

CONCURRENT ACTION AND PERCEPTION

THE EFFECT OF CONCURRENT MOTOR ACTIVITY ON THE PERCEPTION OF
BIOLOGICAL MOTION

By

Simran Singh Ohson, B.Sc.Kin

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PERCEPTION OF BIOLOGICAL MOTION

AUTHOR: Simran Singh Ohson, B.Sc.Kin (McMaster University)

SUPERVISORS: James L. Lyons, PhD. & Timothy. D. Lee, PhD.

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ABSTRACT

Recent efforts to explain the underlying mechanisms of action observation have resulted in several theoretical frameworks. The Common Coding framework proposes that the perception and action areas of the brain share representations of visual and motor feedback such that areas are activated concurrently, there is a benefit to an individual's perceptual ability and confidence. The MOSAIC framework, on the other hand, proposes that these benefits derive from self generations of motor commands during voluntary movement. This study aimed to observe the effects of concurrent motor activity on perceptual ability and judgments of performance. Participants observed an animated avatar performing pairs of symbol tracings on a screen. Participants were also placed into one of three concurrent movement groups: voluntary concurrent symbol tracing, non-voluntary concurrent symbol tracing or observation (no concurrent symbol tracing). It was expected that the group with voluntary concurrent movement would exhibit a higher perceptual accuracy and greater ability to judge performance than both the non-voluntary concurrent movement group and the observation group. However, all participants demonstrated the same level of perceptual accuracy, regardless of the level of concurrent movement. The decreased ability for voluntary movement participants was likely due to significant movement initiation time delays associated with cognitive processing of visual stimuli. As such, voluntary participants did not move in synchrony with the display. Nevertheless, both movement groups had a greater ability of judging performance, suggesting that judgments of performance may be obtained using different pathways than those involved in perceptual accuracy. Findings support both the Common Coding and

MOSAIC frameworks, suggesting that a perceptual benefit can only be obtained when movement is in synchrony with perception.

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Introduction

It's 12:30 pm on a busy university campus. Students are bustling about in all directions. Bicyclists are attempting to weave through the throngs of traffic. You are meeting an old friend for lunch. How will you ever find them in this horde of people? Suddenly you notice someone walking in the distance. Their face is obscured, but you are still able to recognize your friend from their unique walking pattern. How is this possible? For many years now, researchers have been examining this skill. How do we learn to identify individuals based on their actions? Which factors of movement are important in forming these judgments? This area of research, broadly termed "Action Observation", has uncovered the integrity and complexity of human's ability to observe action.

Point Light Displays

Johansson (1973) was one of the first action observation researchers to use a revolutionary new technology called "Point Light Displays" to demonstrate humans' perception of action ability. Participants viewed displays of walking participants wearing black clothing with light bulbs fixed at various major joints. The only information available to the viewer was the collection of several bright light bulbs moving on a black screen. Even in this degraded visual condition, participants were still able to correctly perceive the display as a walking individual. However, it is only when the light bulbs are in motion that the participants are able to recognize the presented action. That is, participants are only able to make predictions on the presented dots

because they reflect joint relationships that an observer would be familiar with, such as the relative movement of a wrist with the contralateral leg. This suggests that unaltered “biological” motion is integral to the perception of point light displays. This was one of the first demonstrations of human movement observation, similar to the initial findings by Maas (1971) (as cited by Johansson, 1973), who observed that participants are able to discriminate between actions involving two or more people in a minimalistic viewing environment. Moreover, the study also introduced the use of point light displays, which allow for the presentation of movement in a minimalistic fashion, usually consisting of 10-32 infrared markers located at important joints or body landmarks.

Point light displays are commonly used tools in Action Observation literature, because they demonstrate perceptual capacity. For example, Cutting and Kozlowski (1977) used a similar point light display paradigm to examine the ability of participants to differentiate between different gait patterns. Upon viewing these stimuli, observers were able to successfully differentiate between their own gait and the gait of other participants. All participants were highly acquainted with each other, thus demonstrating the common day phenomenon of recognizing friends from their movement. Observers' abilities in recognizing actions while viewing minimalistic point light displays and have been replicated with updated point light display technology (Hill & Johnston, 2001, Jokisch, Daum & Troje, 2006). In fact, a multitude of studies have uncovered that these abilities are quite robust, as participants can also extract other information from point light displays such as gender (Cutting, 1978; Pollick, Lestou, Ryu, & Cho, 2002), emotion

(Dittrich, Troscianko, Lea, & Morgan, 1996), and even deceptive behavior from point-light animations (Runeson & Frykholm, 1981).

Neurophysiological Basis of Action Observation

Results by di Pellegrino, Fadiga, Fogassi, Gallese and Rizzolatti (1992) provided insight into the neurological framework of these action observation abilities. It was found that a macaque monkey's prefrontal cortex discharges during the observation of a goal-directed movement (such as reaching for an object) performed by a human researcher. A follow up imaging study reinforced the presence of specialized "mirror" neurons in the prefrontal cortex that are active during both the observation and execution of actions (Rizzolatti, Fadiga, Gallese & Fogassi, 1996). The same "mirror" system has also been observed in humans as well (Fadiga, Fogassi, Pavesi & Rizzolatti, 1995).

However, it is possible that these special neurons are not specific to the prefrontal cortex, but rather a collection of multiple areas in the brain. There is evidence of significant fMRI or PET activation around the parietal areas and the superior temporal sulcus (STS) during action observation tasks (Grafton, Arbib, Fadiga & Rizzolatti, 1996; Iacoboni, Koski, Brass, Bekkering, Woods, Dubeau, Mazziotta & Rizzolatti, 2001, Buccino Binkofski, Fink, Fadiga, Fogassi, Gallese, Seitz, Zilles, Rizzolatti & Freund, 2001; Beauchamp, Lee, Haxby & Martin, 2003). In these tasks, the STS was primarily active during the perception of motion, thus suggesting the STS is integral to successful action observation (Grossman & Blake, 2001; Grossman, Battelli & Pascual-Leone, 2005). One view of these findings is that perception of movement begins with the dorsal and ventral visual pathways in the brain, commonly referred to as processing streams

(Goodale & Milner, 1992). The dorsal stream is primarily involved with extracting basic spatial information, such as where someone's arm is moving during gait, whereas the ventral streams incorporate memory to extract semantic information for recognition or retention, such as if the walker's arm movement is the same as your friend's. It is believed that the STS is essential to the integration of these two streams to extract relevant movement information (Blakemore & Decety, 2001). Decety et al. (1997) applied the two-stream hypothesis to an action observation paradigm. Participants observed meaningful and meaningless actions with the intent to imitate or recognize each action. Meaningful actions consisted of common everyday actions, such as opening a bottle, drawing a line, sewing a button, hammering a nail, pantomimed by a right handed actor. Meaningless actions consisted of American Sign Language (ASL) signs and were chosen according to temporal and spatial appearance similarities to the meaningful actions. Participants were recorded using a PET scan during imitation or recognizing actions. They found that when observing meaningless actions, participants rely on the dorsal pathway's kinematic information for action observation. However, when observing a meaningful action, memory-related structures in the ventral pathway were activated in order to extract relevance out of the movement (Decety et al., 1997). A more recent fMRI study has found activity in the dorsal premotor, supplementary motor, middle cingulate, somatosensory, superior parietal, middle temporal cortex and cerebellum during the observation and execution of action, suggesting that they all may play a part in the perception of action (Gazzola & Keysers, 2009). The STS, along with the aforementioned collection of prefrontal areas relevant to action observation, are

known collectively as the “Action Observation Network” (AON) (e.g. Cross, Kraemer, Hamilton, Kelley & Grafton, 2009).

Action Observation Frameworks

There is still a debate surrounding the mechanism of how the perceptual system predicts observed actions and learns to identify new actions. The two leading hypotheses proposed that the perceptual system either adapts to actions through experience (Johansson, 1973) or is an innate system acquired with birth (Meltzoff & Moore, 1977). For example, results of a study observing the imitation ability of infants supported the later (Meltzoff and Moore, 1977). Parents performed various movements in the presence of their infant children, and they observed that the infants were able to successfully replicate the majority of these movements. Because the infants had little to no experience with movement observation and imitation, it was believed that the mechanism for action observation is innate and present at birth. As such, they formulated the Intermodal Matching hypothesis, which states that sets of unchanging connections between visual and motor areas allow for mimicking and action observation. However, this hypothesis does not explain why observers are better able to identify movements with which they are highly experienced.

Johansson (1973) had originally posited that experience plays a major role in the action observation abilities. Recent research lends credence to this hypothesis, such as Buccino, Lui, Canessa, Patteri, Lagravinese, Benuzzi, Porro, and Rizzolatti (2004), who observed greater fMRI activation in the AON upon observation of human movement over animal movement. Calvo-Merino, Glaser, Grèzes, Passingham and Haggard (2005) and

Calvo-Merino, Grèzes, Glaser, Passingham and Haggard (2006) observed that expert dancers have a higher fMRI activation in the AON when observing types of dances they were experienced with instead of those which they have minimal experience. Orgs, Dombrowski, Heil and Jansen-Osmann (2008) replicated the previous findings using an electrophysiological measure with an electroencephalogram, and were able to see higher AON activation upon viewing familiar movements. Kilner, Paulignan and Blakemore (2003) also observed that human movement was impeded by incongruent human stimuli and not robotic stimuli, suggesting that only familiar movements are adequately processed during concurrent observation.

These results strongly support the second possibility for action observation frameworks. Prinz (1997) proposed a mechanism that accounted for experience and learning in the AON. Prinz observed an interference effect during the Müsseler (1995) arrow task (as cited by Prinz, 1997), which is an interference paradigm where participants were required to observe and perform a 5 arrow-key sequence. Participants were only presented with 4 arrows and the 5th was shown upon the first key press of sequence recall. It was found that the presentation of a perceptual task (viewing the 5th key) while performing a motor task (executing the arrow sequence) impeded the movement time at which the motor task was performed. The fact that these two tasks interfere with each other suggests that, with a common stimulus, a perceptual and motor task can share common areas of the brain, specifically those in the AON: the PMC and inferior parietal areas (Calvo-Merino et al., 2006). Instead of the rigid connections established in the Intermodel Matching framework, Common Coding suggests that the perceptual and

action areas of the AON code observed actions similarly, such that both areas can utilize the same code simultaneously. Therefore, as an action becomes more familiar, its respective coding is more generalizable, which allows for an observer to become better at recognizing it.

This hypothesis also challenges the previous notion of a distinct lack of communication between perception and action. It was thought that the perceptual and motor areas function separately and codes from each system would require active processing to be converted and interpreted by the opposing network (Welford, 1968; Massaro, 1990), as cited by Prinz (1997). The Common Coding framework suggests that the perception and motor areas share codes, thus eliminating the translation of codes during communication. This explanation put forth by Massaro relies on findings in reaction-time research dealing with the translation of perception to action, and is unable to explain the observed interference effect noted by Prinz. The Massaro (1990) framework suggests that the context of concurrent tasks is independent from the degree of interference. Conversely, according to the Common Coding framework, shared representations are interfered by varying degrees, depending on the type of task being performed.

Accordingly, it has been shown that the type of sensory areas involved in a dual task paradigm have a significant effect on deficits in either task. For example, Levy, Pashler, and Boer (2006) demonstrated differences between types of tasks in a driving simulation paradigm. Participants were required to follow a lead car (perceptual task) while driving at a constant speed using a gas and brake pedal (motor task). Once the lead

car applied its brakes, the participant would also have to brake in a timely manner. Moreover, a second auditory task was added, where a participant would be asked to count the number of beeps they heard while continuing to drive at a constant speed. It was found that the degree of interference differed depending on the task being performed; therefore contributing to the growing hypothesis that content determines the degree of task deficiency observed (Müsseler & Hommel, 1997; Hamilton, Wolpert, & Firth, 2004). The dynamic relationship between the perceptual and motor areas, as utilized in the Common Coding framework, is better suited to explain the concurrent interaction between areas of the action observation network. If an action were only learned in a certain context, the same action performed in a different context would require a different perception-action code, and would not result in the same visual acuity.

Contextual interference effects have also been demonstrated in many action observation paradigms. In a study by Kilner, Paulignan, and Blakemore (2003), participants replicated a sinusoidal arm movement made by a robot or another human, which was either performed in the same direction (congruent) or perpendicular (incongruent) to the participant's movement. It was found that the participants' sinusoidal arm movements became significantly more variable, and thus, less accurate, when participants observed an incongruent human performing the arm task. Although the literature is undecided on which specific characteristics of human movement contribute the interference effect, these results bolster the Common Coding framework by suggesting that unrelated perceptual and action tasks require new-shared representations

and will interfere with each other. However, related perceptual and action tasks will share representations and be performed successfully (Prinz, 1997).

Kilner, Hamilton, and Blakemore (2007) reinforced this claim, finding that the interference effect is only present during concurrent perception of a familiar perceptual stimulus, such as human movement; as opposed to visual stimuli with less familiarity, such as robotic non-biological motion. In this study, human biological motion was defined by unaltered movements (“minimum jerk”), whereas non-biological motion was defined as artificially smoothed movements (“constant velocity”). Visual stimuli consisted of a human (biological) or ball (non biological) actor. Participants performed and observed arm movements that were either congruent or incongruent with each other. Kilner et al. found that the non-biological ball stimulus interfered with concurrent movement regardless of the velocity profile. However, the biological human stimuli only interfered with concurrent movement in the biological velocity condition, not the non-biological condition. Kilner et al. propose that this difference is due to the familiarity with the biological stimuli. Because observers are more experienced with the human stimuli, they are unable to process unexpected novel movements such as the observed non-biological smooth movements. The ball condition would interfere with observers regardless of the movement profile because the observers have no experience with the visual stimulus; therefore the stimulus itself is the interfering agent.

These results have been replicated using similar protocols but also involving active imaging of the MNS areas (Shimada, 2010; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). Observers demonstrated left premotor cortex activation during

observation of human movements, but not during robotic non-biological movements, which again, are rarely perceived and not well learned. However, recent studies using human and robot actors have found conflicting results where a robot performing a smooth motion resulted in equal activation of the AON compared to human actions (Gazzola, Rizzolatti, Wicker, & Keysers, 2007; Oberman, McCleery, Ramachandran, & Pineda, 2007).

The key finding inherent to all of these studies is that the AON displays variable results when observing motion with which the observer has limited experience. That is, the AON responds variably to novel movement. Although the Common Coding framework suggests this is due to a lack of established shared representations, it does not provide a mechanism for the perception of novel movement, as it only serves to explain how perception and action can function concurrently.

Specifically, Common Coding does not explain how feedforward systems are utilized in the observation of action. Feedforward processes explain how humans are able to judge their own movements without visual feedback. For example, if a baseball pitcher were to throw a ball to a player, they have the ability of predicting the accuracy of their throw, that is, will they overshoot the target, undershoot the target or deliver the ball directly to the target. It was initially thought that individuals would use proprioception or the awareness of limbs in space, for these predictions (Annett, 1971). However, it was found that the central nervous system creates copies of executed motor commands, or “efference copies” that can be used for feedback (van Holst, 1954). Jones (1974) suggests that proprioception may not be as important for forward predictions of

movement, but rather the efference copies are utilized by the central nervous system to predict self movement. Accordingly, Gallistel (1980) proposed that these efference copies are compared to the executed motor command and create a sensory discrepancy between the performed action and the plan of the performed action. This sensory discrepancy, or error measure, allows an individual to be instantaneously aware of their action. This system became known as feedforward modeling.

Computational Modeling

Wolpert and Miall (1996) expanded on the original feedforward model and aimed to explain feedforward control of movement. As mentioned previously, when an individual performs an action, they create a motor command as well as an efference copy of the motor command. As the motor system is executing the action, the predicted sensory feedback (from the efference copy) and the actual sensory feedback are compared to establish the discrepancy between the executed action and the selected motor command. The motor system would then incorporate the sensory discrepancy to select an optimal motor command for the situation in place.

This loop could be expanded to explain movement selection in response to multiple contexts. Wolpert, Doya, and Kawato (2003) provide an example that if an individual was to lift a teapot without knowing if the teapot was full or empty. The individual would be required to update their movement selection according to the weight of the teapot. To begin, the individual would have two possible motor commands, one specifying the high level of force required to lift a full tea pot, and one specifying the lower level of force required to lift an empty tea pot. Each of these motor commands, or

“controllers”, would also have a respective consequence or “predictor” associated with its selection. For example, if the teapot were to be empty, the predictor would suggest that lift off would occur early due to the less force required. This predicted feedback from each predictor is compared to the actual sensory feedback obtained for executing a motor command. Each controller-predictor pair will then be assigned an error discrepancy value that demonstrates how similar the predicted feedback for each motor command was to the actual sensory feedback received. The motor command with the small error value would be selected at the proper action and inform the motor area to select motor commands relevant to the actual weight of the teapot. That is, if the teapot were actually empty, motor commands that specify lower force outputs would be utilized over motor commands for a full tea pot. However, the only way for the lifter to know the true weight of the object would be through the sensory feedback received from initiating the lift. Initial motor commands either overshoot the required force or select a moderate force production, which adapts to the required force through the optimization of motor error. This framework has been collectively called the “modular selection and identification for control” (MOSAIC) model based on the “modules” of controller-predictor pairs. The MOSAIC model has been expanded to address the issues with perceiving novel movement. In an action observation paradigm, the MOSAIC system proposes that the perceptual areas of the MNS and motor areas operate together, similar to the Common Coding model. Similar to the teapot example, an observer of action would form controller-predictor pairs for the potential motor commands being observed. The difference in this case is that the observer will not receive motor sensory feedback and

can only rely on visual feedback in order to determine the prediction error for each controller-predictor pair. Therefore, the observer has a collection of controller-predictor pairs that would predict the consequence of the action, as if the observer themselves were performing the action. The visual feedback of observing the actor replaces the sensory feedback that would normally be compared with the predictions of each controller, and the controller-predictor pairs are assigned error values again. The prediction error is transmitted up the hierarchy of the mirror neuron system, from lower level sensory areas (STS) to higher level planning areas (PMC), where all internal representations are re-weighted (Kilner, Friston, & Frith, 2007). This cycle repeats until the system arrives at the correction prediction, which would be the heaviest weighted representation. In essence, this is a trial and error process for the MOSAIC system, where a prediction is formed based on the environmental factors available, and is adjusted to accommodate for sensory feedback error. Therefore, subsequent iterations of the MOSAIC loop results in a more accurate prediction and a reduction in error. The controller repertoire of each individual is unique to their experiences, so the controller-predictor pairs are not usually the same as the controller-predictor pairs present in the actor. This becomes an issue for observing a novel action, because the observer would not possess many relevant controller-predictor pairs and would display large prediction error values for each pair.

MOSAIC provides a solid mechanism for why well-learned actions are perceived at a higher degree. As formulated by the Common Coding framework, it states that an observer with more experience with a certain action will have a more relevant controller-predictor pairs and therefore, less prediction error than someone with limited experience

(Haruno, Wolpert & Kawato, 2001). For example, an expert baseball player would be able to differentiate between different pitches due to a large array of controller-predictor pairs relevant to each type of baseball pitch. These expert players would thus experience a behavioural benefit where they would be able to rapidly discriminate between multiple possible relevant environmental stimuli (e.g., type of pitch) and use this information to quickly adapt a motor response (e.g., bat swing).

Concurrent Action and Perception Paradigms

Christensen, Ilg, and Giese (2011) found an advantage for performing concurrent motor activity during an action recognition task. Participants were instructed to detect their own arm movements while viewing a point light display of their own arm, along with multiple false dots that served as “noise”. Although participants were not told that they were controlling the collection of dots on the screen, the group with concurrent motor activity could recognize arm movements at a higher perceptual acuity than baseline trials without concurrent movement. Perceptual acuity was defined by the amount of noise dots a participant could tolerate while still being able to perceive the original five-dot sequence representing their arm. Thus, concurrent motor activity allowed participants to endure more noise dots than in trials where they were not moving concurrently with the display. This perceptual boost was evident under very specific criteria for the point light display feedback. Once the display became delayed by 560 ms, or tilted by greater than 45 degrees, there was a significant detriment noticed for identifying relevant point light dots. Although participants were concurrently actively moving, they were unable to complete the task at a noise level of their baseline trials, i.e. the participants were even

worse than when they would passively observe the point light stimuli. Therefore, concurrent motor behaviour was only beneficial when spatially and temporally in phase with the perceived action. With respect to the Common Coding Theory, Christensen et al. believe that the irrelevant visual information and concurrent motor behaviour compete with each other, similar to the central bottleneck effect explained previously. To incorporate these results into the MOSAIC framework, the participant's motor sensory feedback and visual feedback are not in sync, and therefore the system is not able to calculate accurate prediction error values.

Two recent studies in the area of concurrent motor action benefit have expanded the application of the two aforementioned frameworks. Schubö, Aschersleben, and Prinz (2001) instructed participants to observe a sinusoidal movement while performing the same movement with their arm. Participants displayed a contrast effect, where the participants' performance of a movement would be biased in the direction of the size of an observed wave. For example, when asked to perform a small sinusoidal movement while observing a medium sinusoidal movement, participants created a larger movement. Conversely, movement size decreased when observing a medium sized sinusoidal movement but tasked to create a large movement. Schubö et al. suggest that these results are in accordance with the Common Coding framework due to a selective common coding inhibition of the shared motor and perceptual representations. Recall that the Common Coding framework explains concurrent motor and perceptual activity via shared representations formed by each system. With regards to the Schubö task, a synchronous match between the stimuli and performed movement would result in a perfect harmony

between both systems' activation curves, and no interference would exist. However, once the two systems differ, such as when the perceived wave is medium sized but the performed wave is to be large, the inputs from both systems have to be kept separate in order to prevent misinterpretations by the system. In order to do this, Schubö et al. propose that the shared aspects of both activation curves are inhibited, thus increasing the differences and distinctiveness of each inputted code, but also results in the observed contrast effect as the means of both activation curves are repulsed from each other.

Hamilton et al. (2004) propose a contrasting system, rooted in the MOSAIC framework. Recall that the MOSAIC framework is better suited for answering mechanistic issues with action observation than the Common Coding framework, due to its computational approach. In this task, observers watched videos of actors lifting identical boxes with differing weights and were then asked to judge the weights of each box. Before their decision, they had to hold a heavy or light weight, and, similar to Schubö et al. (2001), a directional bias appeared where holding a heavy weight would bias judgment to overshoot and vice versa for the light weight. Hamilton et al. (2004) explained this finding within the constraints of the MOSAIC framework. As explained before, the observers would view the boxes being lifted, and then compare the observed movement to internal predictions. As the observed movement progressed, predictions with the least amount of error are weighted more heavily than irrelevant predictions. Similar to the repulsion effect observed in the Schubö et al. (2001) task, the concurrent motor task biases the perceptual judgment of the participant. Recall that in a Common Coding model, this is explained by the inhibition of shared representations in order to

prevent interference between common codes. However, the Common Coding framework does not explain how this inhibition occurs precisely. Hamilton et al. propose a mechanism that fits into the MOSAIC framework. The MOSAIC model explains this repulsion effect by stating that motor codes (controllers), such as holding a weight, would lead to the inhibition of controller-predictor pairs in order to reduce interference with irrelevant information. Therefore, any relevant controller-predictor pairs are inhibited from selection, resulting in a selection of less relevant, or contrasting controller-predictor pairs.

Another addition is provided by Zwicker, Grosjean and Prinz (2010), who used a target-following paradigm where participants tracked a target using a stylus, with the goal of learning the target's movement pattern. The degree to which they strayed from the target represented motor error. After each trial, participants were asked to rotate a reference line to align with the learned target's trajectory. The degree to which the participant's perceived movement angle differed from the actual movement angle represented perception error. The task was repeated with pure observation (no tracking), followed by the same reference line alignment task. Zwicker et al. believed that the perception task was not relevant to the motor task, and thus, would cause interference in the Action Observation Network. They expected to find a linear increase in perception error with an equal increase in the motor error. Instead, they found a nonlinear relationship between the perceptual and motor error, which was proposed to be due to a flaw in the action observation models, but it is more likely to be an issue with the task selection. It was found that participants would group lines together, so a 45 degree line in

the top upper right quadrant, for example, would not be distinguishable from a 60 degree line in the same quadrant, which was expected to produce a larger interference effect. Therefore, a new paradigm needs to be used to examine the translation of the MOSAIC framework to action observation.

Concurrent Non-Voluntary Action with Perception

The Christensen et al. (2011) paradigm was very effective in establishing the potential for a perceptual benefit to concurrent motor behaviour, and this benefit has also been observed with respect to concurrent motor and auditory or visual cues (Craighero, Bello, Fadiga, & Rizzolatti, 2002; Miall, Stanley, Todhunter, Levick, Lindo, & Miall, 2006; Repp & Knoblich, 2007). The advantage of this type of paradigm is that it allows for the examination of self generated motor commands during the concurrent motor activity. De Vignemont and Haggard (2008) have proposed that intention in the motor areas during self generated motor commands is possibly the driving force behind shared representations between motor and perceptual areas. With regards to the MOSAIC framework, self generated motor command benefits could also be due to the presence of an efference copy, which are exclusive to active motor movement. When observing non-voluntary concurrent motor activity, one could examine the impact of efference copies on the MOSAIC system. An initial study by Nicolas, Marchand-Pauvert, Lasserre, Guihenneuc-Jouyaux, Pierrot-Deseilligny, and Jami (2005) found results demonstrating the limitations of a participant's ability to utilize non-voluntary movements for force perception or replication. Participants were stimulated by transcranial magnetic stimulation (TMS) in order to elicit a brief non-voluntarily contraction of a wrist flexor

muscle. Participants were then asked to estimate their force outputs on a scale of 1-5, and the results showed that they were unable to do so accurately, suggesting that they are unable use proprioceptive information effectively in force judgment. Moreover, participants were asked to replicate the previous TMS-elicited force outputs via voluntary contractions, either cued by visual force scales or verbal force scores. The results showed that the participants had a limited ability in replicating the force levels previously performed, suggesting that the retention and learning of the previously performed forces are limited in the absence self generated motor commands. The implication for biological motion paradigms is that if a participant were to non-voluntarily perform an action, they would also be unable to internalize the action in the absence of efference copies. This implication, however, has been contradicted by Hepp-Reymond, Chakarov, Huethe, Kristeva and Schulte-Mönting (2009), who found that participants are unable to perform a skilled motor task (cursive handwriting) in the absence of proprioception, which suggests that the proprioception may play a part in the storage and maintenance of skilled motor tasks, and thus, could vary depending on task type e.g., discrete vs. continuous, fine motor vs. gross, novel vs. learned movements. Moreover, Bara and Gentaz (2011) found that children experienced greater improvements with handwriting when led through different letter patterns passively as opposed to pure observation, most like due to greater improvements in the visuo-motor system. In this paradigm, handwriting would be classified as a novel unlearned movement in children, which would answer questions regarding the perception of stimuli where the MOSAIC system has a limited pool of controllers. Therefore, the current paradigm aims to explore the effect of efference copies

on action observation. It would be necessary to utilize three groups of varying concurrent movement: voluntary (with efference copies), non-voluntary movement (no efference copies) and observation (no efference copies and no proprioception).

Full Pictorial Visual Displays

The visual stimuli will not consist of point light displays, but rather full-animated pictorial displays in an effort to maximize ecological validity. The advancements made in perception literature since the original observation of mirror neurons by di Pellegrino et al. (1992) have relied heavily on the point light display. Of course, a point light display is useful in limiting the non-salient information available to an observer, thus becoming a reliable measure for the ability to observe pure kinematic information. However, how important are these non-salient features of an actor? It was found that the STS, previously shown to be vital for action observation (Grossman & Blake, 2001; Grossman et al., 2005), responds stronger during the observation of full videos instead of point light displays (Beauchamp et al., (2003). Moreover, Hodges, Williams, Hayes and Breslin (2007) posited that biological motion perception is a combination of relative limb movement and absolute or directional motion. The literature is currently split on which information is more important during perception, with evidence supporting multiple hypotheses. For example, in hand and arm movement observation tasks, such as Mataric and Pomplun (1998), results suggest that participants who focus on the distal aspects of a limb during motion are more successful at discriminating between actions than focusing on the proximal portion of a limb. This may be due to the fact that distal areas during limb motion result in a more accurate and rich portrayal of the limb, as opposed to

focusing on the proximal portion of a limb (Mather, Radford, & West, 1992).

Conversely, findings from a gait observation study by Pinto and Shiffrar (1999) demonstrate that observer's ability to recognize human action decreases significantly when the mid limb areas are occluded, as opposed to the distal extremities. Giese and Poggio (2003) believe these results are due to a lack of perceivable opposing motion, especially with the occlusion of the elbow. It is possible that both hypotheses are true to a certain extent, and perhaps a total inclusion of all relevant information is required for optimal action observation.

Although there is evidence that point light displays allow for greater motor skill acquisition in a ballet sequence (Scully & Carnegie, 1998), as cited by Hodges et al. (2007), there have been divergent results supporting the contrary. Horn, Williams and Scott (2002) discovered that the observation of point light displays or full videos had no effect on the learning of a soccer kick. Moreover, Hayes, Hodges, Scott, Horn and Williams (2006) found that point light displays did not provide enough perceptual information for proper skill acquisition, and are less effective in facilitating observational learning. Therefore, the visual stimuli were presented in full pictorial animated avatars in order to supply sufficient visual information for participants. Moreover, inconsistencies in the literature regarding point light displays and full video stimuli remains an important question that requires more examination. This study aims to extend the research of action observation into the realm of full video and animation as a technique for action observation. As such, it adds to the literature examining the applicability of theoretical findings to more common, daily stimuli.

Action Observation and Confidence

This study also aims to add to literature related to confidence ratings in concurrent movement during action observation tasks, which is quite limited. General theories of confidence-accuracy processing and visual stimuli, although primarily applied to facial recognition tasks, do apply to this paradigm. The Trace Access theory states that confidence in recognizing a movement is reliant on the strength of the respective movement in a participant's memory (Burke, MacKay, Worthley, & Wade, 1991; Hart, 1967; King, Zechmeister, & Shaughnessy, 1980). Accordingly, one would expect that an increase in the retention of a movement may lead to a similar increase in confidence. It has been shown that participants retain novel movements significantly better with physical practice than pure observation (Cross et al., 2009). It has also been shown that children demonstrate significant improvements in visuo-motor skill and retention in a novel task when being passively led by a robot instead of observing the visual stimuli alone (Bara & Gentaz, 2011). Therefore, there is evidence to suggest that voluntary and non-voluntary movement can both lead to an improved retention of movement, and thus an indirect correlation with associated confidence in recognizing the performed movement.

Literature in this area identifies multiple models that explain the underlying mechanisms of confidence with perceptual accuracy. Busey, Tunnicliff, Loftus and Loftus (2000) contrasted a single dimension model with a proposed dual dimension model for confidence and perceptual accuracy, originally formulated by Wells, Lindsay, and Ferguson (1979). As shown in Figure 1, a single dimension model suggests that both confidence and perceptual accuracy are derived from the same neural pathway, whereas

the dual dimension model suggests that rehearsal contributes to the memory strength of a symbol as well as a separate pathway (certainty). Rehearsal in the frame of this study would refer to movement while observing visual stimuli. As stated by Busey et al. (2000), certainty refers to “sources of information that do not or cannot influence the recognition judgment but give the illusion of accuracy and thus affect confidence.” For example, the mere act of movement would provide the illusion of confidence for the movement group participants. The certainty pathway also allows for a participant to make more accurate judgments on how they performed on each particular trial. For example, if a participant feels like the symbols were very similar, they may be less certain

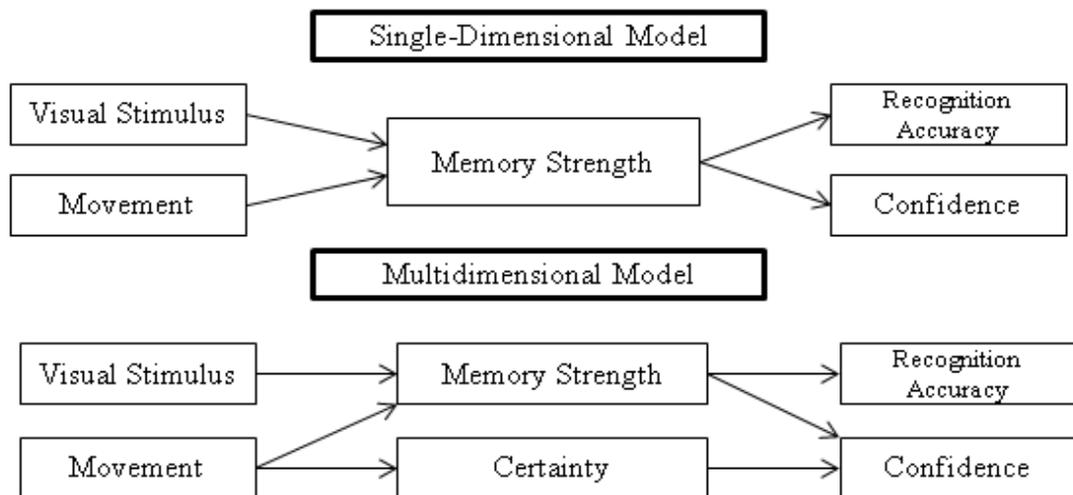


Figure 1: Two possible models for processing Recognition Accuracy and Confidence, or Judgment of Performance, as adapted from Busey, Tunnicliff, Loftus and Loftus (2000). The single dimension model states that visual stimuli and movement will result in stronger memory representations of each movement, resulting in a similar effect on recognition accuracy and confidence. The multidimensional model proposes that movement can also influence confidence through a separate “Certainty” pathway, allowing for differing effects on recognition accuracy and confidence.

with their performance, and therefore would become less confident on that trial.

However, if a participant notices drastic differences between trials, they will be more certain about which trial was correct and therefore have a higher confidence and higher likelihood of being correct. Therefore, certainty allows for participants with movement to have a greater prediction of their success compared to the observation group.

Experimental Design

In this task, participants were asked to identify the most similar pair of symbols between two symbol pairs as well as indicate their confidence with indicating the most similar pair. Participants were placed into one of three groups of differing concurrent motor activity: pure observation (no movement), observation with non-voluntary concurrent action and observation with voluntary concurrent action. It should be noted that both movement groups possess active movement, but they differ by the nature of the movement. The voluntary movement group initiates movement and self generates actions, whereas the non-voluntary movement group is led through movements by a robotic arm.

Hypotheses

Perceptual Accuracy. It is important to compare the aforementioned framework in a concurrent perception and action paradigm. This will serve to determine the influence of self generating motor commands on concurrent action observation.

According to the MOSAIC model, a concurrent voluntary action would result in maximal feedback for controller-predictor pairs and result in a benefit in perceptual ability, as seen

in Christensen et al. (2011). The observation group, therefore, is expected to have a significantly lower perceptual accuracy due to a lack of feedback for organizing controller-predictor pairs. Lastly, the non-voluntary group would be expected to be better than the observation group, but worse than the voluntary group. The non-voluntary group does not generate their own motor commands, but will still receive feedback from proprioception, which would be integrated with vision to allow for a slight improvement in perceptual accuracy relative to the observation group.

Hypothesis 1. *Perceptual accuracy will be the highest in the voluntary movement group. The non-voluntary group will be better than the observation group and worse than the voluntary group. It is expected that each group's perception of similarity will follow the same trend as perceptual accuracy.*

Confidence. A single dimension model would predict no difference between confidence correlations or perceptual accuracy, as both confidence and perceptual accuracy would be processed in the same pathway. For this model to be true, the perceptual accuracy scores for each group would have display the same trends as the confidence-performance correlations. For example, if the movement groups display a higher-level perceptual accuracy, this model would predict that they would also display a higher level of confidence correlations. Because accuracy and confidence are derived from the same pathway, there should not be any difference between the group trends for each measure.

However, the dual dimension model suggests that movement rehearsal contributes to confidence differently than it would to the perceptual accuracy of a participant. Therefore, if the perceptual accuracy scores' group trends differ from the confidence correlation group trends, this would suggest that each measure might be utilizing concurrent movement information differently. As proposed by this model, rehearsal should increase confidence in the movement groups regardless of perceptual ability. Thus, the lack of a group difference for perceptual accuracy, but a significant difference between groups in confidence could support the dual dimension model. Moreover, for this model to be correct there would have to be a significant correlation in the movement groups between confidence and trial difficulty. This would suggest that trial difficulty allows a participant to be more or less certain with their answer, and a better judge of their own performance.

Hypothesis 2. *The voluntary and non-voluntary movement groups' will be better able to judge their own success, and therefore, will have stronger positive correlations between their confidence and performance. Conversely, the observation group, without possessing concurrent movement, will have confidence scores that do not correlate to a participant's perceptual accuracy. Movement groups will be more sensitive to the degree of difference between similarity groups, and will display a significant correlation between confidence and degree of symbol pair similarity score difference.*

Method

Participants

30 university-aged participants (16 males, 14 females) received monetary compensation (\$10.00 CND) for their participation. Participants were recruited from the University of Toronto St. George campus either through posters or from emails sent to the lab's previous participant list. Participants were eligible for participation if they were right hand dominant and had normal or corrected-to-normal vision. Participants were also required to have no history of shoulder, elbow or arm pain, visuo-motor disorders, or any medical condition affecting sensory and/or motor systems. Participants were also required to complete a brief neurological questionnaire and the Oldfield (1971) Hand dominance test to confirm their eligibility to participate. No participants were deemed ineligible. The McMaster Research Ethics Board and University of Toronto Office of Research Ethics both approved the protocol prior to the recruitment of any participants.

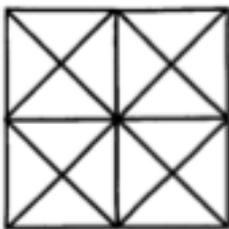


Figure 2. Grid for Symbol Creation. Symbols started at the middle point and then consisted of three connected lines. Adapted from Solso and Raynis (1979).

Symbol Creation

As noted, there is evidence to suggest that previous experience with an action or movement pattern has a positive effect on the perceptual sensitivity of an individual when observing the same action (e.g. Cross et al., 2009). Therefore, novel symbols were created using a pre-existing framework implemented previously by Solso and Raynis (1979). In their study, Solso and Raynis created simple geometric symbols using a 13 cm x 13 cm grid, shown in Figure 2. Symbols consisted of

three connected line segments, but it was not possible to have two continuous lines along the grid in a symbol. In our study, contrary to the original framework, each symbol started from the same home position. Therefore, each symbol was, in essence, four lines, where the first movement was always from the home position (central intersection point of the grid, see Figure 2) to the first point of the symbol. Moreover, none of the symbols were closed shapes. From here, Solso and Raynis created a unique scoring system to assess the similarity between symbols. They first created a base symbol, consisting of a basic 3-line pattern that would serve as the template for the next symbols. The angle and position of each line was manipulated to create a new symbol. Accordingly, each of the three lines was assigned an angular similarity score (out of 1) and a position similarity score (out of 1). The angular similarity score was based on the similarity between the

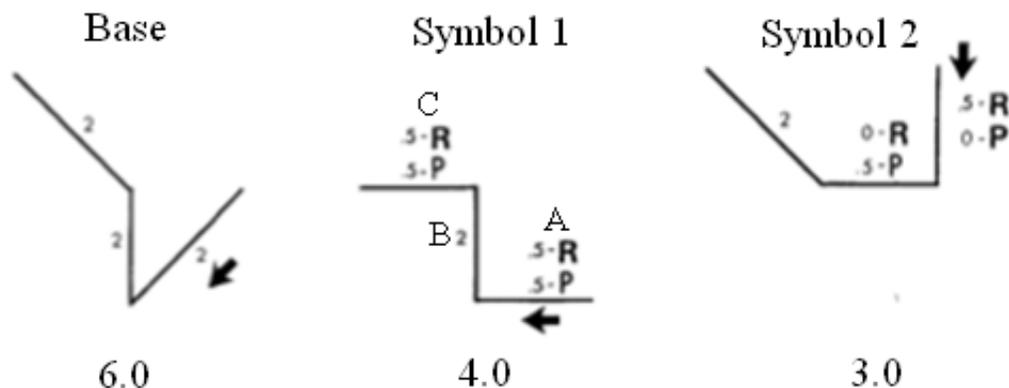


Figure 3. Symbol Similarity Scoring. The base symbol on the left possess the maximum 6 points of similarity because it is being compared to itself. The 2 neighbouring symbols are scored based on their angular and spatial similarity to the base symbol. Adapted from Solso & Raynis, 1979)

angles of the line segment to the respective line segment in the base model. For example, no rotation (i.e. the line is at the same angle on the grid) would result in the maximum of 1 point, whereas a shift of 45 degrees would result in a score of 0.5 and a shift of 90 degrees would result in a score of 0. Similarly, the positional score is based on the respective line being the same quadrant in the grid as the base symbol. If the lines are overlapping, the new line would receive a maximum score of 1, however if the lines are not overlapping but in the same quadrant, it would receive a score of 0.5. Lines that do not overlap and are not in the same quadrant would receive a score of 0. Therefore, the base line would, by default, have the maximum score of 6 (1 point for each angular and positional similarity score, and 3 lines).

An example is shown from the original Solso and Raynis study in Figure 3. The base figure contains the maximum of 6 points, as explained above. Two comparative symbols are presented: Symbol 1 consists of three line segments, A, B and C. Line A is rotated 45 degrees (0.5 out of 1 angular score) and is in the same quadrant but not overlapping (0.5 out of 1 positional score) to give a combined score of 1. Line B is not rotated (1 out of 1 angular score) and is overlapping the base line (1 out of 1 positional score) to give a combined score of 2. Lastly, line C is rotated 45 degrees and in the same quadrant without overlapping, which results in the same score as line A. Therefore, the overall similarity score for Symbol 1 is 1.0 (line A) + 2.0 (line B) + 1.0 (line C) = 4.0.

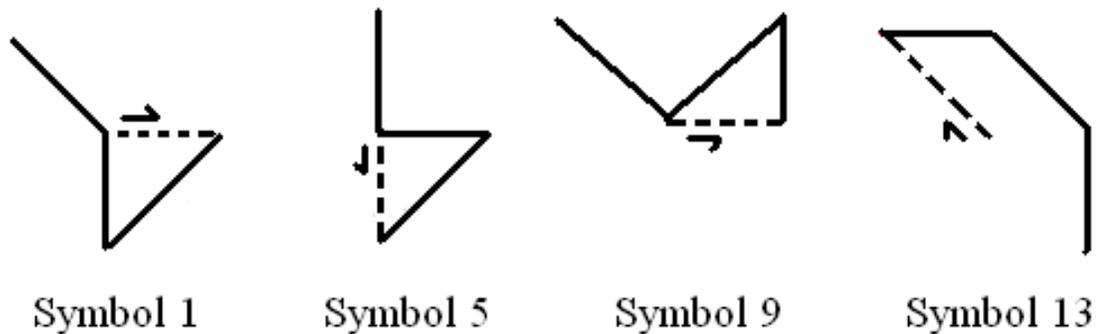


Figure 4. Base symbols for symbol families. The dashed line for each symbol is the movement from the home position to the beginning of the symbol and was not used in similarity scoring. The arrow indicates the first direction of movement from the home position.

For the purpose of our study, we used the same symbol creation and similarity scoring system. Four base symbols (Figure 4) were created to serve as templates for the creation of the rest of the symbols. Each base symbol also served to be the basis behind each separate “symbol family”. Each base symbol went through various manipulations to create three new symbols. Each of the three symbols is only similar to the base symbol within its respective family. Moreover, each family differs according to the spatial arrangement of the line sequence, but the total number of lines is constant.

Symbol pairs within each family were grouped into one of three groups depending on their similarity score: “very similar” (scores of 5), “moderately similar (scores of 3.0-4.5) and “dissimilar” (scores of 1.0-2.5). These groups were created by manually calculating the similarity scores across all 16 unique symbols to create at least 12 symbol

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	x	5	5	3												
2		x	4	4												
3			x	4												
4				x												
5					x	5	5	5								
6						x	5	4								
7							x	5								
8								x								
9									x	5	5	2				
10										x	4.5	3				
11											x	3				
12												x				
13													x	5	5	2.5
14														x	4	2.5
15															x	1
16																x

Figure 5. Similarity scores for all symbol families. Base pairs are indicated in bold on the left column. Pairings were only made within each symbol family.

pairings for each group. A comparison plot for all symbol pairings is presented in Figure

5.

Notice that each symbol family contains different distributions of similar, moderately similar and dissimilar symbol pairs due to the spatial restrictions placed on manipulations related to a base symbol. All symbols arranged by family are presented in Figure 6.

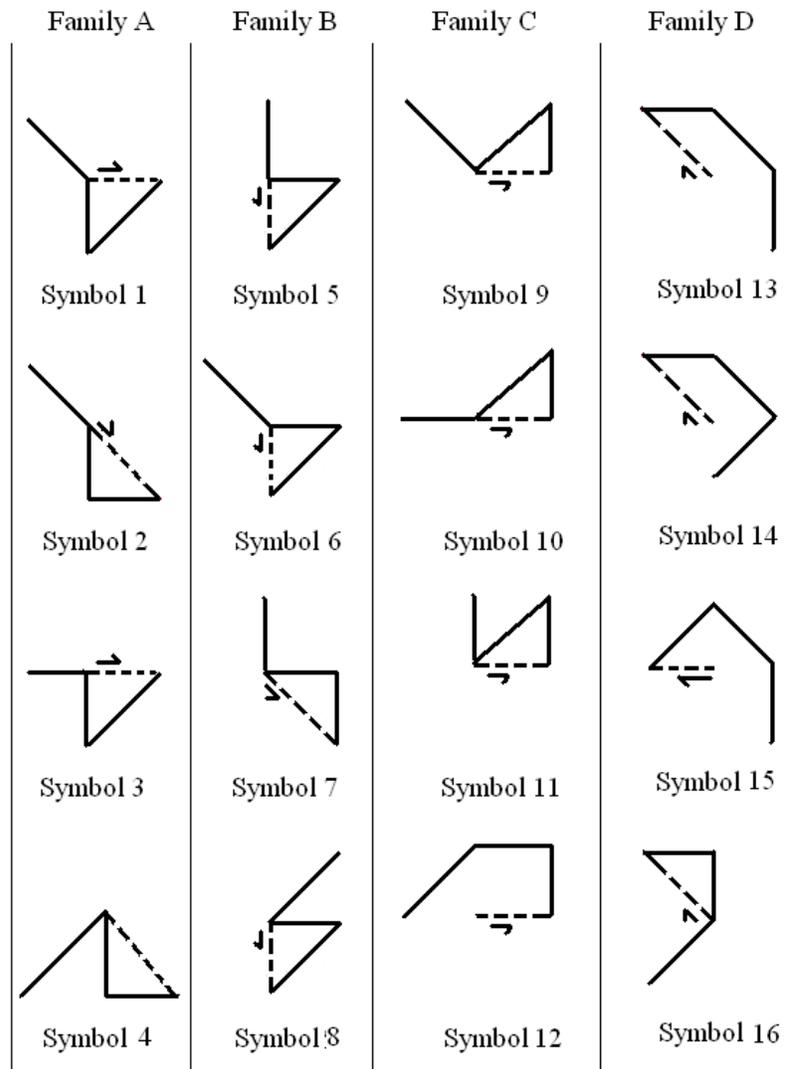


Figure 6: All symbols organized according to family. The base symbols are aligned in the first row of each column. The following 3 rows of symbols are manipulations

Stimulus Generation

Once the symbol pairings were created, the base grid was printed on a 15'' × 15'' board to be used as a guide for tracing symbols. A confederate was outfitted with 35 reflective markers in the PlugInGait FullBody (Oxford Metrics, Oxford, England) marker set up using VICON™ Motion Capture Nexus software (Vicon Motion Systems,

Lake Forest, CA). The only alteration was that instead of having the right finger (RFIN) marker located on the knuckle, it was placed on the distal portion of the index finger. It was more effective to modify the marker set in this manner for the purposes of capturing the symbol tracing accurately. The base grid was placed on a stand 50" from the ground, which corresponded to a comfortable level for the experimenter performing the symbol traces. All tracings were captured using 10 VICON™ Motion Capture cameras sampling at 100 Hz. Each symbol capture was performed in sync with a metronome set to 50 beats per minute, where the critical vertices of each symbol were in sync with the metronome beats. As a result each symbol was no longer than 5 seconds in duration. The experimenter started at the home position, and commenced movement after 4 metronome beeps. Upon completion of a symbol, the finger remained stationary in the final position of each symbol. Because this task required a certain degree of temporal and spatial

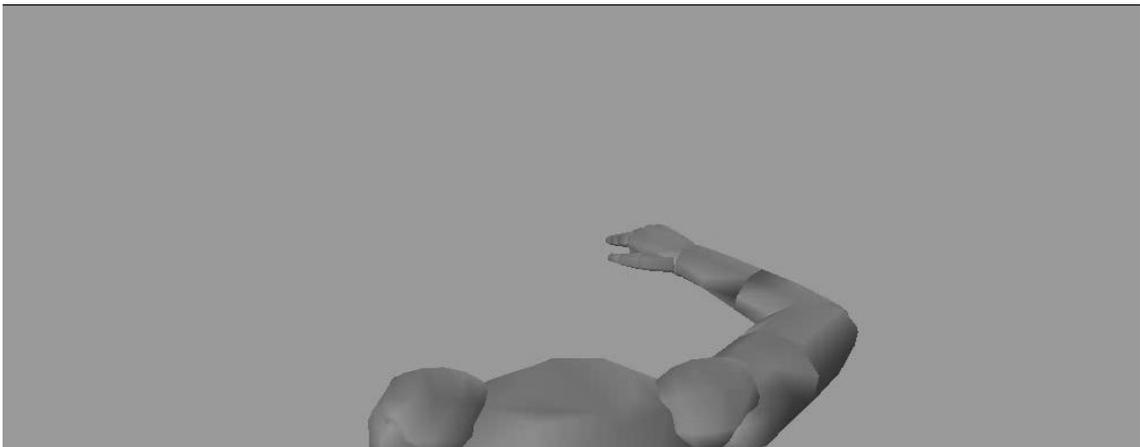


Figure 7. Example of the visual stimulus. The animated avatar is currently at rest at the home position. The home position was consistent for all visual stimuli. All symbols would commence from this point, and were presented in the same view as shown above, which was positioned to imitate what a participant would be viewing. The head of the avatar was removed to allow for a full view of the avatar arm.

accuracy, the experimenter practiced each symbol 3 times before being recorded performing the movement. During motion capture, the symbol was performed 4 times, and the best trial was used for the stimulus. The best trial was defined as a VICON™ trial where the experimenter arrived at the critical vertices in sync with the metronome and without any significant marker drop out. In cases where none of the four performances were adequate, the symbol would be redone.

VICON™ capture data for each symbol were scaled to fit the mimic performance area and exported to Autodesk Motionbuilder 2010 (Motion Builder™, Autodesk, CA) to create the animated avatar stimuli. Each marker set was linked to a featureless avatar and each video was rendered from the same view, i.e. over the right shoulder of the avatar looking down towards the right finger (refer to Figure 7). This is identical to the position the participants would occupy in when mimicking the symbols. In order to simulate a first person view for the participant, the head of the avatar was removed from the videos in order to allow for the participants to have a full view of the arm. The symbol grid or any other reference points used to create the symbols were not included in the final stimulus videos. Therefore, the participant had no reference points in the video other than the avatar tracing.

Robotic Coordinate Translation

As noted, the non-voluntary group would be led through symbols using a selective compliant assembly robot arm (Model Number E2L853S-UL SCARA/M Seiko Epson Corp.), henceforth known as the EPSON robot. The EPSON robot requires a specific coordinate input, point file (.PNT), for each movement specifying X, Y, Z and J (wrist

angle) position for each frame of the movement. For this study, the frames were taken directly from the VICON™ file used for the animation. The RFIN coordinates (X, Y and Z) were exported and run through a custom MATLAB (Mathworks, Natick, MA) program prior to conversion to the robot movement file. Each movement was broken into line segments relative to distances between vertexes in a symbol. The VICON™ coordinates were down sampled by a factor of 8 to create point files consisting of 80-110 frames for the robot. It should be noted that the relative frame count proportions for each line segment were maintained in this stage, (i.e. each line segment was down sampled proportionally to their original frame duration). Therefore, if a certain line segment were shorter than the other segments, it would still be the shortest by the same relative amount.

Time Lag Control Measures

Christensen et al. (2011) discovered that a lag greater than 280 ms would result in an interference of visual and motor signals. Therefore, it was important to ensure the time lag between the presentation of a stimulus symbol and movement of the robotic arm was within the threshold of concurrent observation and motor involvement. This was accomplished as follows:

The general set up was developed to determine the difference in time between the initiation of a signal and the point at which that signal triggered the start of robot movement or the start of a symbol video. Visual stimuli were initiated by the home computer, but actually presented on a separate computer due to computing restraints (this computer will henceforth be referred to as the presentation computer). The two computers were connected using digital input/output (I/O) signals passed between two

National Instrument's data acquisition boards (National Instruments, Austin, TX) connected using RCA cables. A digital signal was first sent from MATLABTM in the home computer to the presentation computer to play a video, and a digital signal was sent from the presentation computer back to the home computer to indicate the conclusion of a video.

To calculate the visual delay, defined as the difference between the initiation command for the video and the onset of a video, a Digi Key PCB-C156-ND 8.02MM clear photo diode was placed at the upper left corner of the presentation computer's monitor to capture the exact time at which the video appeared. The photodiode was connected through a National Instrument's data acquisition board and collected samples at 30 Hz. During data collection, all samples were saved in MATLABTM. The output of the photodiode data was examined manually to determine the point at which the voltage output of the diode indicated a screen change. This point was compared to the time stamp of the digital signal to determine the time lag of sending a video to the presentation computer.

The second step to fixing the time lag was to determine the lag in initiating the robot movement. Robot movements were initiated by MATLABTM, which sent a DLL message to the robot controller program, EPSON, which executed a movement. A single Optotrak (Northern Digital Inc., Waterloo, ON) IRED was placed on the robot arm to capture the point at which the robot commenced movement. The Optotrak system captured samples at 100 Hz, which were saved directly to MATLABTM using custom program codes. To calculate the robot initiation lag, the robot movement initiation point

was determined from the Optotrak code. It was found that the robot, on average, took 2.85 seconds to initiate a movement; which includes various pauses in the code integral for appropriate communication between the DLL and digital IO loops between the two computers.

Once both visual and robotic time lag values were calculated, the master MATLAB™ functional code utilized custom MATLAB™ pauses in the code to ensure that the robot was moving within 50 ms of the visual stimuli. This was confirmed by the use of an Optotrak marker that captured the movement initiation of the robot. There were certain occasions where the robot lagged by approximately 200 ms, which would cause a severe offset between the robot movement and video display. These occurrences, visual determined by the experimenter, were extremely rare (i.e., 1% of all non-voluntary trials) but regardless, the associated trials were not used in the analysis.

Trial Order

Trial order was established using a three-layered, pseudorandomization MATLAB™ code that created a unique trial order for each participant. The schematic in Figure 8 (see below) outlines the procedure in a flowchart format. Recall that every symbol pairing within each family had been assigned a similarity score (refer back to Figure 5), either very similar (scores of 5-6), moderately similar (scores of 3-4.5), and dissimilar (scores from 1 – 2.5) pairs. Moreover, each trial consisted of two pairs. The first level of randomization was to create a random order of the degree of similarity between pairs.

The code created a “degree matrix”, which determined the type of symbol pairs located in that trial. The degree scores of a trial could vary in three ways. First, they could possess the same degree of similarity (i.e. a similar pair-similar pair, moderate pair-moderate pair or a dissimilar-dissimilar pair). Next, they could differ by one degree of similarity (i.e. dissimilar-moderate pair or a moderate-similar pair). Lastly, they could differ by two degrees of similarity (i.e. dissimilar-similar pairs). Therefore, there are three degrees of similarity that are included in this level of pseudorandomization, but this was expanded to account for the presentation of similarities in a reverse order for the one degree and two degree difference trials. For example, one trial could be a dissimilar pair followed by a moderate pair, and another trial could be a moderate pair followed by a dissimilar pair. Both trials differ by the same degree, but the presentation is reversed. Therefore, there are five different types of trials: same similarity, one degree of difference, two degrees of difference, one degree reversed and two degrees reversed. There were exactly 12 trials for each of these five conditions, totaling to 60 total trials. Note that the same degree trials would only appear 12 times, whereas the other trials would appear 24 times due to the inclusion of normal and reversed trials. This was done to temper the difficulty of the trials, as the same degree trials were very difficult and would result in a floor effect for participants, as determined in pilot testing.

The second level of randomization was to create a pairing matrix, which utilized the codes from the degree matrix to randomly select an appropriate level of similarity in each pair. For example, in the 12 same degree trials, the order was set to include a random order of four similar pair-similar pair trials, four moderate pair-moderate pair

trials and four dissimilar-dissimilar pair trials. The same was applied for the 12 one-degree trials, where the order of dissimilar-moderate trials or moderate-similar trials was randomized. Recall that the reverse trials were randomized separately, and would include a random order of moderate-dissimilar trials and similar-moderate trials. The two-degree trials and reverse two-degree trials did not need to be randomized, as there was only one type of symbol pairs that could be used (dissimilar-similar pairs).

The last level of randomization used the codes in the pairing matrix to populate the symbol matrix, which indicates the actual symbol pair that would be utilized as the first and second pairing in each trial. For example, in a trial where the degree code specifies a reverse one-degree trial, followed by a pairing code specifying a moderate pair and dissimilar pair, the symbol matrix would randomize the exact moderate pair and dissimilar pair to be selected. For the moderate pair, it would select any of the pairs listed in Figure 5 as being moderate (scores of 3-4.5), such as Symbol 1 and Symbol 4. The code would randomize the order of the trials to either be Symbol 1 followed by Symbol 4, or Symbol 4 followed by Symbol 1. Trials were equally distributed with normal and reverse presentation of symbols. For the dissimilar pair, it would select any of the dissimilar pairs, such as Symbol 13 and 16 and accordingly randomize the order of presentation. Therefore, the trial would begin with Symbol 1, followed by Symbol 4, Symbol 13 and lastly, Symbol 16.

Each symbol pairing had a counter associated with it such that it would not be selected more than four times in the total trial order. Note that this does not necessarily control for a certain symbol appearing more than others, as it only controls for the actual

pairings. Upon the completion of the code, trial order was saved into a Microsoft Excel spreadsheet to be read in by the MATLAB™ trial execution code.

Procedure

Condition Methods. The following explanation is relevant to all three experimental groups. Group specific procedural methods will be explained separately.

Participants arrived to the lab and filled out a detailed informed consent form, along with the aforementioned eligibility forms. The experimenter then determined their dominant eye using the Miles (1930) test. Participants were randomly placed in a motor group upon arrival.

Participants were then instructed to sit comfortably in the trial chair. The height was fixed for each participant, but the angle and height of the chest rest piece was adjustable for comfort. Symbols were presented on a 21'' Dell LCD monitor (Dell Inc., Round Rock, TX) placed approximately 35-40 cm away from the participant on a table 60 cm from the ground. They were then introduced to the task, and were told to indicate verbally to the experimenter, which of four symbols, presented in two pairs of animated symbol tracings, are more “similar” to each other. That is, are the first and second symbols more similar to each other than the third and fourth symbols?

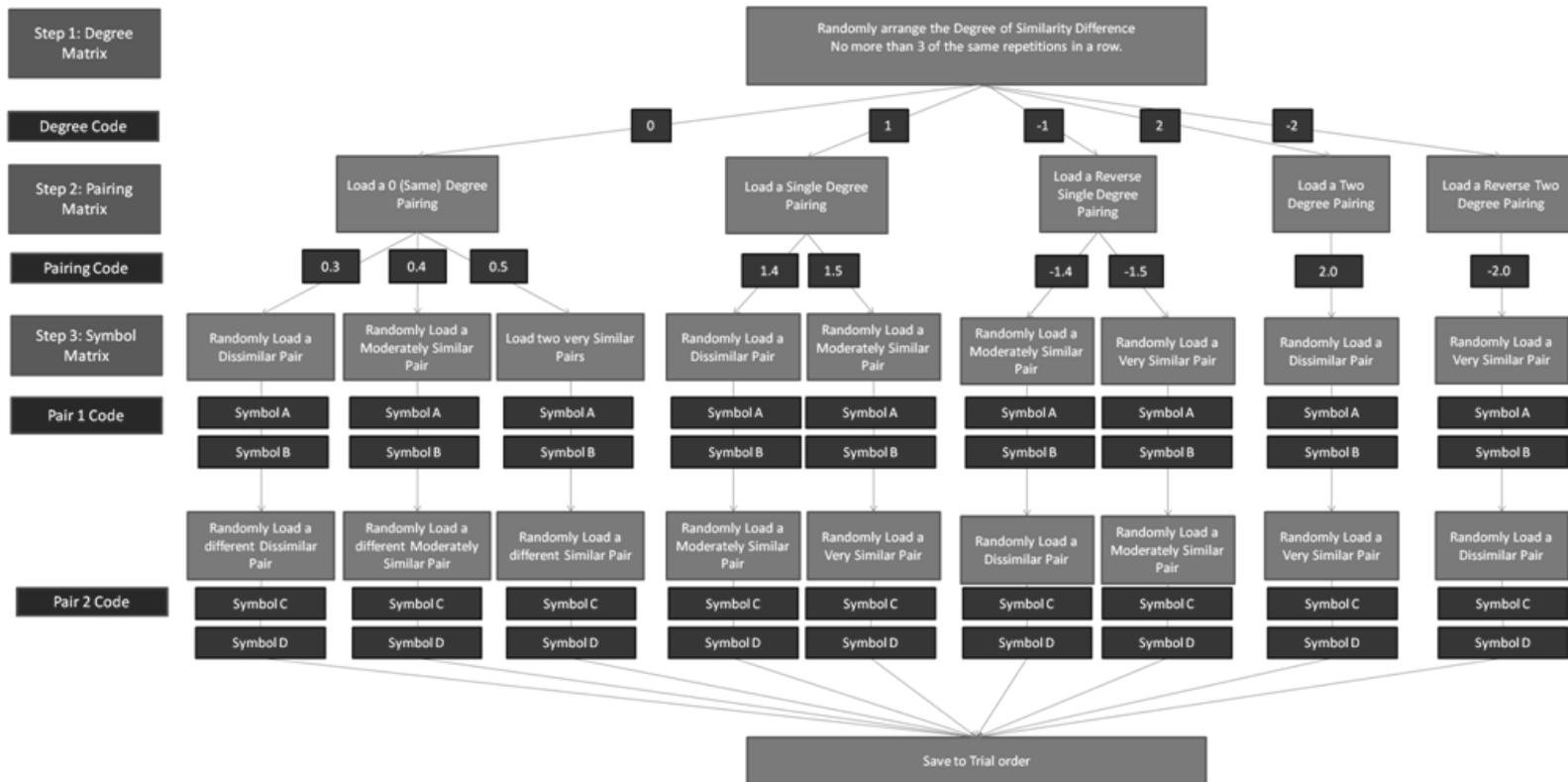


Figure 8. Schematic for the trial randomization code. This code was used to create trial orders for each participant. Each matrix formation step is outlined in the leftmost column. Light coloured boxes in the main schematic outline the function of each matrix and the dark boxes outline the code outputs for each matrix (which are used as inputs for the next matrices.)

The Effect of Non-Voluntary Concurrent Motor Action on Action Observation

Similarity was not given an exact definition, and participants were encouraged to determine similarity on their own. Their only instructions in this regard were to ensure that they utilized the symbol being tracked by the index finger of the animated avatar, not the non-salient avatar movements (i.e. left shoulder movement or trunk movement) in their decision. Moreover, they were also instructed to be as consistent with their strategy as possible. Some participants asked if there was a scoring system, and this was confirmed, but they were encouraged to determine similarity on their own and remain as consistent as possible.

The scoring system was revealed upon request at the conclusion of their participation. Participants were given a single practice trial in which the viewed symbols were described to each participant to emphasize the subtle differences between symbol pairs, as well as to emphasize the importance of using the avatar in their judgments.

All participants were also instructed to fill out their confidence level with their left hand, as the voluntary and non voluntary mimicking groups would be using their right hand for tracing. Ten cm blank horizontal lines were utilized to represent the confidence scales. After each trial, participants were instructed to indicate on the confidence scale, how confident they were that they correctly identified the most similar symbol pair. The further to the left the mark would be on the confidence line, the less confident they would be that they identified the most similar pair. Conversely, the further on the right the mark would be, the more confident the participant is that they identified the most similar symbol pair. Confidence ratings were completed during the 10 s answer period allocated

for identifying the similar symbol pair. Upon completion of a trial, the previous confidence rating was occluded from the view of the participant.

Viewing Methodology. Participants viewed all videos in the same position, seated in the chair with their right hand either resting on the table (observation), on the handgrip for the robot (non voluntary) or at rest on the tracing table (voluntary). The apparatus, including the robot arm, is illustrated in Figure 9. Each trial consisted of four symbol videos, where the first two videos formed the first symbol pair and the third and fourth videos formed the second symbol pair. Each symbol video was preceded by a 4 s preparation video where “Ready” was flashed on the screen for 3 s, followed by “Go!” for 1s. There was approximately a 30 ms period between the “Ready” and “Go!” signals.

At the conclusion of the first symbol pair, a 2 s video read, “Prepare for the next Symbol Pair!” and appeared before the next “Ready, Go!” video.

Upon the completion of a trial, the participant was presented with the answer video, which asked, “Which of the previous pairs were more similar?” This screen lasted for 10 s and participant would verbally communicate their answer to the experimenter and indicate their confidence on the confidence ratings sheet. Participants were told they would only have 10 s to make their decision. No exceptions were made.

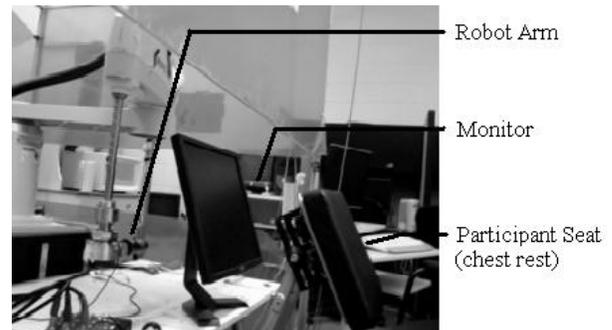


Figure 9. The experimental apparatus. This figure depicts the participant position, LCD monitor screen and robot arm. The robot arm would be moved out of the movement area for the voluntary and observation trials.

Each trial took approximately 1 min, and participants completed 10 trials per block followed by a brief rest period. Breaks would last for at least 2 min and at maximum 6 min. Participants were allowed to get out of the chair or readjust the chest rest to be more comfortable.

Observation Condition. Because participants were not mimicking at all, they were instructed to keep their right hand at rest on the table. They were not allowed to move their hand at all at any point during the trials. Their left hand was used to complete the confidence ratings, and they could rest their hand on their lap or on the table.

Voluntary Condition. An Optotrak IRED was attached to the participants' right index finger using tape. Participants were instructed to actively mimic the symbol tracings they viewed on the screen using their right index finger. Their hand was positioned behind the screen so they would be unable to view their own hand during the movements.

The participants' hand was positioned on a 52.5 cm x 20.6 cm wooden board 10 cm above the collection table. This ensured that the participants' movements were performed at the same height and orientation as the non-voluntary group. Some participants felt some discomfort from moving their finger on the wooden board and received a strip of electrical tape placed on the tip of their finger for comfort.

An audible beep signaled the start of every preparation video, and participants were instructed to remain at rest at a home position, located 13.1 cm from the right edge of the board and 10.5 cm from the bottom of the board. Once the symbol videos began,

the participant was asked to mimic the movements on the screen as accurately as possible and return to the home position upon completion of a movement. Moreover, participants were told to move the entire dominant hand while tracing, not just the finger. They were not given explicit guidelines on the size of the symbol tracing. At the conclusion of each trial, the participant would verbally indicate the most similar symbol pair and use their left hand to indicate their confidence rating.

Non-Voluntary Condition. Participants were outfitted in a sanitary sleeve and a wrist brace on their right hand before using the robot. The right hand was placed on the robot handgrip, which was 10.4 cm from the table, and their index finger was positioned identically to the voluntary mimicking group. Participants were instructed to let the robot lead their hand through the motion they were seeing on the screen. Similar to the voluntary mimic group, the robot movements were positioned behind the screen so they would be occluded for the participant during the viewing of a video.

The robot would move in sync with the screen and return to the home position upon the completion of each symbol video. At the conclusion of each trial, the participant would verbally indicate the most similar symbol pair and use their left hand to indicate their confidence rating.

Data Analysis

Three main performance measures were used: the perceptual accuracy, confidence level and similarity footprint. Similarity was not explicitly defined, so each group's "definition" of similarity was determined by examining trends on symbol pair selection.

Each symbol pair was broken down and coded according to their spatial and angular differences. For example, if the difference between a symbol pair were the third line differing by 45 degrees, the pair would be coded as such. Therefore, every time a pair would be selected as more similar than another, these decisions would be put into the perspective of the spatial differences between the selected symbols. This allows the experimenters to examine which symbol differences a participant would define as similar depending on their concurrent movement.

The remaining measures are those that would be collected at the time of the trial, i.e. the participant's accuracy score in identifying the most similar pair, and their confidence with each answer. Perceptual accuracy is a binary measure assigned to each trial, i.e. the participant was either correct or incorrect in identifying the most similar symbol pair. The percentage of correct trials was divided by the total number of trials with a definite correct answer, i.e. all trials where there was one or two degrees of difference between the similarity pairs in each trial. Twelve trials out of the total 60 contained trials where both symbol pairs had no degrees of difference between similarity scores. These trials were omitted from the perceptual accuracy calculation. Due to the binary and nominal nature of the perceptual accuracy, a non-parametric analysis was required to compare the perceptual accuracy measures of each group. A Kruskal-Wallis test was utilized to determine the effect of movement on perceptual accuracy.

Confidence scores for each trial were correlated to degree of similarity between symbol pairs as well as perceptual accuracy. Spearman Rank Order correlations were computed across each group for the two different correlations. The confidence values for

each participant were first correlated with the degree of difference in similarity scores of the trial pairs (no degrees of difference, one degree of difference or two degrees of difference).

Each group's confidence scores for each trial were also correlated to the perceptual accuracy score for each trial (correct or incorrect). Trials with no degree of difference were not included in this analysis, since both pairs display the same degree of similarity and do not allow for a consistent "right" answer according to the similarity scoring rules. Please refer to the Randomization Procedure section for a more detailed explanation. 120 trials for each group fell into the category of no degrees of difference trials and were omitted for this correlation.

In the voluntary mimicking condition, the participant's onset of movement was calculated in order to determine which trials were performed in sync or not. Christensen et al. (2011) found that any movements performed within at least 240 ms with a visual stimulus lead to a benefit in perceptual ability. A custom MATLABTM code was created to calculate when a participant's finger moved at a speed of 10 mm/s for 40 ms. For all movement initiation analyses, participant movements were discarded if the participant was not at rest upon the presentation of the visual stimulus. In total, 181 movements out of 2400 were discarded.

Results

Perceptual Accuracy

Voluntary Movement Synchrony. Mean movement initiation time was 766 ms, and participants initiated movement in less than 240 ms for 227 of the 2400 total trials. There were no trials where the participant was in sync for all 4 movements, so it is not possible to comment on the effect of synchrony on perceptual accuracy. Participants were not moving in sync with the visual display and, therefore, were not expected to perform at a level significantly higher than the other movement manipulation groups.

Perceptual Accuracy Analysis.

Hypothesis: Perceptual accuracy will be the highest in the voluntary movement group. The non-voluntary group will be better than the observation group and worse than the voluntary group. It is expected that each group's perception of similarity will follow the same trend as perceptual accuracy.

As explained in the Methods, perceptual accuracy was a binary measure where the participant was either correct or incorrect. As well being nominal in nature, the collected data also comprised a skewed distribution thus rendering mean values as indicators of Central Tendency invalid. These violations of standard parametric analyses required us to subject these data sets to non-parametric tests of significance. . Thus each group, containing an equal number of participants ($N = 10$) had their perceptual accuracy scores were ranked from highest to lowest. The Kruskal-Wallis result showed no significant difference between the groups, $H(2) = .565, p = 0.754$; therefore, it would appear that concurrent motor movement has no effect on perceptual accuracy. It should be noted,

however, that the voluntary group displayed a significant time lag in their active tracings. These results fit into the framework of the predominant action observation models mentioned in the introduction, Common Coding and MOSAIC. The exact implication of these results is explained in the discussion.

Symbol Component Analysis

Hypothesis: Perceptual accuracy will be the highest in the voluntary movement group.

The non-voluntary group will be better than the observation group and worse than the voluntary group. It is expected that each group's perception of similarity will follow the same trend as perceptual accuracy.

Because similarity was not explicitly “defined”, it was expected that each group’s similarity definitions would reflect a measure of perceptual accuracy. The group with the highest perceptual accuracy would select pairs with smaller differences in angle and spatial difference as most similar, and pairs with large angular or spatial differences as less similar. The group with the lowest perceptual accuracy would have highly variable proportion selections where less similar components are selected to be similar, such as those with multiple spatial differences or greater angular differences. Should none of the groups differ in perceptual accuracy, no differences in similarity definitions are expected.

Each participant’s “similarity footprint” was calculated by extracting the proportion values for each component in the symbol pairs, i.e. the proportion of times that each component was selected as the most similar pair. There were 9 different components, each referring to the possible differences between symbol pairs, shown in

Table 1. The final symbol pair difference, Line 1, 2 and 3 shifted by 45 degrees, was not utilized in the statistical analysis because it was not present in all movement groups due to the randomization code.

A 3 (group) by 8 (component) mixed factor analysis of variance was performed, where movement group (voluntary movement, non voluntary movement and observation) was the between group factor and component (see Table 1 for each factor) was the within

Table 1

Symbol Pair Differences
Line 1 shifted by 45 degrees
Line 1 shifted by 90 degrees
Line 3 shifted by 45 degrees
Line 3 shifted by 90 degrees
Line 1 shifted by 90 degrees Line 3 shifted by 45 degrees
Line 1 shifted by 45 degrees Line 3 shifted by 45 degrees
Line 2 shifted by 45 degrees Line 3 shifted by 90 degrees
Line 2 shifted by 45 degrees Line 3 shifted by 45 degrees
Line 1 shifted by 45 degrees Line 2 shifted by 45 degrees Line 3 shifted by 45 degrees

Table 1: Types of differences between symbol pairs. Line 1 refers to the first line in a movement, and line 3 is the last movement in a symbol. The movement from the home position to the start of the movement was not included in this analysis.

group measure. A main effect was found for the component proportions, $F(7,189) = 24.01$, $p < .001$, and a Tukey’s HSD post hoc analysis revealed differences across components, displayed in Figure 10. There was no main effect for group, $F(2,27) = .20$, $p = .823$, and no interaction between group and component, $F(14,189) = .62$, $p = .844$, suggesting that each group’s definition of similarity did not significantly differ. These results reflect the same pattern seen in the perceptual accuracy results suggesting that each group perceives similarity in a comparable fashion. Similarity “footprints” are plotted in Figure 11, where each thick line represents group mean data. Each point

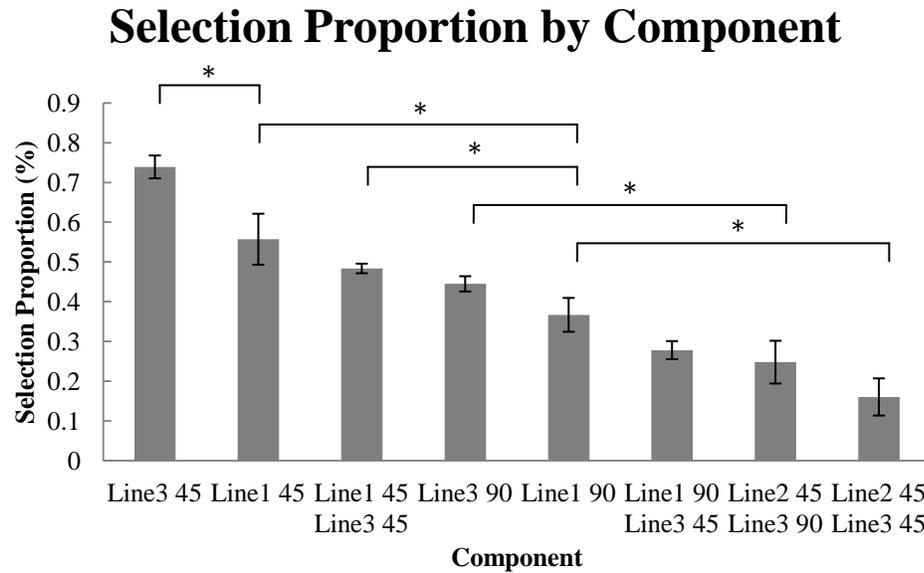


Figure 10. Average Proportion of Selection (%) for each Symbol Pair Component Difference, i.e. how often each component was selected as the most similar pair. * indicates significant differences between means ($\alpha = .05$)

represents the proportion of times that component was selected as the most similar pair in a trial. It appears that each group perceives symbol pairs with single differences (i.e. one line differs between pairs) as more similar than symbol pairs with multiple differences (i.e. more than one line differs between pairs). However, the lack of significant group differences suggests that each group perceived similarity the same way, since none of the similarity footprints for each group were significantly different from each other.

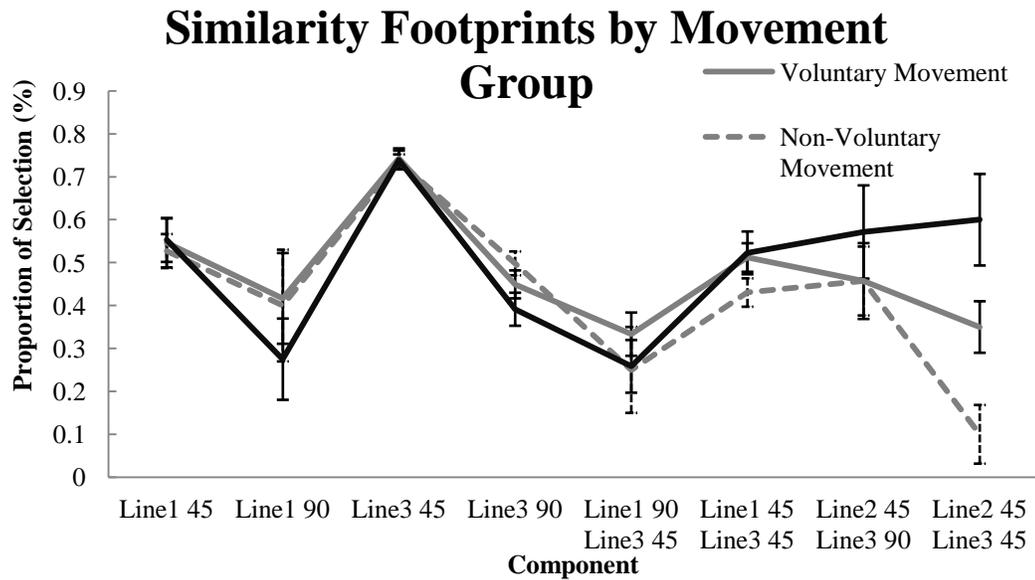


Figure 11: Group by Component "Similarity Footprints". Each line denotes the averaged group proportions for each component's selection as the most similar symbol pair. Components are listed along the horizontal axis, and reflect differences between symbol pairs. The higher a proportion for each component, the more similar that component was perceived by a group. Error bars represent standard errors.

Confidence

Hypothesis: The voluntary and non voluntary movement groups' will be better able to judge their own success, and therefore, will have stronger positive correlations between their confidence and performance. Conversely, the observation group, without possessing concurrent movement, will have confidence scores that do not correlate to a participant's perceptual accuracy. Movement groups will be more sensitive to the degree of difference between similarity groups, and will display a significant correlation between confidence and degree of symbol pair similarity score difference.

Due to the nominal nature of the perceptual accuracy and similarity data, Spearman Rank Order correlations were utilized for these analyses. Due to the large

number of trials, it is possible that between and within subject variability are contributing to this analysis. Spearman Rank Order correlations between confidence and trial pair similarity score difference revealed weak, significant positive correlations for the voluntary group ($r_s(600) = .158, p < .001$) and non voluntary movement groups ($r_s(599) = .122, p = .003$) according to the strength of a correlation defined by Cohen (1988). The observation group displayed a very weak correlation, ($r_s(599) = .095, p = .020$). These results suggest that each groups confidence score was weakly attributable to the degree of difference between trials, such that when a participant observes a trial with two similar pairs, they were not be very confident in their answer. Conversely, if they observed a trial with a large degree of similarity score difference, such as a dissimilar pair followed by a

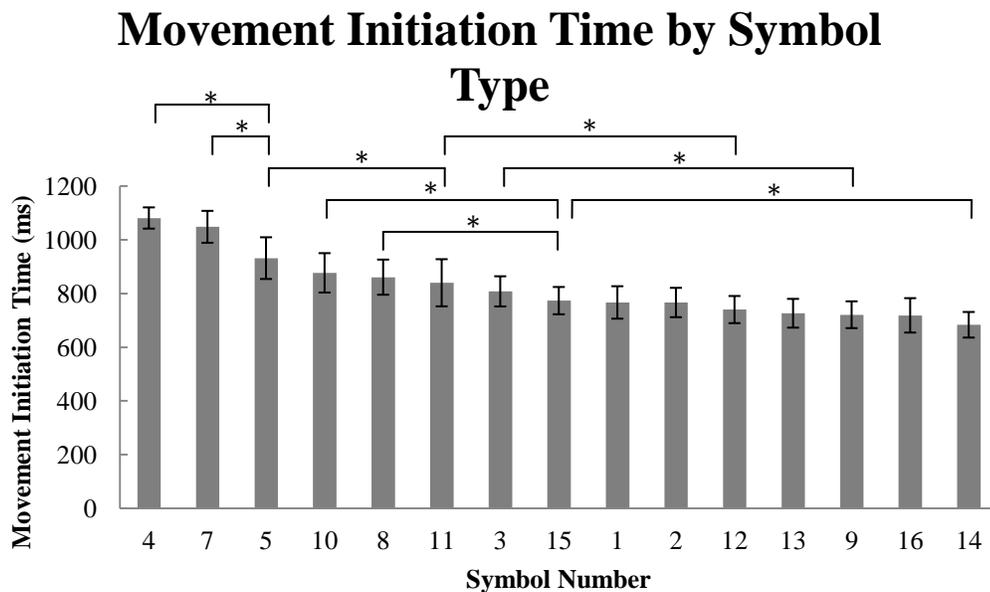


Figure 12: Movement Initiation Time (ms) for each symbol stimulus. Symbols are listed along the horizontal axis in order of their average movement initiation time (ms) by voluntary movement participants. Error bars represent standard errors. * indicates significant differences between means ($\alpha = .05$)

similar pair, they will be more confident in their answer.

As expected, the Spearman Rank Order correlation between confidence and perceptual accuracy revealed the voluntary ($r_s(479) = .208, p < .001$) and non-voluntary ($r_s(479) = .228, p < .001$) movement groups displayed weak positive correlations with perceptual accuracy. The observation group did not display a significant correlation ($r_s(479) = .070, p = .125$), thus suggesting that movement allows participants to be better at judging their own performance. Taken together, these results suggest that concurrent movement (regardless of whether voluntary or not) has a significant influence on confidence scores when perceiving any type of movement.

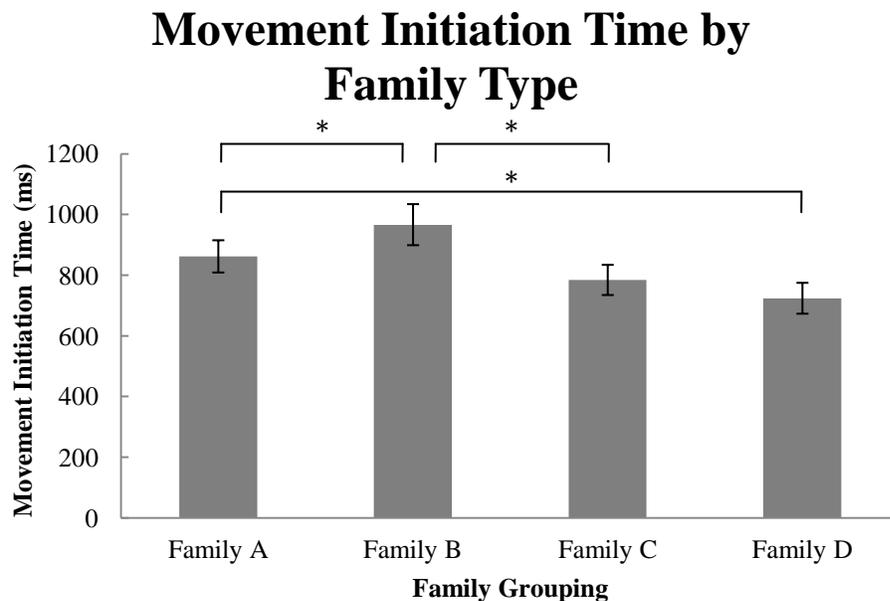


Figure 13: Average Movement Initiation Time (ms) for each Symbol Family. Symbol families consist of 4 related symbols (see figure 5), each forming 6 pairs. Error bars represent standard errors. * indicates significant differences between means ($\alpha = .05$).

Further analysis was run on the groups of family symbols (A, B, C, D) to determine differences in movement initiation time. Recall that each family was grouped depending on the base symbol that was manipulated to form the remaining symbols. Each family, therefore, was based on three manipulations of a different base symbol. Differences in average movement initiation times across families could be attributable to the spatial differences between the families, but could also be due to the different distribution of pair similarity in each family. Recall that each family did not have the same distribution of similar, moderately similar and dissimilar pairs (consult Figure 5 in Methods). A one way repeated measures analysis of variance was run on family grouping and a main effect was found, $F(3, 27) = 28.89, p < .001$, as shown in Figure 13. Tukey's HSD post hoc analysis was performed on the average means of each family and it was found that Family D ($M = 723.43$ ms) had the fastest initiation time, followed by Family C ($M = 783.82$ ms), Family A ($M = 861.50$ ms) and Family B ($M = 966.06$ ms). Family D was significantly faster than Families A and B. Families A and C were significantly faster than Family B, but not significantly different from each other.

These results indicate that each family resulted in different levels of planning. As mentioned previously, it is possible that the similarity of each symbol pair is affecting the movement initiation time, such that a more similar pair may take longer to initiate because the participant needs to determine which symbol they are performing prior to initiating movements. A repeated measures analysis of variance was run on the symbol pairing similarity grouping (dissimilar, moderately similar or very similar). Recall that a pairing similarity can range from 1 to 5, and any pairs in the range of 1-2.5 are dissimilar,

3-4.5 are moderately similar and 5 are very similar. A significant main effect was observed for symbol similarity groupings, $F(2, 18) = 25.63, p < .001$, as shown in Figure 14. A Tukey's HSD Post hoc was performed and it was found that the dissimilar pairs ($M = 757.73$ ms) had significantly faster initiation times than the moderately similar pairs (884.63 ms) and similar pairs (837.55 ms), which were not different from each other.

Make sure

Movement Initiation Time by Symbol Pair Similarity

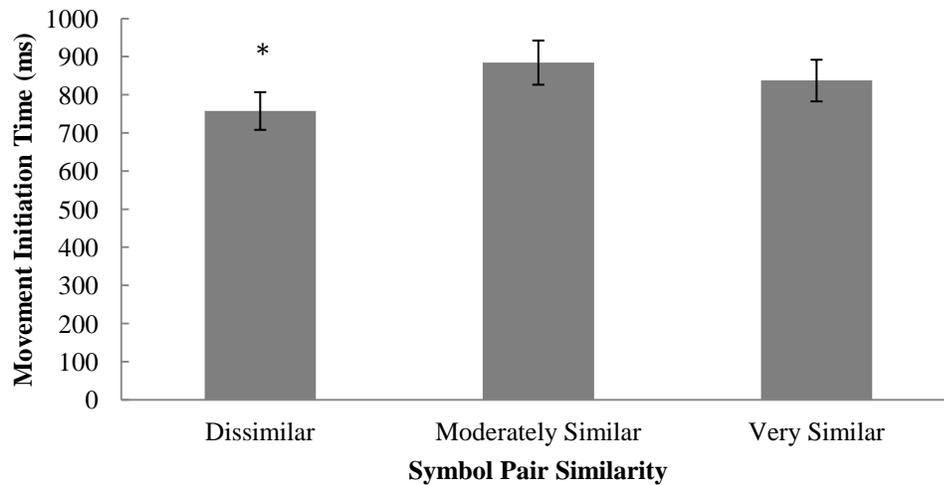


Figure 14: Average Movement Initiation Time (ms) for Symbol Pair similarity. Each degree of pair similarity was significantly different from each other, with the dissimilar pairs possessing the shortest average movement initiation time. * indicates significant differences between means ($\alpha = .05$)

Upon examining the average similarity of each family, it appears that the differences in initiation time are attributable to the similarity between symbols. Average similarity scores for Family B ($M_{\text{similarity}} = 4.8$) and Family A ($M_{\text{similarity}} = 4.4$) indicates

the presence of more similar pairs than Family C ($M_{\text{similarity}} = 3.6$) and Family D ($M_{\text{similarity}} = 3.3$), which possess relatively more dissimilar pairs. In accordance with the results from pair similarity, the family with a higher average similarity would be expected to have a greater initiation time because the participant would need more time to differentiate between each symbol. If this is the case, it would be expected that each symbol tracing would be initiated quicker once the participant is aware of which family they are performing.

The position within each trial was analyzed using a one way repeated measures analysis of variance for each of the four (first, second, third or fourth symbol in a trial)

Movement Initiation Time by Trial Position

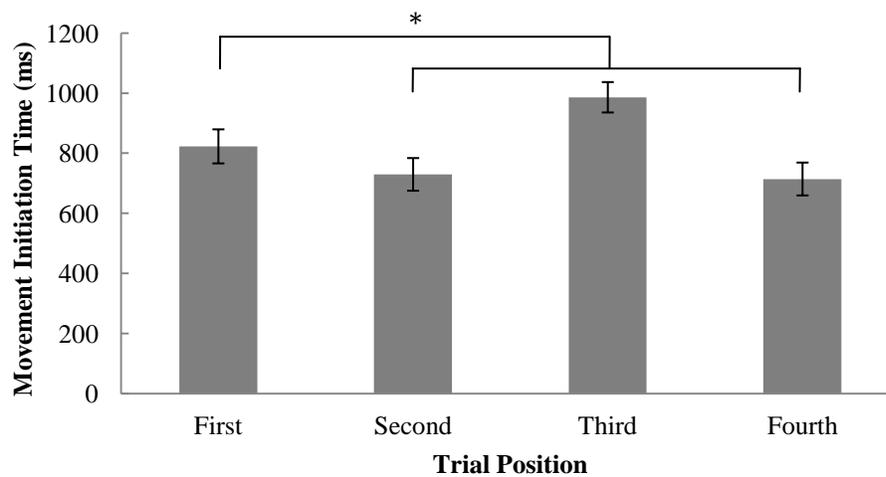


Figure 15: Average Movement Initiation Time (ms) for each Trial Position. Symbols in the first and third position were significantly slower than all other trials. Trials in the second and fourth position were not significantly different from each other. Error bars represent standard errors. * indicates significant differences between means ($\alpha = .05$)

positions in a trial. A significant main effect was observed for position, $F(3, 27) = 63.09$, $p < .001$, and a Tukey's HSD post hoc was performed to determine differences between the average movement initiation times for each position, as shown in Figure 15. It was found that the third ($M = 986.03$ ms) and first ($M = 822.60$ ms) positions were significantly higher than the second ($M = 729.36$ ms) and fourth ($M = 713.97$ ms) positions. The third position was also significantly higher than the first position alone. The second and fourth positions were not significantly different from each other. These results suggest that the participant requires less time to initiate movement in the second symbol of each pair. It is possible that this is because the participant is now aware of the family of symbols being observed. In the first symbol in each pair (first and third movements of the trial), participants may require extra processing time to determine the family being observed. This conclusion is bolstered by a significant interaction between family and position in trial, $F(9, 81) = 2.56$, $p < .05$. These results demonstrate that each family is affected to a similar degree depending on which position in the trial each symbol appears. Once the participant is aware of the family being performed, the movement initiation time decreases.

Effectiveness of the Task

A Kruskal-Wallis test was performed to determine if the similarity scores for each group were significantly above chance. Significant differences were found for each condition, $H(3) = 16.297$, $p < 0.001$, with a mean rank of 13.90 for voluntary movement, 17.80 for non-voluntary movement, 17.30 for observation and 33.00 for chance. Together, these results reveal that each group was basing their decisions of similarity on a

certain criterion instead of pure chance. Analysis on the component selection proportions for all groups was also performed to evaluate each group's performance of the task. A mixed factor 3 (group) by 2 (symbol pair differences) analysis of variance was conducted using the three movement groups (Observation, Non-Voluntary movement and Voluntary movement) as a between group factor and the quantity of symbol pair differences (Single difference pairs and Multi-difference pairs) as a within group factor. As expected, there was a significant main effect for the single and multi difference component selection proportions, $F(1, 27) = 28.60, p < .001$, where the single difference pairs ($M = .53$) were selected more often than the multi difference pairs ($M = .29$). There were no differences between groups, $F(2, 27) = .24, p = .786$, and no group by component type interaction, $F(2, 27) = .72, p = .495$, suggesting that all groups employed the same strategies for denoting similarity. That is, the pairs with only one difference would be perceived as more similar than pairs with multiple differences.

Discussion

The purpose of this thesis was to examine the influence of self generated motor commands on concurrent perception and action. According to the Common Coding framework, perception and action areas share representations and can operate in harmony (Prinz, 1997). Accordingly, previous paradigms have displayed a benefit to perceptual accuracy when performing concurrent voluntary action instead of pure observation (Zwicker et al., 2010; Christensen et al., 2011). According to some models of motor

control, voluntary actions allow for the self generation of motor commands, which results in the formation of motor efference copies. These efference copies are integrated with synchronous perceptual feedback to enhance judgments of movement, outlined in the MOSAIC framework for action imitation (Wolpert et al., 2003). Voluntary action is also expected to improve judgments of performance in perceptual tasks. Movement affects confidence and perception in separate pathways, and appears to affect confidence more than perceptual accuracy (Busey et al., 2000).

It was expected that concurrent voluntary actions would result in an increase in perceptual accuracy due to the benefit of efference copy. Moreover, it was also expected that voluntary action would result in a different perception of similarity, whereby symbol pairs with less difference were selected as similar at a higher rate compared to groups with no voluntary movement. Lastly, it was expected that movement groups would demonstrate a greater judgment of performance compared to the observation group.

Perceptual Accuracy

Hypothesis: Perceptual accuracy will be the highest in the voluntary movement group.

The non-voluntary group will be better than the observation group and worse than the voluntary group. It is expected that each group's perception of similarity will follow the same trend as perceptual accuracy.

The results displayed no difference between groups for perceptual accuracy or similarity footprint, suggesting that concurrent movement has no influence on perceptual accuracy. These results fit into the predominant action observation frameworks supported

in the literature. Recall that the current models of action observation are based on the idea that motor and perceptual areas in the mirror neuron system interact with each other concurrently (di Pellegrino et al., 1992), instead of sending unidirectional messages between each other (Massaro, 1990). The established framework for this concurrent interaction is the idea of Common Coding, which suggests that the perceptual and motor areas of the brain share common representations of an observed action (Prinz, 1997). The mechanism for how this is achieved has been proposed by Wolpert et al. (2003) as an adaptation of the MOSAIC model to explain action observation and imitation. This system is based upon separate “modules” of motor commands and their respective consequences. As an observed action is mimicked, a “comparator” calculates the error between the predicted consequences of the selected motor command (from the efference copy) and the observed sensory feedback from the perceptual stimulus. The comparator assigns an error value to each module, which reflects the degree of similarity between the performed action and the observed action. This error value is used to calculate the most optimal action to perform, which would result in the least amount of error, and thus, would be most similar to the observed action.

For this feedforward system to occur as stated, the participant would need to have a prediction of the performed motor action to be compared to the incoming sensory feedback. However, in the non-voluntary and observation conditions, participants are not actively moving, and it is probable that they do not have efferent copies created by the motor cortex for predictive comparisons to occur.

If a participant were to purely observe an action, they would primarily be utilizing past motor experience for integration with the perceptual area. For example, in Calvo-Merino et al. (2006), expert dancers' motor areas (premotor cortex) demonstrated greater activity when observing actions within their own expertise. Since the perceptual stimuli in the current study were novel symbols, it is plausible that because participants possessed no relevant past motor experience, they were unable to perform at a higher level than the voluntary or non-voluntary groups. Thus, the observation group's performance corresponds with the predictions allotted by the MOSAIC framework model.

Moreover, if an observer is being passively led through a movement, it has been proposed that there is less motor planning occurring than during voluntary movement (Weiller et al. 1996) and thus, the potential for a reduced level of efferent copies of motor commands to be integrated with perceptual representations. Therefore, as the results indicated, the non-voluntary group should not have a heightened perceptual ability, even if all movements were performed in synchrony with the visual stimulus. There has been little to no evidence indicating a benefit in perception during concurrent non-voluntary movement, except with regards to the acquisition of a novel movement pattern (Bara & Gentaz, 2011). With regards to the MOSAIC framework, comparators would not be able to function properly in the absence of self generated motor commands and efference copies. Therefore, non voluntary participants are only able to integrate proprioceptive information with visual information for this action observation task. However, proprioceptive information has been shown to be noisy and unreliable compared to visual input (Bays & Wolpert, 2007). As shown by the results, the non-voluntary group's

perceptual ability and similarity footprint did not differ significantly from the observation group. One reason for this lack of difference may be because participants are unable to effectively integrate proprioception and visual feedback in order to aid perceptual judgments. However, since this study utilized healthy individuals for this task, deficits in multi-sensory integration are not probable. A more likely explanation may be that participants were not taxed by the symbol identification paradigm, and were unable to make use of extra feedback available from somatosensory information, because they would rely primarily on visual information for this task.

Lastly, in the case of the voluntary movement group, the MOSAIC framework suggests that participants would experience a benefit to perceptual ability. The motor representations formed in the premotor cortex and the perceptual representations have an “additive” effect when they are in sync, and perceptual ability in recognizing the performed motor representation is heightened, as found by Christensen et al. (2011). However, the results demonstrated that voluntary mimicking did not result in a benefit in perceptual accuracy, nor did it affect the participant's definition of similarity, indicated by the similarity footprint. This is due to the increase in processing time required for participants to begin initiation of each movement.

Recall that in the Christensen et al. (2011) study, participants receive “live” feedback of their movements, and were not mimicking any movement. In essence, they were observing their own motion in a minimalistic point light display setting. It was found that when the visual display was delayed, participants were unable to integrate the perceptual and motor information and an interference effect was observed. Similarly,

since each movement tracing was out of sync, it would not be a “common” code, and would not be integrated with the respective perceptual input. Specifically, the feedback from each mimicked movement would be, on average, approximately 500 ms behind the visual feedback. Therefore, the MOSAIC comparators are unable to assign error discrepancy values to each comparator-predictor pair, since the two input signals (perceptual feedback and efference copy) are out of phase. As a result, the participants in the voluntary movement condition are unable to perceive differences in symbol pairs any different than the other two movement groups, since they are unable to utilize their extra sensory information in an effective manner. More generally, this finding suggests that observers actively mimicking a novel action require a substantial amount of time to process the visual stimulus, such that the temporal threshold for perceptual benefit is almost impossible to achieve consistently.

Similar to the non-voluntary group, it is also possible that this task was not difficult enough to reveal differences between the groups. It is possible that the voluntary movement participants were relying on visual feedback in making their judgments, and did not incorporate any movement information in their decisions. Therefore, if all three groups were using visual information in a comparable fashion, the lack of perceptual accuracy differences could be attributable to the reliance of the same source of information, and movement groups were not challenged into using movement information for judgments.

In a real world scenario, these paradigms would be comparable to two separate sport practice scenarios involving a novice pitcher attempting to learn to identify different

types of baseball pitches. Imagine a live action practice session where novice baseball pitcher's actions are instantaneously presented on a screen in front of them. Contrast this with a feedback session where novice pitchers are required to actively mimic a pitch presented on the screen, be passively led through the motion by their coach or observe the presented action. These results suggest that the pitcher will be excellent in identifying the performed pitch when the display is synced to the movements of the pitcher, as there would be no interference between perception and action. However, if the pitcher is required to observe an action and then mimic in sync with the display, their perceptual ability is compromised. This is due to an asynchrony between the visual feedback and efference copies created from planning the pitch. These results also show that the level of movement does not influence the perceptual ability. If the pitcher was to be led through the action by their coach, in sync with the display, or if they were to purely observe the action on screen, they would have a similar level of accuracy in identifying the viewed novel pitches. It is clear that a fluctuating motor processing time component before initiating movement seriously hampers the voluntary movement. The influence of processing time on the perceptual ability of voluntary movement participants is examined below.

Movement Initiation Time

Participants' average initiation time was 760 ms, which is significantly higher than the maximal threshold value that would allow for a benefit to perception, as established by Christensen et al. (2011). Fundamentally, this means that participants are unable to recognize, plan and then execute a movement plan concurrent with a visual

display. The key reasoning behind this, as was explored in the Results section, is due to variable processing times due to differing demands by position in the trial or family of symbols being observed. Recall that the four families of symbols were established based on four different base symbols. Each symbol family was spatially different from each other, but symbols within a family were at least minimally related to each other. Also recall that a 6-point scoring system established by Solso and Raynis (1979) determined symbol pair similarity. Symbol similarity was assessed according to spatial similarity and angular similarity. Therefore similar pairs had a limited spatial and positional degree of difference, but dissimilar pairs had drastic differences between pairs in spatial and positional similarity.

There were significant differences between similar and dissimilar pairs of symbols, whereby dissimilar pairs of symbols had lower average movement initiation times compared to similar and moderately similar symbol pairs. It is possible that the more exaggerated the differences between two symbols are, the easier it is for a participant to recognize which symbol is being displayed and would be able to perform the movement relatively in sync. These findings are consistent with findings found in facial recognition studies, where exaggerations in facial expression, or “caricaturing” (Brennan, 1985), lead to faster response times and higher degrees of accuracy (Rhodes, Brennan & Carey, 1987). This effect also exists in biological motion paradigms. For example, Pollick, Fidopiastis and Braden (2001) utilized a tennis serve perception task to examine participants’ perceptual ability in response to exaggerated tennis movements. Tennis serve animations were manipulated to enhance the unique characteristics of

different types of normal tennis serves. They found that the more dissimilar a serve was compared to the normal template, the higher the accuracy for correctly categorizing the type of serves being performed. It is believed that the exaggerated differences between

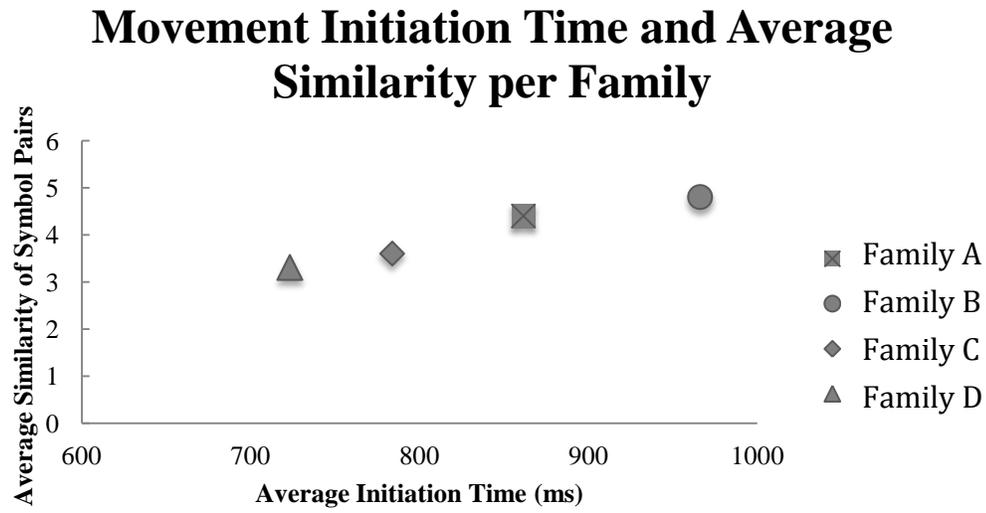


Figure 16: The average initiation time of each family increases as the pairs in a family are more similar. Families with a more similar pairs (Families A and B) require more time for movement initiation than families with more dissimilar pairs (Families C and D).

serves allow participants to easily distinguish between different stimuli, similar to the current study. This would also explain differences in movement initiation time between families, as the average similarity between families appeared to be strongly connected to the average similarity within each family's symbol pairs. Notice that as families increase in movement initiation time, the average similarity also increases (Figure 16).

Effects were also found for the position in the trial, where the first symbol in each pair would result in significantly higher movement initiation times than the second symbol in each pair. It was believed that this is due to a priming effect whereby

participants require more time to identify the symbol pair upon the first viewing, but when observing the second symbol, the symbol family has been established, and the participant is primed to move in a relatively similar fashion. Bidet-Ildei, Chauvin and Coello (2010) found similar results in a motor priming study. Participants demonstrated heightened perceptual ability and decreased response times upon receiving “motor priming” prior to observing a difficult perceptual task. In this case, the task was to determine the direction of a point light runner in a noisy point light display. Observers who performed a motor behaviour before observing the visual stimulus had a significant improvement in perceptual accuracy and decrease in response time compared to groups without priming. It is thought that the motor priming enhances the connection between perceptual and motor areas, as hypothesized by Common Coding models, specifically “motor and perceptual resonance” (Schütz-Bosbach & Prinz, 2007). It has been proposed that producing an action will prime a participant to become perceptually tuned to perceiving similar stimuli. Schütz-Bosbach and Prinz (2007) explain that this point of view is rooted in the social aspect of the Common Coding theory, which suggests that humans are able to empathize and relate to each other due to a “perceptual narrowing” that focuses an observer’s visual system to become more tuned to relevant perceived and mirrored actions. Such a response is integral to observational learning during infancy for example, where an infant’s perceptual system narrows to allow for focused acquisition of new movements, as well as connections with family members through mirrored actions (Trevarnen, 1993), as cited by Schütz-Bosbach and Prinz (2007). This has also been observed in adults, in a well-documented phenomenon where an individual would

subconsciously mirror the actions of another, known as the “chameleon effect” (Chartrand & Bargh, 1999). Therefore, the effects of motor priming experienced in this paradigm seem to reflect those originally posited by Schütz-Bosbach and Prinz, and demonstrate the effect motor movement can have on perception. The observed effect of quicker initiation times in the second symbol in each pair could be due to perceptual narrowing experienced in the participant after performing a similar symbol. When the participant moves to the next (unrelated) symbol pair, their perceptual system has to readjust to the new pair, resulting in a greater initiation time in the movements.

It has also been found that the third symbol in a trial has a longer initiation time than the first and second symbols. It is possible that there are additional cognitive demands placed on the participant in this movement because they are trying to internalize the first symbol pair's similarity as well as prepare to recognize the upcoming symbol pair. It has been well documented that visual short-term memory is severely limited, and can retain a maximum of three to four items (Cowan, 2001; Vogel, Woodman & Luck, 2001). Therefore, part of this increased processing time could be due to the increased demands because they are trying to internalize the first symbol pair's similarity as well as prepare to recognize the upcoming symbol pair. This effect has limited support in the literature and would need to be examined independently.

In accordance to the aforementioned baseball example, if the pitcher were to try to differentiate between multiple groupings of pitches, their abilities would be significantly tied to the similarities within each group of pitches. For example, if a pitcher was to differentiate between different types of fastballs, each requiring the same type of grip on

the ball, they would require a longer time to process the observed pitching movement before initiating movement. Conversely, if the pitcher was observing a pitch from the “off speed” family of pitches, it is well known that these pitches have a vast array of grips and are quite noticeable. The novice pitcher should have an easier time differentiating between pitches in this family and would be able to initiate movements significantly earlier than the fastball family.

Confidence

Recall that the two possible models that account for differences in confidence correlations and perceptual accuracy differ in the number of pathways utilized by the movement groups (Figure 1). In the single dimension model, movement groups contribute to perceptual accuracy and confidence correlations equally, by increasing the strength of each symbol's memory representation. It would predict that the movement groups would have an increase in perceptual accuracy and judgments of performance. Conversely, the dual dimension model proposes that separate pathways derive perceptual accuracy and judgment of performance. Perceptual accuracy is entirely dependent on the strength of memory representations, but confidence relies on memory strength as well as certainty. Movement is the only sensory input that can affect certainty, and certainty can only affect confidence, but not perceptual accuracy. Therefore, differences in confidence may not be reflected in the perceptual accuracy scores.

The results demonstrated that groups with movement, regardless of it being voluntary or non voluntary, had higher confidence correlations than the pure observation

group. Therefore, movement groups had a higher confidence when they were correct and a lower confidence when they were incorrect. Recall that all three groups reflected the same degree of perceptual accuracy, but demonstrate different levels of confidence correlations. Therefore, these results support the dual dimension model with regards to perceptual accuracy and confidence correlations in a biological motion setting.

Since both movement groups had higher confidence correlation scores, it is possible that the act of moving allowed them to have a stronger memory representation for each symbol. There is evidence to suggest movement strengthens a participant's respective internal representations (Cross et al., 2009; Bara & Gentaz, 2011). However, recall that perceptual accuracy is also derived from the "memory strength" pathway, and no group effects were observed for that measure. Thus, it is probable that the group differences are primarily due to the contributions of certainty, which then increases confidence in each participant without affecting perceptual accuracy. That is, confidence measures for participants with movement are more sensitive to the degree of similarity between symbol pairs. However, perceptual accuracy does not reflect this sensitivity. The presence of certainty in the model allows us to account for this difference. It is possible for participants with concurrent movement to become more or less certain with how well each trial was performed dependent on the degree of similarity difference between pairs. The exact mechanism of how this occurs is unclear and is out of the scope of this paradigm. However, it is clear that a separate pathway affects a participant's judgment of performance that does not influence their perceptual accuracy.

Therefore, if a pitcher had concurrent movement of any kind, they would have a greater ability in judging their performance. Pitchers without any movement would remain at approximately the same level of confidence for each type of observed pitch, regardless of how familiar they are with the observed pitch. Conversely, once a pitcher is concurrently moving, they will be more confident in their judgments with pitches that are easier to differentiate. Therefore, when learning to observe new types of pitches, players should have some type of movement while observing to improve their judgments of performance.

Implications

The current study has several important implications for action observation literature. Most importantly, this study effectively observed the effect of voluntary and non-voluntary concurrent movement and perception. Voluntary movement participants were unable to mimic the visual display without significant time delays due to processing time. This suggests that in any visual mimicking of a novel movement, observers will be significantly limited by the processing time required for movement. With regards to non-voluntary movement, participants did not display a perceptual accuracy significantly better than observation, which suggests that self generating motor commands may have a significant role in successful concurrent perception and action.

Moreover, this is one of the few studies to effectively utilize full pictorial visual stimuli instead of point light displays, thereby extending the findings of this study to the application of action observation models in real world scenarios. It is important to evaluate perceptual accuracy in a paradigm that would be similar to daily visual activities.

Constant use of full pictorial visual stimuli as well as point light displays is required; not only to ensure broad applicability, but also to identify scenarios where perceptual models are inconsistent. From here, perceptual research could address more questions with models and how they apply to daily life.

Lastly, this study attempted to establish new methods of determining perceptual ability by utilizing judgments of performance in different movement conditions. These finds provide important insight to the effect of movement on judgments of performance.

Limitations

Although this study provides important contributions to action observation literature, there are certain limitations that require explanation. To begin, the main caveat for this study is due to the use of movement initiation time as a measure of motor planning. First, our analysis ignored trials where the participant was not at rest prior to the presentation of the visual stimuli. It is possible that there are certain important interactions occurring during these trials that lead to a participant's movements. For example, on certain trials, participants forgot to return to the home position after the fourth movement. Therefore, when the next trial began, they would be returned to the home position at the point where they should have been at rest. For the purpose of this study's analyses, these movements were omitted to prevent the inclusion of abnormal movement initiation times.

Moreover, it is important to note that movement initiation time, as computed in this study, does not account for the accuracy of tracings in participants. If a participant

were to begin moving in the wrong direction of the visual stimuli, they may be temporally in sync with the visual stimuli but not spatially. The code would only be able to calculate the point at which the participant initiated movement, but not if the participant was correctly moving. Therefore, while conclusions regarding processing time for each symbol do hold value, they should be examined cautiously.

Another limitation in this study was the use of a between subject group design. A repeated measures design would have eliminated much of the intergroup variability due to individual differences. However, this was not possible due to the nature of the visual stimuli. Each symbol was designed to be novel in appearance, such that each participant would be observing a symbol they would have no experience with. If each participant were to partake in the study in three separate sessions of varying movement manipulations, the novelty of the symbols would disappear. Even if participants were to be counterbalanced across movement groups, each observer would not perceive novel symbols by their third session. As shown by Calvo-Merino et al. (2005; 2006), there is a significant effect for observing well learned visual stimuli, especially those that have been performed actively. Thus, any pure observation or non-voluntary sessions that occur following a voluntary movement session would be seriously biased by the expertise gained through actively performing each symbol. It is possible that these familiarity benefits could disappear following a significant wash-out period between consecutive sessions of symbol observation in order to maintain the novelty of stimuli. It is possible that a within-group design could influence the results observed in this study due to the variable nature of perceptual accuracy.

Lastly, as was suggested in the Perceptual Accuracy section, it is possible that the lack of differences observed between the voluntary, non-voluntary and observation group could be due to a lack of difficulty in the task itself. There are significant benefits to retention of novel movement with voluntary (Cross et al., 2009) and non-voluntary (Bara & Gentaz, 2011) movement. It is possible that by adding a memory aspect to this study, such as learning 16 novel symbols and then asked to recognize them after a substantial time period, one could observe differences between the voluntary concurrent movement group and non-voluntary or observation groups.

Conclusion and Future Study

In the current study, movement does not influence perceptual accuracy in a concurrent perception and action paradigm. There was a significant movement and perceptual asynchrony during voluntary movement, suggesting the presence of an interference effect. As such, these results are in accordance with the Common Coding and MOSAIC frameworks for action observation and mimicking, and demonstrate the strength of these frameworks in explaining non-voluntary concurrent movement.

Movement did have a significant influence on judgments of performance, whereby voluntary and non voluntary movement groups were better able to judge their performance than the observation group. It is possible that judgments of performance are performed in a separate pathway for movement tasks than observation tasks. Future study should be conducted on this topic in order to delineate the mechanism for how movement affects judgments of performance.

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Appendix A

Informed Consent Form

Recruitment Poster

Hand Dominance Test

Eye Dominance Test

Brief Neurological Questionnaire



UNIVERSITY OF TORONTO
FACULTY OF KINESIOLOGY & PHYSICAL EDUCATION

Consent Form

Title of the Study:

Effect of Concurrent Motor Activity on the Perception of Biological Motion

Principal Investigator: Simran Ohson – M.Sc. Candidate at McMaster University

Faculty Supervisors: Dr. Luc Tremblay – Associate Professor (University of Toronto),
Dr. James Lyons (McMaster University) and Dr. Tim Lee (McMaster University)

I agree to participate in a study that is investigating the impact of motor planning on perception. I understand that my participation is entirely voluntary. I may withdraw from the experiment at any time and understand that this will have no bearing on the compensation I receive, nor will it have any other undesirable consequences.

The following points have been explained to me:

1. The purpose of the experiment is to examine the impact of motor planning on perception. I understand I will be required to mimic basic arm movements presented on the screen in front of me. Benefits I may expect from the study are: (a) an appreciation for Motor Control and Learning research, (b) an opportunity to contribute to scientific research, (c) **a financial compensation of 10 dollars.**
2. The procedure will last approximately 60 minutes.
3. A monitor will present animated tracings and I may be required to mimic the movements in one of 3 different motor levels: no mimicking, active mimicking or passive mimicking.
4. In the case that I will be passively mimicking a tracing, my arm will be manipulated by the end-effector of a robot. I will hold the handgrip and allow my

arm to be carried along the robot's trajectory. If I feel uncomfortable with the robot's motion at any time, I may release the gripper and the robot will be disabled.

5. There is one known risk associated with this study:

There is a possible, but unlikely, unexpected motion of the robot arm. I understand that if this occurs I may release my hand from the handgrip at any time to stop the robot. Moreover, I have also been supplied with a wrist orthotic that will be worn during the experiment to minimize any possible injuries should this occur.

The researchers do not see any other foreseeable risk to me for participating in this study, nor do they expect that I will experience any discomfort or stress.

6. I have the right to withdraw at any time during the study and I will be entitled to normal compensation. If Dr. Tremblay is a professor in any of my courses, I understand that I am free to participate, or not, without affecting my grade or any aspect of how my work will be evaluated in the course. In other words, even though I am a student and he is my professor, I understand that I am free to choose to participate in the research study or not, my decision is completely voluntary and that if I choose not to participate there will be no adverse consequences for me.
7. The data collected will remain confidential. Only Simran Ohson, Dr. Tremblay, Dr. Lee and Dr. Lyons will have access to the information. No data will be associated with my name but will be replaced with a code. Results may be published in scholarly publications.
8. The experimenter will be open to any questions or concerns about the experiment. For any other information about your rights as participants, please contact the Office of Research ethics at ethics.review@utoronto.ca or 416-946-3273.
9. Upon completion of the experiment, I will receive a briefing on the rationale and expected results of the study.
10. I have been told that the follow sensory manipulation may be employed in this study:
- Robotic Arm
11. I have been told that the number of experimental trials in this study is: _____.

12. I have been told that offered compensation in this study is: \$_____.

You are being given a copy of this informed consent to keep for your own records.

Signature: _____

Date: _____

**Name of
Experimenter:** _____



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PARTICIPANTS NEEDED

You are invited to participate in a research study in the Perceptual Motor Behaviour Laboratory at the University of Toronto. The study investigates the perception of human movement.

You are eligible to participate if:

1. You are right hand dominant, and
2. Have normal or corrected-to-normal vision, and
3. Have no history of:
 - Shoulder, elbow or arm pain, or
 - Visuo-motor disorders, or
 - Any medical condition affecting sensory and/or motor systems

You will be compensated for your time and only a 1-hour time commitment will be required to complete the experiment. If you are interested, please contact Simran Ohson by email at ohsonss@mcmaster.ca

<p>Perception Study Contact Simran Ohson by email at ohsonss@mcmaster.ca</p>
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Hand Dominance Test

Hand dominance test (adapted from Oldfield, 1971)

Please indicate which hand you would use for the following activities:

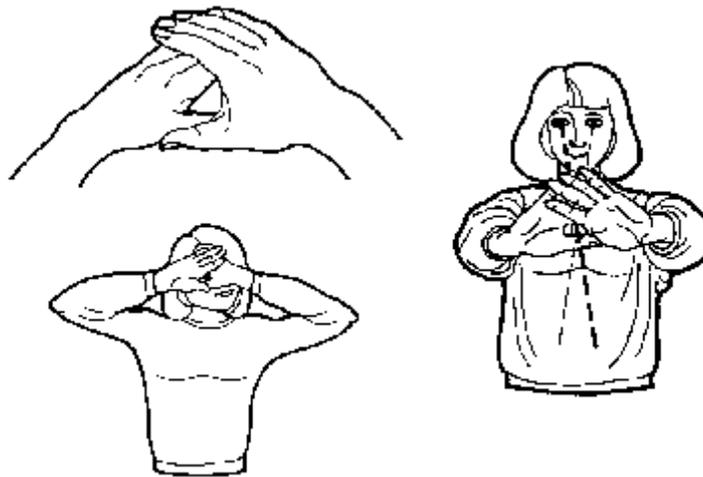
Writing	<input type="checkbox"/> right	<input type="checkbox"/> left
Throwing	<input type="checkbox"/> right	<input type="checkbox"/> left
Scissors	<input type="checkbox"/> right	<input type="checkbox"/> left
Toothbrush	<input type="checkbox"/> right	<input type="checkbox"/> left
Drawing	<input type="checkbox"/> right	<input type="checkbox"/> left

Participants answering right to 4 items or more are deemed to be right hand dominant.

Oldfield, R.C. 1971. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9, 97-113.

Eye Dominance Test

To perform the Miles test (1930), participants will be asked to extend both arms in front of themselves. They are then asked to bring both hands together to create a small opening and then view a distant object through the opening. The experimenter will then ask the participant to close right eye. If the viewed the object is no longer visible, the participant will be deemed to be right-eye dominant.



Miles, W.R. (1930). Ocular dominance in human adults. *The Journal of General Psychology*, 3, 412-430.

Brief Neurological Questionnaire

How often do you experience the following?

Headaches	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Light-headed or dizziness	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Numbness or tingling	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Tremor	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Paralysis	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Convulsions or seizures	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Stroke	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often
Sensory impairment	<input type="checkbox"/> Never	<input type="checkbox"/> Seldom	<input type="checkbox"/> Often

To be considered neurologically intact, participants cannot tick more than one “often” box in the first four categories and must tick “never” in the last four categories.