EXTRA-PERSONAL GAZE INFLUENCES ON THE EYE TO HAND SPATIAL
INTERFERENCE EFFECT

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ABSTRACT

Richardson and colleagues (2013) demonstrated oculo-manual spatial interference by finding that the finger trajectory in a vertical tapping task deviated toward the direction of a concurrent saccade. It was proposed that the entrainment of the hand to the eyes was in part a function of generalized motor planning. Human action observation research has shown that cortical motor planning is also active during action observation (e.g. Buccino *et al.* 2001; Decety *et al.* 1997), which can lead to other forms of spatial interference (Kilner *et al* 2003). We hypothesized that because motor planning subserves both observation and execution of action, simply observing the horizontal saccades of another person would cause sufficient recruitment of oculomotor planning structures, that would result in finger tap trajectory deviations toward the direction of the observed saccade (but would not do so in a non-biological observation control condition).19 participants performed 24 trials of vertical finger taps under three different visual conditions. They were required to: a) saccade horizontally between targets; b) fixate on a biological stimulus (i.e. a video of horizontally saccading human eyes); or c) fixate on a non-biological control stimulus (horizontally moving black dots) while tapping their finger to an auditory metronome beat presented at a 750ms intervals. Results from the saccading condition replicate Richardson et al's (2013) entrainment effect. That is, finger taps deviated to the left when participants saccaded left, and to the right when executed with a rightward saccade. Contrary to expectations however, there was no entrainment induced by observing either the biological stimulus or the control stimulus. This suggests that competing motor plans (eyes and hands) are necessary to induce interference. Further, simply observing eye movements do not recruit the same oculomotor planning networks as action execution.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
EEG	Electroencephalography
IFG	Inferior Frontal Gyrus
M1	Primary Motor Cortex
MCP	Metacarpal-Phalangeal joint
MRI	Magnetic Resonance Imaging
PET	Positron Emission Tomograpy
PMC	Premotor Cortex
PPC	Posterior Parietal Cortex
SMA	Supplementary Motor Area
SMC	Sensorimotor Cortex
SOA	Stimulus Onset Asynchrony
SPSS	Statistical Package for the Social Sciences
STS	Superior Temporal Sulcus
TMS	Transcranial Magnetic Stimulation

DECLARATION OF ACADEMIC ACHIEVEMENT

<u>R.A Marshall's role:</u>
- Created study design and measure selection
- Responsible for participant recruitment
- Lead investigator responsible for preparation of lab settings, equipment and materials
- Responsible for data collection, input, analysis and interpretation

<u>Role of co-authors:</u>
JL and BR assisted RAM with study design and measurement selection
- JL and BR assisted RAM with measurement selection
- BR programmed experiment protocol
- BR coded tap detection, eye movement detection data reduction programs
- JL obtained study funding
- JL and BR assisted RAM with interpretation of the data

INTRODUCTION

Our brains are constantly required to coordinate our eye movements and limb's actions to appropriately interact with our environment. Simultaneous motor programming has to occur for both the eyes and hands in order to successfully coordinate our limb's actions in performing a task. This close spatial and temporal connection between the oculomotor and manual motor systems has an impact on our motor planning, and in turn actions, in order to accurately perform goal directed movements. For example, when horizontal saccades are paired with manual finger taps to a common temporal goal, the finger taps tend to deviate toward the concurrent saccade, the motor plans for these corresponding movements consolidate in an effort to accurately perform the task (Richardson, Cluff, Lyons & Balasubramaniam 2013). Often, we are often required to coordinate these movements with other people in order to successfully complete a task, which can involve both intra and interpersonal eye-hand coordination. The present study seeks to explore the coordination involved in an interpersonal context. Moving forward, this introduction will briefly discuss what is currently known about how the ocular and manual motor systems coordinate, followed by applying current the knowledge on joint action in an effort to provide a short foundation for the present study.

It has been well established that in tasks requiring hand-eye coordination in object manipulation, gaze has been shown to lead manual responses, and eyes proactively fixate a common oculomanual target in order to guide hand movements (Land, Mennie & Rusted, 1999; Ballard, Hayhoe &Whitehead, 1992). More recent work has sought to parse

the close relationship between arm movements and saccades. This is a complicated network to assess from a motor perspective, as saccades tend to be very short and rapid in comparison to longer, slower arm movements they may be paired with for a visually guided task. To our knowledge, demonstrations of oculo-manual interference have only been shown in aiming/saccading tasks until very recently in our lab. Richardson, Cluff, Lyons & Balasubramaniam (2013) set out to establish if simultaneous execution of saccades and finger taps could result in entrainment, or a spatial "magnet effect" somewhat similar to what has been observed in the bimanual interference literature. For example, Franz (1997) reported a bimanual task where participants were required to draw lines of differing amplitudes with each hand, and observed a clear coupling of movement amplitude within each hand in the bimanual condition. Richardson and colleagues (2013) hypothesized that saccades performed in a predictive manner (i.e. involving motor planning) would result in greater associated movements in the hand than if saccades were performed reactively (and don't required complex planning). They tested this utilizing a timed task that required participants to tap their finger to a metronome beat. The tapping task was paired with visual stimuli that participants performed saccades in response to. These circular targets appeared in a predictable manner on the same time course as the finger taps (requiring predictive saccades) and in a second experiment, visual cues appeared separately from the metronome cue, to elicit reactive saccades on the same time course as finger tap execution. Their results for the predictive condition demonstrated spatial interference in finger trajectory when paired with horizontal saccades, with both movements (eye and hand) seemingly entraining to a set cadence. Specifically, it was

found that the finger trajectory in both hands deviated toward the direction of a concurrent saccade. Interestingly, Richardson et al. (2013) discussed that this result points to a generalized motor planning strategy, especially because as the tempo of the saccades and tapping increased, so too did the magnitude of the effect. That is, with a lower inter-stimulus interval (ISI) a decrease in motor planning time occurred, and in this case, resulted in less time to decouple the simultaneous plans on order to accurately execute these movements that required differential trajectories. As this task was predictive in nature, the observation of larger interference paired with greater temporal constraints provides support for the hypothesis that this interference was occurring at the motor planning level, and possibly due to widespread cortical activation in motor planning for both the eyes and hands. This idea is further supported by the result of the reactive saccading condition (that required less planning), where spatial interference occurred to a lesser degree (Richardson et al., 2013). Presumably then, when eye-hand movements are jointly executed, the motor system may consolidate motor commands at the planning stage as a means to minimize the control parameters involved in performing this task accurately under varying temporal constraints. Consequently, this consolidation likely results in the finger's trajectory shifting to move more horizontally along with the primary direction of the saccading eyes. This is in contrast to the phenomenon of motor overflow, where interference occurs due to overlapping cortical activation required for task execution. Further inquiry into this phenomenon - a behavioural response that experimenters termed the "eye to hand magnet" effect - leads into the purpose of the present work.

It is also important to consider that oculo-manual coordination dynamics would naturally become increasingly complex as we introduce interactions with other people. Researchers who study joint action seek to understand how humans coordinate to perform tasks together. One way joint action investigators explore how we plan and coordinate is by focusing what is happening cortically when we observe other people perform a task, and in turn, begin to understand how we perceive and plan in response to other's actions. To that effect, there is a considerable body of evidence supporting the existence of an action observation network of neurons in humans (Rizzolatti & Craighero, 2004; Morin & Grèzes, 2008; Kilner, Neal, Weiskopf, Friston, & Frith 2009; Rizzolatti & Sinigaglia, 2010). One of the proposed mechanisms behind this system involves the common coding of perception and action, wherein it has been suggested that both observed and executed actions share the same representative domain (e.g. Prinz, 1997). By extension, it can be argued that the mere observation of action serves to prime our motor systems for the execution of action. Buccino *et al.* (2001) provided fMRI evidence in support of this hypothesis by showing that observation by one person of an action by the hand, mouth, and foot of another person resulted in cortical activation of the same functional representations of the premotor cortex that would also be activated if one was executing that movement.

As such, it can be predicted that the recruitment of similar neural structures in observation and execution of action may serve to create interference in simultaneous

observation and execution of movement. Kilner and colleagues (2003) demonstrated exactly this by observing spatial interference effects when people who performed arm movements that were incongruent to an experimenter's arm movements they were observing at the same time. More specifically, they had participants observe the arm trajectory of both a human and a robotic model making either horizontal or vertical arm movements. They were instructed to produce arm movements in a congruent and opposite trajectory to the model. It was observed that there was greater deviation in arm trajectory in the incongruent condition in comparison to being paired with a congruent model, and most importantly, only in response to the human model. Similar to Prinz (1997), and Richardson *et al.* (2013), Kilner and colleagues speculated that the observed spatial interference manifests as function of a common neural network which involves both creating a mental representation of observed biological motion, and actual motor execution. This is important to note in the context of the present work, as we look to combine the areas of eye-hand coordination and joint action to examine the influence of observed gaze cues on motor output in the hand.

It has been well documented that observed changes in gaze direction influence the eye movements of the observer in a reflexive fashion. For example, Friesen and Kingstone (1998) had participants fixate on a line drawing of a face with blank eyes with targets to appear in detection, localization and identification trials. Each trial would have the eyes appear and look in a neutral, left or right direction and participants were told that gaze was non predictive of target location. They were told to respond to targets on either

side of the face that would appear varying time periods after the gaze cue. Participants were faster to respond in detection, localization and identification of the target when it was congruent with the observed gaze cue. This effect has been reproduced supported in other work (e.g. Driver, Davis, Ricciardelli, Kidd, Maxwell & Baron-Cohen, 1999; Friesen, Moore & Kingstone, 2005; Langton & Bruce 1999). The information provided by observing where someone is looking can help us predict and plan our movements in coordination and response, and as such, observing another person's gaze direction is a communicative cue, especially in instances of joint action. So, in providing a foundation for the current work, it is important to state that the action observation network likely plays a role in how we resonate with others when we observe their actions (Gallese & Goldman 1998). Thus, developing an understanding of how our hand movements are impacted by gaze cues is a valuable avenue of research. More specifically, in the current study, we are interested in investigating if observation of saccadic eye movements could recruit motor planning structures in the eyes to such a degree that interference in finger taps performed by the observer can occur in a similar protocol to Richardson and colleagues (2013), similarly to if the performer was making the movements themselves.

The significance of the present work lies in its potential contributions to the existing literatures on action observation and motor coordination. If the eye to hand spatial interference is observed under the conditions employed in this experiment, it would suggest that simply observing eye movement recruits oculo-manual motor planning structures in the brain. This would provide evidence that observing extra-

personal gaze cues could recruit the observer's eye motor representation of action in the brain, and furthermore, that this recruitment influences and potentially manifests within manual motor planning. Essentially, the empirical work in this thesis seeks to provide behavioural support for an oculomotor mirror neuron network wherein spatial interference is neither specific to the effector being observed, nor exclusively experienced within a single nervous system. Such a finding would be important because it would serve to illustrate that limb movements could be biased simply through visual fixation on a biological stimulus. If this effect is observed, it would speak to the power and influence of observing eye movements, and show that observing biological stimuli through covert shifts in attention could bias limb movement. This is a valuable distinction to make because when Richardson & Lyons (2013) followed up the finger tapping study they showed that covert shifts in attention did not influence finger taps. They had participants perform finger taps to a cadence while instructed to fixate between alternating targets in contrast to the saccading task in the original study. Further, they instructed participants that they periodically have to identify a letter when it appeared in the place of a target, utilizing non-biological cues to covertly shift attention. Therefore, if we were to differentially elicit interference by having participants observe biological stimuli, it would provide behavioural evidence that we differentially code biological cues (consciously or not).

Lastly, this experiment has the potential to serve as a foundational starting point for many future lines of inquiry in the field of oculo-manual motor planning and its

relationship to joint attention and action. For example, the insight of this study, should our hypotheses be supported, could especially impact Theory of Mind research because the eyes provide important social cues that allow us to understand other's intentions (especially when it comes to action), which may be challenging for special populations such as those with Autism Spectrum Disorder. By utilizing an experiment with small degrees of freedom, we can gain a greater understanding of how gaze cues impact manual motor planning, and demonstrate socially how powerful an observed gaze cue can be. The current thesis hopes to provide a preliminary investigation into the behavioural responses when observing extra personal gaze cues, in addition to expanding on the current body of work on eye to hand coordination and movement interference as a result of observed biological movement.

The following chapters will review the literature with respect to neural structures involved in both motor planning and joint action (as a means to provide a mechanistic explanation for the spatial interference effects discussed above) in addition to outlining a physiological foundation for pursuing this line of research. It will then briefly review past work in oculo-manual coordination and joint action to establish the basis of this study from a behavioural perspective. Following this background, a description of the experimental protocol that was used in the experiment, as well as the results of the study, will be outlined. Lastly, a discussion regarding the impact, limitations and future directions for this work will be presented.

REVIEW OF THE LITERATURE

There is a growing body of research in recent years that has developed the theoretical framework the groundwork for the present study. As this experiment is novel and probative in nature, establishing a strong theoretical foundation is imperative to justify the methods. With respect to observation of movement and joint action, there has been considerable investigation into how our brains respond to human movement and, behaviourally, how observing other people's actions influence our own. This review will begin by discussing oculo-manual coordination, and why we see interference effects in multiple effector actions. This will then be followed by an outline of the cortical structures involved in the observation of action and gaze cues, and how they influence execution of action. Finally, the present study acts as an intersection of these two bodies of research, so a short justification for the present work will be presented, citing where the physiological and psychological models overlap, and stating why interference may potentially be observed in this experimental paradigm.

Multi-effector coordination and Oculo-manual motor control.

Motor control researchers have been working to understand how we coordinate and execute our movements for many years. Historically, evaluating the coordination of multiple effectors has been done within the context of bimanual coordination. Many instances of spatial and temporal coupling of bimanual actions have been demonstrated in the past (e.g. Chan & Chan, 1995; Kelso, 1984; Franz, Zelaznik, & McCabe, 1991; Franz, 1997; Franz & Ramachandran, 1998). The classic example of spatial interference in

bimanual interaction is from Franz et. al (1991) who found that, when participants were required to draw a circle and a line with each hand simultaneously, each hand's movement took on features of the other. That is, the circles became more linear and the lines became more circular. In a follow up study (Franz,1997), it was found that participant's movements were not only temporally coupled but also spatially constrained the more disparate the size of the shapes became. This suggests that in the effort coordinate both arm movements, the greater the difference of amplitude between shapes, the more bias that occurred in each limb to produce a movement amplitude similar to the opposite limb. This inter-effector coupling has been attributed to crosstalk between homologous limb representations in our motor systems, as well as a natural need to perform actions in the most stable manner (Carson, 2005). This kind of temporal synchronization that occurs in bimanual limb coordination can also be referred to as rhythmic entrainment. Entrainment can occur either voluntarily or involuntarily and it is thought to be a means for our motor systems to coordinate with our environment (for reviews see Repp & Su, 2013; Ross & Balasubramaniam, 2014). In the context of the example above, the inherent need to temporally couple the movement of both hands elicits interference in the spatial domain. In establishing the framework for the present study, this is highly relevant because Richardson and colleagues (2013) observed a similar intrapersonal entrainment between the eyes and hands. Their findings were novel because the manual task was not constrained spatially (such as in previous work observing aiming/saccading tasks), but temporally. Under these conditions, they found that when finger taps were performed concurrently with horizontal saccades under

temporal constraints, their trajectory began to adhere to the *spatial* goals of the saccading

task in order to accurately meet the *temporal* goal of the task. Further, with greater

temporal constraints on the hands (i.e. smaller interstimulus intervals or ISIs) the more

pronounced the coupling of movement that occurred suggesting that the degree to which

this entrainment occurs may be linked to the strain it puts on cooperative motor planning

resources.

One theoretical explanation for entrainment effects is neural crosstalk. The theory

is that inter-hemispheric communication between different motor representations results

in consolidation of motor plans when performing actions that require coordination

(Carson, 2005; Hoy, Fitzgerald, Bradshaw, Armatas, & Georgiou-Karistianis, 2004).

Therefore, when limbs are moving concurrently, there is assimilation of motor plans in

performing those movements in a way that they become more similar to one another, and

therefore more stable (Swinnen, 2002). This has been supported in the bimanual

coordination literature by Heuer, Spijkers, Kleinsorge, van der Loo, & Steglich, (1998),

who showed that entrainment of hand movements occurred to a greater extent with

shorter inter-stimulus intervals required to perform the task.

Within the focus of oculo-manual coordination, specifically modeling how this

system works can be a challenge because the eyes and hands are controlled by separate

though interacting structures in the brain (e.g. Levy, Schluppeck, Heeger, & Glimcher,

2007; Mushiake, Fujii, & Tanji, 1996; Snyder Batista, & Andersen, 2000), and the time

course of saccadic movements and arm movements are also quite different. Behaviourally, researchers have sought to explain how these systems interact. Several studies have assessed how saccades bias distance of arm movement time (van Donkelaar, 1997), arm kinematics (van Donkelaar, 1998), in addition to how arm reaching impacts saccadic reaction time and accuracy (Lunenburger, Kutz, & Hoffmann, 2000), and saccade duration (Epelboim *et al.* 1997). Richardson et. al (2013) looked at coordinating concurrent eye and finger movements with the resultant interference supporting the explanation that a more generalized planning strategy is undertaken when coordinating multiple effector systems. This is because in the effort to accurately perform within the temporal constraints of the task, our hands spatially deviated horizontally in the direction of the concurrent saccade. Most interestingly, the scale of this magnet effect in these studies was greater as inter-stimulus interval decreased. Thus, the Richardson et al. (2013) results support the notion that the less time one is given to complete paired movements, the less time there is to suppress the effects of interference that oculomotor encoding has on the direction of the hand responses. Therefore, simplifying execution by creating one, more general motor plan appeases the temporal goal of the task.

In the context of the current work, if there is widespread activation of motor planning structures when we execute movements ourselves, it is important to discuss what is occurring at a cortical level in observation of motion to justify why we expect to see a similar magnet effect by observing eye movements. Cortical activation in visually paced bimanual movements also appear to be widespread, recruiting areas such as the

premotor cortex, supplementary motor area, M1 and the middle temporal region of the visual cortex (area V5; Grefkes, Eickhoff, Nowak, Dafotakis, & Fink, 2008). Furthermore, advances in neuroimaging have allowed the most recent evidence to suggest that there is a complex network of cortical activation when performing tasks involving multiple effectors. More specifically, the primary motor cortex, sensorimotor cortex, the supplementary motor area, premotor cortex, cingulate motor area, and the posterior parietal cortex have all been found to be active in coordinating more complex motor tasks (Immisch, Waldvogel, van Gelderen, & Hallett, 2001; Jäncke et. al 2000; Kermadi Liu, & Rouiller, 2000; Stephan, Binkofski, Posse, Seitz, & Freund 1999).

The Action Observation Network

The mirror neuron system is a complex network of neurons that are activated by both the observation and execution of action (for review see Rizzolatti & Craighero, 2004). The mirror neuron system was first discovered in monkeys using single cell recordings, where it was found that the premotor cortex (PMC) became active when a monkey observed a human or another monkey performing an action that was similar to when the monkey was performing the action itself (e.g. Gallese, Fadiga, Fogassi, & Rizzolatti, 1996, Rizzolatti *et al.* 1996; Rizzolatti & Luppino, 2001). Upon further investigation, it was found that action observation also recruited neurons in the superior temporal sulcus (STS), and the posterior parietal cortex (PPC) (Gallese, Fogassi, Fadiga, & Rizzolatti, 2002; Perret et. al 1989). The STS does not have motor properties, so while it is related, it is only the PMC and PPC that have "mirror properties" (that is, active in

both observation and execution) and therefore are considered to make up the mirror neuron circuit (Rizzolatti & Craighero, 2004).

Moving forward, recent advances in technology and imaging in the past 20 years has allowed for researchers to rapidly expand our understanding of the mirror neuron system in humans. There have been a large number of imaging studies that have shown activation of the PMC, STS, the inferior parietal lobule, and inferior frontal gyrus, as well as visual areas in the temporal and posterior parietal cortex in the observation of action (Buccino *et al.* 2001; Buccino, Binkofski, & Riggio, 2004; Decety *et al.* 1997; Hari et. al 1998; Iacoboni *et al.* 1999, Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Grèzes, Armony, Rowe, & Passingham. 2003; Manthey, Schubotz, & von Cramon 2003; Puce, Allison, Bentin, Gore, & McCarthy 1998; Rizzolatti *et al.* 1996). In a review in 2001, Rizzolatti & Luppino compiled evidence from single neuron recording studies in monkeys to map the trajectory of cortical activation in motor control. They presented evidence that observed action begins in at the STS where the visual information from observing biological motion is coded (Perrett *et al.* 1990), then outputs information to the inferior parietal lobule responsible for interpreting the context of the visual stimuli (Fogassi et. al 2005), which has extensions into the monkey equivalent of our premotor cortex (area F5) (Petrides & Pandya 1984; Seltzer & Pandya 1994). The best evidence to support the notion that observation of action recruits similar cortical circuitry in humans is from imaging studies that have shown STS, PPC and PMC activation in action observation (e.g. Buccino *et al.* 2001; Calvin-Merino Glaser, Grèzes, Passingham, & Haggard, 2005;

Grèzes *et al.,* 2003). It is essential to note that activation of these areas are present in execution of complex motor actions too (Bestmann et. al 2008; Grefkes, Eickhoff, Nowak, Dafotakis, & Fink, 2008), so in a simultaneous observation and execution paradigm, interference can be observed when conflicting motor plans are being coded and performed (Kilner et. al 2003, 2007).

One of the proposed purposes of the mirror neuron network in humans is to facilitate the imitation of action. Most current evidence provides some support for a common coding model of perception and action (Prinz, 1997) as a mechanism to explain some of the movement interference that occurs in action observation wherein both ventral and dorsal visual streams are recruited in observation (however the extent to which each pathway is recruited depends on the context of the action). For example, Grèzes, Costes, & Decety (1999) showed that intention and learning level were important modulators of brain activation in observing action. Specifically, using positron emission tomography (PET) the dorsal pathway from the STS to the premotor cortex was most activated when observing actions with the intention to imitate it later. The authors interpreted this finding to mean that observation of action establishes a resonance in our motor system in order to prime us for executing that action. This interpretation has been supported in several other studies. For example, from a neurophysiological perspective, an experiment by Fadiga *et al.* (1995) used transcranial magnetic stimulation (TMS) to stimulate the motor cortex during the observation of a grasping action. They found that motor evoked potentials in response to stimulation (the amplitude of motor output is considered a measure of cortical

excitability) were facilitated when paired with observing hand movements (pantomiming and with object manipulation) specifically in the muscle representations that were the same as the muscles active in the observed task and to the same extent if they were executing the action. This also suggests that there may be some similar cortical circuitry in observation and execution or action. From a behavioural perspective, Brass and colleagues (2000, 2001) found that observed finger movements facilitated movement times of executed finger movements. This effect was especially pronounced when observed movements were congruent with executed actions whereas executing incongruent actions results in movement interference (as indexed by increased reaction times). This effect has been duplicated across several tasks (e.g. Brass, Bekkering, Wohlschlager, & Prinz, 2000; Craighero, Bello, Fadiga, & Rizzolatti, 2002; Vogt, Taylor, & Hopkins, 2003).

This facilitation of action is thought to be a result of our motor systems being primed by the witnessing the action. This is because mirror neurons are active in both observation and execution. As such, co-activation of these neurons in an incompatible observation/execution paradigm is one possible explanation for why interference effects occur in performing incongruent movements (Blakemore & Firth, 2005; Kilner *et al.* 2003, 2007; Stanley Gowen, & Miall 2007). However, much of the work discussed thus far has been focused on the observation of upper limb movements. Therefore, within the context of this thesis, we must consider how our brain codes and responds to gaze cues.

Joint attention and cortical pathways in gaze observation

Thus far, much of the cited work in support of a human action observation network has had to do with observation of hand movements. However, it is important to consider the perceived gaze literature in the context of the current work. Firstly, perception of gaze cues, and preferential fixation on the eyes begins to develop in infancy (Maurer, 1985). Babies as young as three months can detect a shift in gaze on an adults face (Hood, Willen & Driver, 1998) and by one year of age can shift their attention reliably to where someone else is looking (Corkum & Moore, 1998). Observing another person's eyes is an essential communicative skill in a variety of ways, such as coordinating conversation, information gathering from others behaviour (such as submissiveness or aggressiveness from averted or direct gaze), and even learning (for review see Kleinke, 1986). Friesen and Kingstone (1998) demonstrated the robustness of this effect by having participants respond to a line drawing of a face with either a neutral, a leftward or a rightward gaze. Participants were asked to fixate on the center of the screen while responding to targets as they appeared and were told that gaze direction was not predictive of target location. It was found that despite these instructions, people were faster at responding to targets that were in the same direction as the gaze cue. This also happened at very rapid stimulus onset asynchronies (e.g. 108ms) and disappeared in longer SOA's (1000ms), suggesting that we reflexively or covertly shift our attention to where the observed gaze is going. This result has been replicated and supported by several other studies with similar paradigms (e.g., Driver *et al.* 1999; Langton & Bruce,

1999). The authors interpreted this to mean that we have a specialized network for attending to biologically relevant stimuli.

However, it can be argued that a similar priming effect exists for a non-biological directional cue. That is, it has also been found that response times to a non-predictive arrow cue are faster when the arrow was pointing in the same direction as the target appeared (Eimer, 1997; Ristic, Freisen & Kingstone, 2002). However, evidence strongly suggests that our responses to human gaze cues are in fact quite different from our responses to non-biological directional cues. For example, when participants are told that the directional cue is counter predictive (i.e. target is more likely to appear opposite to the cue), if the cue is gaze, reflexive shifts in attention still occur in the direction of the observed gaze even if they know the target likely won't appear there and are voluntarily attending to the target. This is in contrast to counter predictive arrow cues where there was no reflexive visual orientation in the direction of the cue, thus authors confirmed their prediction that there is differential attention in response to gaze cues (Ristic, Freisen & Kingstone, 2002).

Thus, understanding the underlying cortical networks that respond to observed gaze is imperative in rationalizing why we predict that observed gaze cues may influence finger movements. Several imaging studies have shown activation the STS and the temporal-parietal network when observing gaze (Pelphry, Singerman, Allison, & McCarthy 2003; Puce et. al 1998; Puce, Smith & Allison 2000; Wicker Michel, Henaff, & Decety, 1998). More specifically, EEG studies have found that event related potentials

are higher in the STS in response to observing averting gaze from the viewer (Puce et. al, 2000), and are also higher when people are presented just with eyes as opposed to a whole facial cue (Benton, McCarthy & Wood, 1985). The STS is thought to be the region of the brain responsible for the perception of biological motion and social signals such as gaze cues (Allison, Puce, & McCarthy, 2000). Paired along with the previously discussed work on the action observation network, it would appear that the superior temporal region and the connecting temporal-parietal networks play an integral role in our perception of biological stimuli and perception of gaze. In a meta-analysis by Grosbras, Laird & Paus (2005) it was found that the fronto-parietal cortical circuit, that is engaged in reflexive saccadic eye movements and covert shifts in attention, have some overlap with neural activity in response to gaze perception. Therefore, while a similar "mirror neuron" circuit has yet to be fully examined in observing gaze, it is reasonable to predict this overlap in cortical activity by observing ones eyes may elicit a magnet effect in the hand, as if we were making these eye movements ourselves.

The current experiment

In summary, much of the literature discussed has outlined a foundation for why it may be possible for observed gaze to elicit a eye to hand magnet effect in the current experiment. Richardson et. al (2013) showed a spatial interference effect within one motor system and hypothesized that this finger entrainment was the result of that motor system creating a motor plan to execute the most stable movements for both the eyes and hand within the temporal constraints of the task. Similarly, Kilner and colleagues (2003,

2007) hypothesized that the interference effects that occurred in executing movements that were incongruent to observed movements were a result of competing signals in the motor planning structures of the brain: the action observation network primed to understand and perform the observed movement along with the motor areas actively trying to create a stable movement opposite to what is observed. These interference effects are further supported by the overlap of cortical structures (namely the STS, PMC and PPC) presented in studies of movement interference on observed biological motion (Brass et. al, 2000; Craighero et. al 2002), observed gaze cues (Allison et al 2002 Wheaton et. al 2004,) and multi-effector coordination (Grefkes et. al 2008; van Donkelaar et al 2002). Finally, the presented intersection of several avenues of research, and as such, the present experiment was a means to approach this intersection between oculo-manual motor planning and joint action/attention. Previous work in both areas lends to the theory that observing horizontal extra-personal eye movements while performing vertical finger taps may result in horizontal deviation in the observer's finger movements. Moving forward, we designed this experiment specifically with minimal degrees of freedom (that is, just observing eyes saccading and finger tapping as opposed to a gross motor movement) in order to see if we could elicit oculo-manual interference across motor systems. The following chapters describe the methods we chose to answer our research question, the results we observed and how they can be interpreted.

Statement of the Problem

While there has been years of research examining action observation, joint action, joint attention and oculo-manual coordination, there is a fairly significant gap where these areas intersect. Thus, by examining how the observation of extra-personal gaze cues can influence finger trajectory, we can open doors to expand our understanding of the power of observed gaze as a stimulus, and its influence on motor output. This will be done by implementing a protocol similar to Richardson *et al.* (2013), except the comparison will be of finger trajectories while participants observe either saccades on a video, are saccading themselves, or are fixating on a non-biological stimulus.

HYPOTHESES

Hypothesis 1. Firstly, it is predicted that we will duplicate the eye to hand magnet effect previously demonstrated by Richardson *et al.* (2013) in that participants finger trajectories will deviate in the direction of the concurrent saccade. That is, in the visual condition with the same saccading task as Richardson *et al.* (2013) it is predicted that the same manual interference as previously observed. This control condition is designed to validate Richardson's previous work and act as a comparison between observed and executed gaze influences on motor output.

Hypothesis 2. Further, it is predicted that in the experimental condition, where participants are fixated on a "biological stimulus (a video of eyes horizontally saccading), that similar spatial interference in finger taps by the observer will occur as if the person is

performing the eye movements themselves. This hypothesis is founded in the joint action and attention literature outlined above, where the overlap in motor structures for the eyes and hands are similar in observing and performing ocular and manual movements.

Hypothesis 3. Finally, if fixated on a non-biological stimulus, the observer will experience no spatial interference effects in the hand. This is because the observer is hypothetically not activating the oculomotor planning network. Thus, this "non-biological" fixation condition serves as a control in order to compare how observing a biological versus a non-biological stimulus can impact motor output.

METHOD

Materials & Setup

Nineteen healthy individuals (9 M, age X =23.86) were recruited from the McMaster University student population for participation in this study. They were naïve to the goals of the experiment and consented to participate voluntarily in the study. They were seated at a desk and instructed to keep their hands flat on the table surface with their index fingers pointing forward. Participants sat approximately 65cm in front of a flat panel monitor (17") that was connected to a Windows XP computer system. Auditory stimuli were presented through desktop speakers placed on either side of the monitor. The experiment was programmed using Experiment Builder software paired with the Eye-Link II head mounted eye tracker (SR Research Ltd.). The eye tracker sampled gaze position at 250Hz. Three-dimensional finger trajectory position was collected using a seven-camera (MX-T040) motion captures system (Vicon Motion Systems) at 250hz.

Participants were equipped with 9mm reflective markers on both the left and right hands. One marker was placed on the tip of the index finger, each metacarpal-phalangeal (MCP) joint on the index finger, and two 14mm markers were worn on a wristband over the wrist joint on each hand (See Fig.1) additional 9mm marker was placed on the 5th MCP on the left hand in order to distinguish each hand in three-dimensional space. The data streams of eye and hand movements were matched via analog input from the computer displaying the experiment to the computer equipped with the Vicon system.

Visual Stimuli

Participants were required to perform a total of 6 practice trials (2×Hand, 3×Visual stimulus) one for each visual condition prior to the start of the experiment, to familiarize themselves with the behavioural task, and the visual stimuli they would be presented with. After familiarization, a total of 24 trials were presented in a randomized order for each participant. There were three conditions of visual stimuli that were presented to participants in order to compare finger tap deviations while either horizontally saccading, observing a biological stimulus, or a non-biological control stimulus. Each visual condition repeated four times for each hand in order to assess within subject measures of task performance. The first visual condition was a saccading task similar to the protocol Richardson and colleagues (2013) wherein participants were either required to track periodic target jumps by saccading leftward and rightward between targets as they appear. The remaining two visual stimuli conditions required

fixation on a cross at the center of the screen. In the biological observation condition, participants were required to fixate on a cross that was central to a video of two human eyes saccading left and right for the length of a trial (see Table 1). In the non-biological control condition, participants fixated on a cross between two round targets (5mm) that were at the same distance apart as the eyes in the biological condition (see Table 1). These circles jumped left and right to the pacing tone, similarly to the biological stimuli. However, as opposed to the smooth nature of eye movements in the biological condition, these targets simply appeared and disappeared on either side of the fixation cross.

Behavioral Task

Participants performed unimanual finger taps paired with the visual task in one the three conditions discussed previously. Finger taps were performed with the index finger of either the left or right hand and were timed to an auditory metronomic pacing tone that presented auditory stimuli at an inter-stimulus interval of 750ms, which resulted in approximately 80 metronomic signals per trial. These pacing tones also corresponded to target jump in each visual condition. In total, 6 trial conditions were repeated four times for a total of twenty-four trials, and the experiment lasted approximately 45 minutes.

Data Reduction and Analyses

The two streams of data (finger kinematics, eye movement) were reduced and temporally synchronized in custom Matlab scripts developed in our lab. The onset and

offset of each tap was extracted using a two-dimension phase flow reconstruction from the fingertip position and velocity time series data. Tapping responses were paired with the most closely associated metronome cue by using the warp align function from Elliot, Welchman & Wing's (2009) published utilities package MatTap. These trial data were then sorted by condition, and for the purpose of the analyzing the present study's objectives, only taps that were paired with saccades, observed saccades, or control target jumps were assessed. This exclusion was made because the tapping task and the observed target jumps all in coordination with the pacing tone, and as such, any taps that occurred outside of temporal constraint of the task would not show any interference because they did not coincide with the visual stimuli that hypothetically causes the interference.

Extraction of taps that corresponded with target jumps was performed by matching the time stamp of specific visual events taken from the eye tracker to the time stamp of a detected tap, with a lift index (time stamp of when the finger left the table) that occurred before the next target jump. Threshold values in both position and velocity were applied to determine the last sample of each tapping cycle before phase wrapping occurred on the next tapping cycle. This was useful for avoiding false tap detections when the fingertip reversed directions in mid-air, which was common with participants who lacked smoothness in their fingertip trajectory data. Relative to the forward facing participant, the coordinate system of movements was defined on the x-axis as taps to the positive side of zero corresponding to horizontal finger deviations to the right, and taps negative to zero were horizontal deviations to the left; y axis as positive being anterior

and negative being posterior deviation; and the positive z-axis corresponding to the vertical trajectory of the finger. For the present study, only the horizontal deviation (x-axis) data was extracted for each tap. Once the taps that corresponded with visual events were extracted, the mean deviation in x was calculated by direction. That is, for each trial, every tap that corresponded with a target jump (as well as an observed or executed eye movement) to the left or right, an average "leftward" or "rightward" tap deviation value was calculated. This was done by taking the x-value of each tap that corresponded only with a target jump (or saccade) in the specified direction, subtracting it from the previous "leftward" or "rightward" tap deviation to get an overall average horizontal drift for taps within each trial. Once this was calculated for each trial, a custom matlab script concatenated the average of every participant by condition (Saccading, Biological, Non Biological), Hand (Left or Right) and the direction of the target jump the tap was paired with (leftward or rightward). At this time one participant was excluded from the data set as an outlier, because their susceptibility to the eye-to-hand magnet effect was much higher than average.

Following this, analysis was conducted in SPSS using a 2(Hand) × 2(Direction) × 3(Condition) repeated measures ANOVA to analyze the influence of each condition, hand performing the task and direction on horizontal deviation of finger taps. To test the hypothesis that target/saccade direction influenced finger tap displacement, we inverted the signs of all taps in the "leftward" direction because presumably if deviation of the finger tap was occurring in response to the visual stimuli, positive values would indicate

that the mean displacement would be in the direction of the concurrent target jump or saccade. Assumptions of repeated measures ANOVA were tested using Mauchly's Test of Sphericity across groups. On all variables the assumption of sphericity was met, except Hand x Condition interaction where the Greenhouse-Geisser correction was applied. Post hoc one sample t-tests were run for each variable against a test statistic of 0, to see if the visual condition produced horizontal finger displacement significantly different from zero. Statistical significance was established at $p < .05$ for all analyses.

RESULTS

Repeated measures ANOVA revealed a main effect for condition, $F(2,17) =$ 1.179, $p. = 0.002$ (see table 2), but no significant impact for Hand $F(1,17) =1.603$, $p.=0.317$ or Direction $F(1,17) =0.694$, $p.=0.416$. Post Hoc one sample T-Tests revealed that only the saccading condition elicited a displacement in finger taps that was significantly different from zero (see table 3).

Hypothesis 1

In the saccading condition, the mean displacement was negative (i.e. leftward) when paired with leftward saccades (Left Hand $\acute{X}=-0.574$mm, +/-0.797, $p. =0.007$; Right Hand $\acute{X}= -0.305$mm, +/- 0.598, $p. =0.045$), and positive when paired with rightward saccades (Left Hand $\acute{X}=-0. 0.442$mm, +/-0.880, p= 0.048; Right Hand $\acute{X}= 0.462$mm, +/- 0.554, $p. =0.003$). This results support our hypothesis that finger taps will deviate in the direction of a concurrently occurring saccade, and validates Richardson and colleagues (2013) eye to hand magnet effect (see table 3, Figure 2a).

Hypothesis 2

In contrast to the second hypothesis however, observation of a video of saccadic eye movements did not result in finger tap deviation in a similar manner. Specifically, in the left direction there was a slight trend to negative deviation of finger taps that were paired with the visual stimulus of eyes looking leftward, but it did not significantly differ from zero: Left Hand $\bar{x}$ -0.076mm, +/- 0.207, $p. =0.138$; Right Hand $\acute{X} = 0.076$mm, +/-

0.342, *p.* =0.486. In the rightward direction a similar trend was observed, but again was not significantly different from zero (see table 3, Figure 2b).

Hypothesis 3

Our hypothesis that a non-biological control would not elicit interference in the hand was supported by an average displacement that also did not significantly differ from zero (see table 3, Figure 2c). Interestingly, in the leftward direction there was differing mean displacement pattern between the left hand ($\acute{X}$ = -0.026mm, +/- 0.251 *p.* =0.661), and the right hand ($\acute{X}$ = 0.151mm +/- 0.352 *p.* =0.088). The taps that were paired with rightward target jumps were closer to zero than having any significant deviation from it: Left Hand $\acute{X}$ = -0.004mm +/- 0.272, *p.* =0.952; Right hand $\acute{X}$ = -0.029 +/- 0.356, *p.* =0.727. As such, as predicted the control condition did not generate any significant spatial interference in finger taps.

DISCUSSION

This study sought to reveal more detail about the impact that interpersonal observations of someone else's eye movements have on synchronous hand movements. The outcomes of this study are intriguing and speak to the complexity of the oculo-manual motor network in relation to biological cues. The results outlined above supported the original findings of Richardson et. al (2013), in that an eye to hand magnet effect was observed in concurrently executed ocular and manual movement. It seems however, that simply *observing* horizontal saccadic eye movements is not a strong enough biological imperative to generate manual interference. Since this study was probative in nature,

these results are informative and important, as it provides evidence to support that an actual execution of the ocular motor plan has to occur for interference in the hand to occur. Furthermore, the results are intriguing in that we did not see interference in the biological observation condition. This null effect carries with it some important implications for understanding the complex mechanisms subserving interpersonal joint action. The following discussion will outline possible explanations for the observed outcomes from this experiment.

The Eye to Hand Magnet Effect: Saccading Condition

Firstly, it was outlined in the introductory review that the entrainment effects observed in Richardson's (2013) original work was possibly due to neural cross talk and widespread cortical activation when performing simultaneous movements (Carson, 2005; Franz & Ramachandran, 1998; Hoy, Fitzgerald, Bradshaw, Armatas, & Georgiou-Karistianis, 2004). This cross talk results in a consolidation of motor plans that allowed for visible entrainment of one limb to another's movement, or the eyes in the direction of a concurrent saccade. Greater entrainment occurred with lower ISI's in Richardson's (2013) work provided strong evidence to support that an overlap in motor planning structures could be the culprit for the consolidated movements. Although the present study only had participants tap at one ISI, the results provide evidence that validate and support the robust nature of this effect.

Motor Plan Execution Needed: Biological & Control Condition

However, the fundamental difference between the work referred to above, and the experimental and control conditions in the current study is that our current paradigm required no concurrent eye movement paired with the finger taps in the biological condition, just the observations thereof. Quite simply, the oculo-manual task that was discussed is a dual task for the participant, requiring them to consolidate motor plans to perform both movements within the constraints of the task. The experimental and control conditions in this study were technically a single task; although they were instructed to fixate on the visual stimulus. So, because there was no conflicting motor plan being executed, it is now clear based on the results that entrainment in the finger does not occur. In addition, any shifts of attention by means of covert tracking of the target's movements (in both fixation conditions) did not cause any interference. This provides further support for follow-up work done by Richardson & Lyons (in prep, 2013). It was shown in this study, and in past work that the entrainment effect was only observed in a condition where saccades were voluntarily executed. Richardson & Lyons (2013) had participants fixate on crosshairs where there were alternating stimuli (similar to the non-biological condition in the present work), with the exception that some stimuli were letters that had to be identified by the participant, requiring rapid covert shifts of attention in the event that they had to identify the letter. The results of the present study in the context of this information support that voluntary execution of a planned saccade has to occur in order for the manual interference to be observed. This is a valuable and important piece of

information that has been gained by the current work, as it provides insight into the observer's use (or lack thereof) of the biological stimuli in this specific type of timed task.

Consequently, it appears that in order to elicit the *eye-to-hand magnet effect*, there has to be concurrent activation and execution of conflicting motor plans. The initial contention is that in Kilner's (2003) work, there was no conflicting movement within the system of the participant in the experimental condition. The observers of the biological movement in those studies illustrated that interference can occur in simply observing a movement that is opposite to the movement they were performing. The assumption in the hypotheses that were tested here are in line with generalist theories of imitation - that observed movements could elicit interference in the executing effector through mechanisms of activating general motor processes (Brass & Heyes, 2005). This was theoretically supported extensively by neuroimaging work, where inactive observation of a movement is sufficient to widespread cortical activation was observed in (Grezes & Decety (2001).

However, the difference between Kilner's work and the present study is that the observed limb was the same effector as the limb that was executing the movement by the observer. Another way to interpret Buccino et al's (2001) somatotopic activation of the PMC in action observation is that this is an effector specific mechanism. That is, the observation of eye movements may not have been enough to produce the predicted widespread cortical motor-planning areas to activate, to a point where it would need to

consolidate motor plans to entrain the hand. The tightly coupled nature of the oculo-manual motor system led to the assumption that that may not be the case in the instance of this study, as it was well outlined that observing gaze cues can impact hand movements (e.g. Driver *et al.* 1999; van Donkelaar, 1998; Wang, Newport and Hamilton, 2011).

Furthermore, in framing this work, it was stated that observing eye movements would activate the temporo-parietal network and the superior temporal sulcus (e.g. Pelphry et al, 2003, Puce, Smith, & Allison 2000) and suggested that due to the tightly coupled oculo-manual motor network that general premotor cortex and posterior parietal cortex activation would occur. However, it was also stated that that the STS is not considered part of the mirror neuron network due to its lack of motor properties. Thus, it provides behavioural evidence that simply observing eye movements while tapping does not co-activate motor planning areas for the hands and the eyes. So, without the intent to execute the motor plan (such as in the condition that required participants to saccade), there is theoretically no cortical drive to consolidate motor plans and generate manual interference – however future imaging work on observed gaze could possibly examine this.

Limitations and Future Inquiries

Leading into a discussion of what could come of this work it is necessary to consider potential limitations in the present study. In our effort to control for degrees of freedom by constraining the task quite heavily (by means of small tapping movements

and fixation conditions), it would be wise to consider the visual stimuli and small degrees of freedom of as potential limitations for this study. That is, the lack of interference may have been a function of the stimulus consisting of rapid, predictive saccadic eye movements, or simply a function of the small range of movement required by a finger-tapping task. It is possible the visual stimuli may have been too quick, and because they were paired with no voluntary eye movements themselves, observers that were performing the task were planning less in relation to the visual cues and more to the metronomic taps as the instructions were clear requiring them to fixate on the crosshairs and temporally constraining them by requiring them to tap to the metronome. This idea is supported by sensorimotor synchronization research, where it has been found that we unintentionally entrain to a predictable stimulus sequence (e.g. Repp B.H., 2006). It would be fascinating to see in future work if the visual stimulus would have a greater influence in a continuation paradigm, where participants would be required to continue tapping to the pace after the disappearance of the external pacing stimulus was removed. It would also be interesting to see in future work if the type of observed eye movement (i.e. predictive saccades versus smooth pursuit tracking) may have differential impacts on the hand movements of the observer.

In the process of developing this project, the relationship between the eyes and the hands was discussed at length. In analyzing the results of this study, it was found that the ability to coordinate these systems and even participant's susceptibility the entrainment effect vary greatly from person to person. This high variability between individuals also

serves as a limitation to contemplate because there were no controls in place to exclude people who might have a background in music and are excellent tappers who may experience less of a magnet effect; or people who have very little experience timing such as the outlier in this study whose mean tap displacement varied up to a couple centimeters in the direction of the concurrent saccade (e.g. Aschersleben, 2003). Evaluating what factors correlate with varying degrees of entrainment in future studies would help provide insight to allow researchers to control for the high variability between participants in follow-up explorations into the eye-to-hand magnet effect.

Although entrainment effects occurred unintentionally in the execution of timed oculomotor movements, it was shown in the present work that some context or intention to execute may be why simply fixating on saccadic eye movement was not as powerful a signal as was originally hypothesized. Especially in consideration of information gathering in day-to-day life, another person's eyes and where they look provide a wealth of information to the observer. So, it makes sense that in an instance where no social context was provided, (specifically, the observer could not see where or what the eyes in the biological condition were looking to) that the lack of pertinent information to act on would prevent any motor plans from coming to fruition (and thus eliciting spatial interference).

In addition, where a person attends is a powerful piece of information that has been shown to prime movements in past work on observed gaze cues (e.g. Freisen and

Kingstone, 1998). So, because the observers were not permitted free range of their eye movements (i.e. they were required to fixate) when observing the biological stimulus, it is possible that it prevented voluntary eye movements that could have potentially produced manual interference. Both of these constraints are not natural to regular social contexts, but for the purpose of this study both of these constraints were essential in order to generate future questions based on the results they generated.

CONCLUSION

The hypotheses tested in this thesis were based on the body of work currently available in the intersecting fields of hand-eye coordination and joint action. The results raise exciting questions that could assist in continuing to fill the gap between joint action and oculo-manual motor coordination, which might explore research modalities including imaging and behavioural research. For example, does execution of a concurrent oculomotor plan *have* to occur to generate manual interference or is there a means to drive it through priming by means of a different biological stimulus? It would appear by Kingstone's (2003) and Brass and colleagues (2000, 2001) work that observing a conflicting movement may be a strong enough stimulus *if* the observed effector is the same as the executing one. With support from Richardson's (2013) previous work, the current study additionally corroborates the suggestion that conflicting motor plans, or at least a related effector to be observed is needed in order to drive entrainment. This study was an initial step into investigating the power of extra-personal gaze cues. Now that entrainment was not demonstrated in a most controlled, constrained setting, moving

forward to change and expand the amount of visual information available to the observer, as well as the timing requirements of the task, we may begin to piece together the informative influence of observing another's gaze on the observers motor output.

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APPENDIX A: STUDY MATERIALS
Consent Form
Demographics Questionnaire

Department of Kinesiology   1280 Main St. West
                               Hamilton, ON
                               L8S 4K1

December, 2013

Letter of Information and Consent

Principal Investigator: Dr. James Lyons
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                                     McMaster University, Hamilton, Ontario, Canada
                                     (905) 525-9140 ext. 23579
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Investigator: Dr. Brian Richardson
                                     Department of Kinesiology
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Research Sponsor: Natural Sciences and Engineering Research Council (NSERC)

Purpose of the Study

The purpose of this study is to examine if a timed unimanual finger-tapping task is impacted when presented concurrently with different types of visual stimuli.

Procedures involved in the Research

If you agree to participate in this study, you will be asked to complete 1 session that is approximately 45 minutes long. During this session, you will be fitted with 9 kinematic markers on your hands and wrist, and have an eye tracker mounted on your head. The task will consist of 6 familiarization trials (10 minutes), followed by 24 experimental trials (approximately 35 minutes) of the timed tapping task. Each trial is one minute in length. You will be required to tap your index finger to the beat of a metronome while observing 3 different types of visual stimuli. The data obtained in this study will help us further understand generalized motor planning with respect to simultaneous eye and hand movements.

Potential Harms, Risks or Discomforts:

There are no serious risks involved in this research. The experimental session may be a bit tedious and induce some fatigue in the eyes; therefore breaks will be encouraged and can be requested any time

throughout the session. Participation in this study is completely voluntary, so if you do experience any discomfort and cannot complete the study, you can withdraw from the experiment at any time without penalty.

Confidentiality:

Your privacy will be respected. All data will be combined with other participants in this research and discussed by referring to anonymous, group means and other descriptive statistics. All data obtained will be kept secured in a locked file cabinet and reviewed by Rachèle Marshall, Dr. Richardson or Dr. Lyons.

Participation and Withdrawal:

Your participation in this study is voluntary. It is your choice to be part of the study or not. If you decide to participate, you can decide to stop at any time, even after signing the consent form or partway through the study without consequences of any kind. You may exercise the option of removing your data from the study if you decide to withdraw.

Information about Participating as a Study Subject:

If you have questions or require more information about the study itself, please contact Rachèle Marshall, Department of Kinesiology, McMaster University, Hamilton, ON, L8S 4K1 (marshra@mcmaster.ca).

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

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

CONSENT

I have read the information presented in the information letter about a study being conducted by Rachèle Marshall, Dr. Richardson and Dr. Lyons of McMaster University. I have had the opportunity to ask questions about my involvement in this study, and to receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so. I have been given a copy of this form.

_____

Signature of Participant

In my opinion, the person who has signed above is agreeing to participate in this study voluntarily, and understands the nature of the study and the consequences of participation in it.

_____

Signature of Researcher or Witness

If you wish to receive a copy of the final report of this investigation, please include below an email address to which this report may be sent:

_____

Demographics

Age:_____ years

Which is your dominant hand (the one you use to write with)?   R   L

Sex: Female _____ Male _____ Other _____

Do you wear eye glasses or contact lenses to correct your visions?   Y   N