $MSE = 0.001$, $\eta_p^2 = 0.002$, power = 0.06 and the control condition, $F(1, 22) = 0.44$, $p = 0.52$, $MSE = 0.001$, $\eta_p^2 = 0.02$, power = 0.1. The results for each condition are displayed in figure 7.

After splitting the perception conditions a significant main effect of size was shown for the manual estimation condition, $F(4, 44) = 4.01$, $p = 0.01$, $MSE = 0.001$, $\eta_p^2 = 0.27$, power = 0.88, but no significant linear trend of size, $F(1, 11) = 3.11$, $p = 0.11$, $MSE = 0.001$, $\eta_p^2 = 0.22$, power = 0.36 was found. However, no main effect of size was shown for the verbal estimation condition, $F(2.12, 21.17) = 2.12$, $p = 0.14$, $MSE = 0.001$, $\eta_p^2 = 0.18$, power = 0.58, but a significant linear trend of size was found, $F(1, 10) = 7.97$, $p = 0.02$, $MSE = 0.01$, $\eta_p^2 = 0.44$, power = 0.72. The results of each perception condition are seen in figure 8.

4.3 Reaction Time

A 3 (perception condition; action condition; control condition) x 5 (size of second object) repeated measures ANOVA was performed on the mean reaction time for grasping the first object. No significant interaction between type of condition and size of second object was found, $F(8, 176) = 1.2$, $p = 0.33$, $MSE = 7116.73$, $\eta_p^2 = 0.05$, power = 0.52. However, when solely comparing the types of condition a significant effect was

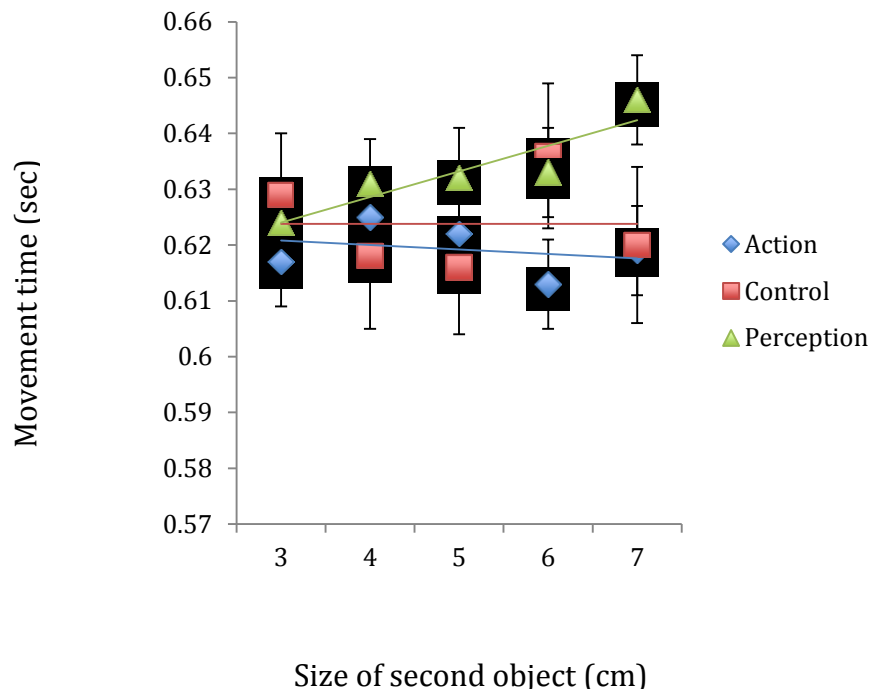


Figure 7. Mean movement time for each condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

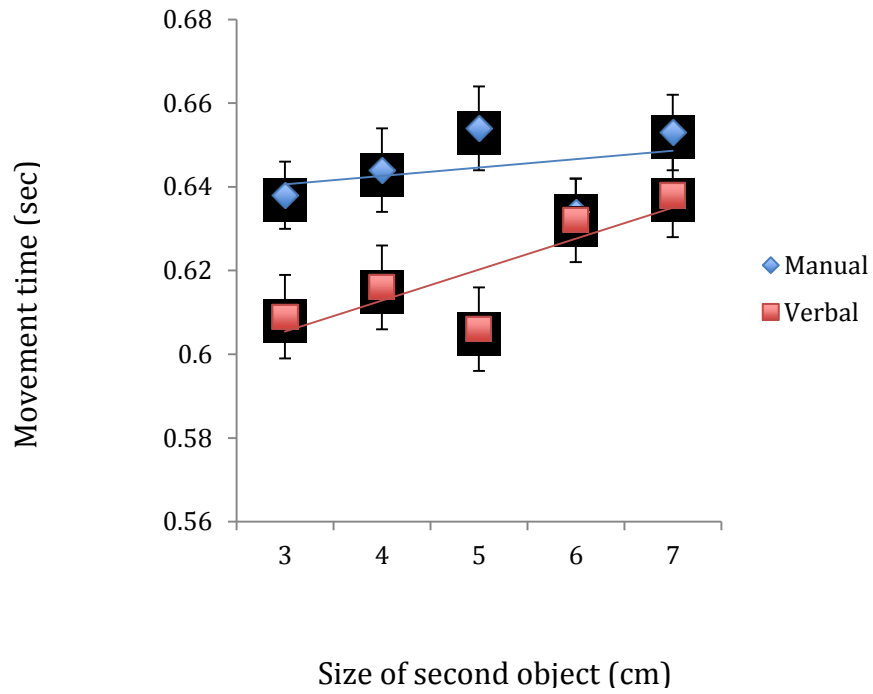


Figure 8. Mean movement time for each type of perception condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

found, $F(2, 44) = 11.83, p < 0.001, MSE = 5688.92, \eta_p^2 = 0.35, \text{power} = 0.99$.

Specifically, overall participants were faster at reacting to the first object in the action condition ($M = 424.17$ msec, $SD = 179.45$) relative to the control condition ($M = 451.12$ msec, $SD = 265.65$) and the perception condition ($M = 471.54$ msec, $SD = 260.18$).

Nevertheless, the results revealed no main effect of size, $F(4, 88) = 1.08, p = 0.37, MSE = 6644.31, \eta_p^2 = 0.05, \text{power} = 0.33$.

In addition, when separating the data into the three types of conditions, no main effect of size was shown for the action condition, $F(1.92, 42.29) = 0.74, p = 0.48, MSE = 6249.18, \eta_p^2 = 0.03, \text{power} = 0.17$, the control condition, $F(2.08, 45.85) = 0.99, p = 0.38, MSE = 25583.27, \eta_p^2 = 0.04, \text{power} = 0.21$, and the perception condition, $F(1.91, 41.9) = 1.78, p = 0.18, MSE = 9542.99, \eta_p^2 = 0.08, \text{power} = 0.34$. In addition, there was no significant linear trend of size for the action condition, $F(1, 22) = 0.001, p = 0.99, MSE = 2357.06, \eta_p^2 = 0.001, \text{power} = 0.05$, control condition, $F(1, 22) = 1.43, p = 0.25, MSE = 7390.64, \eta_p^2 = 0.06, \text{power} = 0.21$ and the perception condition, $F(1, 22) = 1.13, p = 0.3, MSE = 794.15, \eta_p^2 = 0.05, \text{power} = 0.17$. The results for each condition are displayed in figure 9.

Furthermore, no significant main effect of size was shown for each type of perception condition; the manual estimation condition, $F(1.46, 16.06) = 2.28, p = 0.14, MSE = 16332.73, \eta_p^2 = 0.17, \text{power} = 0.35$, and the verbal estimation condition, $F(2.72, 27.16) = 0.74, p = 0.52, MSE = 3959.28, \eta_p^2 = 0.07, \text{power} = 0.18$. Additionally, no significant linear trend of size was found for the manual estimation condition,

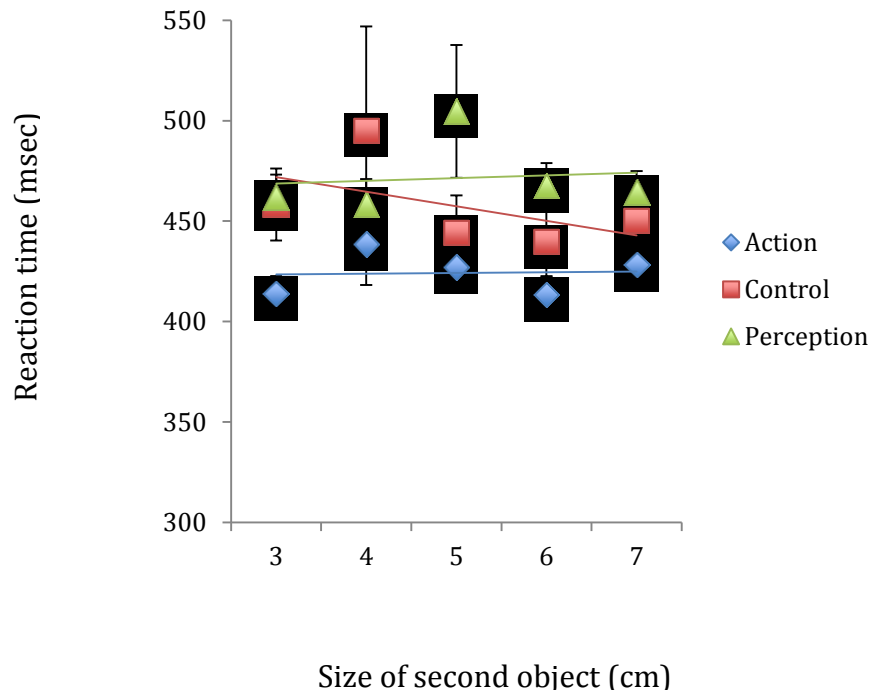


Figure 9. Mean reaction time for each condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

$F(1,11) = 0.001, p = 0.98, MSE = 998.93, \eta_p^2 = 0.001, \text{power} = 0.05$ and the verbal estimation condition, $F(1,10) = 3.6, p = 0.09, MSE = 542.47, \eta_p^2 = 0.27, \text{power} = 0.4$.

Results for each type of perception condition can be seen in figure 10.

4.4 Time to peak grip aperture

A 3 (perception condition; action condition; control condition) x 5 (size of second object) repeated measures ANOVA was performed on the mean time to peak grip aperture for grasping the first object. No interaction was found between type of condition and size of second object, $F(8, 176) = 1.07, p = 0.39, MSE = 0.001, \eta_p^2 = 0.05, \text{power} = 0.49$. Also, no significant difference was found between each condition, $F(2, 44) = 0.68, p = 0.51, MSE = 0.001, \eta_p^2 = 0.03, \text{power} = 0.16$ and between the size of the second object, $F(4, 88) = 0.69, p = 0.6, MSE = 0.001, \eta_p^2 = 0.03, \text{power} = 0.21$.

The analysis also revealed, when separating the data into the three types of conditions, no significant main effect of size for the action condition, $F(4, 88) = 0.05, p = 0.99, MSE = 0.001, \eta_p^2 = 0.002, \text{power} = 0.06$, the control condition, $F(3.23, 71.001) = 1.41, p = 0.25, MSE = 0.002, \eta_p^2 = 0.06, \text{power} = 0.37$ and the perception condition $F(4, 88) = 1, p = 0.41, MSE = 0.001, \eta_p^2 = 0.04, \text{power} = 0.3$. The analysis also revealed, no significant linear trend of size for the action condition, $F(1,22) = 0.08, p = 0.79, MSE = 0.001, \eta_p^2 = 0.003, \text{power} = 0.06$, control condition, $F(1,22) = 1.18, p = 0.29, MSE = 0.001, \eta_p^2 = 0.05, \text{power} = 0.18$ and perception condition, $F(1,22) = 1.39, p = 0.25, MSE = 0.0001, \eta_p^2 = 0.06, \text{power} = 0.2$. The results for each condition are displayed in figure 11.

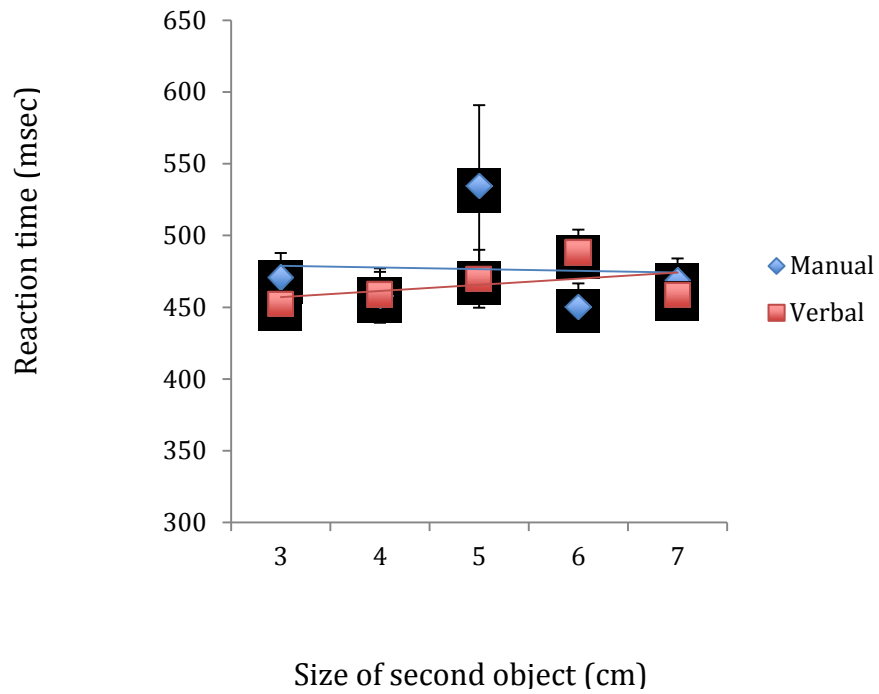


Figure 10. Mean reaction time for each type of perception condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

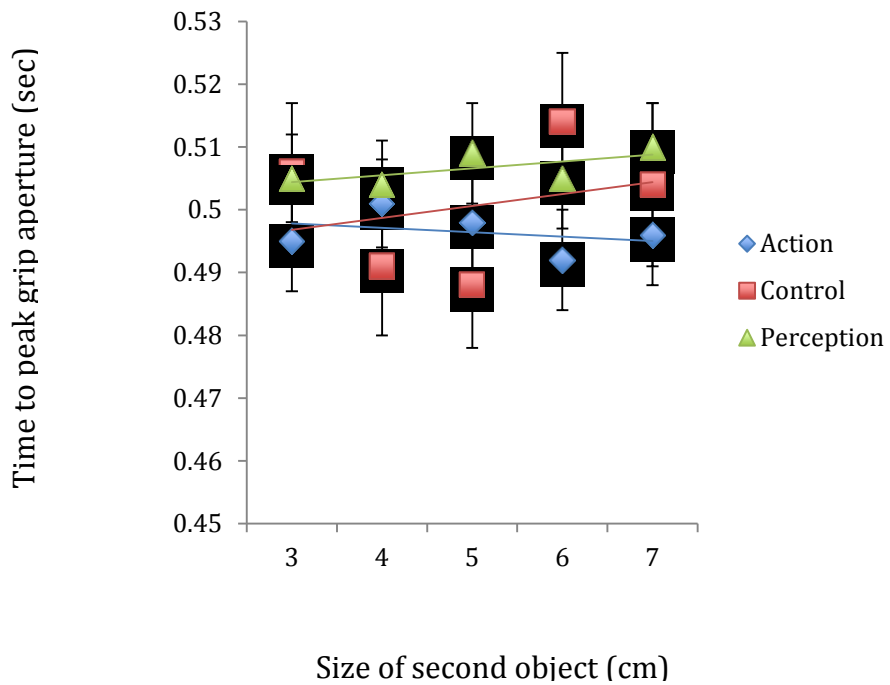


Figure 11. Mean amount of time to reach peak grip aperture for each condition, when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

Furthermore, when analyzing each perception condition separately, no significant main effect of size was shown for the manual estimation condition, $F(4, 44) = 2.14, p = 0.09, MSE = 0.001, \eta_p^2 = 0.16, \text{power} = 0.59$, and the verbal estimation condition, $F(1.93, 19.32) = 0.19, p = 0.94, MSE = 0.001, \eta_p^2 = 0.02, \text{power} = 0.09$. In addition, no significant linear trend of size was found for the manual estimation condition, $F(1, 11) = 0.39, p = 0.55, MSE = 0.0001, \eta_p^2 = 0.03, \text{power} = 0.09$ and the verbal estimation condition, $F(1, 10) = 0.99, p = 0.34, MSE = 0.0001, \eta_p^2 = 0.09, \text{power} = 0.15$. The results for each type of perception condition can be seen in figure 12.

4.5 Peak hand speed

A 3 (perception condition; action condition; control condition) x 5 (size of second object) repeated measures ANOVA was performed on the mean peak hand speed for grasping the first object. No interaction was shown between the type of condition and size of second object, $F(8, 176) = 1.2, p = 0.3, MSE = 727.44, \eta_p^2 = 0.05, \text{power} = 0.54$. No significant difference was found when comparing between each condition, $F(2, 44) = 2.03, p = 0.14, MSE = 895.49, \eta_p^2 = 0.09, \text{power} = 0.34$ and between the size of the second object, $F(4, 88) = 0.53, p = 0.72, MSE = 589.24, \eta_p^2 = 0.02, \text{power} = 0.17$.

In addition, when separating the data into the three types of conditions, no significant main effect of size was found for the action condition, $F(3.1, 68.29) = 0.42, p = 0.8, MSE = 519.34, \eta_p^2 = 0.02, \text{power} = 0.13$, the control condition, $F(4, 88) = 0.86, p = 0.49, MSE = 1305.6, \eta_p^2 = 0.04, \text{power} = 0.26$, and the perception condition, $F(4, 88) =$

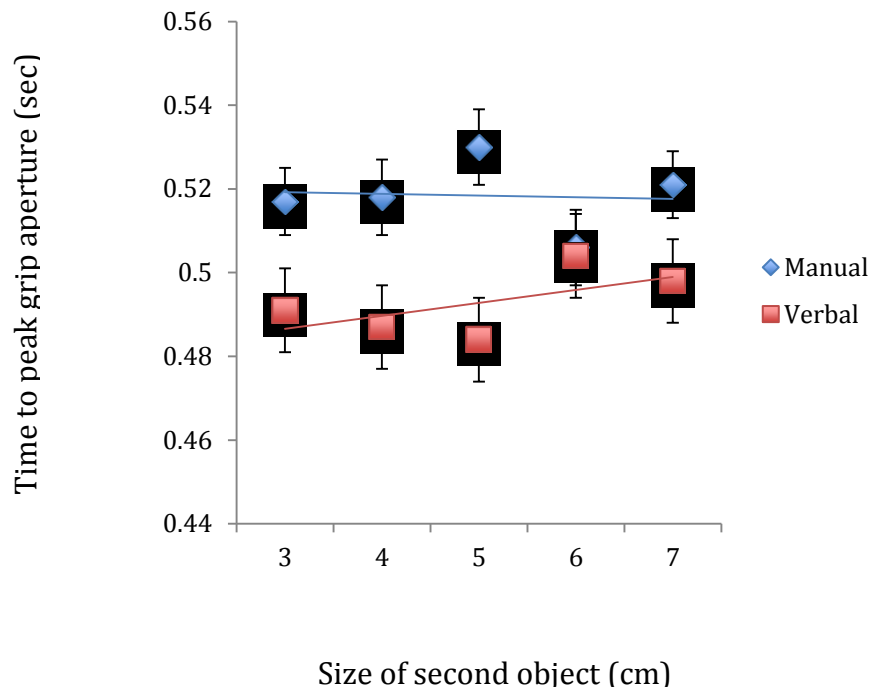


Figure 12. Mean amount of time to reach peak grip aperture for each type of perception condition, when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

2.28, $p = 0.07$, $MSE = 335.5$, $\eta_p^2 = 0.09$, power = 0.64. The results also showed no significant linear trend of size or the action condition, $F(1,22) = 1.18$, $p = 0.29$, $MSE = 358.9$, $\eta_p^2 = 0.05$, power = 0.18, control condition, $F(1,22) = 0.04$, $p = 0.85$, $MSE = 1164.9$, $\eta_p^2 = 0.002$, power = 0.05 and the perception condition, $F(1,22) = 2.2$, $p = 0.15$, $MSE = 300.8$, $\eta_p^2 = 0.09$, power = 0.29. The results for each condition are displayed in figure 13.

Furthermore, the analysis also revealed no significant main effect size when separately analyzing each perception condition; manual estimation condition, $F(4, 44) = 1.32$, $p = 0.28$, $MSE = 270.84$, $\eta_p^2 = 0.11$, power = 0.38 and the verbal estimation condition, $F(4, 40) = 1.84$, $p = 0.14$, $MSE = 406.27$, $\eta_p^2 = 0.16$, power = 0.51. Also, no significant linear trend of size was shown in the manual estimation condition, $F(1,11) = 4.29$, $p = 0.06$, $MSE = 206.98$, $\eta_p^2 = 0.28$, power = 0.47 and the verbal estimation condition, $F(1,10) = 0.09$, $p = 0.77$, $MSE = 407.67$, $\eta_p^2 = 0.009$, power = 0.06. The results for each type of perception condition can be see in figure 14.

4.6 Time to peak hand speed

A 3 (perception condition; action condition; control condition) x 5 (size of second object) repeated measures ANOVA was performed on the mean time to peak hand speed for grasping the first object. The results showed no interaction between the type of condition and the size of the second object, $F(8, 176) = 0.48$, $p = 0.87$, $MSE = 0.0001$, $\eta_p^2 = 0.02$, power = 0.22. It was also shown that there was no significant difference between each condition, $F(2,44) = 0.28$, $p = 0.76$, $MSE = 0.001$, $\eta_p^2 = 0.01$, power = 0.09

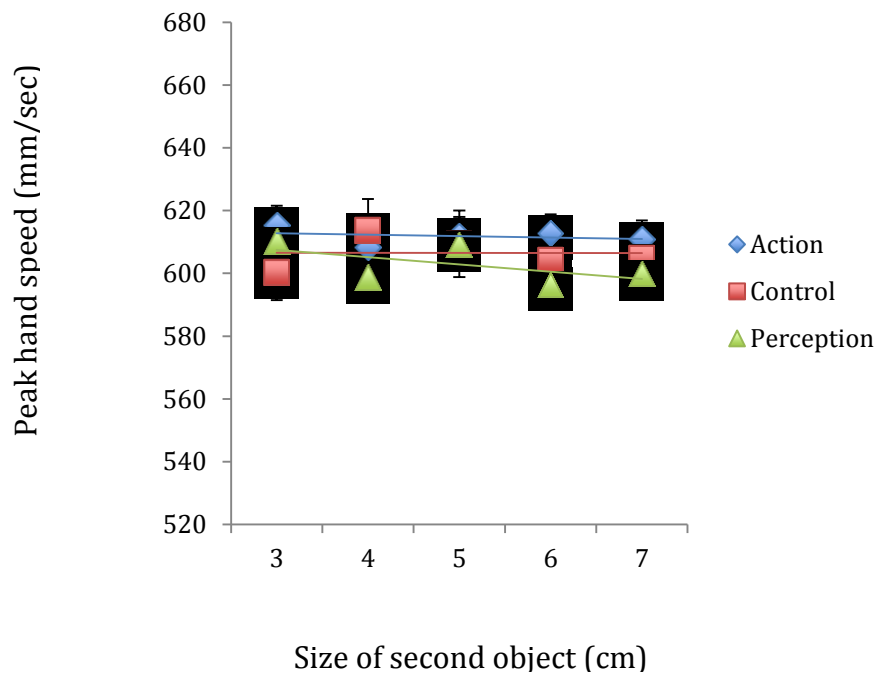


Figure 13. Mean peak hand speed for each condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

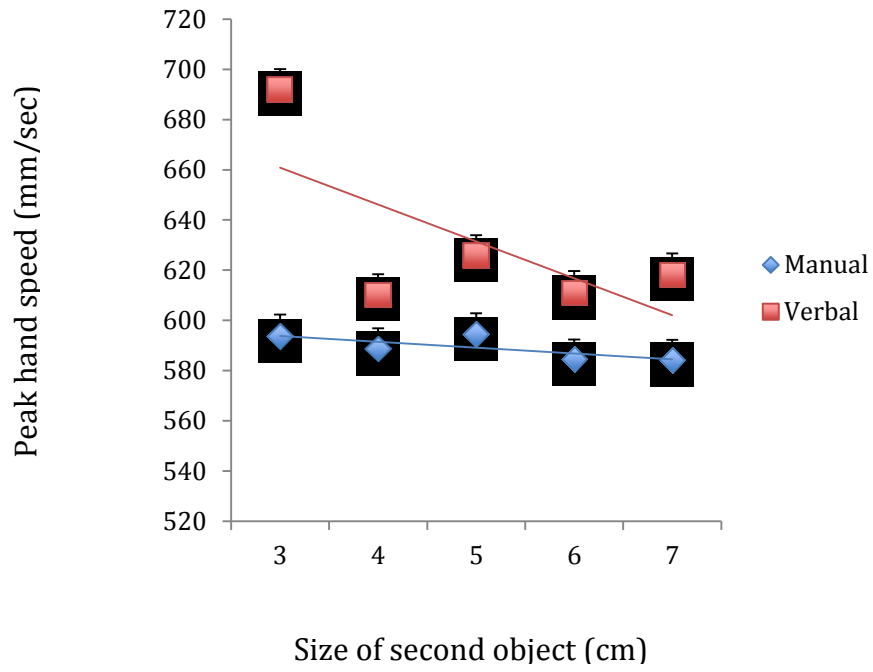


Figure 14. Mean peak hand speed for each type of perception condition when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition

and between the size of the second object, $F(4, 88) = 0.85, p = 0.5, MSE = 0.0001, \eta_p^2 = 0.04, \text{power} = 0.26$.

There was also no main effect of size for the action condition, $F(2.75, 60.42) = 0.19, p = 0.89, MSE = 0.001, \eta_p^2 = 0.01, \text{power} = 0.08$, the control condition, $F(4, 88) = 0.64, p = 0.64, MSE = 0.001, \eta_p^2 = 0.03, \text{power} = 0.2$ and the perception condition, $F(2.48, 54.46) = 1.04, p = 0.37, MSE = 0.0001, \eta_p^2 = 0.05, \text{power} = 0.24$. No significant linear trend of size effect was found for the action condition, $F(1, 22) = 0.15, p = 0.71, MSE = 0.001, \eta_p^2 = 0.01, \text{power} = 0.07$ and the control condition, $F(1, 22) = 1.65, p = 0.21, MSE = 0.0001, \eta_p^2 = 0.07, \text{power} = 0.23$. However, an almost significant linear trend of size was found for the perception condition, $F(1, 22) = 4.01, p = 0.06, MSE = 0.001, \eta_p^2 = 0.15, \text{power} = 0.48$. The results of each condition can be seen in figure 15.

A separate analysis was performed on each type of perception condition. A main effect of size was shown for the manual estimation condition, $F(4, 44) = 2.71, p = 0.04, MSE = 0.0001, \eta_p^2 = 0.2, \text{power} = 0.7$. But, no significant linear trend of size effect was found, $F(1, 11) = 2.34, p = 0.27, MSE = 0.0001, \eta_p^2 = 0.11, \text{power} = 0.19$. However, no main effect of size was shown for the verbal estimation condition, $F(4, 40) = 0.34, p = 0.85, MSE = 0.001, \eta_p^2 = 0.03, \text{power} = 0.12$ and no significant linear trend of size, $F(1, 10) = 2.61, p = 0.14, MSE = 0.0001, \eta_p^2 = 0.21, \text{power} = 0.31$. The results for each perception condition are displayed in figure 16.

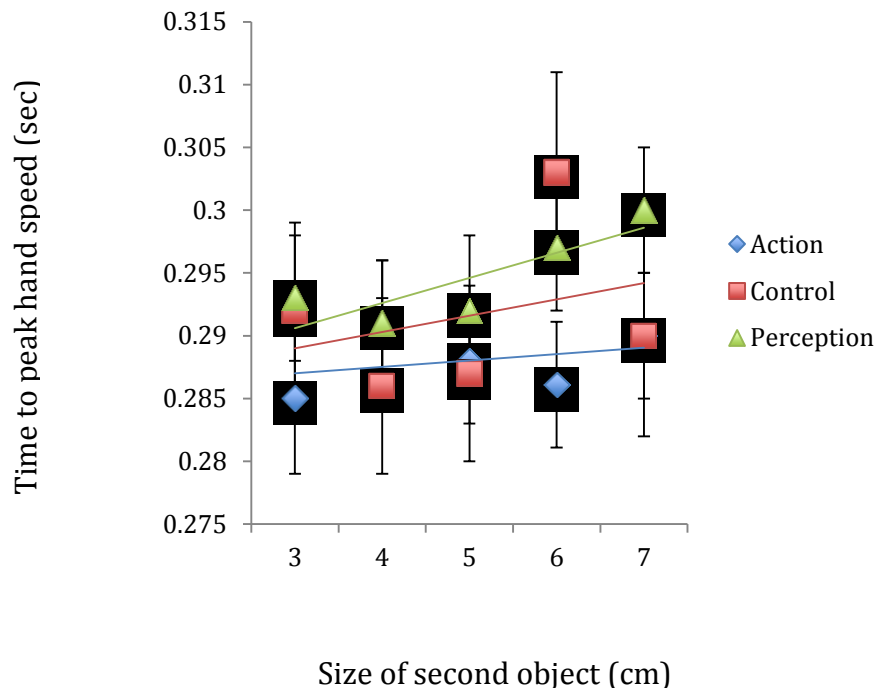


Figure 15. Mean amount of time to reach peak hand speed for each condition, when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

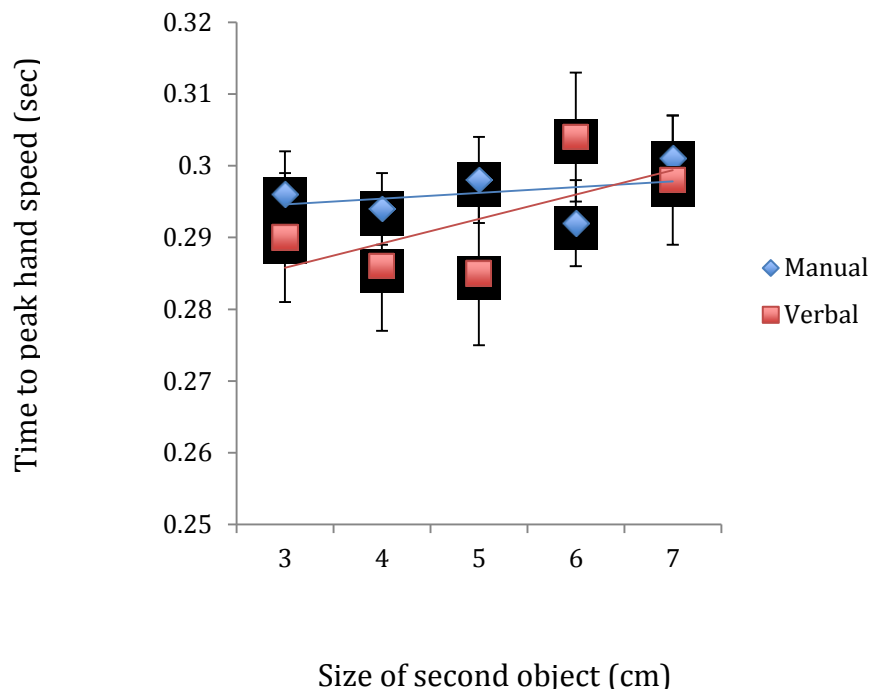


Figure 16. Mean amount of time to reach peak hand speed for each type of perception condition, when performing a grasping action to the first object in relation to the size of the second object. The lines display the linear trend of each condition.

CHAPTER 5 DISCUSSION

It has been demonstrated that performing a subsidiary task, counting the light flicks on an object, can affect the grasp component of a goal-directed movement (Castiello, 1996). Specifically, it has been shown that the grasping kinematics towards a centrally placed fruit can be interfered by another lateral fruit when the participants are required to actively pay attention to the lateral fruit (e.g., participants grasped a cherry with a larger peak grip aperture when the lateral fruit was an apple compared to when it was a mandarin). The author of this study believed that interference occurred due to an interface between identifying the lateral fruit (when counting the light flicks) and processing its associated motor patterns. Based on this logic it is believed that when participants are actively paying attention to the lateral fruit they have to attend to the fruits perceptual properties which in return activates its associated motor programs. Thus, when reaching towards the central fruit the motor program of the lateral fruit leaks into the programming of the action towards the central fruit.

Although Castiello (1996) believed that the interference arising from the distracting fruit arose from involuntary processing of motor associations, suggesting that a dorsal stream task (grasping a target stimulus) was interfered with by another dorsal stream task (implicitly preparing a grasping movement to a non-target stimulus), it was actually never tested. It could be that participants were merely drawn to implicitly perceive the visual properties of the distracting stimulus, and this was sufficient to interfere with the preparation of grasping. Therefore, making it possible that Castiello's result arises from a dorsal stream task being interfered with by a ventral stream task (implicitly perceiving a non-target stimulus without necessarily preparing an action).

However, due to the design of his study, it remains unclear what is driving the interference to happen.

The purpose of this thesis was to determine whether the interference seen in a grasping movement indeed arises from the obligatory processing of motor associations for an attended object that is not the current target of an action. Specifically, participants were required to always first grasp a 5cm x 5cm object and place it on its associated target area. Once the first action was completed participants immediately performed the next task. Critically, the nature of the task was known before viewing the two objects and before the initial grasping movement was executed. As such, the possibility was created for interference to occur in the first action based on processing related to the second, yet-to-be-completed task.

For the second task participants were required to either perform an action, perception or control task. The action task consisted of participants grasping the second object and placing it on its associated target area. For the perception condition participants made a perceptual judgment regarding the length of the second object. For half of the participants they performed a manual perceptual estimation (judging the length of the object with their index finger and thumb, without making physical contact to the object) and the other half did a verbal perceptual estimation (verbally guess the length of the object in cm). Finally, the control condition consisted of participants to simply ignore the second object, hence only performing the initial action task. The type of condition was randomized on a trial-by-trial basis. In addition, the second object could be one of five objects. Two of the possible objects were shorter in length than the first one (3 cm & 4 cm), two other were greater in length (6 cm & 7 cm) and one was the same size as the first object (5cm). The second object was also randomized on a trial-by-trial basis.

5.1 Summary of results

It was predicted that participants' peak grip aperture to the first object would increase as the size of the second object increased in both the perception and action condition. However, since participants did not have to actively pay attention to the second object within the control condition no change in participants' peak grip aperture was expected in response to the size of the second object. As predicted there was no significant change in peak grip aperture to the first object, in regards to the size of the second object, when performing the control condition. Unlike predicted, when performing the action condition, there was also no significant change in peak grip aperture to the first object in relation to the size of the second object. When analyzing the perception condition as a whole (the two types of perception condition combined), unlike predicted, no significant change in peak grip aperture to the first object was shown in response to the size of the second object. However, in contrast to the action and the control condition, a significant linear trend of size was found for the perception condition. Specifically, the trend was positively scaled based on the size of the second object. Thus, the perception condition practically displayed the behavior we predicted in which participants' peak grip aperture towards the first object scaled positively with the size of the second object; that is, peak grip aperture when grasping the first object was larger when the second object was larger, as compared to when the second object was smaller.

A separate analysis was also performed on each type of perception condition. Since, both the manual perceptual estimation and the verbal perceptual estimation rely on ventral stream processing, it was expected to not find any difference between each subtype of perception condition. However, unlike predicted, no main effect of size and no significant linear trend of size was shown for the manual estimation condition; whereas, a

significant main effect of size and a significant linear trend of size was shown for the verbal estimation condition. Therefore, a change in participants' peak grip aperture to the first object in relation to the size of the second object was shown when performing the verbal estimation but not the manual estimation. Specifically, participants' peak grip aperture to the first object became larger when the size of the second object was larger compared to when the second object was smaller, albeit only for the verbal estimation condition not for the manual condition.

Thus, as the size of the second object increases the peak grip aperture towards the first object also increases when performing the verbal perception condition. In contrast, the size of the second object did not increase peak grip aperture to the first object when performing the control, action and manual perception condition. Based on these results, it seems as though preparing an action to the next object does not produce interference, but attending to its size for verbal judgment does.

It was also predicted that participants reaction time to the first object would be faster when performing the control condition compared to the other two conditions. Based on the sequential task literature (Henry & Roger, 1960; Hesse & Deubel, 2010), participants should be faster at reacting to the control condition since only one task is to be performed. In contrast, when performing the action and perception condition, participants must perform two tasks back to back; in which they must implement what to do with the second object prior to grasping the first object. The results revealed that there was significant difference in reaction times to the first object when comparing each condition. However, unlike expected, it was shown that participants were overall faster at performing the action condition relative to the control and the perception condition. The results also showed no differences between each subtype of perception conditions.

In the Castiello (1996) study, it was found that participants' movement time, time to reach peak grip aperture and movement speed were slower when they had to actively pay attention the distractor fruit before their movement onset in comparison to when they only had to actively pay attention after the initiation of the movement. Therefore, it was predicted that participants' movement time, time to peak grip aperture, peak hand speed and time to reach peak hand speed to the first object would be slower for the perception and action condition relative to the control condition. The results revealed, unlike predicted, that overall there was no difference in movement time, time to peak grip aperture, peak hand speed and time to reach peak hand speed to the first object when comparing each condition.

However, the results did show a main effect of size and significant linear trend of size for movement time in the perception condition. This surprise finding demonstrates that participants' movement time increased as the size of the second object increased when performing the perception condition, but not when performing the other conditions. Moreover, when splitting the subtype of perception conditions, a significant main effect of size was found for the manual estimation condition. However, no significant linear trend of size was found, whereas a significant linear trend of size was found for the verbal estimation condition (despite not having an overall main effect of size). Thus, similar to the peak grip aperture analysis, a different pattern of results was revealed when comparing both types of perception conditions for the dependent measure of movement time.

As for peak hand speed, no significant main effect of size or linear trend of size was shown for each condition. Furthermore, when splitting the perception conditions there was also no significant main effect of size and no significant linear trend of size.

However, a significant main effect of size of was shown for the manual estimation condition when measuring time to reach peak hand speed. Moreover, there was no significant linear trend of size and there was no significant main effect of size and linear trend of size when analyzing each type of perception condition separately. In addition, there was also no significant main effect of size and linear trend of size for both the action and control condition.

In regards to time to reach peak grip aperture, no significant difference was found between each condition and no significant main effect of size or significant linear trend of size was found. Additionally, when separately analyzing each perception condition no significant main effect of size or significant linear trend of size was found.

5.2 Main findings and limitations

Overall it was found that, when performing a verbal estimation as the second task, participants reached out for the first object with a larger peak grip aperture and a longer movement time when the size of the second object was larger compared to when the second object was smaller. However, no such results were found when performing the action or the control condition. This potentially demonstrates that a ventral stream task (verbal estimation) to be performed later can interfere with a current dorsal stream task (the first action), whereas a dorsal stream task to be performed later does not interfere with a current dorsal stream task (the action condition). Therefore, the results of the present study suggest that the results of the Castiello (1996) study were not due to the implicit processing of the motor associations of the distractor fruit, but purely due to an interference of a perceptual nature.

However, because each stream has distinct functional properties (Westwood & Goodale, 2011) but a shared attentional mechanism (Hesse, Schenk & Deubel, 2012) it

would make sense to see a difference in the type of interference when comparing the perception condition to the action condition. Specifically, it could be that because perception uses a holistic processing of object shape whereas the visual control of action uses an analytical type of processing (Ganel & Goodale, 2003), a difference arises when comparing the interference effect between perception and action. However, because we found a null effect for the action condition (similar to the control condition) the conclusions about these results should be taken lightly. Moreover, the null effect could potentially demonstrate that a dorsal stream task cannot interfere with another dorsal stream task; or that participants actually never actively paid attention to the second object before doing the first action.

Furthermore, the fact that participants' reaction times were faster in the action condition, relative to the other conditions, shows strong evidence that the second object might not have been actively processed prior to initiating the first movement. Moreover, when performing the action condition participants could have processed the trial as two separate tasks since the second object was visible both during and after the first grasping action. Specifically, participants could have simply planned the second action after completing the first action. As a result, no interference might have been produced.

Although performing a verbal estimation as the second task interfered with participants' movement time and peak grip aperture to the first object, this was not found when performing the manual estimation as the second task. Three possible conclusions can be drawn to why the manual estimation condition was not affected in the same way as the verbal estimation condition: 1) the manual estimation task was treated as an action task; hence a dorsal stream task cannot interfere with another dorsal stream task. 2) The manual estimation task was treated as a perception task, but not in the same nature as the

verbal perception task. 3) The manual estimation task was treated as a perception task, but participants did not pay attention to the second object prior to initiating the first movement.

The first conclusion can most likely be rejected since many studies have shown that the manual estimation task does not produce the same behavioral results than when actually performing the action (Hu & Goodale, 2000; Haffenden, Schiff & Goodale, 2001; Ganel & Goodale, 2003). Also, the fact that the results of this study showed that participants' hand speed was affected by the size of the second object in the perception conditions but not in the action condition is a great indication that the perception tasks and the action task were not processed the same way.

However, this is not the first study to find a difference between a manual estimation task and a more pure perceptual task (such as the verbal judgment). Franz (2003) showed that when people are using manual estimations they are more susceptible to the effect of a perceptual illusion (Ebbinghaus–Titchener illusion) than when participants used a method of adjustment, which can be considered equal to a verbal perceptual judgment since the thumb and index finger are not used to do the judgment. Therefore, the second conclusion could possibly be true based on these results and Franz (2003) results. Specifically, the fact that the manual estimation condition and verbal estimation condition did not produce the same results, for peak grip aperture and movement time, could indeed support the view that these are two totally different measures of perception.

However, one main difference between the results of this study and Franz (2003) study is the fact that we actually found the opposite effect than what he found. In our results, it was the verbal estimation that showed to be more vulnerable to an interference

effect, not the manual estimation. Therefore, this makes the second conclusion less appealing to explaining the results. However, because the manual estimation showed null effects, like the action condition, it makes it possible that during the manual estimation condition participants were not processing the second object prior to making the first movement. It could be possible that somehow the design of this experiment makes it more beneficial for the participants to process each object separately when using the thumb and index finger sequentially, therefore causing null effects in the action and manual estimation condition. Or it could be that since the participants did not have the pressure of directly telling their judgment orally, as in the verbal perception condition, they might have never engaged in the active processing of the second object. Specifically, they could have consistently used the same judgment for each object. As a result, this would cause major limitation to what this study was trying to measure. However, it is important to mention that when comparing participants' verbal judgment to the second object, a pairwise comparison revealed that participants' were significantly able to judge the difference between each object size ($p < 0.001$). Therefore, an analysis should be done to see if the manual judgments' show the same pattern of results.

Another limitation to consider is the fact that the first object was always the same one throughout the study. Therefore, it could be that participants were not actively paying attention to their first action since it was always the same one. If this is the case, it is questionable whether we were actually measuring a dorsal stream task. It could be that participants just simply relayed on memory, hence making the first action task actually a combined dorsal/ventral task; as seen in the memory guided action literature (Cohen et al. 2009; Monaco, Kaufman & Culham, 2011). Therefore, we cannot say for certain that, based on the results of the verbal estimation condition, a future ventral stream task

interferes with a current dorsal stream task. In reality, it could potentially be more like a ventral stream task interfering with another ventral stream task.

5.3 Future directions

From this study, we can conclude that performing a verbal estimation on the second object interferes with the kinematics of how you approach to grasp the first object. But, it remains unclear, due to limitations, whether the first object is actively processed (dorsal stream) or guided by memory (collaboration between each stream). Furthermore, although we found no interference on the first object when performing an action or a manual estimation on the second object, we cannot actually conclude that this is the case due to the possible limitations.

One possible way to circumvent these limitations would be to use a similar study design but with two possible lengths for the first object and including a memory-guided condition. By adding the possibility between two objects for the first target object it will require participants to actively pay attention to its size. Since, it will not always be the same object this will ensure that the participants are actually engaging in a pure dorsal stream task. The addition of a memory-guided condition would be implied for both the action condition and manual estimation condition. Specifically, after the completion of the first action participants' LCD goggles would become opaque. This will force them to pay attention to what the second object is prior to initiating the first movement. However, the addition of a memory-guided action condition could potentially make the participants recruit their ventral stream on task we wanted to measure their dorsal stream

Therefore, perhaps a more simple way to approach the limitations of this study would be to incorporate an eye-tracker to the experiment. By using the same procedure we could see whether participants' eye-movements are actually attending to the objects.

More specifically, we could see when the participants are starting to look at the second object and take the result into consideration when looking at the interference effects. It could be the case that in the manual estimation and action condition participants are only looking at the second object after the completion of the first movement. In contrast, within the verbal estimation condition participants are looking at the second object prior to doing the first movement. Therefore, by adding the eye-tracker we could potentially show that the difference found in the amount of interference produce on the first action could be due to where the participants are looking. However, it could also show that participants' eye movements are the same in each condition. In this case, the interference would not be due to where they are looking but more likely due to what they are actively paying attention to.

A possible way of avoiding the attention limitation, of whether participants are attaining to the second object prior to movement onset, would be to use a bimanual grasping task. Instead of grasping the objects sequentially, each object could be picked up at the same time (the second object would be grasped with the left hand). This type of task would force the participants to pay attention to the second object prior to picking up the first one. Furthermore, another way to approach this problem would be to use different starting tones. The tones would be learned to represent a sequence (e.g., high pitch = pick up the first object than the second object; whereas low pitch= pick up the second object than pick up the first one). Once again, with different starting tones, it would force the participants to pay attention to the second object prior to initiating the first movement.

However, the possibility remains that we would still find the same pattern of results, despite solving the limitations. If this is the case it is essential to further

investigate what are the mechanisms causing a ventral stream process to interfere with the operation of a dorsal stream process.

5.4 The nature of the interference

There are at least three potential hypotheses relating to how a task requiring a ventral stream process can cause interference during a task requiring a dorsal stream process. One prediction would be that the second ventral stream task takes over the programming of the first task. Thus, meaning that the second object is kept within the memory of the ventral stream and it takes over the computations of the first dorsal stream task. If this were the case, an experiment using TMS could demonstrate this by applying the TMS current onto area LOC of the ventral stream prior to initiating the first movement. If the interference persists then we can conclude that the interference is not due to information stored within the ventral stream. But if the interference disappears it would be with great certainty that the interference is due to information stored within the ventral stream.

Another possible explanation could be that the information processed by the ventral stream is immediately projected to the dorsal stream. Thus, the information about the second object is leaked into the motor programming of the first action. If the TMS study mentioned above would indeed still show an interference effect, this hypothesis would be supported. Nevertheless, it would not rule out another possible explanation. Specifically, it could be that the actual physical appearance of the second object blends into the first object. Therefore, when the second object is bigger the participants actually perceive the first object as being bigger than it actually is, hence the larger movement time and peak grip aperture directed towards it. If this is shown to be true, we can rule out

any interplay between the dorsal and ventral stream in regards to the interference effect found within this sequential task.

5.5 Conclusion

As the size of the second object increases, the movement time and the amplitude of peak grip aperture towards the first object also increases when performing the verbal perception condition. However, no such interference was found when performing the action, control or the manual perception condition. Furthermore, participants were overall faster at reacting to the first action when performing the action condition compared to the perception and control condition. Despite these findings many limitations are considered and more experiments should be conducted to find out the true nature of how and when a second task interferes with a goal-directed grasping movement.

The overall significance of this research could potentially show how the presence of non-target objects plays a factor when preparing a grasping action towards a target object. Thus, although more experiments are needed to discover the true nature of the interference caused by non-target objects, the implications of this research could potentially lead to new approaches when rehabilitating patients with motor disorders. Specifically, if a patient has difficulty performing a grasping action it would be beneficial to include other non-target objects when performing his rehabilitation instead of using the traditional approach of just focusing on one single target object. Therefore, because of the potential clinical application of this research, it is important that the quest to find the true nature of how this interference occurs continues.

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APPENDIX A



Title of Study: Interference in sequential grasping: effects of action and perception

PARTICIPANT SCREENING FORM

If the answer to any of these questions is “YES”, you are not eligible to participate in this study. It is not necessary to disclose which of the questions or conditions applies to you.

- Please inform the investigator you are unable to participate.
- If you have any questions regarding the question or any of the conditions listed below, (please ask the investigator).
- 1. Have you ever been diagnosed with any form of visual disorder? Possible examples may include (but are not limited to):**
 - Amblyopia
 - Astigmatism
 - Glaucoma
 - Monocular deprivation for an extended period (e.g. eye patching)
 - Strabismus
 - Uncorrected** near- or far-sightedness

2. Have you ever been diagnosed with any form of neurological challenge or diagnosis which has affected your ability for coordinated eye movements, visual and cognitive processing skills, head and neck control in a seated position, or upper limb fine motor coordination? Possible examples may include (but are not limited to):

- Acquired Brain Injury as a result of: Trauma, Cerebral palsy, Encephalitis, (Hydrocephalus, Meningitis, Stroke, Tumour, etc.
- Developmental Coordinator Disorder
- Learning Disability
- Movement Challenges such as: athetosis, chorea, dystonia, spasticity, rigidity, etc.
- Peripheral neuropathy
- Seizure disorder
- Vestibular disorder
- Progressive conditions such as: Amyotrophic Lateral Sclerosis (ALS), Huntington's, (Multiple sclerosis, Parkinson's disease, etc.

3. Are you left-handed?

APPENDIX B



INFORMED CONSENT FORM

Study Title

Interference in sequential grasping: effects of action and perception

Principal Investigator

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Study Supervisor:

Dr. David Westwood Faculty School of Health and Human Performance and Department of Psychology Dalhousie University (902) 494-1164 Email: David.Westwood@dal.ca

Psychology Department Code Number TBA

1) To All Subjects

You are invited to take part in the research project described below. The Human Research Participants & Ethics Committee of the Department of Psychology has reviewed the project and found it to conform to current ethical guidelines. These guidelines require:

(1) That you be informed of the purpose of the research project and any attendant inconvenience, risk or benefits.

(2) That the character of the task required be explained to you.

- (3) That you be made aware that participation is voluntary and that you may decline to continue at any point during the course of the research project, without loss of expected compensation.
- (4) That you be assured that all information assembled is entirely confidential.

• 2) Purpose of the Study

- The purpose of this study is to learn more about how healthy individuals use visual information to interact with objects in their surroundings. Specifically, how the nature of a second task affects the performance of a first task. A more detailed explanation of the study purpose will be given upon completion of experimental trials.

3) Study Design

- You will wear emitting diodes (IREDs) fixed to the tips of your finger and thumb, and wrist of your right hand. We will measure your peak grip aperture (the opening of the hand during grasping) while performing the grasping actions towards rectangular objects. You will also be wearing LCD glasses, in order to occlude your vision (darkened the lenses) at the beginning of each trial. The experiment will consist of a total of 120 trials.

4) Who can participate in the study

You are eligible to participate in this study if you are over the

age of 18, have no history of neurological illness and have normal or corrected-to-normal vision You will be asked to complete a participant screening form before agreeing to participate in this study, to make sure that these requirements are satisfied.

5) Who will be conducting the research

Kevin LeBlanc, a M.Sc. student in Kinesiology at Dalhousie University will be conducting the study, and Dr. David Westwood, a faculty member of the School of Health and Human Performance at Dalhousie University, will be supervising the study. Kevin LeBlanc, the principal investigator, will carry out the experimental session in which you are participating.

6) What you will be asked to do

You will be asked to volunteer for a one time visit of a maximum of 80 minutes. Before you come to the lab, you will be given a questionnaire to determine whether you meet the inclusion criteria for the study. The study will take place in the Actionlab in Dalplex room 218, Dalhousie University. During your visit you will be asked to sit at a comfortable, adjustable chair in front of a table and complete a consent form. You will then be asked to wear emitting diodes (IREDs) fixed to the tips of your index finger and thumb, and wrist (right hand), in order to measure your peak grip aperture (the opening of the hand during grasping). You will also be wearing LCD glasses, since at the beginning of each new trial your vision will be occluded (the lens will be darkened). At the beginning of each trial you will be instructed to make a grasping action towards a rectangular object and then either make a perceptual judgment or a grasping action to another rectangular object placed directly in front of the other. You will be granted a total of two breaks of 1-2 minutes each. The

whole process will take no longer than 80 minutes. We will then explain the purpose of the study, including the research question being investigated.

7) Possible risks and discomforts

You may experience slight mental fatigue over the course of the trials. You will be allowed to take breaks, and you can choose to stop participating in the study at any time.

8) Possible benefits

There are no benefits to you for your participation.

9) Compensation / Expense reimbursement

If you are a Psychology student, recruited through the Undergraduate Psychology Participant Pool and are participating in the present study for your course credit, you will be compensated with one course credit. You can withdraw at any time and still receive a full credit point.

10) Confidentiality & Anonymity

You will be assigned a participant number after completing this form, so your name will not be included beside any information from this experiment. Your identity will not be revealed when the data from the study are reported in papers and presentations. All data from the study will be kept in a locked cabinet in Dr. David Westwood's faculty office in Dalplex 215F for 5 years after the publication of the results from the study, at which point all physical and electronic data from this study will be destroyed. No one will have direct access to your data except Kevin LeBlanc and Dr. David Westwood. You will be permitted to withdraw your data at any point, during or after completion of the study.

11) Questions

Feel free to address any questions you may have about the study to the Principal Investigator either now, or after you have participated.

12) Summary

For a maximum of 80 minutes, you will perform an experiment which you will be asked to repeatedly perform a grasping action and make perceptual judgments towards rectangular objects. We will measure peak grip aperture (the opening of the hand during grasping). There is no significant risk of injury or discomfort (refer to above for potential risks)

13) Problems or concerns

In the event that you have difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact a member of the Human Research Participants & Ethics Committee of the Department of Psychology, Tel: 494. 1580, email Beatrice@dal.ca, and/or Catherine Connors, Director, Dalhousie University's Office of Human Research Ethics Administration, ph. 494-1462 email: Catherine.connors@dal.ca

As a volunteer from the department of psychology you will receive credit for participation in the study you have the following options. Please note, you will receive course credit for either of the following.

I choose to participate as:

Participant: (use my data)

Observer: (destroy my data)

(circle one)

INFORMED CONSENT SIGNATURE PAGE

Title of Study: Interference in sequential grasping: effects of perception and action

I have read the information consent letter and meet the requirements for participation as outlined on the screening form for this study. I agree to participate in this study being conducted by Kevin LeBlanc, a M.Sc. student in Kinesiology at Dalhousie University. I have had the opportunity to ask any additional questions and understand that I may withdraw my consent from the study at any time, and/or refrain from answering any questions by contacting the principal investigator at any time without penalty.

I understand that this study has received ethics review through the office of Human Research Ethics Administration at Dalhousie University. If I have any concerns or comments as a result of my participation in this study I may contact Catherine Connors, Director, Dalhousie University's Office of Human Research Ethics Administration, ph. 494-1462 email: Catherine.connors@dal.ca

I agree to participate in this study.

Participant Name (please print)	Participant Signature	Date:
Researcher Name (please print)	Researcher Signature	Date:

Participant Code: _____

APPENDIX C



DEBRIEFING FORM

Project title: Interference in sequential grasping: effects of action and perception.

Principal investigator:

Kevin LeBlanc (School of Health and Human Performance)

Email: Kevin.LeBlanc@dal.ca

Thank you for your participation in this research study! We are conducting this study so that we can learn more about how healthy individuals use visual information to interact with objects in their surroundings. Specifically, how the nature of a second task affects the performance of a first task.

Past research has shown strong evidence supporting the notion that the visual control of action and the visual perception of objects are mediated by two functionally and anatomically distinct visual systems (Milner & Goodale, 1992). Although it is well established that vision-for-perception occurs in the ventral stream whereas vision-for-action occurs in the dorsal stream, little research has been done to investigate how each stream can possibly interfere with the other when performing a sequential task. However, it has been demonstrated that performing a subsidiary task can affect the grasp component of a goal-directed movement (Castiello, 1996). Specifically, participants were asked to reach out and grasp a centrally placed fruit while simultaneously counting how many light flicks were flashed on another fruit (placed laterally beside the other one). Results showed that the peak grip aperture of grasping the central fruit was interfered by the lateral fruit. For example, if the central fruit was a cherry, the amplitude of peak grip aperture was greater when the lateral fruit was an apple compared to when the lateral fruit was a mandarin. The results of this study potentially demonstrate that a subsidiary perceptual task (ventral stream process) interferes with an action task (dorsal stream process). However, it is actually unclear whether the nature of the subsidiary task was processed via the ventral stream or dorsal stream. Perhaps that when performing the subsidiary task the participants' sustained attention was actually processing the associated action to the object (dorsal stream process). Thus, not leaving out the possibility that the

results simply just demonstrate that the interferences are due to a dorsal stream task affecting another dorsal stream task.

The role of this study was to test how the nature of a task to be performed later (action vs. perception) affects a current action task. The design of this study permitted a systematic control over what the second task is via explicit instructions. Before grasping the first object participants were told what they were required to do for the second task (either grasp the object or make a perceptual judgment about it). We expected that the type of interference the second task creates would be dependent on the nature of the second task. For the perception condition, it is predicted that there will be an interference associated with a size contrast effect (Westwood & Goodale, 2004) (e.g., the second object is larger than the first object, the first object will appear smaller and hence participants peak grip aperture will be smaller compared to the control trials when grasping the first object). However, for the action conditions it is predicted that there will be an interference that is constant with the size of the second object (e.g., the second object is larger than the first object, participants peak grip aperture will be larger compared to the control trials when grasping the first object). Thus, demonstrating interference between two motor plans.

If you have any questions or comments about this experiment, please feel free to communicate them to us.

Thanks again for your participation!

Kevin LeBlanc
Dalhousie University

Discussion Questions

- It has been shown that the visual control of action and the visual perception of objects are mediated by the same visual system?

- a) True
- b) False

- It is possible that when performing a subsidiary task it can affect the grasp component of your goal-directed movement.

- a) True
- b) False

References

Castiello, U. (1996). Grasping a fruit: Selection for action. *Journal of Experimental Psychology: Human Perception and Performance*, 22, 582-603.

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

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