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**Movement interference effects during the tracking of biological and non biological movement**

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**Movement interference effects during the tracking of biological  
and non biological movement.**

by

Rojiemiahd Edjoc

B.Sc., University of Ottawa, 2007

**THESIS**

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## Abstract

Are the neural and behavioural mechanisms underlying the tracking of another human's movement different from that of tracking the movement of a non-biological system? In an experiment by Kilner, Paulignan, Blakemore, (2003) an interference effect was found during the observation and tracking of incongruent biological movements (another human performing a different action), but not so with incongruent non-biological movements (a robot performing a different action). They defined this interference effect as the degree of change in the movement trajectory of the observer due to observed movement. Recent studies have shown that interference of this kind was subject to both biological and non biological stimuli. However, the question of whether a similar interference effect is present during the observation of movements that possess the same invariant characteristics of human movement such as minimum jerk trajectories with bell-shaped velocity profiles but are not produced by a human (Flash & Hogan, 1985) has not been previously addressed. The present experiment asked eight participants to perform vertical and horizontal movements either congruently or incongruently to novel non-biological movement stimuli sets that resemble human movement (added invariant characteristics) ranging from point light displays to 3D virtual models of humans. This was followed by an interpersonal task while tracking the movements of a human experimenter. Results demonstrated that a congruency effect was observed where incongruent human movements exhibited the most interference. In other conditions, similar congruency effects were observed where the magnitude of the interference was dependent on the biological similarity of the stimuli to actual human movement. Also a main effect of “biologicalness” (Sinusoidal vs. Sinusoidal with noise vs. Minimum Jerk), type (3d human vs. Human) and a main interaction of type and congruency (3d human vs. Human) were observed. We argue that the central nervous system is highly attuned to biological characteristics at the most deep-rooted level. It seems that biological characteristics such as movement optimality leading to the abstract representation of human movement are tightly coupled as they elicit similar interference effects as tracking movements performed by a human.

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## **Introduction**

As vision evolved in simple vertebrates along with the complexity of interactions with the environment, so did the various visual control systems modulating different behaviours (Milner & Goodale, 1995). Simple sensory control was not adequate to support the changing complexities of interactions with the environment. Therefore, an emergence of complex cognitive systems that permitted many animals, particularly humans and primates, to visually perceive and interact with the surroundings became necessary; thus, the emergence of visuo-motor control (Milner & Goodale, 1995).

This emergence of visuo-motor control through evolution has allowed the human brain to transition from early humans instinctively hunting for food to fully cognitive organisms with the ability to differentiate from harmless moving stimuli to more dangerous stimuli such as a moving car. For survival reasons, it is as pertinent today as it was a million years ago to have the ability to track a moving object. Tracking or visuo-motor tracking is defined as the ability to visually and motorically pursue a moving object (Milner & Goodale, 1995). Though the context for the application of this ability has changed over time, the level of complexity surrounding it remains the same.

Tracking can be defined as a goal-directed movement (Milner & Goodale, 1995). It has inherent visual and motor properties (i.e. the use of both visual and motor system to perform a visually guided task) and is smooth upon their execution (Harris & Wolpert 1998; Van Beers, Baraduc, & Wolpert, 2002). The smooth execution of these goal-directed movements is surprising as researchers (Harris & Wolpert 1998; Van Beer et al., 2002) have hypothesized the presence of signal dependent noise at every stage prior to and during the execution of these movements. Noise in general is defined by Harris &

Wolpert (1998) as the presence of uncertainty in the system and causes degradation of motor signals. According to Van Beer et al., (2002), in a simple visuo-motor task such as tracking or reaching, several steps must occur in order to achieve the desired goal. First, localization of the target and the hand must occur. Second the appropriate motor commands must be determined to align the hand to the target position. Finally, those motor commands must be delivered to the appropriate muscles for the execution of the movement itself. At every stage of this process, signal dependent noise (firing of motor signals) produces a deviation from the desired trajectory path of a movement (Harris & Wolpert 1998). Regardless of the presence of this signal dependent noise, goal-directed movements such as pointing from point A to point B are executed in a smooth fashion. Furthermore, upon closer examination of the trajectories of these movements, stereotypical patterns are produced. These stereotypical patterns or invariant characteristics during goal-directed movements are as follows: the trajectory of the movement is smooth and curvilinear, the velocity of the trajectory peaks at the midpoint of the movement creating a typical bell shape profile (Harris & Wolpert 1998). These invariant characteristics are hypothesized by many researchers as the result of the central nervous system's (CNS) optimization of noise at end-point variability leading to the smooth execution of goal-directed movements (Harris & Wolpert 1998). Out of the infinite trajectories that humans may use for any goal-directed movement, there is a tendency for the smoothest path to be chosen because of the CNS's hypothesized ability to optimize noise that hinders accuracy and efficiency of movements. There is a single physiological assumption that neural signals (i.e. the appropriate motor command chosen from the integration of sensory modalities) become corrupted by noise with increasing

variance and control signal (Harris & Wolpert, 1998). According to their account, the presence of this single-dependent noise, stereotypical trajectories are chosen to minimize variance of the final position of the eye or arm movement. A typical bell-shaped velocity-profile can be observed and predicted from empirically gathered data for both saccadic and arm movements. The authors conclude that these trajectories minimize post-variance movement in the presence of single-dependent noise and might very well be the biological underpinning of both saccadic eye and arm movement (Harris & Wolpert, 1998).

However, recent tracking experiments have showed that this smoothness characteristic during movement tracking can be perturbed. These experiments (Kilner et al., 2003; Oztop, Franklin & Chaminade, 2005; Stanley, Gowen & Miall, 2007) have questioned if the neural and behavioural mechanisms share an underlying similarity while tracking a biological system such as that of human movements differ from tracking the movements of a non-biological system such as that of a robot. In an experiment by Kilner et al., (2003), an interference effect was found during the observation and tracking of incongruent biological movements (another human performing a different action), but not so with incongruent non-biological movements (a robot performing a different action). This interference effect was quantified as the degree of change in the observer's movement trajectory due to the observed action. They argued that interference experienced by the performer was the result of the overlap in cognitive and neural resources involved in action observation and execution (Kilner et al., 2003; Blakemore & Frith, 2005). This overlap was believed to be due to the selective recruitment of mirror neurons which are a class of visuo-motor neurons (Rizzolatti & Craighero, 2004) that

discharge selectively during self-movement or the observation of a goal-directed movement by another biological organism (human).

In summary, goal-directed movements such as tracking exclusively stems from the evolution of highly specialized areas that integrate information from the visual and motor system. Furthermore, when goal-directed movements are performed, there is a tendency for smooth movements to be executed due to the optimization of signal dependent noise creating these minimum jerk trajectories with bell shape velocity profiles.

### *Statement of the Problem*

In light of this evidence of movement optimality during human goal-directed movements and the tenets argued by Kilner et al., (2003) in regards to our sensitivity to biological characteristics, an important question stem from these converging lines of literature. Could the tracking of non biological movements that possess invariant characteristics of human movement but not produced by a human result in similar interference effects as observed by Kilner et al., (2003)? The results of this study will help to extend their work by furthering our understanding of brain mechanisms in the tracking of biological and non-biological movement during action observation and execution. This will be specifically determined by 1) observing the extent of interference effects seen in motor performance during the observation of biological motion 2) confirming that the interference effect is more dominant when observing classes of biological movements such as movements made by another human and those that possess invariant characteristics of human movement. This will be experimentally tested by varying the biological characteristics of human movement added to non-biological stimulus sets ranging from point light displays to 3D human virtual models.

## CHAPTER II

### Literature Review

Kilner et al., (2003) found that observing an action made by a human, but not by a robot, interferes with executed actions. The observed interference effects by Kilner et al., (2003) suggest that there is an overlap between cognitive and neural resources responsible for action observation and execution. This overlap according to Kilner et al., (2003) and Blakemore & Frith (2005) are due to the selective recruitment of mirror neurons as part of the human mirror neuron system (MNS). But what are mirror neurons? The following paragraphs will elucidate the basic properties of mirror neurons and elaborate their functional role in action understanding and imitation.

#### *Mirror neurons characteristics*

Mirror neurons were first discovered in the ventral pre-motor cortex (area F5) of macaque monkeys (Di Pellegrino, Fadiga & Fogassi, 1992). They are activated when movement is observed and executed. Results from early experiments (Di Pellegrino et al., 1992; Gallese, Fadiga, Fogassi & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese & Fogassi, 1996; Rizzolatti, Fogassi & Gallese, 2001) suggests that mirror neurons offer a broad degree of generalization with the presented visual stimuli. In monkeys for example, mirror neurons encoded for grasping will be activated regardless of whether the observed hand performing the action is performed by a monkey or a human. In order for this activation to transpire however an interaction must occur between a biological organism and an object (Rizollati & Craighero, 2004). An object alone, non biological movements or another agent mimicking such an interaction (such as a robot grasping; an object) will not illicit a response (Rizolatti & Craighero, 2004).

Miall (2003) supported the aforementioned information but also suggested that though certain mirror neurons are dependent on purposeful movement (such as grasping) towards an object in order to be activated, they are not limited by visual stimuli alone. They are also activated to the mere intention of a purposeful movement as long as the intention itself is clear. This was supported in an experiment done by Kohler and colleagues (Kohler, Keysers, Umiltà, Fogassi, Gallese, Rizzolatti, 2002). They deemed these particular types of mirror neurons as having audio properties as such that the mere sound of an intended action after observing the actual movement will produce a response. In their experiment, functional magnetic resonance imaging (fMRI) was used to record highly dense areas containing mirror neurons that characteristically responded to visual stimuli. A piece of paper was being torn in front of participants and immediately taken away from their visual field. This was followed by a condition in which only the audio feedback of that trial was presented to the participants. They found that as long as the intention, which in this case was the tearing of a piece of paper, was heard and was clear, the same areas responded to the audio feedback as if the visual stimulus was presented.

Overall according to Gallese and colleagues (Gallese, Fadiga, Fogassi, Rizzolatti, 1996), visual stimuli are the most effective in triggering a response from these neurons. As mentioned above, an interaction between a biological organism's effector, such as hands interacting with an object (whether it is food or a geometric solid), are among the most consistent stimuli that evoked a positive response from these neurons while performing actions such as grasping, placing and manipulating.

### *The human mirror neuron system*

The discovery of mirror neurons in monkeys has prompted many studies to determine whether similar neurons were present in humans. Using neurophysiological (Fadiga, Fogassi, Pavesi & Rizzolatti, 1995; Cochin, Barthelemy, Roux & Martineau, 1999; Strafella & Paus, 2000) and brain imaging technologies (Rizzolatti et al., 1996; Rizzolatti et al., 1996; Binkofski, Buccino, Posse, Seitz, Rizzolatti & Freund, 1999; Ehrsson, Fagergren, Jonsson, Westling, Johansson & Forssberg, 2000; Buccino, Binkofski, Fink, Fadiga, Fogassi, Gallese, 2001) have confirmed and localized similar mirror neurons in humans in the homologue form of Broca's area found in the rostral part of the inferior frontal gyrus. Along with this homologue form of area F5, Gallese et al., (1996) and Rizzolatti, et al., (2001), have reported similar neurons with the same characteristics that reside in the inferior parietal lobule (PF or BA7b) and the superior temporal sulcus (STS) of the pre-motor area.

Because electrophysiology is only possible in very rare cases and at specific brain sites in humans, it is not possible to find individual mirror neurons in human participants (Fadiga et al., 1995). Therefore, mirror neurons in humans are referred to areas that possess "mirror" properties and labelled as a "mirror region" or a 'mirror system'. Researchers (Rizzolatti et al., 1996, Buccino et al., 2001; Fadiga et al., 1995) hypothesize that the human MNS may have evolved to provide humans the ability to understand observed motor events by internally generating an action representation eventually leading to the ability to imitate.

### *Functional role of mirror neurons*

Data from Di Pellegrino et al., (1992) suggests that the pre-motor and parietal (areas now known to be part of the human MNS) cortex are endowed with an observation/execution matching system. This exclusive matching system allows observed movement to be represented within the motor system and retrieved in case of wanted execution.

It was William James (1890) that proposed that actions are intrinsically linked to perception (through observation) and that every mental presentation of a movement awakens to some degree [of] the actual movement. The possible validity of this statement can be explained through the functional role of mirror neurons.

According to Rizzolatti et al., (1996), intuitively because of their properties, mirror neurons were first thought to be used in the preparation of movement in order for its' rapid execution.

In humans, mirror neuron areas seem to be highly activated during action observation and execution, similar to its macaque monkey counter part. This activation is increased during the observation of an action with the intention to imitate in comparison to the mere recognition of actions (Buccino et al., 2001). According to Buccino et al., (2001) this overlap is highly somatotopic in these regions of the brain similar to the classic somatosensory and motor homunculus analogy. In their fMRI study, they found that during the observation and performance of hand, mouth and foot actions in isolation or with a respective object, the same functional areas became activated. These results suggest that there is a somatotopic organization of these areas. Specifically, goal-directed movements that involved a biological effector (hand, mouth, foot) manipulating an object

activated the parietal cortex during observation and execution of the respective movement. It was also observed that the execution of actions without object manipulation, the pre-motor cortex was activated. This is a key distinction between mirror neurons that are found in monkeys and that of humans. Mirror neuron activation in monkeys is dependant on the observation of goal-directed movement (Rizzolatti et al., 1996) whereas in humans the mirror neuron system is activated in the observation of both goal and non goal-directed movement (Blakemore & Frith, 2005).

There are two main arguments that Rizzolatti et al., (1996) and Gallese et al., (1996) pointed out that challenge the explanation of mirror neurons are used solely for the motor pre-preparation of movements. First, after the activation of mirror neurons through the observation of an action, this event is not necessarily followed by the action that was prepared through that particular observation. For example, if an individual was to observe the finger movements of another person, that individual will not subsequently move their fingers simply because it was observed. Second, mirror neurons cease to be activated when the purposeful movement towards an object is accomplished. If mirror neurons were related to the motor preparation of movement, there would be an increase in neuron activity preceding the execution of that movement as opposed to a decrease.

The arguments put forth by Rizzolatti et al., (1996) and Gallese et al., (1996) is valid and requires some analysis and interpretation. These authors believe that the functional role of mirror neurons are more than a simple observation/matching system where the observed movements are exclusively matched to the desired output as was found in monkeys. This statement seem to parallel with the literature that states monkeys lack to the capacity to attribute mental states to others in their species, referred to as the

lack of Theory of Mind (Iacoboni, 2005). It seems mirror neurons in humans have evolved to not only be used as observation/matching system, but also provided the ability for humans to understand motor events (Gallese et al., 1996; Rizzolatti et al., 1996).

This ability to understand a motor event is supported by Jeannerod (1994) in his review article. He states that these neurons are used to internally represent an action to be produced later to enhance the learning of a particular skill. In his review article, he hypothesized that motor actions are neurally encoded and can be studied through mental imagery. He gave an example in which a student can enhance their learning of a musical instrument by observing the actions of the instructor. By observing the actions of the instructor, the student will be able to internalize these actions in preparation to produce them later. This idea of internally representing an observed action is supported by Rizzolatti et al., (1996) and emphasized the role of mirror neurons in internally representing movement for the purpose of understanding motor events leading to imitation. Furthermore, they state that movement representation in cortical areas and the movement consequences are associated with each other. In other words, a cortical activation pattern represents the meaning of the observed action (i.e. 'grasp'). Mirror neurons provide movement knowledge from observed movements made by others because mirror neurons internally represent observed movements allowing for the extraction of information needed to understand them (Rizzolatti & Craighero 2004). For example, when a movement is observed, the movement is understood due to the internal action representation of this movement. Comparisons are made between the external stimulus and the evoked cortical action representation allowing for the extraction of the meaning of the movement leading to its inevitable imitation.

This notion of action understanding through observation was further developed by Blakemore & Frith (2005). In their recent article they proposed that mirror neurons are part of a more sophisticated predictive system that consists of three levels. In this first level there is an automatic motor contagion from movements as long as the actual action is made by biological entities. For example, we are apt to observe in the direction of a biological entity or an actor during action observation and execution of movements. This automatic motor contagion refers to the influences of observed biological movement on ones own movements (Blakemore & Frith, 2005). At a higher level, there is mirroring of specific goal-directed movements (with an involvement of mirror neurons). For example, observed movements are made by an actor, may activate the same movements in the observer's motor repertoire (Blakemore & Frith, 2005).

Essentially this system allows us to internally represent observed movements and trigger an action representation. From this action representation, underlying goals and specific movement parameters could be inferred and extracted on the basis of what our own goals and intentions would be for the same action; leading to the ability to imitate. These arguments put forth by Blakemore & Frith (2005) support the original arguments put forth by Rizzolatti et al., (1996) and Gallese et al., (1996). It is now generally understood that the human MNS serves as a way for the observer to get into the mental shoes of the observers' (Gallese & Goldman 1998) target and may bridge the link between perception (movement observation) and action.

#### *The role of the Superior Temporal Sulcus*

But how do these neurons gather information about biological and non biological movements? Rizzolatti et al., (2001) have proposed the possible contribution of the

superior temporal sulcus (STS) in distinguishing between these movements. The STS and the pre-motor cortex are connected via the parietal cortex and are also attuned to biological movements. Given a point-light display that resembles a human form performing an action, this particular area will respond as if an actual human was performing this action through spatially integrating dot trajectories (Johansson, 1973). In a more recent fMRI experiment by Peuskens and colleagues (Peuskens, Vanrie, Verfaillie & Orban, 2005), they found that the stimuli that most resembled biological movements such as point light displays of a pre-recorded human dancing or walking, activated visual cortical regions, including human middle-temporal complex (hMT/V5+), posterior inferior temporal gyrus and the STS. Specifically, the human STS activity reflects the action portrayed in the biological motion stimuli, whereas posterior inferior temporal gyrus responds to the figure of the stimuli and hMT/V5+ to the complex motion pattern present in biological motion stimuli.

To further support the role of the STS in biological movement recognition, single cell experiments (Oram & Perrett, 1994; Perrett, Smith, Potter, Mistlin, Head, Milner, 1985a; Perrett, Smith, Mistlin, Chitty, Head, Potter, Broennimann, Milner & Jeeves, 1985b; Perrett, Hietanen, Oram & Benson, 1992), found that in the pre-motor cortex of macaque monkeys, originally where mirror neurons were first discovered, STSa cells responded to face and body depictions during action or static representations. Interpretations from these studies have suggested that the STSa cells provide the ability of the STS to visually recognize the action of others during observation.

*The relationship between mirror neurons and internal models*

Apart from distinguishing from biological and non-biological movement, the STS of the pre-motor cortex have a vital role in visually tracking movements. Tracking is largely mediated by the dorsal visual pathway projecting from the striate cortex (area V1). Miall (2003) suggests that mirror neurons in the STS share a relationship between internal models that help this pathway visually track movements. These internal models consist of an inverse and forward model. Inverse models convert visual representation into an internal plan such as a motor command to perform the desired action. Forward models acts as a predictor where it maps the relationship the between the motor commands and current state of the system through sensory reafferent flow. Therefore, it estimates the future sensory state of the system based on the information of current state of the system. Neural connections between the STS, the PF followed by mirror neurons in Broca's area, form an inverse model in charge of converting visual representation into a motor plan. For example when you reach for a pen, the inverse model would transform sensory representation of relative positions of the pen and arm into motor commands to perform that action. The reverse of this connection forms a forward model in charge of returning predicted motor plans back into a predicted visual representation.

This two-way process plays an important role in mapping motor commands onto the motor system in order to reach a goal and in estimating subsequent sensory states of the motor system. During action observation and execution, the following would occur in theory. First the inverse model would map the motor command onto the motor system in order to achieve the desired goal while the forward model would attempt to estimate the next sensory state of the motor system by comparing the predicted movements to the

exemplar visual image. Therefore, while performing visually guided tasks, humans are able to compare the intended action to the visual image of the world and make changes and predictions as they arise.

Miall (2003) states that this two-way process could explain how mirror neurons play a role in imitation learning. Actions are first observed, then transformed by the inverse model into potential motor commands, and the visual consequence for these movements are then predicted by the forward model, for the comparison with the exemplar visual images (Miall, 2003). It could also explain visually tracking hand movement's with predictive eye movements where the gaze shifts in advance anticipating during self or observing another's movements.

This elegant process, however has unresolved issues, as these neural circuits ignore the role of the cerebellum, which has been favoured to act as an internal model (Miall, 2003). The role of the cerebellum in updating motor commands through the comparison between the desired state and that of the efferent copy is evident when the output of motor cortex can be followed to the cerebellum itself. Miall (2003) explains that the posterior parietal cortex (PPC) projects to the cerebellum which then outputs to the ventral pre-motor cortex amongst other areas. He claims that this may be a major route for visuo-motor information that reaches the ventral pre-motor cortex and may act in parallel with mirror neurons and internal models in order track moving objects.

The previous paragraphs provide evidence that the human mirror neuron system is a collection of neural networks that have a high affinity for biological movements.

According to many authors (see Calvert, Bullmore, Brammer, Campbell, Williams, McGuire, Woodruff, Iversen & David, 1997; Puce, Allison, Bentin, Gore & McCarthy,

1998; Grezes, Costes & Decety, 1999; Beauchamp, Lee, Haxby & Martin, 2002), these areas enable humans to distinguish biological from non biological movements because of the high level processes found in the visual dorsal pathway. The probable evolution of the mirror neuron system stems from the importance in the recognition of movement of animated beings; especially in the ability to differentiate between threatening or enticing movements, in order to predict and produce an appropriate response (Blakemore & Frith, 2005).

*Observed interference during incongruent movements*

According to mirror neuron literature, as argued by Kilner et al., (2003), observed interference in motor performance is due to the cognitive and neural resources that overlap during action observation and execution. This overlap seems to be due to the recruitment of mirror neurons and might explain the increased variability in movement performance during tracking of biological movement. Furthermore, these interference effects are amplified during incongruent trials which are widely studied in behavioural studies which adopt a stimulus response compatibility paradigm. The logic of these paradigms is simple. The observation of action A should lead to an internal motor representation of that action. If an alternative action, for example action B, were to be executed while observing action A, action B by virtue of its difference from action A should interfere with the execution of action A. This theory, which has been referred to as ideo-motor, or visuo-motor priming generally states, that congruent movements are performed faster than incongruent movements due to the common area which stimulus and response commands are encoded.

*Experimental Studies I*

Ideo-motor and visuo-motor priming theories have been widely explored in the literature using behavioural studies. Brass, Bekkering & Prinz, (2001) examined movement observation and how it affects movement execution of a simple reaction task. Their experiment tested the assumption that in simple response tasks (i.e. extension or flexion of the index finger), the stimulus-response arrangements with high ideo-motor compatibility led to compatibility effects. In other words, the act to be performed should assist response execution by activating the actual response image, whereas an incompatible action should interfere with response execution (Brass et al., 2001).

In their study, participants were instructed to perform finger tapping movements (extension or flexion) in response to a visual stimuli representing a go signal. The go signal was visualized as photographs of finger movements, the same movement as the participants' (compatible) or different finger movements as the participants' (incompatible). They found that a reaction time (RT) advantage was found during the observation of compatible finger motions than the observation of incompatible finger motions. They attributed their findings due to the compatibility between observed (GO signal) and executed (extension or flexion of the index finger) movement. This finding corresponds with the ideo-motor theory that states that those stimuli with high ideo-motor compatibility activate the corresponding response through the activation of the response image (Brass et al., 2001); resulting in a decrease RT if there is high compatibility between observed and executed movements.

Similarly, in an experiment by Craighero and colleagues (Craighero, Bello, Fadiga & Rizzolatti, 2002), they reviewed the effects of visual stimuli in triggering a

hand grasping movement and the subsequent action. In their experiment, participants were asked to grasp a bar, either statically oriented clockwise or counter-clockwise and to grasp it as fast as possible on the presentation of a visual stimulus. The visual stimulus consisted of a representation of the right hand as reflected on a mirror. The participants were to grasp the bar based on a photograph of the final hand posture necessary for the grasping action, which was either in the same orientation (congruent) or a different orientation (incongruent). They found that RT was the fastest when the presented visual stimuli triggering the hand grasping movement shared a similarity to that of the final hand position required to grasp the bar. Likewise, delayed RT times were found in incongruent presented visual stimuli. They attribute their findings to a strict link between motor activity and perception of visual stimuli as specific neural networks are already attuned for observed actions (Jeannerod, 1994).

These experiments highlight the functional role of congruency in movement performance and increased interference during incongruent movement execution. This premise coupled with the mirror neuron literature might explain why Kilner et al., (2003) observed that performing incongruent biological movements is susceptible to significant interference as opposed to congruent or even incongruent non-biological movements. However, more recent experiments have shown that along with these congruency effects, movement execution and thus performance (such as those observed by Kilner et al., 2003 and previously discussed studies) can also be affected while perceiving non-biological stimuli with human movement characteristics. In fact according to these recent experiments, interference effects may not be subject to the presence of biological agent

such as a human. Interference as observed in the Kilner study may manifest itself with the amount of visual information available to participants.

### *Experimental Studies II*

A study by Press and colleagues (Press, Bird, Flach & Heyes, 2005); found that the presentation of human or robotic hand both elicited automatic imitation. In their experiment, participants were required to perform a compatible (open) or incompatible (closed) movement to either image of human and or robotic hands. There were two styles of each of these stimulus types, one naturalistic and the other schematic. Naturalistic stimulus types were a true image of a human and robotic hand whose size and shape were similar and life-like only differing in colour palette (flesh vs. metallic tones). The schematic stimulus consisted of caricature of both human and robotic hand. They were controlled for colour (all were blue), size, luminance and surface area. They found that reaction time (RT) was significantly faster in compatible movement stimulus as opposed to incompatible movement stimulus particularly in the human trials. However contrary to the results of Kilner et al., (2003) this interference as quantified by delayed RT was found to be in both human and robot trials. The interference effect seemed to increase with the amount of information available to the participants where naturalistic stimulus types resulted in a more delayed RT compared to schematic stimulus types. These results suggest that the action observation/execution system (mirror neuron system) can prime or inhibit action performance for realistic hand images while producing similar priming effects for schematic images of hands. They suggest that this system may be able to distinguish between varying degrees of human and robotic action due to this system's ability to simulate actions within the premotor and parietal cortices.

Along the same vein, several experiments have replicated the Kilner study to tease out what aspects of human movement characteristics that creates this interference effect. Oztop et al., (2005) investigated how similar the implicit perception of a humanoid robot is to a human agent. They asked participants to perform rhythmic arm movements while observing both a human experimenter and a robotic humanoid performing either congruent or incongruent movements. This robotic humanoid, in comparison to the robot used in the Kilner study, had a full body scaled to an actual human with appendages; but most importantly, its movements' were pre-programmed to produce movement trajectories that resembled actual human movement. The variance of the executed movements was used as a measure of the amount of interference in the movements. They found that using a humanoid robot whose movements trajectories closely mimicked that of a human produced similar interference effects as tracking another human. Unlike the Kilner study (2003), both the human and humanoid agents produced a significant interference effect. The authors argue that observing the action of humanoid robots with biological characteristics and human agents may rely on similar perceptual processes.

Similarly, in a recent article by Bouquet and colleagues (Bouquet, Gaurier, Shipley, Toussaint, Blandin, 2007), they investigated the specific behavioural information available to participants from the visual stimuli that triggered the change in their performance. In two experiments, participants were asked to track the congruent and incongruent movements of a human model and point light displays with either biological (pre-recorded human movement) or non biological (artificially manufactured) velocity profiles. During the human model trials, they found that human incongruent trials provided the most interference while similar results were found in both biological and

non-biological point light displays. They argue that movement execution was affected by the information available during biological motion observation where the observer's behaviour is sensitive to movement variability and trajectory not present in non-biological motion. Finally they suggested that upon observation of an incongruent trajectory (point light or human model), the participants perceived the goal of the movement thus interfering with the observer's movement execution.

Finally, in a study by Stanley et al., (2007), two new conditions were added to the Kilner study paradigm. These authors asked participants to track a human experimenter and a set of point-light displays. These conditions saw manipulations to 1) the velocity profile of point-light displays to be biological plausible (pre-recorded human movement) or non-biologically plausible (artificially manufactured), 2) the knowledge of the origin of the stimuli (biological plausible vs. non-biological plausible) given to the participants prior to the start of the trials. For example in one condition, participants would have the knowledge of whether the stimulus they were tracking was either biologically plausible or non-biologically plausible prior to the start of the trial; whereas, in the alternate condition, participants would have no prior knowledge of the origin of the stimuli. They measured the interference effect as the degree of change of the observer's movement performance as affected by observed visual stimuli. Overall, these authors found that tracking another human produced the most interference similar to what the Kilner study (2003) had found. But interestingly, unlike the Kilner study (2003), they found tracking point light displays with biological and non-biological features was enough to elicit the same interference as tracking another human as long as participants were informed of the origin of the visual stimuli. The authors attributed this finding to the participants' ability

to abstractly interpret non-biological stimuli as actual human movement. The authors suggested that participants were able to imagine the movement of the experimenters' effectors from simply informing them of the origin of the stimulus creating a sense of agency from these point-light displays. They argue that the sense of agency or the belief regarding the origin of the point light display (biological/non-biological) is a more determinant factor to the interference effect, as this belief may modulate the processing of the dot movement stimuli upon their later integration within the motor system.

#### *Gaps in the Literature*

Collectively these studies suggest that perceived incongruent movements resulted in significant interference for the concomitant movement execution during observation of biological movements. However it was also evidenced that similar interference effects are present during the observation of non-biological movements with biological characteristics. These biological characteristics that created similar interference effects as observed by Kilner et al., (2003) were as follows: the presentation of increasing similarity to naturalistic hand images (Press et al., 2005), presence of a humanoid robot whose movements mimicked human movements (Oztop et al., 2005), manipulation of velocity profiles from pre-recorded human movements and the knowledge of their origin (Boquet 2007; Stanley et al., 2007). These studies have demonstrated that interference effects may not be subject to the mere observation of a human agent. The mere presence of these biological characteristics in non-biological movements such as the ones cited above seems to produce similar interference effects as observed by Kilner et al., (2003). However, it seems that the presence of minimum jerk trajectories such as bell shape velocity profiles have an inherent biological property due to the CNS ability to minimize

signal dependent noise at end point variability. In light of this evidence, the question of whether similar interference effects as observed by Kilner et al., (2003) present during the tracking of movements that possess the same invariant characteristics of human movement but are not produced by a human (Flash & Hogan, 1985) has not been previously addressed. Could the presence of invariant characteristics in varying levels of non-biological stimuli such as point-light and robot displays, along with the varied information available in 3d virtual human display show similar interference as tracking the movements of a human?

### Hypothesis

Our primary hypothesis is that the overall *interference effect experienced by the participant is positively related to the degree of similarity to actual biological movement.* Furthermore, the interference effect will be heightened with incongruent observation and movement execution. It is expected that visual displays such as point light and robot displays (respectively) will have the least amount of interference due to their non biological characteristics. In contrast, the 3d virtual human and “Human” trials (respectively) due to their biological characteristics should elicit a stronger interference upon movement execution. It is also expected that the overall interference effect for each condition (i.e. point light/robot display, 3d human and Human) will increase according to its similarity to biological movement.

Our secondary hypothesis is that interference found in visual displays will be dependent on its added invariant characteristic of human movement. It is expected that visual displays with invariant characteristics should illicit stronger interference on

movement execution than those visual displays that do not possess these characteristics of human movement (such as sinusoidal or sinusoidal with noise movement characteristic).

## CHAPTER III

### Methods

#### *Participants and Task*

Eight undergraduate and graduate students (mean age= 22.625 yrs, 6 females and 2 males) were asked to perform a visuo-motor tracking task with their right arm either vertically or horizontally at an amplitude of 60 cm to each of the four conditions. These conditions were as follows: (1) An oscillating point light display (PLD) 10cm in diameter on a projected screen, (2) An animated image of a humanoid robot display (RD), (3) A 3-D motion capture human, (4) A human experimenter. Condition one and two were programmed using 3DS Max™ animation program. Each of the four conditions was presented in a randomized counterbalanced order; participants were instructed prior to the start of each trial to perform either a congruent movement (same movement direction as the stimuli) or an incongruent movement (orthogonal movement to the stimuli).

#### *Stimulus Presentation*

The PLD, the arm of the humanoid RD, and the arm of the 3-D motion capture human oscillated at two frequencies (0.75 Hz, 1.0 Hz) either vertically or horizontally across the screen (conditions one to three). The stimuli presentation of the PLD and humanoid RD were presented in one of three ways: (1) Sinusoidal, (2) Sinusoidal with added white noise and (3) With a bell-shaped velocity profile in both phases of the oscillation. All three conditions were programmed using an animation program called 3DS Max™ where standard velocity profiles can be chosen from a resource library. The

added white-noise introduces random undulation of the visual stimuli along a specified movement trajectory. The 3-d motion capture human display consisted of a pre-recorded human in a standard 41 reflective full body marker set. The displays were projected onto a screen (1.27 m X 1.8 m) two metres away from the participant using a laptop connected to a multimedia projector with a refresh rate of 60 Hz.

The human experimenter was in clear view of the participant and stood two metres from the participant and was moving in phase with a light metronome (0.75 Hz, 1.0 Hz) either vertically or horizontally. The light metronome was placed out of the sight of the participants. Recordings began two to three seconds after participants were moving in time with the visual displays or human experimenter. There were five trials in each tested condition lasting 30 seconds each, with a total of 320 tested trials.

#### *Materials and Apparatus*

The experiment was performed in the Sensorimotor Neuroscience Laboratory located at the University of Ottawa (MNT 320). The laboratory contains an eight-camera VICON™ MX-40 system which records kinematic data at 200Hz. The cameras are calibrated for 3D motion capture in two phases; (1) a static calibration phase and (2) a dynamic calibration phase. During the static calibration phase, an L-shaped frame with four reflective markers attached is placed on the floor. The corner of the L-frame represents the origin of the global coordinate system and was placed in the center of the area to be calibrated. The VICON™ system captured the movement kinematics in the vertical and horizontal plane from the reflective markers placed on the index fingers of the participants during the tracking tasks.

### *Data Collection*

Trajectories were recorded from a single reflective marker placed on the participants' right index finger using the VICON™ motion capture system and stored in a conventional PC for analysis. The 3-D kinematic data movement in the vertical and horizontal planes (perpendicular and parallel to the body's coronal plane) were included for each condition and was stored onto a conventional PC for reduction and analysis in MATLAB®.

### *Analysis*

The interference effect or index of interference (IOI) was measured by the variability of the movement in the direction perpendicular to that of the tracking task. For example, the instructed movement (either x plane-horizontal, z plane-vertical) was deemed the dominant plane of movement; while orthogonal to it, the error plane. Therefore, the IOI was quantified as the standard deviation of data points in the error plane orthogonal to the dominant plane of movement (i.e. error plane standard deviation, Figure 1).

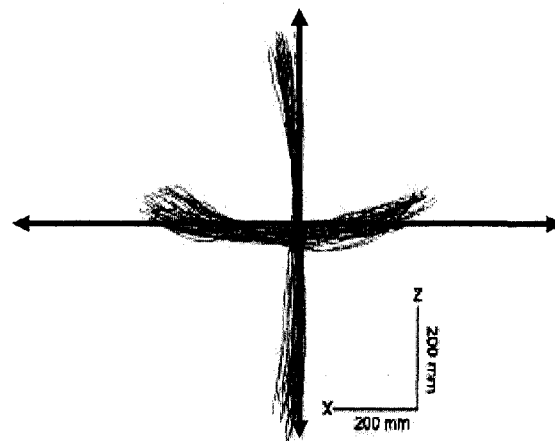


Figure 1. IOI measurement. All vertical and horizontal trajectory points that lie outside a pre-set axis were combined, followed by the calculation of their means.

Two within subject analysis of variance (ANOVA) with repeated measures ( $\alpha < 0.05$ ) were performed based on the nature of the stimuli (PLD versus RD) (3D human versus Human). The first ANOVA with repeated measures (PLD versus RD) was a 2 (Frequency: 075 Hz, 1.0 Hz) x 2 (type: PLD, RD) x 2 (Congruency: Congruent, Incongruent) x 2 (Direction: Vertical, Horizontal) x 3 (Biologicalness: Sinusoidal, Sinusoidal with noise, Minimum Jerk). “Biologicalness” was defined as the type of display presented to the participants with increasing similarity to actual human movement ranging from a sinusoidal to minimum jerk velocity profile. The second ANOVA with repeated measures (3D Human vs Human) was a 2 (Frequency: 075 Hz, 1.0 Hz) x 2 (Congruency: Congruent, Incongruent) x 2 (Type: 3D human, Human) x 2 (direction: Vertical, Horizontal).

## CHAPTER IV

### Results

The primary hypothesis of this study was that the variability experienced by participants would be positively related to the similarity of the visual stimuli to actual biological movement. Specifically, it was hypothesized that tracking incongruent biological stimuli such as that of the 3d human and human would illicit the most interference as well as non-biological stimuli with biological characteristics such as that of a PLD and RD with invariant characteristics. Finally it was hypothesized that the overall variability experienced by the participants would increase in a linear fashion in this manner (PLD < RD < 3d human < Human. Appendix 1: Expected results). Contrary to what was originally hypothesized, the overall interference effect manifested itself in a similar fashion but yet in a different order (RD < PLD < 3d human < Human, Figure 2).

### Grand mean variability comparison for all conditions

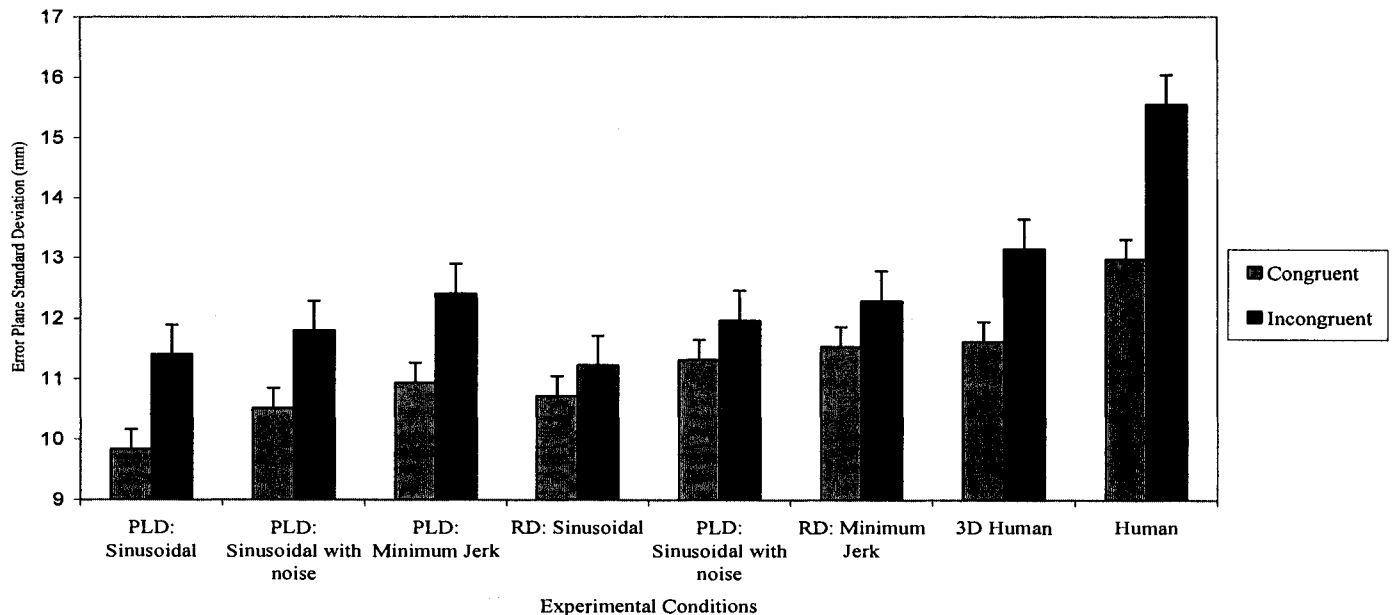


Figure 2: Grand mean variability comparison across all conditions for N=8. PLD and RD represent Point-light and Robot display. An overall congruency effect was observed. Error bars represent standard error.

A main effect of congruency was found at  $F(1, 7) = 24.49, p < 0.002$  (Figure 3).

This analysis demonstrates the general trend of the IOI (thus performance variability) to increase with incongruent stimuli sets ( $M = 11.86$ ) than congruent stimuli sets ( $M = 10.77$ ).

### Mean variability comparison for congruency effect for visual displays

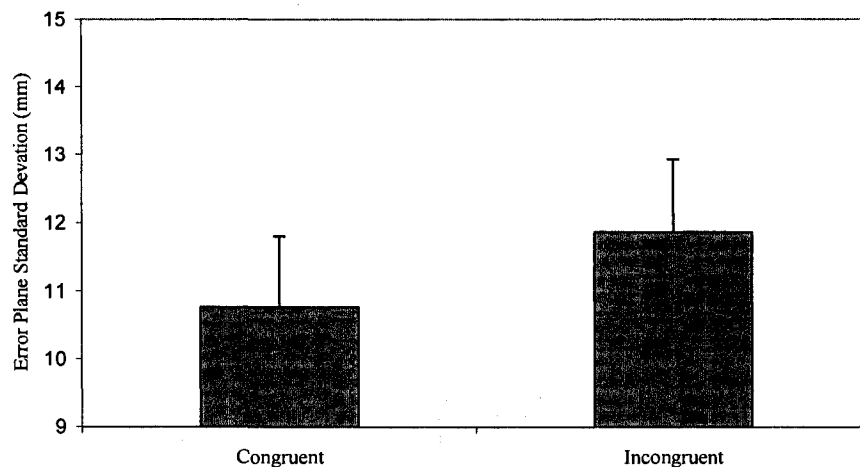


Figure 3: Mean variability comparison for congruency effect in visual display (PLD vs. RD) trials for  $N=8$ . Incongruent trials were observed to be more variable than congruent trials. Error bars represent standard error.

Similarly, a main effect of “biologicalness” was found at  $F(2, 6) = 10.05, p < 0.028$  (Figure 4). This indicated IOI increase as the stimulus sets become more progressively biological (Sinusoidal < Sinusoidal/noise < Minimum Jerk). The sinusoidal visual stimuli resulted in a mean of ( $M = 10.80$ ), sinusoidal with noise visual stimuli resulted in a mean of ( $M = 11.35$ ) and minimum jerk visual stimuli with a mean of ( $M = 11.79$ ).

Upon a closer examination of the pairwise comparisons for the main effect of “biologicalness”, a significant difference between Sinusoidal and Minimum Jerk

Stimulus sets was found at  $p < 0.017$  (Figure 4). No significant differences were found between Sinusoidal and Sinusoidal with noise or Sinusoidal with noise between Minimum Jerk.

### Means variability comparison for “biologicalness” effect for visual displays

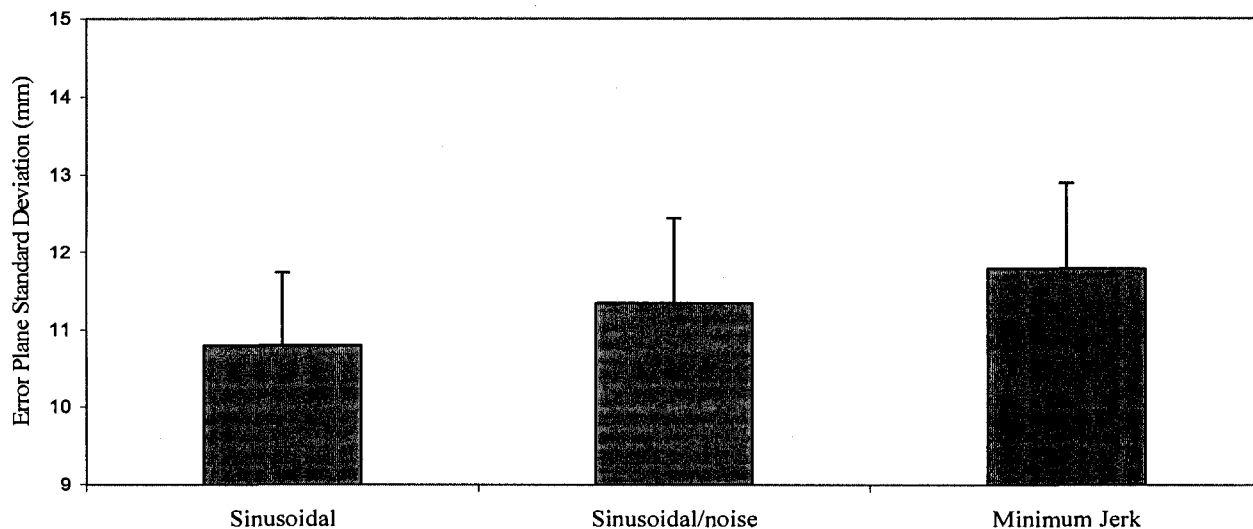


Figure 4: Mean variability comparison for “biologicalness” effect in the visual display trials (PLD vs. RD) for  $N=8$ . It was observed that a general increase of IOI with the increase of biological stimuli. A pairwise comparison revealed a significant difference between Sinusoidal and Minimum Jerk. Error bars represent standard error.

There was a marginally significant effect of type at  $F(1, 7) = 4.932$ ,  $p < 0.062$  (Figure 5), where PLD stimulus sets had a marginally higher interference than RD stimulus sets with respective means of ( $M=11.47$ ) and ( $M=11.05$ ). There were no significant main effects for frequency and direction ( $p=0.713$ ,  $p=0.619$  respectively). An interesting conundrum that was found in the results is the apparent exchange of magnitude of the IOI in RD congruent trials compared to PLD congruent trials. As Figure 6 demonstrates, the IOI of the RD congruent trials seem to have a higher magnitude of

interference compared to the IOI of the PLD congruent trials. Exactly opposite that was observed in incongruent PLD and RD trials.

### Means variability comparison for PLD and RD

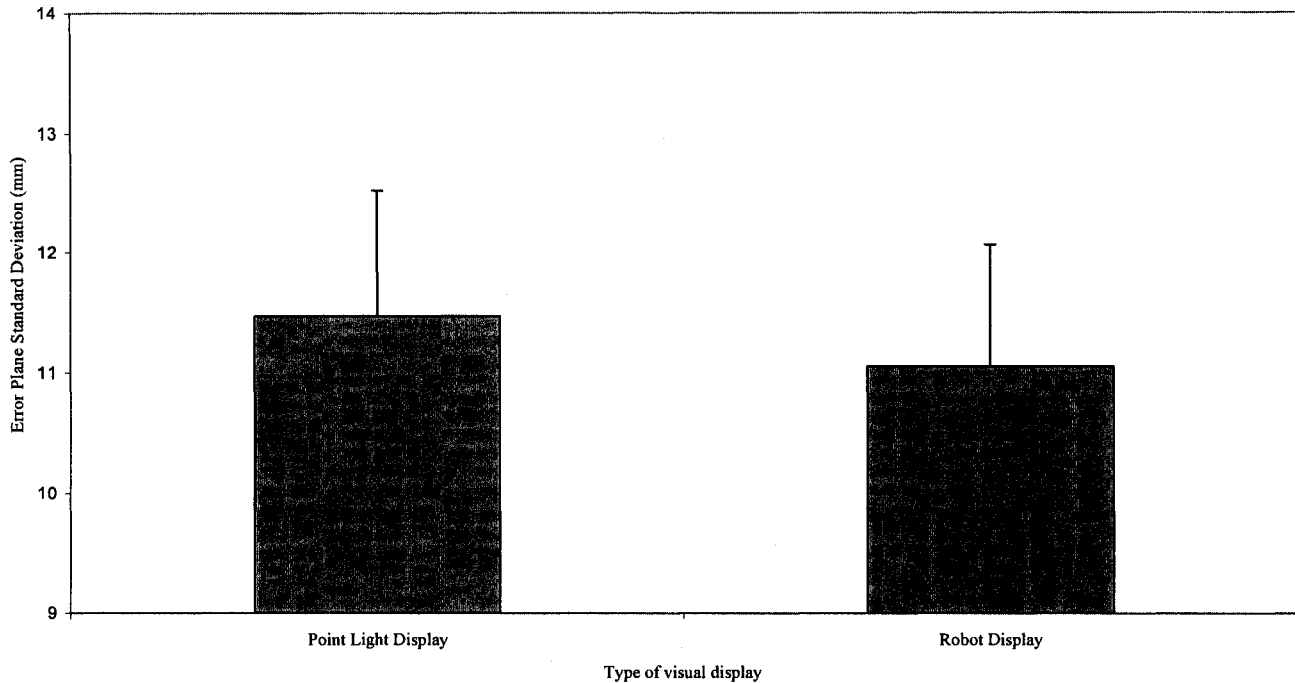


Figure 5: Mean variability comparison of PLD and RD for N=8. It was observed that PLD had marginally significant difference from RD. Error bars represent standard error.

### Mean variability comparison for congruency and type for visual displays

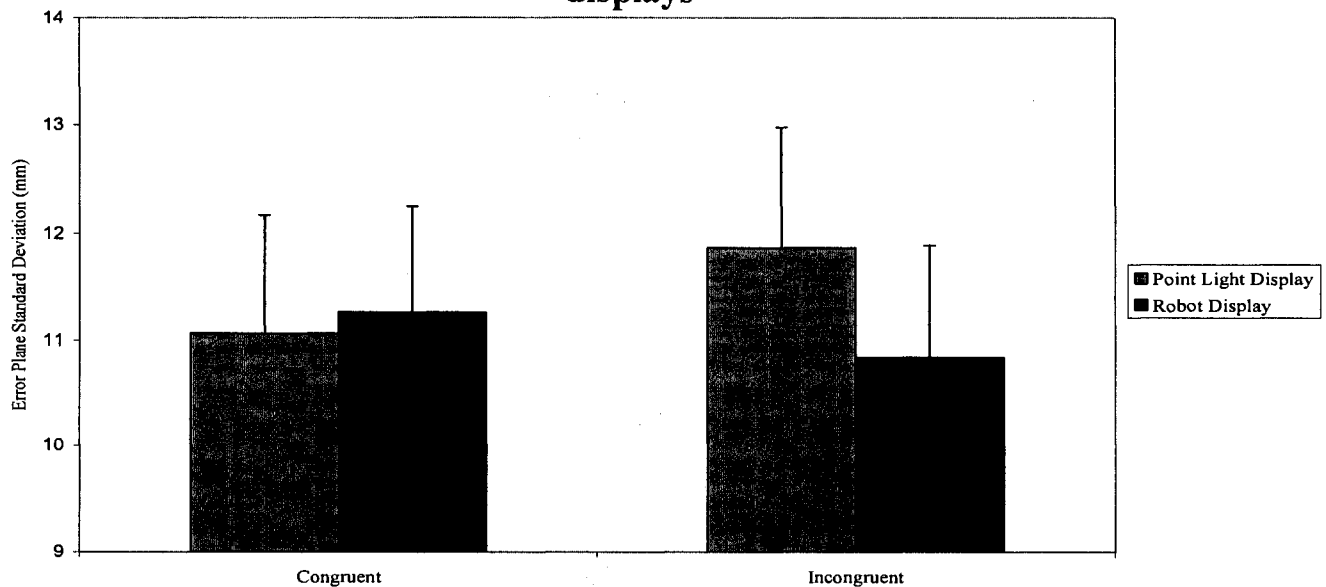


Figure 6: Mean variability comparison between point light and robot displays for N=8. An exchange of IOI magnitude during congruent trials was observed. Error bars represent standard error.

### *“Human” Condition Analysis*

A main effect of congruency was found at  $F(1, 7) = 24.70, p < 0.002$  (Figure 7) with incongruent trials resulting in higher IOI ( $M = 14.35$ ) compared to congruent trials resulting in lower IOI ( $M = 12.30$ ). Figure 8 demonstrates a main effect of type found at  $F(1, 7) = 21.73, p < 0.002$ , with human trials had a higher IOI ( $M = 14.26$ ) mean than 3d human trials ( $M = 12.38$ ). Similar to the previous analysis, there is a general trend for the IOI to increase as stimulus sets became more biological (3D Human < Human, Figure 9). Furthermore, a two way interaction between congruency and type  $F(1, 7) = 6.75, p < 0.036$  (Figure 9a) was found where incongruent 3d human and Human trials ( $M = 13.15, M = 15.55$ ; respectively) were clearly more variable than the congruent trials counterpart (3d human,  $M = 11.63$ ; Human,  $M = 12.97$ ). It seems that congruency was significantly affected by the type of visual stimuli being perceived. The observation of a progressively more biological stimulus (3d human to Human) produced greater interference.

### **Mean variability comparison for congruency effect for “Human” conditions**

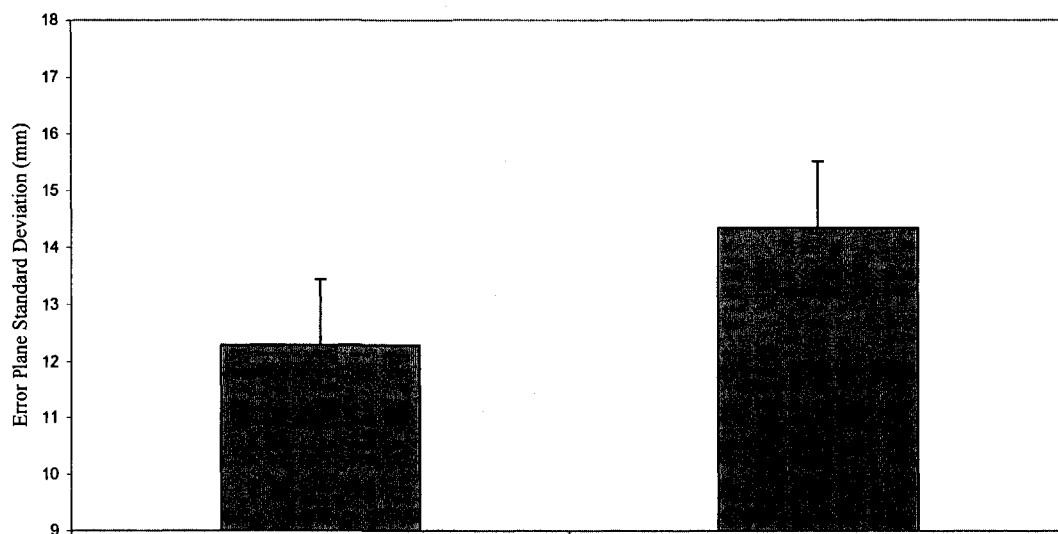


Figure 7: Mean variability comparison for main effect of congruency for “Human” conditions for  $N = 8$ . Error bars represent standard error.

### Mean variability comparison for effect of type for “Human” conditions

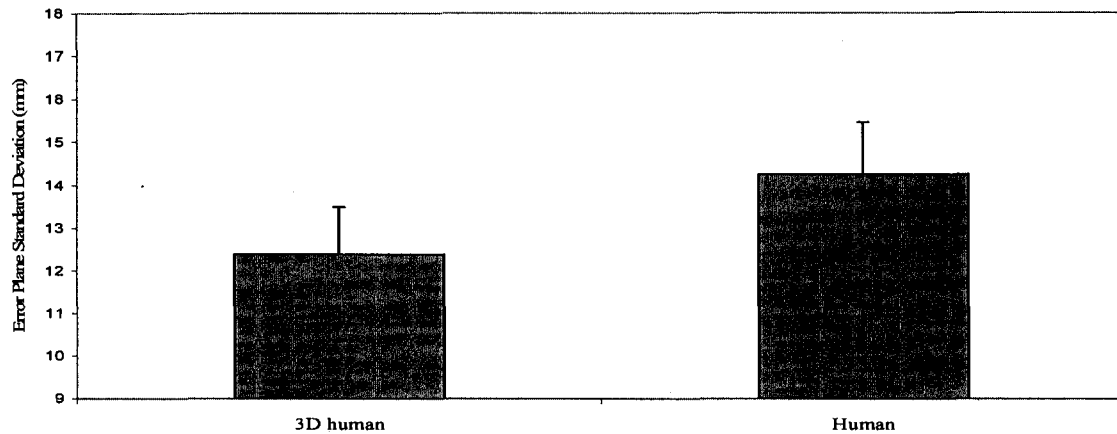


Figure 8: Mean variability comparison for main effect of type (3d human vs Human) for “Human” conditions for N=8. Error bars represent standard error.

No other significant main effects for frequency and direction ( $p=0.525$ ,  $p=0.215$  respectively) or interactions were discovered.

### Mean variability comparison for congruency and type for “Human” conditions

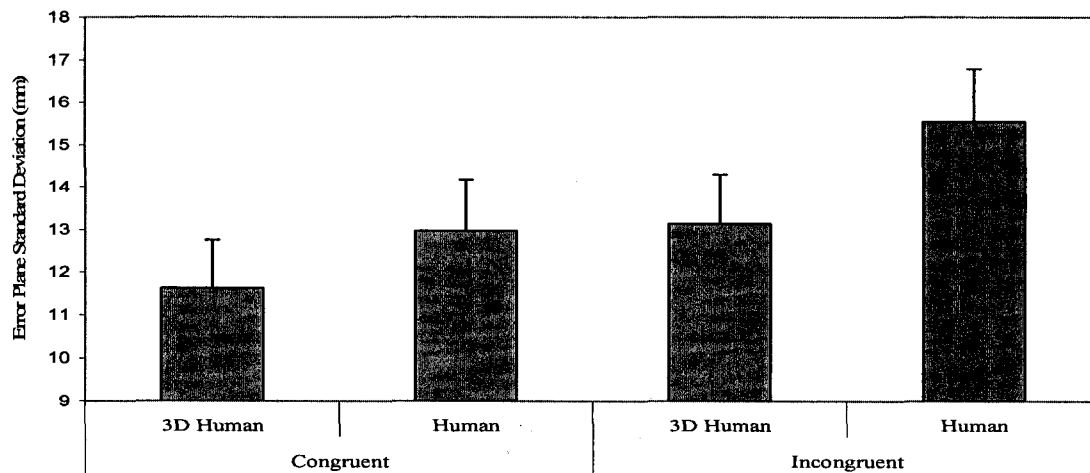


Figure 9: Mean variability comparison between congruency and type for 3d human and Human trials for N=8. Error bars represent standard error.

**Mean variability comparison for main interaction congruency x type for  
"Human" conditions**

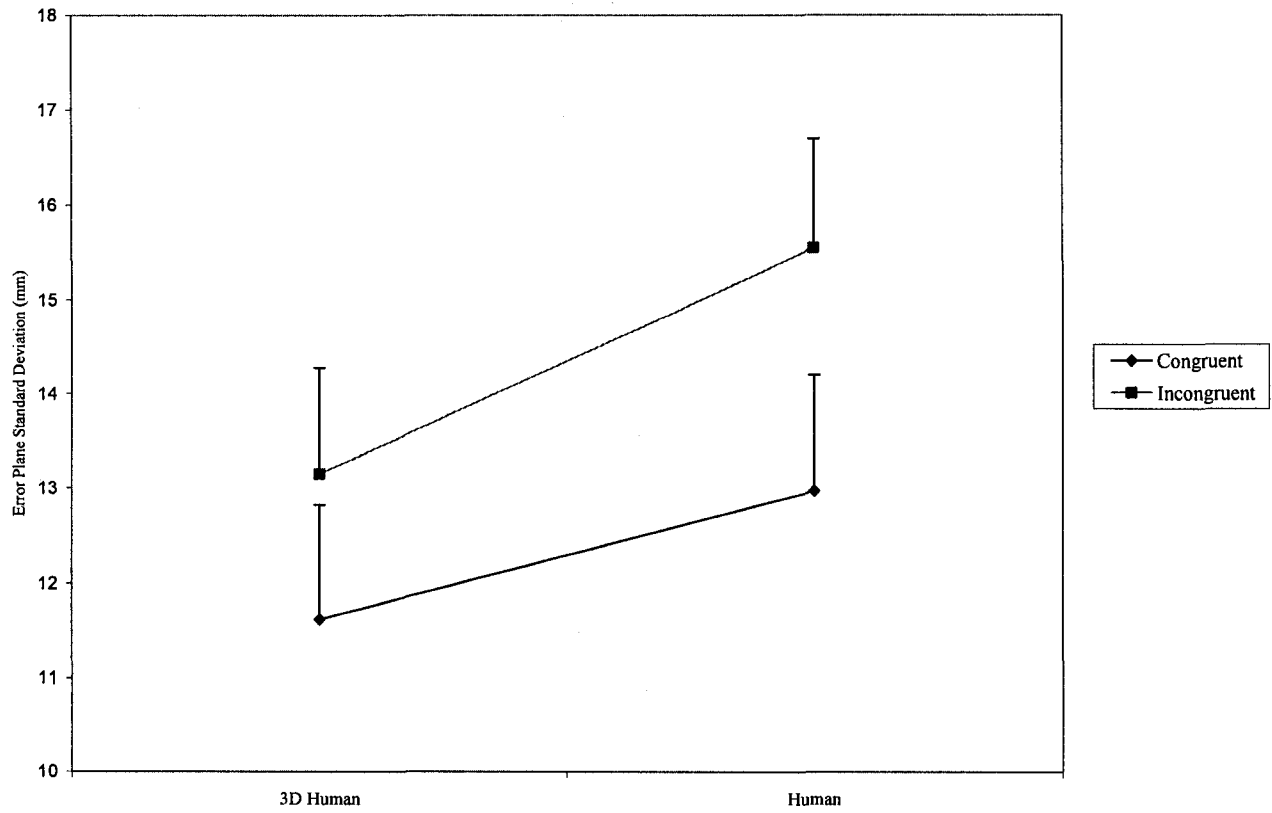


Figure 9a: Main interaction of congruency x type for 3d human and "Human" conditions for N=8. Error bars represent standard error.

## CHAPTER IV

*Discussion*

The present study investigated the influences of the varied levels of “biologicalness” that can be introduced in a non-biological visual display that is not humanoid, as well as having the visual displays of non-biological movement and the human displays of biological movement vary in the amount of visual information available as observed by Kilner et al., (2003) and previously discussed studies (Bouquet et al., 2007; Press et al., 2005; Oztop et al., 2005; Stanley et al., 2007)

Collectively, these studies suggest that more interference is observed for perceived incongruent stimuli on concomitant executed movements during perception of both biological and non biological movements with biological characteristics.

*Source of congruency effects*

In our dynamic environment, humans are continuously bombarded with visual information that frequently creates interference upon their perception. These interference effects have been quantified by many studies as the increased variance of executed movement trajectories or delayed reaction times. Moreover, these effects are heightened when perceived visual stimuli are incongruent to the intended movement to be executed (Brass et al., 2001; Craighero et al., 2002; Kilner et al., 2003; Oztop et al., 2005; Press et al., 2005; Stanley et al., 2007). Collectively, these studies suggest that there is an overlap between the perception of visual stimuli and the execution of an intended movement.

Prinz (1997) proposed that a common coding region bridges this relationship insomuch that cognitive representations of action, play a critical role in the planning and control of actions. Essentially, he argued that the encoding of observed and executed

movements occurs within a common coding region. Thus, interference observed at the periphery as movement variability may occur at the level of this common coding region by virtue of differences between the encoded observed and to-be-executed movements of the observer.

It has been suggested that the source of this interference effect might be explained by the two main classifications of mirror neurons (Rizzolatti et al., 1996; Stanley et al., 2007). First, strictly congruent mirror neurons that respond to effector and muscle grouping and second, broadly congruent mirror neurons that respond to a more abstract representation of movement where the action is interpreted on the basis of its goal. Blakemore & Frith (2005) outlined that these mirror neurons might be part of a higher order sophisticated predictive system in a form of a motor contagion resulting in the interference effect. They hypothesize that during incongruent observed movements, the observed interference effect is a result of a partial blending of the encoded observed movement and ongoing motor output. According to Iacoboni (2005) and Kilner et al., (2003) this whole process is presumably initiated at the STS which is hypothesized to be indirectly connected to the ventral pre-motor cortex.

We propose that the interference effects experienced by the participants are due to automatic motor contagion that is elicited by the activation of mirror neurons. From visual inspection of Figure 2, our experiments confirm these congruency effects in both visual displays and “Human” conditions. As expected, greater interference was observed in tracking another human during incongruent trials (Figure 2), essentially replicating the results from Kilner et al., (2003). We suggest that during “Human” conditions, strictly congruent mirror neurons were activated as part of this overlap in neural processes

(Kilner et al., 2003) or common coding region (Prinz, 1997), where movement specificity (processing of fine motor details) is processed resulting in this congruency effect. As per the finding illustrated on Figure 9 & 9a respectively, of a main effect of type (human vs. 3d human) and a main interaction between type and congruency, this is supported by the robust research that argues that movements of biological systems (humans) are sensitive to biological movements and characteristic (Johansson, 1973; Johansson, von Hofsen & Jansson, 1980). Visual cues in the form of point light displays such a representation of a human movement such as walking or dancing is enough to be recognized by activating biological motion recognition areas in the brain such as the STS (Johansson, 1973; Johansson et al., 1980; Perrett 1994; Perrett et al., 1985a, 1985b; Perrett et al., 1992) amongst others such as the human MT/V5 complex, posterior inferior temporal gyrus (Peuskens et al., 2005). The role of the STS was highlighted in the introduction where it serves as a center for differentiating between biological and non biological movement. However, though this robust research does support our findings, it should be noted that perhaps another source of the interference effect might also be due to the some protocol shortcomings. For example, during “Human” conditions, particularly during the Human trials (tracking the movements of the human experimenter), the interference experienced by the performer might have been heightened by the interference experienced by the experimenter and vice versa. By observing the movements of the performer, the experimenter’s movements are susceptible to the same interference effects as the observer. Thus, this effect could have added to the overall interference found in the results, particularly during Human incongruent trials. Perhaps for future studies, particularly ones that adopt an action observation and execution paradigm where

observing biological movements are employed, the human experimenter should be blindfolded. This protocol change could minimize the influence of movement observation on the experimenter and on the participant.

*Effects of agency on biological movement during PLD stimuli*

Similar to Stanley et al., (2007), we propose that our results that indicate interference during tracking of non biological stimulus sets with invariant characteristics occurs at an abstract level (participants are processing the goal of the actor's movement); therefore, activating broadly congruent mirror neurons. We believe that our participants were able to interpret biological movements from visual displays (PLD vs. RD) with the mere manipulation of their velocity profiles to resemble actual human movement (minimum jerk trajectories with bell shape velocity profiles). This velocity based "biologicalness" property will be discussed in the following section.

Particularly during PLD stimuli, participants may have imagined the unobserved arm of the experimenter in turn activating pre-motor neurons resulting in the interference effect. This is supported by Umiltà et al., (2001) where pre-motor neurons are activated even after the occlusion of an observed end-point action and studies that show activation of motion processing sites such as the STS (Johanson 1973; Johanson et al., 1980; Oram & Perrett 1994; Perrett et al., 1985a, 1985b; Perrett et al., 1992; Peuskens et al., 2005) from static or action representation stimuli. This agency effect, as observed in our experiment, is seen in the overall trend of the interference effect in PLD displays to have a larger magnitude than that of RD stimuli (Figure 5). We believe that this was only approaching significance ( $p < 0.062$ ) because in contrast to Stanley et al., (2007) where

they divulged the origin of the visual stimuli (biological vs. non biological), whereas our protocol did not, may have accentuated the agency effect.

*“Biologicalness” effects from invariant characteristics of movement*

Our sensitivity to biological movements is highlighted by the above discussion which explains two main points as summarized here: Congruency effects may be due to an activation of mirror neurons (strictly vs. broadly congruent) as part of an overlap between neural processes that involve action observation and execution. Activations of these neurons may perhaps be stimuli based (movement specific or abstract), possibly accounting for agency effects. However, the highlight of our study stems from manipulating the velocity profiles of non-biological stimulus sets presented in varied levels to resemble actual human movement.

Flash & Hogan (1985) discovered that discrete goal-directed movements seem to produce bell shape velocity profiles regardless of trajectory path. It has been suggested that this invariant characteristic is a result of the CNS ability to optimize noise within the system (Harris & Wolpert 1998). They conclude that these trajectories optimize post-variance movement in the presence of single-dependent noise and might very well be the biological underpinning of both saccadic eye and arm movement.

From visual inspection of Figure 4, the interference effect is directly related with the stimuli's increasing similarity to biological movement (Sinusoidal<Sinusoidal/ noise< Minimum Jerk). Our results seem to suggest that the observation of these invariant characteristics may also activate broadly congruent mirror neurons presumably due to the abstract nature of the stimuli. Furthermore, this evidence leads us to believe that our CNS is highly attuned to biological properties at the most fundamental level. The mere

observation of a PLD with a bell shape velocity profile is assumed to be enough to perceive it as human movement suggesting that the neural mechanism for the observation of movement optimality has similar roots as the perception of it. This is supported by previous research that has stated that biological motions can be unconsciously processed (Stanley et al., 2007; Viviani & Stucchi, 1992a, 1992b; Viviani, BaudBovy & Redolfi, 1997) and that biological motion is detected by the perceptual system through movement kinematics rather than location or spatial information (Orliaguet, Kandel & Boe, 1997).

Quite interestingly, this “biologicalness” effect (Sinusoidal/Sinusoidal/ noise/ Minimum Jerk) seems to be stimulus dependent. For example, when you inspect the IOI for PLD and RD independently, this “biologicalness” effect is observed (Figure 2 and 4) but when compared to each other, the overall IOI for PLD’s seem to have a greater magnitude than that of the overall IOI for RD’s (Figure 5). This finding seems to support the importance of the belief of the biological origin or abstract representation of the stimuli is a more determinant factor for the interference effect.

However, a conundrum was found during the IOI comparison between the PLD and RD during congruent trials. Unlike what was seen during incongruent trials, it was observed that there was a switch in the interference effect in the RD than in PLD during congruent trials (Figure 6). It is unclear to why this was only observed in the congruent trials between these two visual displays. It is important to note that when the 3d human and “Human” trial conditions were compared, the “Human” trials had a higher interference for both congruent and incongruent trials compared to that of the 3d human trial conditions (Figure 9 & 9a). In light of this unsolved puzzle we propose that this effect could be the result of different tracking strategies that participants may have used

during congruent trials. Participants were told at the beginning of each trial to perform either congruent or incongruent movement to the stimuli, which implies to track the visual stimuli. It is plausible that due to the lack of further instructions such as to track the movement stimuli throughout its movement trajectory; other strategies might have been employed. We suggest that one of the strategies that were employed include: timing to a pre-defined macro-scopic landmark. Participants might have only kept synchronized with the stimuli by assigning landmarks on the screen to follow as opposed to actually tracking the visual stimuli throughout the whole trial. Perhaps similar to the agency effect as seen in the Stanley et al., (2007) experiment, where informed instruction of the origin of the stimuli affected motor performance in their experiment, informed instructions to how to track the visual stimuli could have resulted in the conundrum found in our results. Also it is possible that this effect is not present during incongruent trials and is more agreement with the results of Stanley et al., (2007) (effect of agency) due to the increase cognitive and neural processes that are involved in performing incongruent movements. Thus, the neural processes needed to be recruited to track an incongruent stimulus may have accentuated the congruency effect. This is supported by studies that have suggested (Blakemore and Frith, 2005; Brass et al., 2001; Kilner et al., 2003; Oztop et al., 2005; Stanley et al., 2007) that there is an overlap in cognitive and neural resources involved in action observation and execution.

#### *Limitations and future directions*

A main limitation of this study is the inability to directly assess the role that mirror neurons play during the tracking of biological and non biological movements. Theoretically, mirror neurons are activated during these particular tasks such as self

movement and observing a biological organism performing goal-directed movements. Given the equipment constraints such as the lack of access to neuro-imaging technologies to record activated brain areas, researchers can only make inferences to the origin of the neural pathway of the interference effect. Only assumptions based on previous studies provide indirect evidence and further study should focus on using such devices to provide direct evidence implicating these areas during the tracking of biological and non biological movements with invariant characteristics.

Possible future studies that have stemmed from the current study is 1) explore if interference effects as observed in our study using point light displays with invariant characteristics of movement, are present in special populations such as autism who have been hypothesized to have a less than normal functioning mirror neuron systems (Oberman, Hubbard, McCleery, Altschuler, Ramachandran & Pineda, 2005) and 2) the effect agency on the tracking of biological and non biological movement. The 2<sup>nd</sup> future study is currently under investigation in our laboratory where the origin of the velocity profiles is disclosed to participants prior to the start of the tracking task while manipulating the velocity profiles of the point light displays.

### Conclusion

In conclusion, do movement interference effects during tracking of biological and non-biological movements with biological characteristics share a common behavioural and neural mechanism? Though our results are unable to answer this question, our results seem to suggest that these biological characteristics seem to be dependent on two elements, velocity based “biologicalness” and the abstract representations of visual stimuli. We argue that the observation and perception of movement optimality that result

in the abstract representation of human movement seem to produce similar interference effects as tracking another human. These effects occur due to the overlap between action observation and execution processes which are invariably initiated at the STS, feeding into the ventral pre-motor cortex. Though our results are unable to differentiate which element contributes more to the interference effect, it is clear that the interplay between them is its elicitor. Behavioural studies such as ours are limited to making inferences of the origin of these neural pathways that illicit this interference effect, thus these results need to be verified through neuro-imaging techniques to fully understand the constituents responsible.

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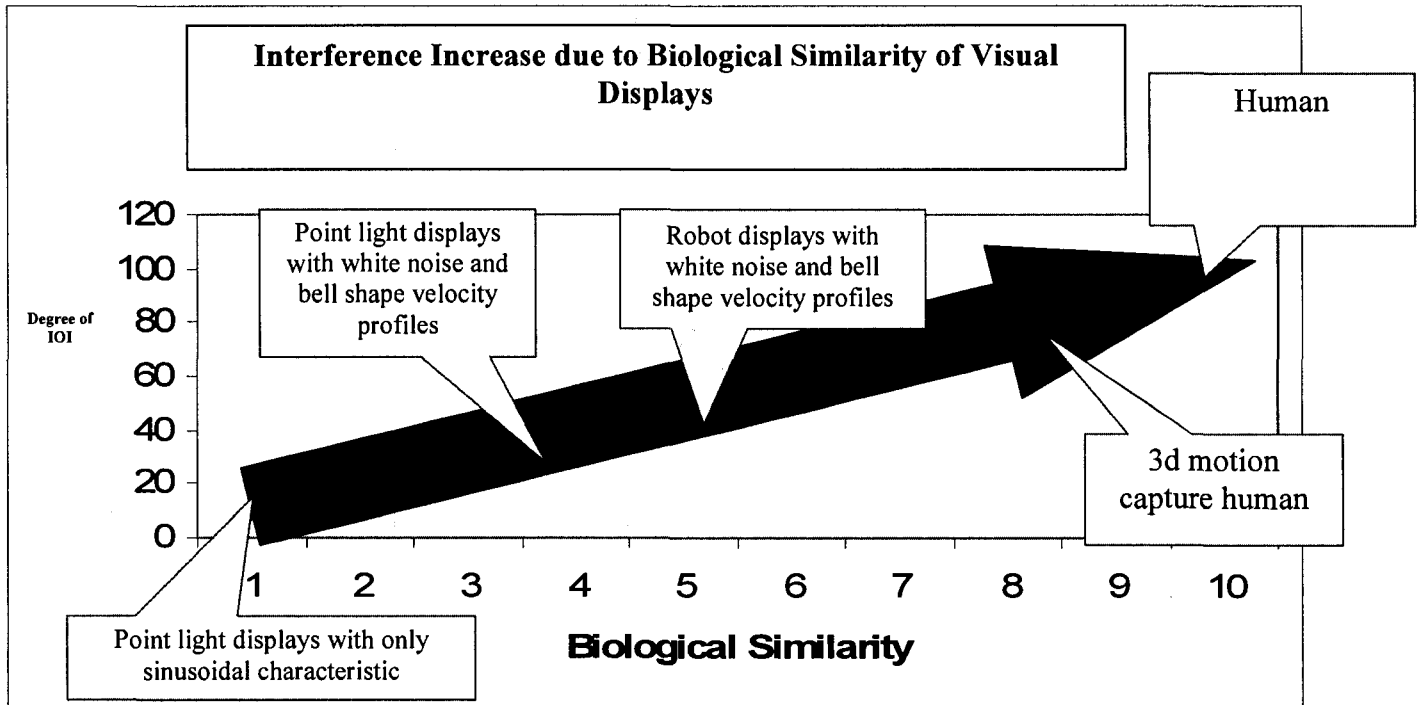
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Appendix 1- Expected summary of results



## Appendix 2

Table 1- Summary of results: Visual condition analysis. Mean IOI for each condition.

Main Effect/Interaction	Frequency		Congruency*		Type**		Direction		Biologicalness**		
	0.75 Hz	1.0 Hz	Congruent	Incongruent	PLD	RD	Vertical	Horizontal	Sinusoidal***	Sinusoidal/noise	Minimum Jerk***
IOI (mm) (mean $\pm$ SD)	11.43 $\pm$ 1.52	11.20 $\pm$ 1.06	10.77 $\pm$ 1.04	11.86 $\pm$ 1.06	11.47 $\pm$ 1.05	11.05 $\pm$ 1.14	11.04 $\pm$ 1.06	11.23 $\pm$ 1.06	10.8 $\pm$ 0.94	11.35 $\pm$ 1.1	11.79 $\pm$ 1.11

\* $p < 0.002$ , \*\*  $p < 0.028$ , \*\*\*  $p < 0.017$

## Appendix 3

Main Effect/Interaction	Frequency		Congruency*		Type**		Direction		Type x Congruency***			
	0.75 Hz	1.0 Hz	Congruent	Incongruent	3d human	Human	Vertical	Horizontal	Congruent		Incongruent	
IOI (mm) (mean ± SD)	13.48± 1.20	13.17 ± 1.12	12.30 ± 1.14	14.35 ± 1.17	12.39 ± 1.11	14.26 ± 1.20	13.10 ± 1.10	13.61 ± 1.22	3d Human	Human	3d Human	Human
									11.63 ± 1.13	12.97 ± 1.20	13.15 ± 1.15	15.55 ± 1.23

\* $p < 0.002$ , \*\*  $p < 0.002$ , \*\*\*  $p < 0.036$



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Service de subventions de recherche et de technologie Research Grants and Ethics Services

## HEALTH SCIENCES AND SCIENCE RESEARCH ETHICS BOARD

### CERTIFICATE OF ETHICAL APPROVAL

This is to certify that the University of Ottawa Health Sciences and Science Research Ethics Board has examined the application for ethical approval of the research project entitled **Mirror neurons and the interference effect during visuo-motor tracking of biological movement (file H 10-05-07)** submitted by Dr. Ramesh Balasubramaniam of the School of Human Kinetics, University of Ottawa. The Board found that this research project met appropriate ethical standards as outlined in the Tri-Council Policy Statement and in the Procedures of the University of Ottawa Research Ethics Boards, and accordingly gave it a Category 1a (approval). This certification is valid one year from the date indicated below.

January 26 2006

Date

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Rita D'Alessandro  
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Services de subventions de recherche et de technologie Research Grants and Ethics Services

## HEALTH SCIENCES AND SCIENCE RESEARCH ETHICS BOARD

### CERTIFICATION OF ETHICS APPROVAL

This is to certify that the University of Ottawa Health Sciences and Science Research Ethics Board (REB) examined the application for extension of ethics approval for the research project **Mirror Neurons and the Interference Effect during Visuo-Motor Tracking of Biological Movement** (file H 10-05-07) submitted by Ramesh Balasubramaniam of the School of Human Kinetics. This project received initial ethics approval on January 26, 2006 by the REB as meeting appropriate ethical standards set out in the Tri-Council Policy Statement and in the Procedures of the University of Ottawa Research Ethics Boards. The University of Ottawa REB members accordingly gave it a one-year extension of ethics approval. This ethics renewal certification is retroactive to January 26, 2007 and valid until January 26, 2008.

January 26, 2007

Date

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Rita D'Alessandro  
Protocol Officer for Ethics in Research  
For Dr. Daniel Lagarec, Chair of the  
Health Sciences and Science REB