EXPLORING PERCEPTION AND ACTION RESPONSE TO

MULTISENSORY INCOMPATIBILITY EFFECTS

EXPLORING PERCEPTION AND ACTION RESPONSE TO MULTISENSORY INCOMPATIBILITY EFFECTS

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ABSTRACT

It has been suggested that both visual (e.g., Ward et al., 2002) and auditory (e.g., Sinnett & Kingstone, 2010; Cañal-Bruland, 2018) stimuli can influence anticipatory judgements. The following studies address the nature of the perceptuomotor mechanisms underlying these judgments by contrasting two well-established theoretical frameworks that differentially explain the linkage of perception and action (i.e., a perception-action dissociation model, Milner & Goodale, 2006; a planning-control model, Glover & Dixon, 2001). Specifically, this thesis explores how, when two sources of sensory information (audition and vision) are put into conflict, motor actions may mediate simple perceptual judgements. With reference to the theoretical models noted above, perception-action dissociation theory would predict that incompatible sensory information would have no influence on action. Conversely, the planning-control model would predict incompatible sensory information to significantly influence action. In the three studies comprising this thesis, participants completed two tasks under two distinct response conditions: Perception only; and perception combined with a goal-directed aiming action.

In Studies 1 and 3, participants (n=16) predicted when a visual stimulus travelling at either a fast (224 mm/s) or slow (113 mm/s) velocity in a straight-line trajectory would enter a specified target zone. In Study 1, this was accomplished by simply pushing a button whereas in Study 3, participants moved a stylus controlling an on-screen cursor to the predicted interception point. In both experiments, either a loud (70dB), soft (50db), and no (0db) burst of white noise was presented for 150 ms at the initiation of visual

stimulus movement. On each trial, the stimulus would disappear after either 33% or 66% of distance traveled. Results of Study 1 suggest that when the loud sound accompanied the 33% vision stimulus, overshoot bias was significantly reduced. Conversely, when the loud sound accompanied the 66% vision stimulus, overshoot bias increased (and vice versa) suggesting that in situations where visual information is less reliable, robust auditory information may serve as a useful substitute. When, however, more vision is available, that same robust auditory information may interfere with perceptual judgements. In Study 2, no differences were observed in participants' accuracy and directional bias when the auditory stimulus originated from a different hemifield than the origin of the visual stimulus. Lastly, in Study 3, participants were less accurate overall in predicting the point of interception. In addition, results from the kinematic markers associated with participants moving the stylus (e.g., Movement Time, Peak Velocities and Acceleration, etc.) suggest that differing combinations of auditory and visual stimulus information affect how motor actions are generated and executed in these types of multisensory anticipatory interception tasks.

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DECLARATION OF ACADEMIC ACHIEVEMENT

I, Jacqueline Brillantes, was responsible for the collection and analyses of data, as well as manuscript preparation. Dr. Jim Lyons was involved in the conceptualization of the experimental idea, study design and editing and reviewing all chapters.

Additionally, Dr. Jim Burkitt helped in the editing process and with creating custom analyses programs. Dr. Mike Carter provided the experimental apparatus, Dam Nguyen also helped with creating custom analyses programs, and Soroush Bagheri and Sarah Scott helped with participant recruitment and data organization.

CHAPTER 1: LITERATURE REVIEW

1.1: GENERAL INTRODUCTION

Humans are constantly presented with multiple sources of sensory information, and it is through these sensory stimuli (e.g., vision and audition) that we create a unified internal representation of the external environment to serve as a foundation for thought and action.

The nature of human perception, and the translation of these perceptions to action, has been of interest for many years in various scientific fields of study. The idea that multiple sources of sensory information compete with one another to complete a task has its historical roots in both the philosophy and psychology literatures. For example, the notion that when a strong sensory source arises, while another sensory source in opposition catches the attention for a moment causing the initial sensory source to slip away, a "volition arises to its maintenance causing the will to support the weaker motive" (Shand, 1895). Adding onto the idea of how multiple sources are perceived, further studies merely approach perception as a problem of selection and elimination, and one that does not result in addition or enhancement (Dewey, 1912). Moreover, perception was once thought of as being solely concerned directly with physical objects without any mental states intervening (Dewey, 1912). The concept of perception not involving the mental state was further scrutinized and ultimately the idea was opposed. It appears that simple body movements (that are a result of anticipation) are followed by the movements themselves, however, only if there is a neural correlation between the ideal anticipation

and the act that is in question (Thorndike, 1915). Our ideas of multisensory integration have evolved and come a long way since then.

Going beyond the philosophy and psychology literatures, and with the enhancement of technology, studies of perceiving multiple sources of sensory information and potentially acting upon them were further explored. Neurons found in the superior colliculus (SC) were used as an ideal model to show how a single neuron can deal with cues that are simultaneously coming from different sensory modalities, such as vision and audition (Meredith & Stein, 1986). Before multisensory integration studies had been completed on human participants, both invasive and non-invasive studies were conducted on animals to further understand how stimuli are integrated. Studies that have looked at the deep layers of the SC of kittens have shown that the appearance of multisensory neurons do not appear during the first ten days of postnatal life, however, a high proportion of multisensory neurons can be found in adult animals (Wallace & Stein, 1997). When investigating the developmental stages in humans, evident differences between neonatal and adult multisensory neurons are evident. For example, early multisensory neurons have been shown to respond weakly to sensory stimuli, have longer latencies, and have poorly developed response selectivities (Wallace & Stein, 1997). Additionally, when compared to adult multisensory neurons, early multisensory neurons have more difficulty integrating combinations (both temporally synchronous and asynchronous stimuli) of "sensory cues to produce significant response enhancement or depression" (Wallace & Stein, 1997).

To further understand multisensory integration, past literature has examined human performance in unisensory and multisensory environments. The process of visual and auditory integration is similar in the sense that both stimuli transduce into a comprehensive signal that the brain can understand. Signals from the environment are transduced at the peripheral level (i.e., receptors in the eyes and ears) into neural impulses that are ultimately relayed to the central nervous system (Thesan, Vibell Calvert, & Osterbauer, 2004). In the initial process of transduction, it has been suggested that the senses are processed separately, however, once the sensory signals reach the brain, these individually streamed signals are processed simultaneously to create a perceptual representation of the external world (Thesan et al., 2004). These perceptual representations serve as the foundation upon which we plan and execute our interactions with our environment. For these interactions to be successful, the integration of information from multiple sensory modalities must be accurate.

The sport of tennis is an example of an activity that requires highly accurate and complex interactions between visual and auditory sensory stimuli. This includes, for example, the necessity of anticipating the terminal location of a tennis serve from an opponent originating on the opposite side of the court. When visually inputting information, one must consider the area of space in which the opponent is standing, the perception of the amount of momentum the opponent is about to exert onto the tennis ball, as well as the opponent's stroke follow through. Perceiving the velocity of the ball early/late in the trajectory has also been considered to be another factor to take into consideration when observing ball trajectory (Cochran & Lucia, 1985). Although the

results of the study conducted by Cochran & Lucia (1985) demonstrated that individuals

can extract perceptual information throughout the entire trajectory of a ball, some studies

predict the future position of the ball by strictly tracking the initial pathway of the ball

(Hubbard & Seng, 1954). Lastly, the resulting motor output would be using online

feedback to update the hand position according to the visual percepts and striking the

tennis ball with the racquet using the correct amount of force for the intended shot.

If an auditory cue were to be added to the task, the central nervous system would

have to resolve the relative compatibilities between those two sensory sources. For

example if, in the tennis situation, the opponent grunted while striking the tennis ball, the

opponent would have to consider the magnitude of the sound, as louder grunting noises

are perceived to be associated with longer ball trajectories, and softer grunting noises are

associated with shorter ball trajectories (Cañal-Bruland, 2018). The additional sound

stimulus leads to an interference between visual and auditory perception if a conflict is

presented between the two sensory sources, such as a soft serve paired with a loud grunt.

The conflict may be resolved, however, when compatible stimuli are paired together, such

as when a loud grunt is paired when an opponent that has exerted a large amount of effort

in striking the ball. On the other hand, when an opponent exerts the same large amount of

effort with a low grunting noise, uncertainties may arise due to the interference

(incompatibility) in auditory-visual perception and interaction.

Factors that can affect the unity or separation of the two unimodal stimuli (vision

and audition) are spatial and temporal congruency and incongruency (Spence, 2007;

Radeau & Bertelson, 1987; Spence, Sanabria & Soto-Fraco, 2007; Sinnett & Kinstone,

2010; Cañal-Bruland, 2018). When visual and auditory information are presented, either simultaneously or separately, they provide extensive information that aids in the identification, organization and interpretation of the external world.

The studies comprising this thesis explore perceptual and action based interceptive tasks that rely on visual and auditory cues that may be incompatible or compatible with each other.

1.2: INTEGRATION OF AUDITION AND VISION

The auditory and visual signals we receive travel at different speeds. In comparison to sound, light travels through the air faster at nearly 300,000,000 m/s versus sound at nearly 340 m/s (Navarra et al., 2009). Thus, auditory signals are slower to reach an observer in comparison to the visual signals emitted from the same event (Sugita and Suzuki, 2003). However, the distance that the signal travels plays a crucial role in perception. Within 10 m, sounds will reach the brain before visual signals, whereas visual signals will lead auditory signals after 10 m (Navarra et al., 2009). The reason is because the integration of auditory signals (acoustic transduction) occurs at a faster rate between the outer and inner ear (approximately 1 ms or less) compared to the integration of visual stimuli using phototransduction (which is a slow photochemical process involving cascading neurochemical stages that takes approximately 50 ms). As such, it is necessary for auditory signals to be delayed in order to perceptually align with a visual stimulus (Alasi & Carlile, 2006). On the other hand, cue asynchrony would occur when one receives auditory and visual stimuli that do not arrive at the same time.

Once we receive visual and auditory signals, different areas of the brain are involved with neuronal responses to those stimuli (Calvert, 2001). Whether the visual and auditory information are presented in synchrony or in asynchrony, multisensory cortical areas in the insular, posterior parietal, and prefrontal regions are predominantly activated (Bushara et al. 2001). Additionally, the posterior thalamus (the main function of which is to relay motor and sensory signals to the cerebral cortex) and superior colliculus (a structure that transforms sensory input into movement output) show significant interactions with the right insula (a fissure that separates the frontal and parietal lobes from the temporal lobe; Bushara et al., 2001). To elaborate on the insular cortex, electrophysiological and anatomical connectivity studies in primates have indicated that auditory and/or visual inputs are received by the insular cortex through multiple parallel pathways from the auditory cortex, the temporal, prefrontal, and posterior parietal multisensory regions, as well as via subcortical projections from the superior colliculus through the posterior group of thalamic nuclei (Bushara et al., 2001). This information provides a greater understanding of the components of the brain that involve neuronal responses to sensory cues.

When the central nervous system integrates multiple sources of sensory information to create a single percept, it has been proposed that each sensory input is allocated a weight (Kabbaligere et al., 2017). The shift and reweighting process of stimuli dominance throughout the integration process can be seen within the integration of auditory and visual stimuli. Temporally, audition has traditionally been identified to be the dominant sensory stimuli in comparison to vision, as seen in the temporal

ventriloquism phenomenon (Burr, Banks & Morrone, 2009) and in the illusory flash

effect (Shams, Kamitani & Shimojo, 2000). Temporal ventriloquism occurs when the

presentation of an asynchronous auditory stimulus impacts the perceived time of

occurrence of a visual stimulus, and the illusory flash effect occurs when a flashed spot is

presented with more than one beep and the spot is perceived to flash twice. Auditory

dominance has also been found in studies that explore early development. Specifically,

when infants and young children were presented with auditory and visual stimuli

simultaneously, they often failed to encode the visual stimulus. However, the infants and

young children were able to encode the visual stimulus when it was presented unimodally

(Robinson & Sloutsky, 2013). These results suggest that during the early developmental

stages, there is an affinity towards auditory stimuli when presented simultaneously with

visual stimuli. It is notable that auditory dominance does not vanish as humans develop

however. Rather, we strategically find more efficient responses in favour of visual input

(Robinson & Sloutsky, 2013).

Due to the poor alerting abilities that are inherent in the visual system, attention

leads to visual dominance (Posner et al., 1976). The low alerting nature of visual stimuli

leads individuals to deliberately focus attention on the visual modality, strategically bias

responses to favour visual input. However, despite the studies that show how audition can

be a dominant stimulus throughout temporal judgement tasks, it has been shown that this

is not always the case. A study by Andersen, Tiippana & Sams (2004) shows that the

threshold of the sound should be taken into consideration, because if the sound is barely

above the threshold (10 dB), there is a possibility that the visual stimulus can dominate over the auditory stimulus.

In contrast to audition being the typical dominating stimulus during temporal tasks, vision has been shown to dominate auditory stimuli in spatial tasks. One example is the ventriloquist effect, which occurs when there is a discrepancy between the spatial location of synchronized auditory and visual events, ultimately leading to a bias of the perceived auditory location toward the visual location (Stekelenburg & Vroomen, 2009). Another example can be found in a study by Colavita (1974), where they observed that when participants were presented with visual and auditory signals simultaneously and asked to press one key whenever a light came on and to press another key whenever the auditory stimulus occurred, the participants responded to the visual input more and were often unaware of the occurrence of the auditory signal. One reason these instances occurred could be due to the fact that vision determines the perceived location as it specifies the location in a more accurate manner in comparison to audition (Burr et al., 2009).

Following the integration of sensory stimuli, typically a decision to make a response or not make a response is made based on the developed percept. Participants' responses to auditory and visual stimuli differentiates depending on whether the stimuli are presented synchronously or asynchronously. As shown by Navarra et al. (2009), exposure to audiovisual asynchrony only affected the speed of the participants' responses to sound stimuli, but not to light stimuli. Moreover, when audiovisual asynchrony is displayed, the speed at which auditory signal is processed changes in order to enhance the

subjective impression of audiovisual synchrony (Navarra et al., 2009). However, this does not mean that no changes are made to the processing of visual stimuli. A possible reason for this phenomenon could be due to the fact that the effects of audiovisual asynchrony influences the processing of auditory and visual signals in various and different ways, as well as in different stages of neural processing (Navarra et al., 2009).

A similar pattern emerges from the various ways multiple sensory stimuli are integrated - one stimuli competing and potentially dominating over another throughout the processing stages. For example, Butchel and Butter (1988) show that when presented with auditory cues, visual orienting is more rapid in response to visual cues as opposed to auditory cues. According to the previous literature, auditory and visual stimuli compete for access to the central processor that is responsible for controlling responses (Robinson & Sloutsky, 2013).

1.3: VISUAL INFORMATION RECEPTION

Once the visual information has entered the eyes, the information travels to the lateral geniculate nucleus in the thalamus, which then enters the primary visual cortex (visual area 1, V1, Brodmann area 17) and the striate cortex (Eckert, Kamdar, Chang, Beckmann, Greicius & Menon, 2008). Located in the occipital lobe is V1 and it receives information from its ipsilateral geniculate nucleus (that is located in the thalamus) that receives signals from the contralateral visual hemifield. The visual cortex is located in both hemispheres of the brain. Furthermore, the visual cortex in the left hemisphere receives signals from the right visual field, and the visual cortex in the right hemisphere

receives signals from the left visual field. Neurons in the visual cortex fire action potentials when visual stimuli appear within their receptive field (the area that elicits an action potential) (Hendee & Wells, 1997).

Following the neural processing of visual information is the process of brain cells selectively representing a particular type of sensory, motor, association or cognitive information is called neuronal tuning. Neuronal tuning differs from earlier visual areas and higher visual areas in the sense that it is simpler in the earlier stages.

It is important to consider that the pathway of how visual information travels throughout the brain generally is the same between individuals that are typically developing, however, differences tend to arise once individuals perceive the visual information.

1.4: VISUAL PERCEPTION

One way visual perceptions have been investigated is through the use of illusions, such as the Ebbinghaus or Titchener illusion. Some visual illusions occur in the early stages of the visual system, for example with the Hermann Grid, smudges are perceived at the intersections of a white grid presented on a background that is black (Schiller & Carvey, 2005). While others, such as inattentional blindness (an illusion that occurs when unattended visual or auditory information goes unnoticed) require top-down processing where attentional mechanisms work from the general to specific details (Ziat, Smith, Brown, DeWolfe & Hayward, 2014). These illusions have shown that they have the

ability to affect one's perception, additionally, they have the ability to affect the visual system at difference stages and through different processes (i.e., top-down processing).

Considering an illusion is a distortion of the senses, it is interesting to investigate whether the same results to visual perception occur when multisensory synchronous and asynchronous stimuli are presented. When participants were repeatedly exposed to asynchronous stimuli (shown a video with an audio stream lagging 300 ms behind), the point of subjective simultaneity shifted towards the repeatedly experienced delay (Vroomen and Keetels, 2010). One reason perceptual simultaneity occurs after temporal adaptation is because of the changing processing speed of the independent signals, resulting in changes in the perceived simultaneity (Harra, Harris & Spence, 2017). Another study that examined multisensory asynchrony and visual perception found that multisensory facilitation of RTs only occurred when the stimuli presented were physically synchronous with each other, in comparison to when the participants perceived the stimuli to be in synchrony (Harra et al., 2017). The results of these studies give us a better understanding of the perception of multisensory synchrony and the complexity of combining visual and acoustic information in an unexpected manner.

1.5: AUDITORY PERCEPTION

The human ear perceives the pitch of sounds by associating the sound wave frequencies that impact the ear. When high and/or low frequencies are detected by the ear, they are associated with the pitch of the sound. More specifically, high frequencies are associated with a high pitch, and low frequencies are associated with a low pitch.

On the other hand, the loudness of a sound is detected by the sound wave's amplitude and is more of a subjective response that varies with multiple factors. Loudness perception varies between individuals and age is another factor that can affect the human ears response to a sound. Additionally, two sounds with the same amplitude intensity but different frequencies will be perceived to be different and will be perceived to not have the same loudness. The human ear has a tendency to amplify sounds that have frequencies of 1000 Hz to 5000 Hz, and sounds with these intensities are perceived to be louder to the human ear (Fletcher & Munson, 1933). Although there is a distinct difference between sound intensity and sound loudness, more intense sounds tend to be perceived to be the loudest sounds. High frequency sounds are often perceived to be louder, more salient and create a larger physiological response in comparison to when low frequency sounds are being presented despite being the same physical intensity (Fletcher & Munson, 1933). Higher frequencies have also shown to have a larger influence on the spatial perception of the stimuli when compared to lower frequency sounds (Deutsch & Roll, 1976).

The placement of ears on either side of the head allows humans to benefit from stereophonic hearing, meaning that sound can be localized from various directions. That is, if a sound originates from the left side of a person's head, the left ear will receive the sound slightly sooner and with more intensity in comparison to the right ear. Although the distance between the two ears on opposite sides of the head is approximately six inches and sound waves travel at approximately 750 miles an hour, the time and intensity differences are easily detected (Middlebrooks & Green, 1991). Sounds that are

equidistant to both ears indicate the front, back, beneath, or overhead directions and are more difficult to determine the exact location.

1.6: MULTISENSORY INTEGRATION

Unimodal sensory processing occurs in sensory-specific areas of the cortex before multisensory processing. Multisensory processing occurs in specialized cortical modules relatively late in the processing hierarchy, such as in polysensory areas in the parietal (Duhamel et al., 1991), temporal (Bruce et al., 1981) and frontal (Benevento et al., 1977) lobes of the brain.

Once the senses have been processed unimodally, the senses have the ability to have an impact on each other at the level of the primary sensory cortices. The primary sensory cortex consists of five sensory systems in the brain including taste, olfaction, touch, hearing and vision. The origin of the name primary is due to the fact that these cortical areas are the first level in a hierarchy of sensory information processing in the brain. Sensory stimuli are interdependent meaning that one modality can affect the processing in another modality. This process can be both facilitative and conflicting. For example, an auditory stimulus can elicit one response while a visual stimulus can elicit a different response resulting in cross-modal competition (Robinson & Sloutsky, 2012). Cross-modal competition can occur in various and multiple ways (Robinson & Sloutsky, 2012). For example, when information is simultaneously presented to multiple sensory modalities, that information can weaken the processing of one modality, while having little to no effect on the processing of another modality.

Although the multisensory integration process in the brain has been shown to be both facilitative and conflicting (Welch and Warren, 1986), movement studies that incorporate multimodal sensory stimuli have indicated an improvement in human performances. For example, studies that had individuals complete speeded detection tasks have shown that when paired with simultaneous audio-visual targets or unimodal auditory or visual signals, the measured reaction times (RTs) are shorter to bimodal signals in comparison to the unimodal counterparts that occurred in isolation (Welch and Warren, 1986). In addition to shorter RTs to bimodal signals, multisensory performances have shown to be improved and more accurate. For example, the redundant signals effect shows that responses to stimuli that are presented simultaneously from multiple sensory systems are more accurate in comparison to responses to the same stimuli that was presented in isolation (Hershenson, 1962; Kinchla, 1974). The merging of multiple information across various senses is illustrated in the ventriloquism effect (Alais & Burr, 2004), the McGurk effect (McGurk and MacDonald, 1976), the freezing effect (Vroomen and de Gelder, 2000), and the double-flash illusion (Shams et al., 2000).

In some cases, multiple sources of sensory stimuli may be presented asynchronously. Exposure to asynchronous stimuli for long periods of time have shown to influence temporal "aftereffects" in perception of subsequently presented stimuli (Navarra et al., 2009). The temporal recalibration that occurs due to asynchronous stimuli could be based on the way speeds are readjusted when different sensory signals (i.e., visual and auditory) are transmitted neurally (Navarra et al., 2009).

1.7: CONCEPTUAL COMPATIBILITY

There are inherent spatial properties with perceived pitch. For example, a study by Sonnadara et al. (2009) exhibited that responses to low (500 Hz) tones were faster when performed with the left hand and responses to high (1000 Hz) tones were faster when performed with the right hand. When presented with incompatibilities (i.e., left hand/ high tone and right hand/ low tone), participants made slower responses. This relationship suggests that there is a compatibility between spatial representations of tones and movement planning. More specifically, low tones are associated with left hemifield attributes and high tones with right hemifield attributes. The horizontal representation of sound pitch could also be in relation to the brain inherently creating a mental representation of quantities, with small quantities being located on the left and larger quantities on the right (Fernandez-Prieto and Navarra, 2017). As shown by Rusconi et al. (2006), the horizontal representation of pitch is largely influenced by musical training experience. One prime example is the layout of a piano, as low pitch sounds are positioned on the left side of the piano, and the pitch continues to rise as you move from the left side of the piano to the right side of the piano.

In addition to being represented along the horizontal axis, pitch has also been shown to be represented along the vertical axis. Sonnadara et al. (2009) showed that higher frequency sounds influenced individuals' motor responses upwards (positive vertical displacement) and lower frequency tones influenced their motor responses downward (negative vertical displacement). There was a result of undershoot errors when presented with an incompatible relationship (i.e., high tone/ bottom speaker and lower

tone/ top speaker). The result of participants undershooting in the movement task is an indication that the participants were conflicted when they were presented with incompatible stimuli. In study 3 of this experiment, participants were asked to respond to a tone that was presented from an identical physical location. However, the results indicate that pitch seems to bias decisions about the location of a presented tone. Higher tones directed responses more upward or to the right and lower tones towards downward or to the left. In another study, when rising sound frequency sweeps were presented with visual targets on the superior part of a screen, RT was faster in comparison to visual targets that were presented on the inferior part of the screen (Fernandez-Prieto and Navarra, 2017). Using a similar task, Spence (2007) showed that targets appearing in an upper position of a screen with a rising sound frequency were congruent (represented by a decreased RT), while visual targets presented in lower positions of the screen with a rising sound frequency were incongruent (represented by an increased RT). However, contrasting the results of the study by Sonnadera et al. (2009), spatial cueing with a rising sound frequency sweep did not show to have a specific position (i.e., right-up corner), in fact it had a more global (i.e., up and down position) than local (i.e., particular position in space) account of the spatial representation of pitch.

Moreover, spatial representation of pitch has shown to modulate visuospatial attention (Chiou & Rich, 2012; Mossbridge et al., 2011). For example, higher frequencies seem to drive sound localization and affect perceivers' alertness (Tomatis, 1978). Additionally, as measured by electroencephalogram (EEG), high-pitched sounds generate

more psycho-physiological responses in comparison to low-pitched tones (Naatanen, 1990; Ruusuvirta & Astikainen, 2012).

In addition to horizontal and vertical spatial representations of sound, the Doppler Effect shows that sound can be a dynamic and ongoing representation. The Doppler effect (Doppler, 1842) creates the illusory percept that as an object approaches, passes by, and continues past an observer, the frequency of a sound from that moving object is perceived to be higher, identical and lower, respectively (i.e., an ambulance passing by an observer). There is an association between rising sound frequencies, approaching objects and an increase of alertness by the observer. Contrary to sounds with an increasing frequency, it is often perceived by the observer that when an object is moving away there is a decrease in frequency and possibly even a reduction of the level of alertness (Doppler, 1842).

Developmental studies have also looked into the spatial properties of pitch. Walker et al. (2010) examined 3 - 4-month-old infants looking at visual stimuli with an accompanied sound that ascended and descended in frequency. The infants in this study looked at the presented visual stimuli longer when the stimuli were moving towards the upper part of the screen while simultaneously being presented with an ascending frequency sweep, in comparison to visual stimuli presented with descending frequencies. These studies further demonstrate the innate ability for humans to associate an auditory stimulus with a congruent spatial representation, and any form of incongruence can lead to longer processes when integrating the stimuli and longer responses when completing a task.

An increase in sound intensity has been associated with greater force or power (Ikai and Steinhaus, 1961; Welch and Tschampl, 2012, Sinnett, Maglinti & Kingstone, 2018) and having a higher velocity (Farhead and Punt, 2015; Shimojo & Shams, 2001; Stein, London, Wilkinson & Price, 1996). In a study by Farhead and Punt (2015), participants were tasked to observe video clips of tennis serves that were sometimes accompanied with a grunting sound. After measuring accuracy and response times, one result of the study was that the grunting sound led the participants to have poorer accuracy whenever the serve was travelling at below average speed. This is an indication that individuals tend to associate a loud sound with a higher velocity, and if incompatibilities were to occur (i.e., loud sound and slower velocity), such as in this experiment by Farhead and Punt (2015), individuals would have difficulty integrating information from different senses about a single event that is incompatible with each other. An additional finding from this study was that the participants' perception of the serve speed degraded whenever a grunt sound accompanied the tennis serve. More specifically, the participants had a tendency to overestimate the speed of the slow velocity serves whenever a grunt accompanied the serve. Therefore, it was suggested that whenever the grunting noise accompanied the slower serves, it would result in an additional processing cost for the participants, as slower response times were observed with slower serves accompanied with a grunt in comparison to serves where there was no grunt.

1.8: EXOGENOUS VERSUS ENDOGENOUS PROCESSING

Overt orienting refers to mechanical changes in the sensory apparatus causing spatial orienting (e.g., a shift in gaze), whereas internal attentional and self-generated adjustments lead to covert orienting in the absence of an external sensory stimulus (Klein, 2018). Traditionally, the definition of exogenous control refers to attention that is automatically drawn towards a stimulus and is referred to as overt orienting. Exogenous cues, such as a flash of light, are most effective at stimulus onset asynchrony of 100-150 ms (Müller & Rabbitt, 1989) and when an individual cannot predict the target's location (Macquistan, 1997). Endogenous control, on the other hand, refers to attention voluntarily being directed toward a stimulus and is also referred to as covert orienting. Endogenous cues are most effective when the stimulus onset asynchrony between the cue and the target is 300 ms or longer, as well as if the subsequent target location is predictive (Macquistan, 1997).

For the purpose of this study, exogenous cues infer cues that are coming from a specific spatial location, while endogenous cues are originating from non-specific spatial localization cues. [1]

Localizable auditory stimuli, whether originating from the left or right side of space, sparks a rapid initial response and is an exogenously controlled shift of visual attention to the cued location (Klein, 2018). When presented with incompatible cues (i.e.,

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[1] Although it would have been optimal to have completed this experiment with the speakers physically close to the sound of origin in order to have a truly exogenous presentation, because of the small size of the computer monitor and the close proximation of the participant to the computer monitor, it was difficult to determine the origin of the sound due to the omnidirectional nature of the sound. More specifically, it was as if no direction of sound information was being provided to the participants. For this reason, headphones were used for Study 2 and sound was directed to either side of the headphones.

a tone presented on the right side while a visual target appears on the left), it appears that over 500 ms is required in order for endogenous orienting to respond to incompatible information to overcome exogenous control of visual attention by localizable auditory stimulation (Klein, 2018).

1.9: PERCEPTION VERSUS ACTION

Multiple and complex information is provided by the external world, and sometimes that information can be stable, or it can shift both consciously and unconsciously. Identifying and integrating this information is completed through the act of perception. Perception extends to unconscious (Merikle & Daneman, 1998) or preconscious (Shervin & Luborsky, 1958) perception of objects and events, which are mental representations that have the capability of reaching conscious awareness. Whether one is unconsciously or consciously perceiving an object, the act of identifying possible and definite goal objects and selecting appropriate actions to interact with those objects, is simultaneously occurring. If one is requested or forced to make an action, they may use the perceived information that was drawn from the external world and use that material to aid in the detailed specification and online control of movements.

1.10: PERCEPTION- ACTION DISSOCIATION THEORY

One theory that attempts to understand the communication between perception and action is the perception-action dissociation theory (Milner & Goodale, 2006). This theory stems from the idea that there are two streams that process and transmit visual

information differently (Dewar & Carey, 2006). These include the ventral stream that inputs visual information for perception and the dorsal stream that mediates the visual control of actions. The ventral stream enables an observer to parse the scene and think about objects and events in the visual world. On the other hand, the dorsal stream registers visual information on a moment-to-moment basis and transforms it to appropriate coordinates for the effector being used (Carey 2001; Dewar & Carey, 2006).

The functional dorsal/ventral stream dichotomy (Schneider, 1969) was initially discovered via lesion studies, such as that completed by Ungerleider and Mishkin (1982) that found two distinct streams in the cerebral cortex of the macaque monkey brain. In humans, the ventral stream occurs in the occipito-temporal pathway; this starts at the primary visual cortex (V1), passes through V2 and V4, and ends at the infero-temporal cortex (Orban & Vogels, 1998). In contrast, the dorsal stream involves the occipito-parietal pathway; which starts at the primary visual cortex (V1) and passes through V2 (similar to the occipito-temporal pathway), goes to the dorsomedial area (DM/V6) and medial temporal area (MT/V5), and lastly makes its way to the posterior parietal region (an area critical for sensorimotor transformation; Rosa & Tweedale, 2005).

More studies (Goodale, Milner, Jakobson, & Carey, 1991; Goodale et al., 1994) delved into the idea of a double dissociation between perceiving the shape of an object and grasping it. For example, Milner & Goodale (1995) suggested that the role of the ventral stream is to perform computations for object recognition and conscious perception, while the dorsal stream is not to simply analyze the location of an object, but instead to guide the manipulation of objects.

The two streams also use different frames of references. For example, vision for perception uses an allocentric frame of reference that measures, objects in comparison to other surrounding objects and is concerned with viewer invariant relationships. Conversely, vision for action codes object positions using an egocentric frame of reference that measures object position in comparison to the effector and the spatial dimensions are in absolute metrics. One case that seems to provide strong evidence for the two different streams is that of patient DF who experienced damage to the ventral stream. Patient DF was a woman who developed visual form agnosia because of anoxic lesions that destroyed the lateral occipital area bilaterally, and as a result was shown to proficiently use visual size and orientation to guide her hand for reaching and grasping, however, she was unable to discriminate the properties explicitly (James, Culham, Humphrey, Milner & Goodale, 2003). In terms of how the two systems visually input and output information, Schenk and McIntosh (2010) states that the streams analyze spatial information differently depending on their own behaviour goals. For example, for action, as the visual representations encode egocentric relationships between the observer and the object of the action, the connection is constantly updating and decaying rapidly. Perception on the other hand uses allocentric viewpoints to conceal the more stable properties of the scene. The ventral stream is responsible for capturing essential material for visual memory and furnish visual awareness (Schenk and McIntosh, 2010).

One way studies have been testing the perception-action dissociation theory is through the use of illusions (Aglioti, DeSouza, and Goodale, 1995; Haffenden and Goodale, 1998), more specifically with the Ebbinghaus (or Titchener) illusion. With this

illusion, a central circle appears larger when surrounded by small circles (annuli) in comparison to when it is surrounded by large circles. Results of the studies that involved reaching tasks showed a larger effect of the illusion on perception when compared to the maximum preshape aperture. The maximum preshape aperture is shaped before the hand has contacted the object and is a reflection of the size estimate that the visual system transfers to the motor system (Franz, Gegenfurtner and Fahle, 2000). As stated earlier, the perceptual ventral stream uses an allocentric frame that is object-to-object based, while the action dorsal stream uses an egocentric frame that is subject-to-object based. For this reason, it is assumed that illusion effects on actions will be small for the reason that actions use visual representations that do not strongly encode the information surrounding the target. However, actions can be affected by illusions in the case when perception and action interact prior to movement initiation (Westwood & Goodale, 2003). For example, the information related to the targets' identity, such as its weight, is a required source of information to complete the action.

Despite the studies mentioned above suggesting a dissociation between perception and action, the results of Franz et al. (2000) show that if the perceptual and grasping tasks are appropriately matched (in other words, the only difference between the perception and action task is the participants' response), no differences can be found in the sizes of the perceptual and grasp illusions. Perhaps past studies that did show a difference between the two streams can be accounted for by a non-additive effect in the illusion. Specifically, when comparing two Ebbinghaus figures, participants experience a larger-size illusion than predicted by the sum of the size illusions experienced when looking at each figure

separately. Another factor to take into consideration is the usage of illusions to provide evidence for the dissociation of the two pathways for perception and action in the visual system.

1.11: PLANNING-CONTROL MODEL

Actions are composed of two stages, the premovement planning of the action, such as the initial impulse, and the subsequent current control of the action that reflects online correction (e.g., Woodworth, 1899; Keel & Posner, 1968; Jeannerod, 1988). The planning-control model is similar to the perception-action dissociation theory in the sense that there are two separate visual representations, however, the dichotomy is between planning and control, as opposed to perception and action (Glover and Dixon, 2002). Further anatomical differences between the planning and control system have also been examined when observing motor behaviour, as the planning system has been shown to have an increase in activity in the inferior parietal lobe (IPL), frontal lobes and basal ganglia, and the control system in the SPL and cerebellum (Glover, Wall & Smith, 2012).

Studies that have examined the two stages of action (e.g., Woodworth, 1899; Keele & Posner, 1968; Meyer, Abrams, Kornblum, Wright, & Smith, 1988; Elliott, Binsted, & Heath, 1999) have discovered differences between the two stages. Planning appears to be a slower process at an approximately minimum time of 250 ms (Stark, 1968) in comparison to the proprioceptive feedback during on-line control at 70-150 ms (Glover and Dixon, 2002). The two-component model does not only successfully explain movement accuracy (Fitts, 1954; Beggs & Howarth, 1970), but the model also explains

the spatial and temporal components of movement trajectories (Carlton, 1979). More studies that have looked into the two-component model (e.g., Elliott, Hansen, Mendoza, & Tremblay, 2004) suggest that as the travelled distance or the necessary speed of a movement increases, the impulses required to produce the movement increase as well (Schmidt et al., 1979). These factors may result in greater noise in the neuromuscular system, causing the endpoint variability of the initial ballistic portion of a movement to increase. In order to correct any errors that may have been made in the original motor plan, the response produced visual feedback from the limb can then be utilized (Grierson & Elliott, 2009).

Spatial characteristics, non-spatial characteristics and the dependency on affordances and surrounding context are all included in the planning phase; overall, the planning system uses a context-dependent visual representation (Glover & Dixon, 2001). The spatial characteristics of the actor and the target can include the size, shape and orientation of the target, as well as the spatial relations between the actor and the target. Non-spatial characteristics include the function, weight, fragility and coefficient of friction of the target's surface. Additionally, the overarching goals of the action, the visual context surrounding the target, and memories of past experiences are all integrated throughout the planning system (Glover & Dixon, 2001).

The control system, on the other hand, considers the spatial characteristics of the object and environment and uses a context-independent visual representation, with high accuracy on the target itself. Updated visual representation in the SPL, proprioceptive feedback, and an efference copy are all used throughout the execution of a movement. In

Glover and Dixon (2002), they examined illusion effects on grasping, and found that continuous visual information was not required throughout the whole on-line correction portion of the movement. Moreover, the independence of the control system from cognitive processes like goal formation and conscious perception means that the control system operates outside of conscious awareness and influence. Further providing evidence of the planning control model where actions are planned using a context-dependent visual representation, but corrected on-line using context-independent representations.

More studies that are consistent with the planning control model (Gentilucci, Chieffi, Daprati, Saetti & Toni, 1996; Westwood, Heath, & Roy, 2000) have shown that illusions do, in fact, have an impact on actions. More specifically, when participants were provided with visual feedback, illusion effects on actions were still present, however smaller in comparison to when visual feedback was not provided. This idea is consistent with the hypothesis that online control processes are less affected by the illusion in comparison to the planning phase. These results run counter to the perception action dissociation theory that states that actions are relatively immune to illusions in the first place. Furthermore, studies that have examined the dynamic illusion effect (Glover and Dixon, 2001) have shown to further provide evidence of the planning control model. The dynamic illusion effect includes observing and measuring the orientation of the hand as participants reach out to grasp a bar. Results show that the effect of the illusion largely affected the early phase of the reaching movement (planning), however, the effect decreased to nearly zero by the end of the reach, ultimately allowing the participants to

grasp the bar with ease. These results show that the effect of the illusion on hand orientation decreased because it merely only affected the planning phase, and not the control phase of the movement. If the perception action dissociation theory were true, the illusion would have a small and consistent effect throughout the action portion only (Glover and Dixon, 2002).

1.12: SUMMARY AND STUDY OBJECTIVES

The integration of multiple sensory stimuli such as vision and audition is a competitive process, and the controversy on whether auditory integration is more dominant than visual integration, and when exactly sensory reweighting occurs throughout multisensory integration, is still a work in progress. Furthermore, the integration of multiple sensory stimuli is also interdependent, meaning that when the two sources are presented simultaneously, one stimulus can affect another, and it can be facilitative and/or conflicting. It is clear that when combining visual and auditory stimuli, humans have a tendency to perceive pitch to have spatial properties, in particular there seems to be a vertical and horizontal representation with pitch. Moreover, there is a relationship between increased alertness and faster RT with higher frequency sounds. Although it is also clear that rapid responses are typically accomplished by localizable auditory stimuli or exogenous cues, it would be interesting to further explore how individuals perceptually respond to compatible or incompatible sources when the auditory information is endogenous or exogenous in nature. Additionally, the difference between individuals' perceptual responses to action responses to a complex multisensory task

using the planning-control model and perception-action dissociation theory as a foundation, has yet to be explored to further understand which theory better explains the relationship between how one perceives and acts upon incompatible multisensory tasks.

STUDY OBJECTIVES

Three studies were conducted to further understand the relationship of compatibility and incompatibility with multisensory integration, and to compare how one perceives this relationship and how one acts upon it. More specifically, if two sources of environmental sensory information (auditory and visual) are put into conflict, does an interaction between compatible (e.g., loud/fast; soft/slow) or incompatible (e.g., loud/slow; soft/fast) sources exist? The first two studies seek to determine if this interaction is mediated by whether the auditory information is endogenous (non-specific spatial localization cues) or exogenous (specific spatial localization cues) in nature. In addition to the visual stimuli presented in the first study, the second study seeks to explore the effects that may occur when attention is directed to a specific side of space by the unexpected onset of an auditory stimulus. The third study examines auditory information from non-specific spatial localization cues, and determine if the interaction is mediated by whether the response dimension is primarily perceptual (by using a predictive button press) in nature or if it involves motoric (interceptive action) interaction with the visual stimulus.

HYPOTHESIS

In the first study, it is hypothesized that if the presentation of two sensory sources are compatible, participants will have more accuracy (decreased absolute error) and less directional bias (constant error approaching zero). In line with previous findings, it is hypothesized that compatible sensory sources (Sonnadara et al., 2009 & Klein, 2018), and the presentation of simultaneous audio-visual targets (Hershenson, 1962; Kinchla, 1974) result in a faster RT and more accurate response, respectively.

In the second study, while sound and vision stimuli continue to interact, differential action performances would be expected depending on the origin of the sound stimulus. As an additional incompatible source of information is added to this study, constant error (CE) and absolute error (AE) would be expected to be further impacted.

The hypotheses of the third study are based on the perception-action dissociation theory and the planning-control model. As the perception-action dissociation theory predicts that visual illusory stimuli biases perceptual-cognitive processing, but does not affect action-oriented processing (Milner & Goodale, 1995), the planning-control model predicts that feedforward processes (pre movement organization and planning) are susceptible to visual illusion, but processes associated with on-line control are immune to the influence of visual context (Glover & Dixon, 2001). Therefore, if the perception-action dissociation theory holds true, then it is predicted that incompatible sensory information (auditory and visual) to have no influence on action. Contrastingly, if the planning-control model holds true (perception-action coupling), then it is predicted that incompatible sensory information to significantly influence action.

CHAPTER TWO: STUDY 1

2.1 METHODS

2.1.1 PARTICIPANTS

A total of sixteen participants (eight males and eight females), between the ages of 18- 30 years were recruited from the McMaster University population and Hamilton community to participate in this study (see Table 2.1). All participants were presented with no self-reported upper limb musculoskeletal impairments, normal or corrected-to-normal vision, and were right-handed. Prior to participation in the study, individuals signed the informed consent form that outlined the nature of the study and the experimental protocol. Upon completion of the two-part (perception and perception-action) counterbalanced study, participants received financial compensation in the amount of $10 for their time.

2.1.2 APPARATUS

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software was used to generate the study. More specifically, LabVIEW was used to provide the visual stimuli that was presented on the computer monitor. Two speakers were placed alongside the computer monitor, with one speaker on the left and one speaker on the right side, to provide the auditory stimuli. A push-button, positioned in between the computer monitor and the participant, was used for participants to make a response.

2.1.3 EXPERIMENTAL PROCEDURES AND PROTOCOL

Participants sat at a table centrally facing a computer monitor positioned posterior to the push-button (see Figure 2.1). Participants were instructed to observe the stimulus (presented as a white 10mm x 12mm square) on the computer monitor and press the push button with their right (dominant) index finger when they predicted that the moving stimulus (that is originating from either the left or right side) would enter the target zone, which is represented by two vertical lines 12 mm apart situated in the middle of the computer monitor.

Throughout the study, two vertical lines were always presented in the middle of the screen (12 mm apart) to represent the target zone. Each trial began when a stimulus, represented by a white filled square (10mm x 12mm), would appear on the left or right side of the screen and move towards the target zone (placed in the center). For each trial, the stimulus would start at one of four possible starting positions, with two possible locations from the left side (top and bottom left) and two possible locations from the right side (top and bottom right) (see Figure 2.2). The varying start locations of the visual stimulus would be beneficial when analyzing the participants' movement kinematics. The stimulus would travel at either a fast (224.13 mm/s) or slow (113.49 mm/s) speed in a straight horizontal line trajectory (see Figure 2.3). On each trial, the stimulus would disappear after either 33% or 66% of distance traveled from its start position.

Additionally, at the initiation of stimulus movement, a loud (70dB), soft (50dB), or no (0dB) burst of white noise was presented for 150 ms. The following variations were used to further explore compatibilities and incompatibilities between auditory and visual stimuli.

Prior to the experimental portion of each task, five practice trials were completed to familiarize the participants with the task. Afterwards, a total of 96 trials were performed, consisting of 8 trials that included each of the conditions uniquely: 2 vision (occlusion at 33% and 66%), 3 sound (loud, soft and no sound) and 2 speeds (fast and slow).

2.1.4 DATA REDUCTION

Reaction times (RT) were analyzed for each participant using LabVIEW software. RT was defined as the time elapsing between the beginning of the reaction stimulus of both the auditory and visual stimulus and the beginning of the participants' response (Nieme & Naatanen, 1981) (presented through the participant pressing the button), and was measured in milliseconds.

All of the participants' RTs were collected and sorted according to the condition and participant number. Constant error (CE), absolute error (AE), and variable error (VE) were then calculated from the sorted data. CE is used to measure deviations from the target and has a positive or negative sign pointing to the direction of the error, AE represents the overall deviation without considering the direction, and VE measures the

consistency of the participants' responses. CE, AE and VE will be measured in temporal domain (as seen in Figure 2.3).

Outliers typically arise from spurious events such as loss of attention, daydreaming, or any form of distraction (Ratcliff, 1993). Outliers were defined as trials in which participants missed the trial or had a delayed reaction. As each trial was specifically programmed to last 7000 ms, a missed trial was categorized as a RT that was 7000 ms. A delayed reaction was categorized as a trial RT that fell outside ± 2.5 standard deviation units of the mean for that participant (Glazebrook et al., 2006).

2.1.5 STATISTICAL ANALYSES

Using R, factorial repeated measures analysis of variance (ANOVA) was used on the three independent variables: audition, velocity and vision. The three variables completely crossed over, producing 12 experimental conditions, and the participants in the study participated in all of the conditions. Regarding stimulus origin, the data were pooled because the origin of the stimulus (top left, bottom left, top right, bottom right) had no effect on the timing of the stimulus to arrive at the target zone. The dependent measures were CE, AE and VE, with the significance set at $p < 0.05$. Mauchly's tests were used to test for sphericity and a Greenhouse-Geisser correction factor was applied to the degrees of freedom and test statistic when the data violated assumptions of sphericity. Bonferonni's post hoc comparisons were conducted to determine the exact location of significant differences, as it is the most robust of the univariate techniques that controls for the Type I error rate (when a true null hypothesis is incorrectly rejected). Effect sizes

were calculated using eta squared (η^2) and interpreted using the magnitude of the effect: small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$) and large ($\eta^2 = 0.14$) (Cohen, 1988).

2.2 RESULTS

ABSOLUTE ERROR

The sound accompanying the visual stimulus did not appear to have an effect on the participants' accuracy as there was no significant main effect, $F(2, 30) = 2.66$, $p > 0.05$, $\eta^2 = 0.01$ (see Figure 2.4). However, there was a significant main effect for vision, $F(1, 15) = 23.56$, $p < 0.001$, $\eta^2 = 0.05$, as participants were more accurate in the task when they were provided with less vision (33%), compared to more vision (66%) (see Figure 2.5). An interaction was found between audition and vision, $F(2, 30) = 13.02$, $p < 0.001$, $\eta^2 = 0.09$. Somewhat surprisingly, this interaction (see Figure 2.6) suggests that when presented with a loud sound, participants were more temporally accurate with less vision (as represented by a smaller mean absolute error) compared to more vision.

Additionally, Figure 2.7 displays the interaction between audition and velocity wherein participants were more accurate at predicting when the stimulus would enter the target zone when the stimulus was moving at a slower velocity depending on whether a loud sound, soft sound or no sound was accompanied with the visual stimulus $F(1,15) = 5.19$, $p < 0.05$, $\eta^2 = 0.01$. Lastly, it is important to consider that although the treatment effects reported are statistically significant, in all cases the associated effect sizes range only from small to medium.

CONSTANT ERROR

The main effect of velocity $F(1,15) = 3867$, $p < 0.001$, $\eta^2 = 0.96$ (see Figure 2.8) suggests that participants tend to overestimate the timing of the visual stimulus entering the target zone if the stimulus was moving at a fast velocity. Conversely, when the stimulus was moving at a slow velocity, participants tend to underestimate the time for the visual stimulus to enter the target zone. This effect is represented by the greater mean CE (862 ms) when the stimuli was moving at a fast velocity in comparison to the mean CE (-405 ms) when the stimuli was moving at a slower velocity.

Additionally, an interaction was found between sound and vision, $F(2,30) = 53.17$, $p < 0.001$, $\eta^2 = 0.44$. This interaction (see Figure 2.9) suggests that participants tend to overestimate the position of the visual stimulus to a greater degree when a loud sound is accompanied with more vision (66%) in comparison to less vision (33%), and the opposite is true for when a soft sound accompanies the stimulus. Participants tend to overestimate the position of the visual stimulus to a greater degree when a soft sound is accompanied with less vision (33%), in comparison to more vision (66%). The effect sizes that are indicated here are large.

VARIABLE ERROR

As seen in Figure 2.10, no significant effects for VE when exploring audition were revealed suggesting that variability across all conditions remains consistent.

2.3: DISCUSSION

It is evident that participants were more accurate, and had less directional bias, in the perception task when the visual stimulus was moving at a slower velocity. Additionally, two interesting interactions were observed between vision and audition. Specifically, participants were more accurate when less vision was provided to them with a loud sound, however when that same loud sound was accompanied with more vision, the participants' accuracy decreased. Moreover, participants had less directional bias when less vision was provided to them with a loud sound, however when the same loud sound was accompanied with more vision, the participants had a greater directional bias.

As evident in Figure 2.5, participants generally had a greater mean AE (i.e., they were less accurate) when they were provided with more vision, a finding that was not expected. However, when viewing this anomalous main effect in the context of auditory accompaniment (vision by sound interaction; See Figure 2.6), it becomes somewhat clearer as to why participants had a greater mean AE when provided with more vision. This interaction suggests that there was no difference in accuracy if no sound or a soft sound accompanied the stimulus, however, changes started to occur when a loud sound accompanied the stimulus. More specifically, when a loud sound was paired with more vision, participants were significantly less accurate in the task. One possible explanation for this is that the loud sound was in some way interfering with the greater available vision (Robinson & Sloutsky, 2013). Specifically, in these conditions of maximum salience in both sensory modalities, participants were perhaps switching weights between the two sources of sensory information with the outcome being a less than optimal interpretation of either. Conversely, when the loud sound was paired with less vision,

participants were more accurate in the task suggesting that participants, recognizing the reduced value of the visual information, may be weighting the auditory information to a greater degree. In other words, participants may be "substituting" the more robust information provided by the loud auditory stimulus for the less reliable visual information with the result being a more stable representation of the sensory environment.

A similar pattern is observed between sound and vision when observing participants' directional biases (see Figure 2.9). No differences were observed when no sound accompanied the stimulus, however differences were observed when a soft and loud sound accompanied the stimulus. Similar to accuracy, participants had greater directional bias away from the target zone when a loud sound was accompanied with more vision, and when a soft sound was accompanied with less vision. One possible explanation for this interaction is that the loud sound again was interfering with the pronounced available vision provided to the participants. The maximum salience for both vision and audition led to participants having a greater directional bias, more specifically greatly overestimating the timing of the stimulus to enter the target zone. On the other hand, when the same loud sound was paired with less vision, participants had less directional bias. Similar to participants' accuracy, when a loud sound was paired with less vision, the participants perhaps recognized that the visual information was lessened to a smaller degree, therefore enhancing the weight of the auditory information. As the participants use the more robust information that was provided by the loud sound for the less definitive visual information, they exhibited less directional bias.

The purpose of the study is to further explore the relationship between auditory and visual information when these two sensory sources are put into conflict. Specifically, is there an observable, interaction between compatible and incompatible sources of this information, and if that interaction is mediated by whether the auditory information is endogenous (non-specific spatial localization cues) in nature. The results of this study suggest that less visual information served as a more helpful tool for participants' accuracy when accompanied with a loud sound. Interestingly, in opposition of our first hypothesis, participants performed with greater accuracy when the two sensory sources were incompatible with each other (less vision and loud sound). Additionally, to address the second part of our hypothesis, compatibility of the two sensory sources did not have an effect on the participants' directional bias, as velocity was the main factor that affected the participants' directional bias in the perceptual task. As this study explored sound originating from one source, the following study aims to explore individuals' responses to sound originating from more than one source. More specifically, a sound origin that is in opposition/ incompatible from the origin of the visual stimulus (i.e., sound originating from the left hemifield, and visual stimulus originating from the right hemifield).

Table 2. 1

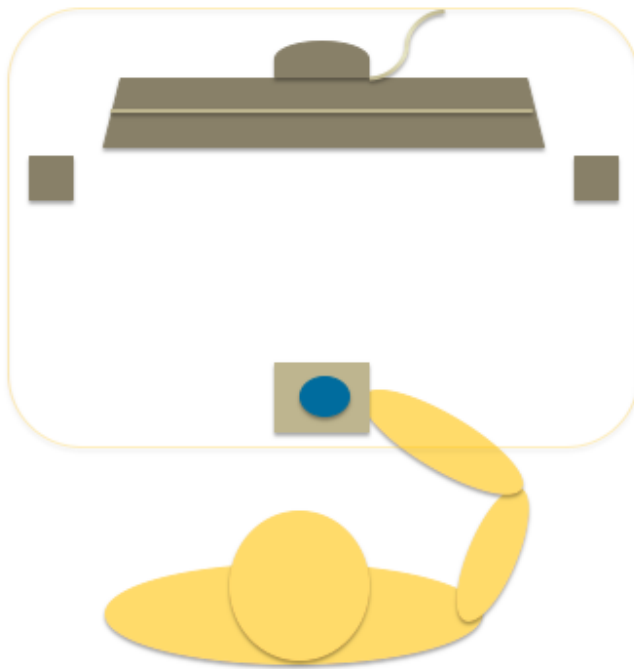*Summary of Participant Characteristics*

Participant	Age	Sex	Handedness
1	22	F	R
2	23	M	R
3	21	F	R
4	23	F	R
5	23	M	R
6	24	M	R
7	25	F	R
8	19	M	R
9	24	M	R
10	23	M	R
11	23	M	R
12	20	M	R
13	21	F	R

14	23	F	R
15	23	F	R
16	22	F	R

Age = 22.44 years ± 1.55; mean ± standard deviation

Figure 2. 1

Diagram of Experimental Setup

Note. Diagram of the experimental setup displaying the participant sitting across the computer monitor, speakers on each side of the computer monitor, and press-button for participants to make a response.

Figure 2. 2

Visual Stimulus Origin
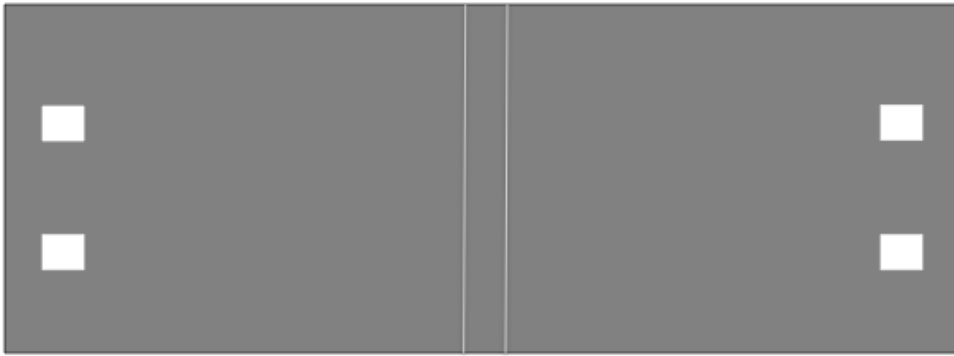
Note. Layout of possible visual stimulus origin, and target zone. The visual stimulus can originate from the top left, top right, bottom left and bottom right position.

Figure 2. 3

Visual Stimulus Measurements
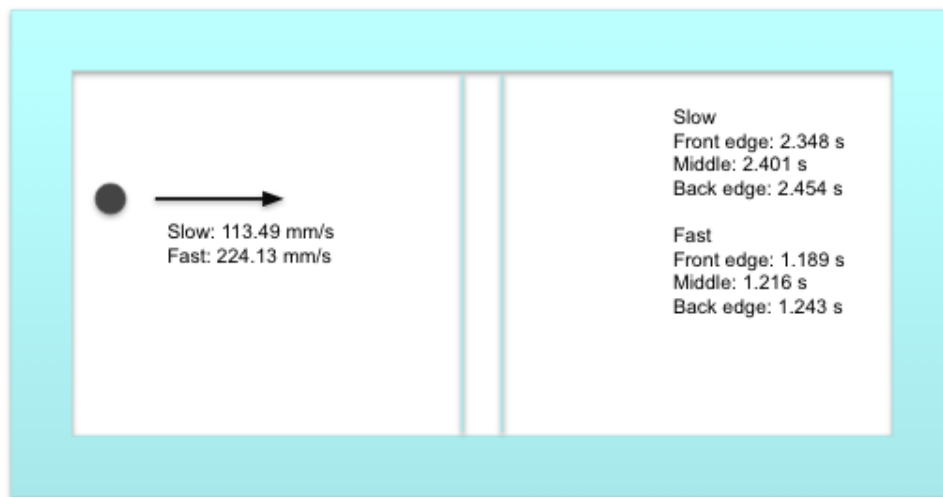
 Note. The following measurements were used to calculate AE, CE and VE in a temporal domain. The velocity of the visual stimulus is indicated whether the stimulus is moving at a fast or slow velocity. As well as the timing of when the stimulus enters the front edge, middle and back edge of the target zone, in accordance to the velocity of the visual stimulus.
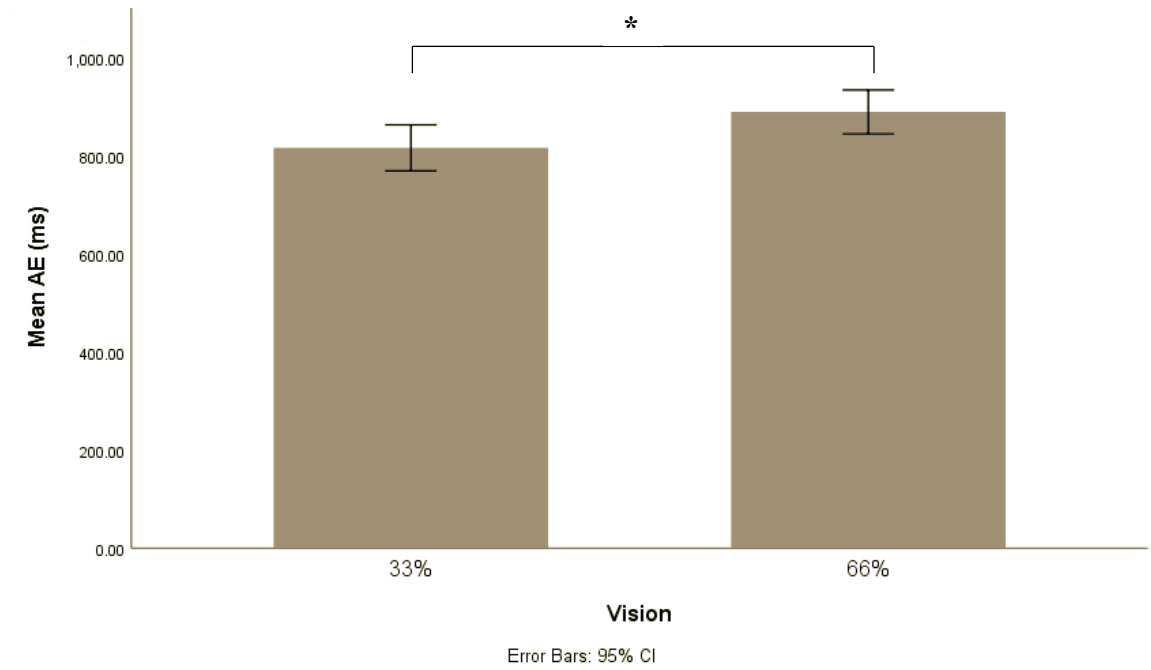
Figure 2. 4

Mean AE (ms) as a Function of Auditory Stimulus
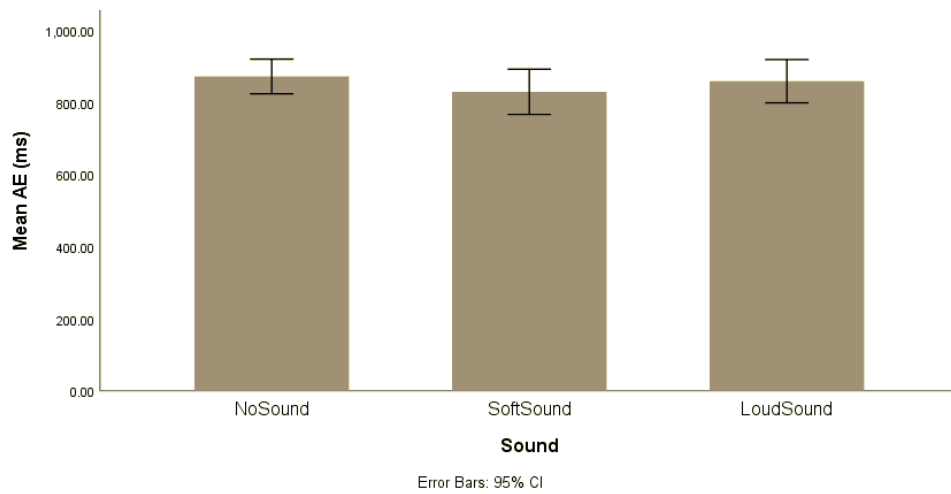
Note. Mean AE results are shown for when a stimulus is accompanied with no sound, soft sound or loud sound. Error bars show 95% confidence interval.

Figure 2. 5

Mean AE Results in Relation to Vision

Note. Mean AE results are shown for when less vision of the stimulus trajectory is presented in comparison to when more vision of the stimulus trajectory is presented. Participants had a greater mean AE when presented with more vision, and error bars show 95% confidence interval.

Figure 2. 6

Mean AE (ms) as a Function of Auditory Stimulus and Vision
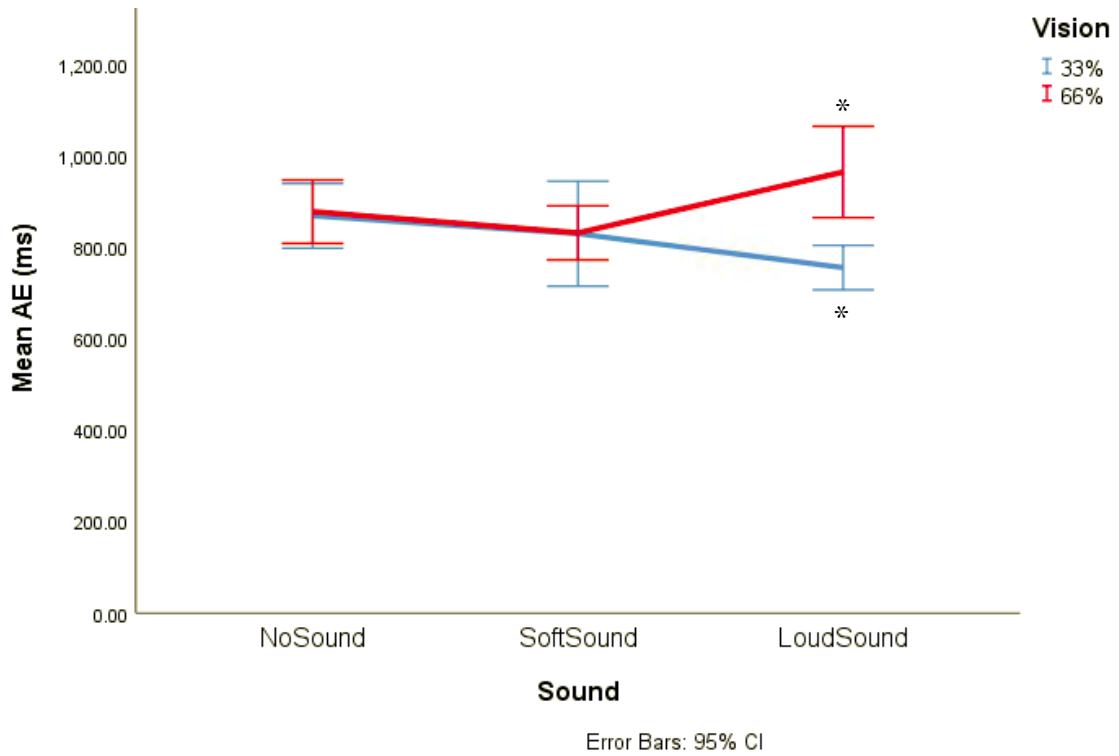
Note. An interaction between sound and vision of the stimulus movement trajectory is shown. Significant differences are observed when a loud sound is accompanied with less or more vision of the movement trajectory, and error bars show 95% confidence interval.

Figure 2. 7

Mean AE Results in Relation to the Interaction Between Sound and Velocity


Error Bars: 95% CI
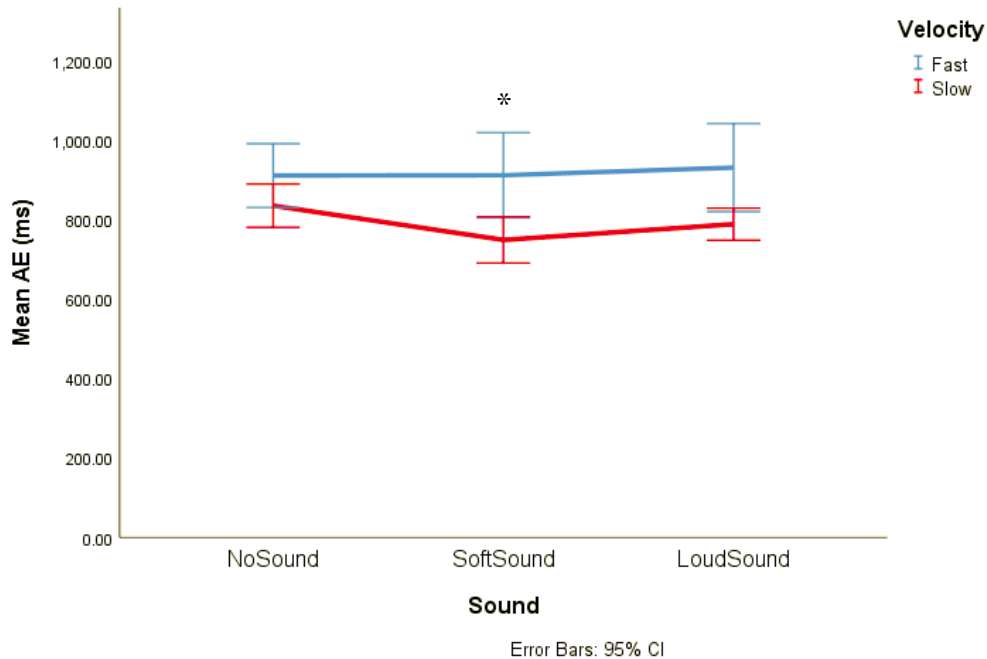
Note. An interaction between sound and the velocity of the stimulus is shown. Participants had a generally greater mean AE whenever the stimulus was moving at a fast velocity, regardless of the sound that accompanied the stimulus. Additionally, although

no differences were observed when no sound or a loud sound accompanied the stimulus moving at a fast or slow velocity, participants were more accurate in the task when a soft sound was accompanied with a stimulus moving at a slow velocity, in comparison to when the same soft sound was accompanied with a stimulus moving at fast velocity. Error bars show 95% confidence interval.

Figure 2. 8

Mean CE Results in Relation to the Interaction Between Sound and Velocity

Error Bars: 95% CI
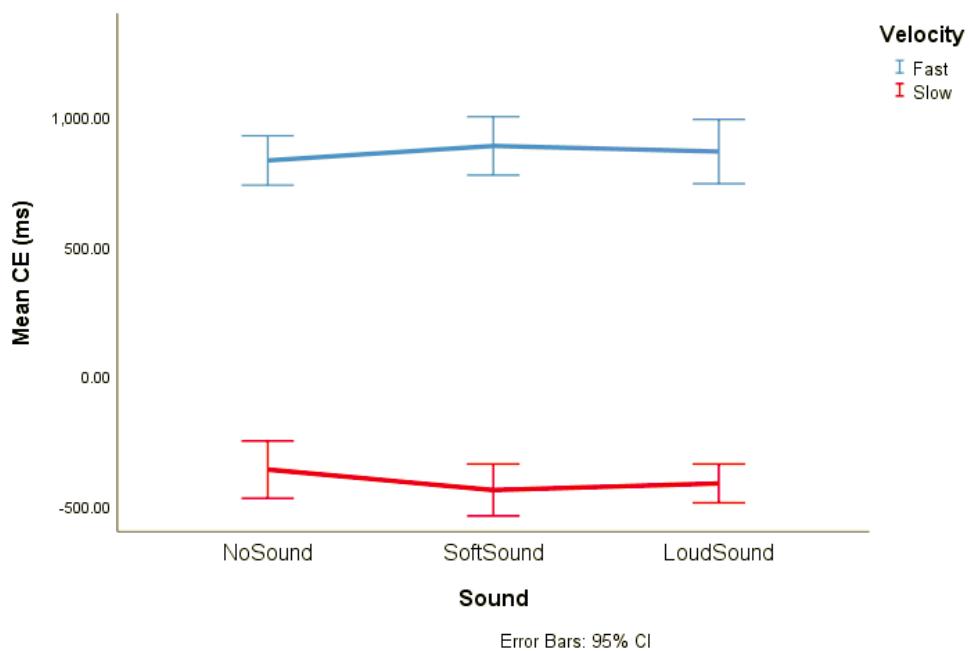
Note. An interaction between sound and velocity is shown. Participants generally overestimated the timing of the stimulus to enter the target zone whenever the stimulus was travelling at a fast velocity and underestimate the timing of the stimulus to enter the target zone whenever the stimulus was travelling at a slow velocity. Error bars show 95% confidence interval.

Figure 2.9

Mean CE Results in Relation to the Interaction Between Sound and Vision
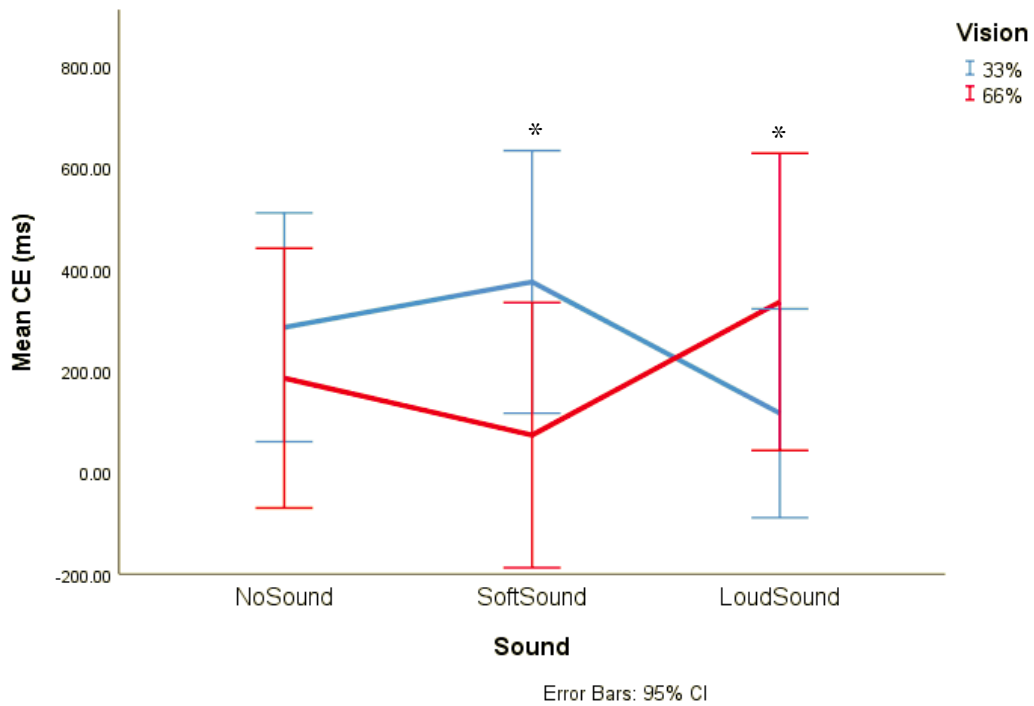
Note. An interaction between sound and vision of the stimulus movement trajectory is shown. Significant differences are seen when a loud sound is paired with less or more vision of the movement trajectory. Error bars show 95% confidence interval.

Figure 2. 10

Mean VE Results in Relation to Sound
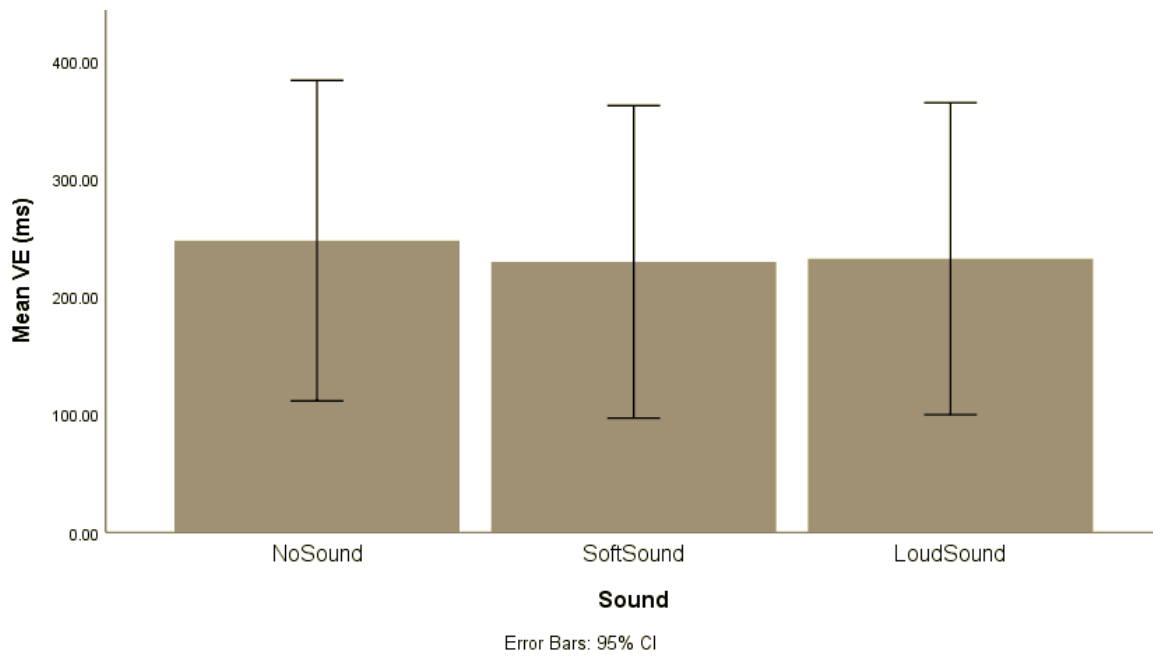
Note. Mean VE results are shown for when a stimulus is accompanied with no sound, soft sound or loud sound. Error bars show 95% confidence interval.

CHAPTER THREE: STUDY 2

3.1: INTRODUCTION

The following studies seek to further understand the relationship of spatially incompatible auditory and visual information with multisensory integration, specifically how one perceives this relationship when auditory information is exogenous in nature. The new auditory condition is introduced to explore the effects that may occur when attention is directed to a specific side of space by the unexpected onset of the auditory stimulus.

A compatible cue will represent an auditory stimulus originating from the same hemifield as the visual stimulus, and an incompatible cue will represent an auditory stimulus that is originating from the opposite hemifield of the visual stimulus origin. When incompatible cues are presented, it is expected that the CE and AE would be further impacted. The reason for this prediction is because localizable auditory stimuli, whether it is originating from the left or right hemifield, sparks a rapid initial response and is an exogenously controlled shift of visual attention to the cued location (Klein, 2018). It is of interest to explore how individuals will perceive unpredictable auditory stimuli that is originating from a different hemifield than the visual stimuli, and whether CE and AE are in fact impacted when comparing compatible and incompatible cues.

3.2: METHODS

3.2.1 PARTICIPANTS

Ten participants between the ages of 18- 30 years were recruited from the McMaster University population and Hamilton community to participate in this study, as seen in Table 3.1. The participants in this study did not participate in the first or third study, nor did they have any knowledge of either two studies. All participants were presented with no self-reported upper limb musculoskeletal impairments, had normal or corrected-to-normal vision, and were right-handed. Prior to participation in the study, individuals signed the informed consent form that outlined the nature of the study and the experimental protocol. Upon completion of the study, participants received financial compensation in the amount of $5 for their time.

3.2.2 APPARATUS

Similar to the first study, Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software, was used to generate the study. The same push-button, was positioned in between the computer monitor and the participant, to be used for participants to make a response.

3.2.3 EXPERIMENTAL PROCEDURES AND PROTOCOL

Participants sat at a table centrally facing a computer monitor positioned posterior to the push-button as seen in Figure 3.1. As illustrated in the figure, the sound originates from the headphones that is positioned on the participants, and the sound is either originating from the left side of the headphones, or from the right side of the headphones.

For the perception task, participants were instructed to observe the stimulus on the screen and press the push button with their right (dominant) index finger when they predicted the moving stimulus (that is coming from either the left or right side) would enter the target zone, represented by two vertical lines 12 mm apart situated in the middle of the computer monitor.

Each trial began when a red cross was presented on the screen. After a variable foreperiod (1 - 3 seconds), a stimulus, represented by a white filled square (10mm x 12mm), would appear on the left or right side of the screen and move towards the target zone. For each trial, the stimulus would start at one of four possible starting positions, with two possible locations from the left side (top and bottom left) and two possible locations from the right side (top and bottom right) (see Figure 3.2). The stimulus would travel at either a fast (448.26 mm/s) or slow (224.13 mm/s) speed in a straight horizontal line trajectory. On each trial, the stimulus would disappear after either 33% or 66% of distance traveled from its start position. Additionally, at the initiation of stimulus movement, a loud (70dB) or soft (50dB) burst of white noise was presented for 150 ms from the headphones. The auditory stimulus was detected via an app called Decibel X: dB Sound Level Meter. Moreover, the sound would originate from either the left side, right side or from both.

Prior to the experimental portion of each task, five practice trials were completed to familiarize the participants with the task. Afterwards, a total of 192 trials which was divided into three blocks of 64 trials, consisted of each of the conditions uniquely: 4 starting locations, 2 vision (occlusion at 33% and 66%), 2 speeds (fast and slow), and 6 sounds (left soft sound, right soft sound, left loud sound, right loud sound, both soft sound, both loud sound). A participant would experience a combination of all of the conditions twice.

3.2.4 DATA ANALYSES

Reaction times (RT) were analyzed for each participant using LabVIEW software. RT was defined as the time elapsing between the beginning of the reaction stimulus of both the auditory and visual stimulus (when the auditory and visual stimuli were presented) and the beginning of the participants' response (Nieme & Naatanen, 1981) (presented through the participant pressing the button), and was measured in milliseconds (see Figure 3.3).

All of the participants' RTs were collected and sorted according to the condition and participant number. Constant error (CE), absolute error (AE), and variable error (VE) were then calculated from the sorted data. CE is used to measure deviations from the target and has a positive or negative sign pointing to the direction of the error, AE represents the overall deviation without considering the direction, and VE measures the consistency of the participants' responses. A temporal criterion was used to asses CE, AE and VE, as seen in Figure 3.3.

Outliers were defined as trials in which participants missed the trial or had a delayed reaction. Specifically, a missed trial was categorized as a RT greater than 7000 ms (as each trial was specifically programmed to last 7000 ms) and a delayed reaction was categorized as a RT that fell ± 2.5 standard deviation units beyond of the mean for that participant (Glazebrook et al., 2006).

3.2.5 STATISTICAL ANALYSES

Using R, factorial repeated measures analysis of variance (ANOVA) was used as there are three independent variables: audition, velocity, vision. The three variables completely crossed over, producing 24 experimental conditions, and the participants in the study participated in all of the conditions. Regarding visual stimulus origin, the data was pooled because the origin of the visual stimulus (top left, bottom left, top right, bottom right) had no effect on the timing of the stimulus to arrive at the target zone. The dependent measures were CE, AE and VE, with the significance set at $p < 0.05$. Mauchly's tests were used to test for sphericity and a Greenhouse-Geisser correction factor was applied to the degrees of freedom and test statistic when the data violated assumptions of sphericity. Bonferonni's post hoc comparisons were conducted to determine the exact location of significant differences, as it is the most robust of the univariate techniques that controls for the Type I error rate (when a true null hypothesis is incorrectly rejected). Effect sizes were calculated using eta squared (η^2) and interpreted using the magnitude of the effect: small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$) and large ($\eta^2 = 0.14$) (Cohen, 1988).

3.3: RESULTS

ABSOLUTE ERROR

Sound and stimuli origin were of particular interest to this study since sound was localized and it was essential to determine whether there is a relationship between participants being more accurate in the task if the origin of the sound was congruent with the stimuli origin, as seen in Figure 3.4 As shown through the factorial repeated-measures ANOVA test, there were no significant main effects for sound $F (3, 27)= 2.63$, $p > 0.05$, $\eta^2= 0.03$, and stimuli origin $F (1, 9)= 2.45$, $p > 0.05$, $\eta^2= 0.01$, or interaction between the two conditions $F (3, 27)= 1.32$, $p > 0.05$, $\eta^2= 0.01$. Therefore, we can conclude that participants' temporal accuracy in completing the task was not affected by the sound origin being congruent with the stimuli origin.

Moreover, as seen in Figure 3.5, the only significant main effect found was with velocity $F (1,9) = 5.3$, $p < 0.05$, $\eta^2= 0.04$, as participants were more accurate when the stimulus was moving at a slow velocity.

CONSTANT ERROR

As seen in Figure 3.6, participants always overestimated when the stimulus would enter the target zone. However, it was observed that participants tend to overestimate the timing of the stimulus to enter the target zone more when the stimulus was moving at a fast velocity, in comparison to when the stimuli was moving at a slow velocity $F(1,9)=$

165.6, $p < 0.001$, $\eta^2 = 0.3$. Drawing attention to audition, as seen in Figure 3.7, the location and intensity of the sound that accompanied the stimulus did not have any main effect on the participants' directional bias $F_{(3,27)} = 1.91$, $p > 0.05$, $\eta^2 = 0.2$.

VARIABLE ERROR

The results of the repeated-measures ANOVA test examining variable error showed only a significant main effect of velocity $F_{(1,9)} = 6.04$, $p < 0.05$, $\eta^2 = 0.02$, as seen in Figure 3.8. Therefore, we can conclude that participants' variable error increased whenever the stimulus was traveling at a fast velocity.

3.4: DISCUSSION

In this study it was observed that there was no significant interaction between the origin of the sound stimulus and the origin of the visual stimulus. More specifically, the origin of the auditory and visual stimuli had no effect on the participants' accuracy -- an idea that is in opposition of our hypothesis for this study. We did however see that participants were more accurate in the task when the stimulus was moving at a slow velocity. Additionally, it was observed that participants always overestimated the timing of the stimulus to enter the target zone, independent of whether the stimulus was moving at a slow or fast velocity – an observation that differs from Study 1.

Another finding observed was that there was a fairly high degree of variability of the within-participants' RT. As seen in Figure 3.8, within participants' variability was greater when the stimulus was moving at a fast velocity, in comparison to when the

stimulus was moving at a slow velocity. Perhaps the stimulus travelling at a fast velocity did not provide enough time for participants to make a decision, ultimately compromising the participants' RT. This finding aligns with studies that have shown within-patient spatial variability being linearly related to the average velocity (Zelaznik, Schmidt & Gelen, 1986).

The purpose of Study 2 is to expand upon Study 1 and explore the effects that will occur when attention is directed to a specific side of space by the unexpected onset of the auditory stimulus. In contrast to our hypothesis, we did not see any effect on participants' accuracy when the visual and auditory stimuli did not originate from the same side of space, in fact, the origin of the sound stimuli had no effect on the participants' RT accuracy. However, we did see that the additional incompatible source of information in the form of an auditory stimulus did further impact within-participant variability (see Figure 3.8).

A similarity that was observed between the two perceptual studies was that whether the sound was endogenous (Study 01) or exogenous (Study 02) in nature, participants appeared to be more accurate in the perceptual task whenever the stimuli was moving at a slow velocity. With the stimulus moving at a slower pace, it allowed more time for the participants to make a more accurate temporal decision in determining when the stimulus will enter the target zone.

In regard to directional bias, when the sound was endogenous (Study1), participants overestimated when the stimuli was moving at a fast velocity and underestimated whenever the stimuli were moving at a slow velocity. However, when the

sound was exogenous (Study 2), participants tend to always temporally overestimate the timing of when the stimulus would enter the target zone. The velocity was faster for study 2, in fact it was twice as fast as the first study. In the first study, it was observed that participants tend to overestimate when the stimulus is moving at a fast velocity and underestimate when the stimulus is moving at a slow velocity. For the second study, we saw participants always overestimating, as the velocity was faster than the first study. This pattern could emerge from the fact that since the stimulus was moving at a fast velocity, the participants did not have enough time to process the information, therefore delaying their RT.

     Study 1 and Study 2 illustrate how individuals respond to incompatible sources of sensory information in a perceptual task. The following study seeks to explore how individuals will respond to incompatible sources of sensory information in an action task.
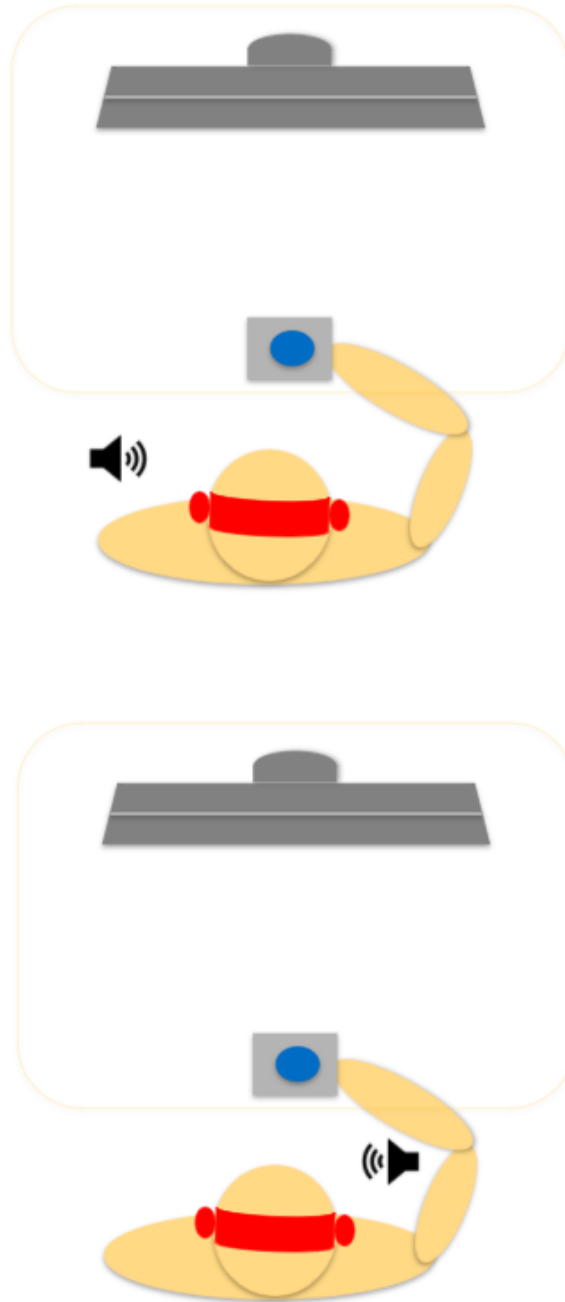
Table 3. 1

Summary of participant characteristics for Study 2

Participant	Age	Sex	Handedness
1	22	F	R
2	23	M	R
3	21	F	R
4	23	F	R
5	23	M	R
6	24	M	R
7	25	F	R
8	19	M	R
9	24	M	R
10	23	M	R

Age = 22.44 years +/- 1.55; mean +/- standard deviation

Figure 3. 1

Diagram of Experimental Setup for Study 2

Note. Diagram of the experimental setup displaying the participant sitting across the computer monitor, headphones that present the auditory stimulus on either the left or right side of the participants' ears, and a press-button for participants to make a response.
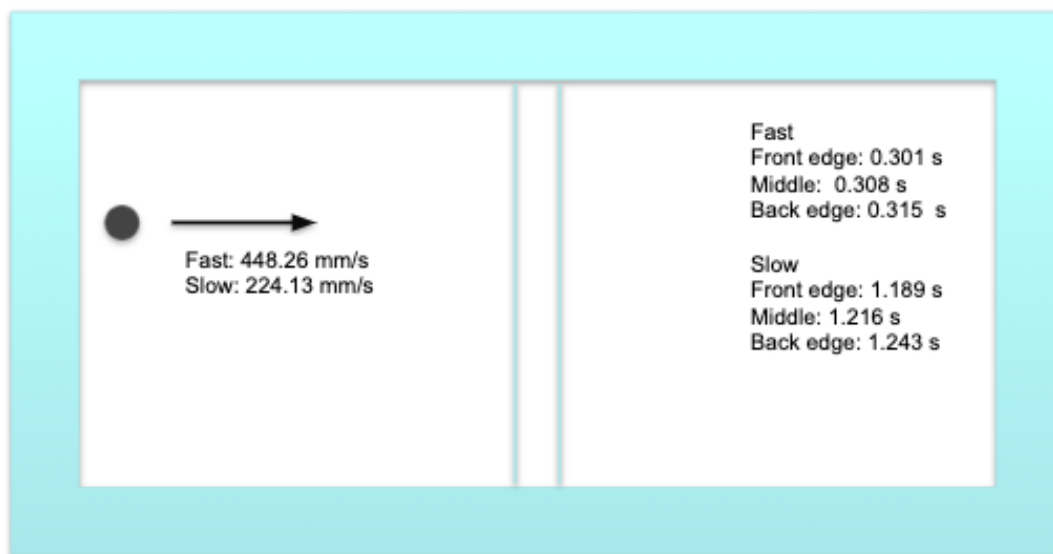
Figure 3. 2
Visual Stimulus Origin for Study 2
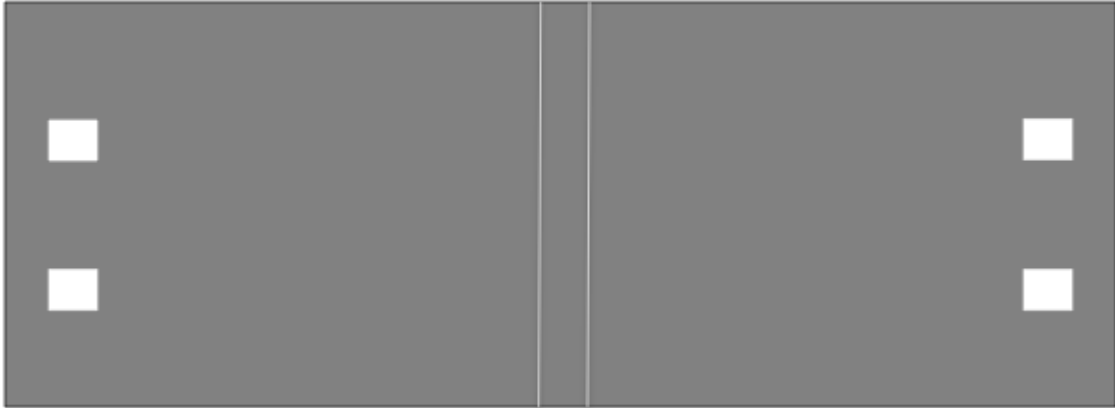
Note. The layout of the possible visual stimulus origin, and target zone. For each trial, the visual stimulus can originate from the top left, top right, bottom left and bottom right position.
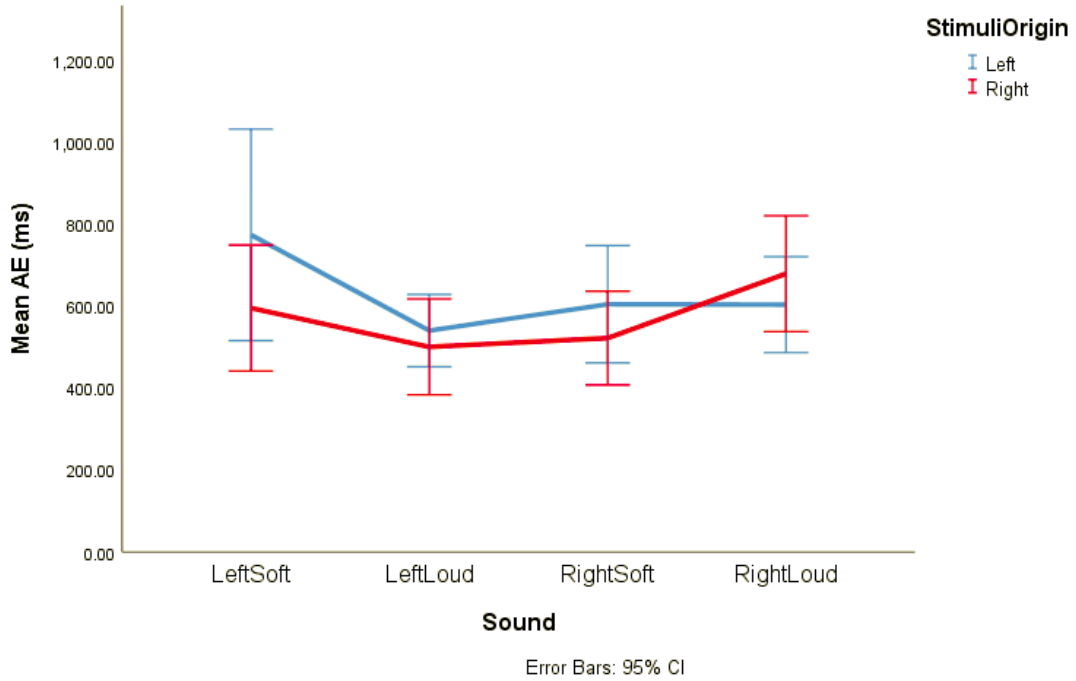
Figure 3. 3

Visual Stimulus Measurements

Note. The following measurements were used to calculate AE, CE and VE in a temporal domain. The velocity of the visual stimulus is indicated whether the stimulus is moving at a fast or slow velocity. As well as the time of when the stimulus enters the front edge, middle and back edge of the target zone, in accordance to the velocity of the visual stimulus.
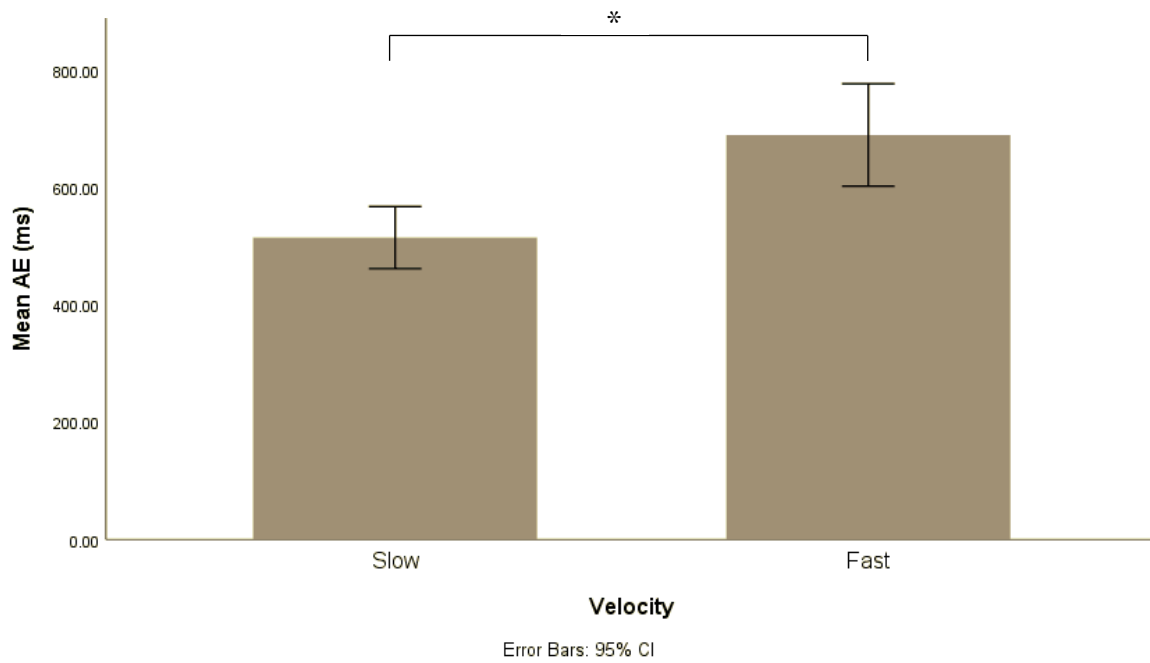
Figure 3. 4

Mean AE Results in Relation to the Interaction Between Sound and Stimuli Origin

Note. An interaction between the origin of the sound and origin of the stimulus. Error bars show 95% confidence interval.
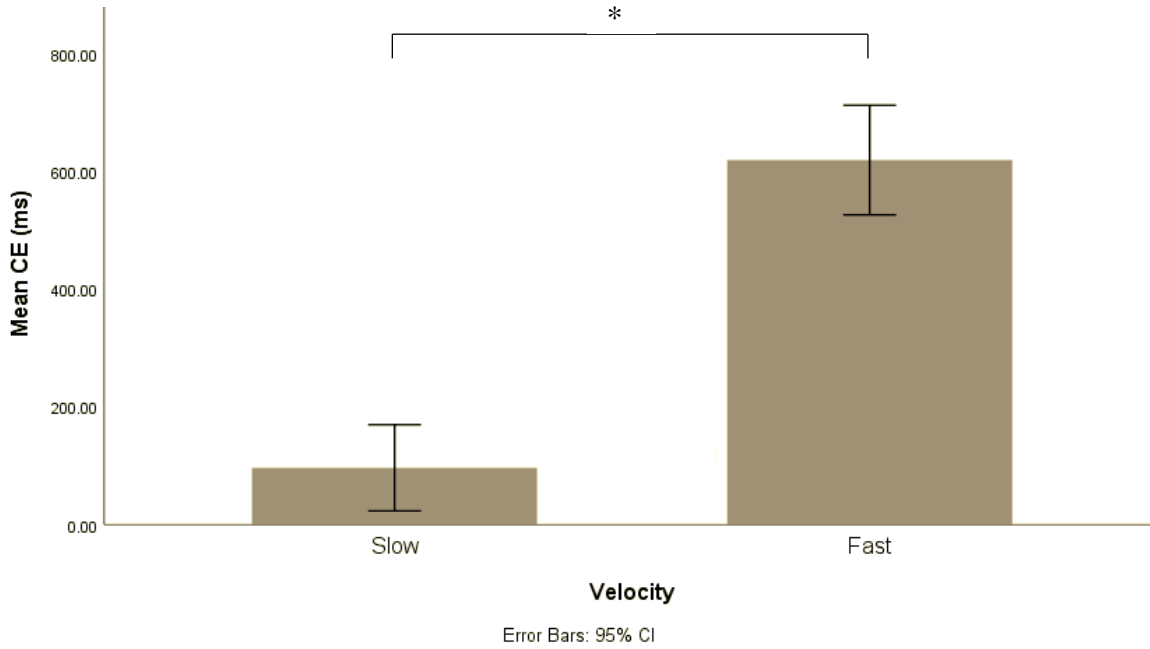
Figure 3. 5

Mean AE Results in Relation to Velocity

Note. Mean AE results are shown for when the stimulus is travelling in a fast or slow velocity. Participants had a greater mean AE when the stimulus was travelling at a fast velocity, and error bars show 95% confidence interval.
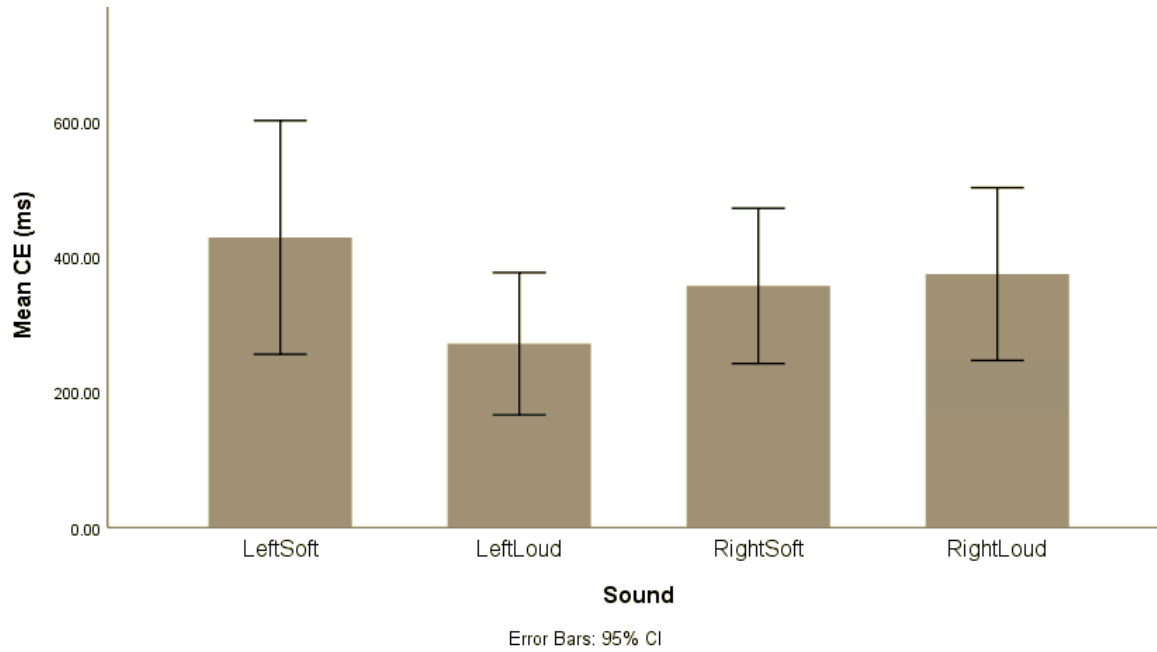
Figure 3. 6

Mean CE Results in Relation to Velocity

Note. Mean CE results are shown for when a stimulus is travelling at a fast or slow velocity. Participants generally have a greater directional bias for when the stimulus is travelling at a fast velocity in comparison to when the stimulus is travelling at a slow velocity. Error bar show 95% confidence interval.
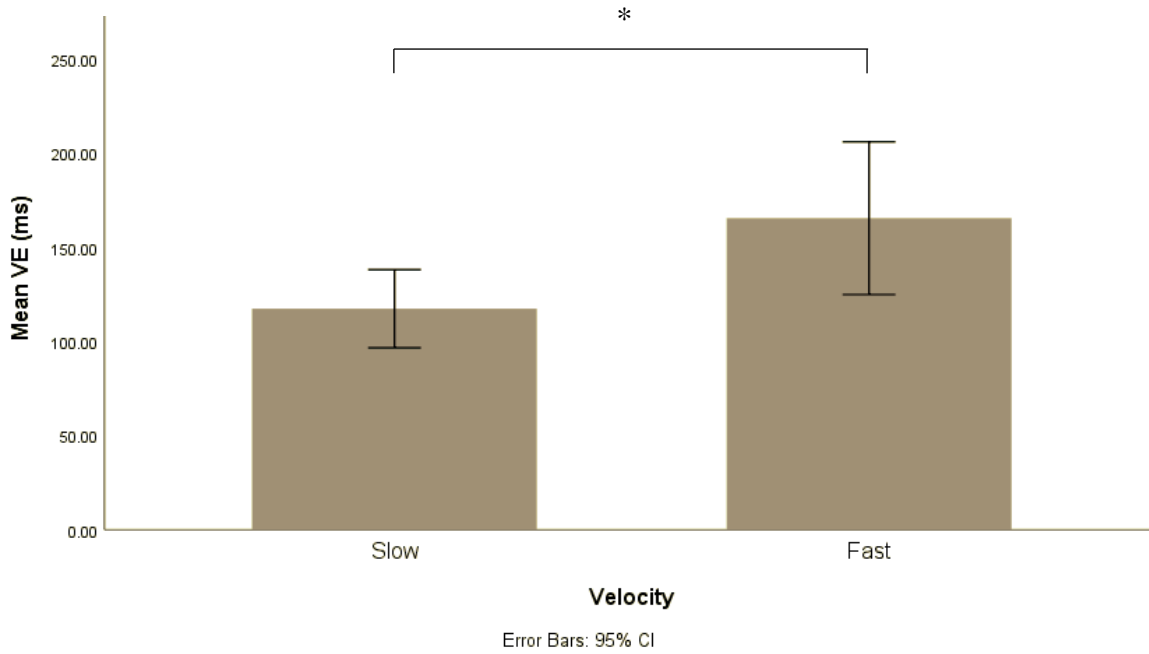
Figure 3. 7

Mean CE Results in Relation to Sound Origin

Note. Mean CE results are shown for the origin of the sound stimulus. Error bars show 95% confidence interval.

Figure 3. 8

Mean VE Results in Relation to Velocity

Note. Mean VE results are shown for when a stimulus is travelling at a fast or slow velocity. Participants generally have a larger mean VE for when the stimulus is travelling at a fast velocity in comparison to when the stimulus is travelling at a slow velocity. Error bars show 95% confidence interval.

CHAPTER FOUR: STUDY 3

4.1: INTRODUCTION

This study seeks to further explore the perceptual task of Study 1 by adding a motor task. Studies have explored distinct dissociations of completing a perceptual task and an action-based task (Goodale, Milner, Jakobson, & Carey, 1991; Goodale et al., 1994) mainly due to the differences between the role of the ventral stream and the dorsal stream (Milner & Goodale, 1995). Therefore, it is of interest in this study to explore the differences between how one perceives multisensory incompatible information and how one acts upon incompatible information. The foundation of this study will compare the two theories: perception-action dissociation theory (Milner & Goodale, 2006) and the planning-control model (Glover & Dixon, 2001).

According to the perception-action dissociation theory, if one were to be presented with visual illusory stimuli perceptual-cognitive processing would be affected, however, the illusory stimuli would not affect action-oriented processing, because of the presence of two streams that process and transmit visual information differently (Carey 2001; Dewar & Carey, 2006). According to the planning-control model on the other hand, action-oriented processing would be affected by illusory stimuli/ incompatible sensory information. The reason action-oriented processing would be affected is due to the fact that the feedforward processes of the action (including the pre movement organization and planning) are susceptible to visual illusion/ incompatible sensory information, however, processes associated with on-line control are immune to the incompatible information (Glover & Dixon, 2001).

4.2: METHODS

4.2.1 PARTICIPANTS

A total of 16 participants, between the ages of 18- 30 years were recruited from the McMaster University population and Hamilton community to participate in this study, as seen in Table 2.1. As Study 1 and Study 3 are a counterbalanced study, all of the participants that participated in Study 1, also participated in this study. All participants were presented with no self-reported upper limb musculoskeletal impairments, had normal or corrected-to-normal vision, and were right-handed. Prior to participation in the study, individuals signed the informed consent form that outlined the nature of the study and the experimental protocol. Upon completion of the first and third study, participants received financial compensation in the amount of $10 for their time.

4.2.2 APPARATUS

Similar to the first two studies, Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software was used to generate the study. For the perception action task, the push-button was replaced and positional data were collected using a Wacom PTK1240 Intuos 4 tablet and stylus (Wacom, Kazo, Japan). The spatial coordinate system was measured relative to the participant; anterior-posterior movements in the vertical direction represented movements in the Y direction, or primary movement axis, whereas medial-lateral movements in the horizontal direction resulted in changes in the X direction, or secondary movement axis. Relative to the participant, the origin (0,0) was set to the bottom left of the computer monitor. The computer mouse, represented by

the conventional white arrow, was controlled by movements of the stylus on the graphics tablet. Relative to the participant, anterior-posterior and medial-lateral movements of the stylus resulted in a visual representation of the mouse moving upward and downward, and leftward and rightward on the monitor, respectively.

4.2.3 EXPERIMENTAL PROCEDURES AND PROTOCOL

Participants sat at a table centrally facing a computer monitor positioned posterior to the tablet, as illustrated in Figure 4.1.

The perception-action task is very similar to the perception task; however, the tablet was utilized as opposed to the push-button for participants to make a response. Participants were presented with the exact same visuals as the perception task on the screen, however they were asked to respond differently. Participants were instructed to use the stylus to move along the graphics tablet simultaneously with the moving stimulus on the screen. Participants were able to see their movements with the stylus on the screen. Generally, for each trial, participants saw their movement along the target zone, perpendicular to the moving stimulus that only moves in a horizontal plane.

Throughout the study, two vertical lines were always presented in the middle of the screen (12 mm apart) to represent the target zone. Participants began each trial on the bottom of the screen, in between the target zone, and had to remain in that area before they saw the stimulus.

Each trial began with a stimulus represented by a white filled square (10mm x 12mm) would appear on the left or right side of the screen and move towards the target

zone. For each trial, the stimulus would start at one of four possible starting positions, with two possible locations from the left side (top and bottom left) and two possible locations from the right side (top and bottom right) (see Figure 4.2). The stimulus would travel at either a fast (224.13 mm/s) or slow (113.49 mm/s) speed in a straight horizontal line trajectory (see Figure 4.3). On each trial, the stimulus would disappear after either 33% or 66% of distance traveled from its start position. Additionally, at the initiation of stimulus movement, a loud (70dB), soft (50dB), or no (0dB) burst of white noise was presented for 150 ms via speakers.

Participants moved from a home position directly in front of them to a distance of either approximately 96 mm (if the stimulus originated from the bottom part of the screen), or 157 mm (if the stimulus originated from the top part of the screen) away. Both the home position and the target end positions were at the midline; therefore the aiming movement primarily involved the elbow extension.

Prior to the experimental portion of each task, five practice trials were completed to familiarize the participants with the task. Afterwards, a total of 96 trials were performed, consisting of 2 trials that included each of the conditions uniquely: 4 starting locations, 2 vision (occlusion at 33% and 66%), 3 sound (loud, soft and no sound) and 2 speeds (fast and slow).

4.2.4 DATA ANALYSES

Movement kinematics were analyzed for each participant using Matlab software. Raw movement data were filtered at 6 Hz with a second order dual-pass Butterworth

filter. The filtered displacement data was then differentiated once to obtain velocity and a second time to obtain acceleration. Movement time (MT), end position, peak velocity (PV), time to peak velocity (TPV), peak acceleration (PA), time to peak acceleration (TPA) and peak deceleration were all analyzed. MT, similar to RT that was measured in the past two studies are measures of the time that participants need in order to prepare for a movement (RT) and execute a movement (MT). MT includes movement preparation and execution times. The kinematic measures on the other hand provides more insight on the timing and magnitude of the initial impulse that is needed to move the limb and intercept the target. Furthermore, analyzing the kinematic measures provides more information on the online processes and early trajectory feedback-based control that may be associated throughout the movement. The start and end of each movement were defined as the frame where the velocity of the stylus rose above or fell below 30 mm/s and remained for more than 70 ms (Glazebrook, Elliott and Lyons, 2006).

Outliers were defined as trials in which participants missed the trial or had a delayed reaction. As each trial was specifically programmed to last 10 000 ms, a missed trial was categorized as a RT that was 10 000 ms. A delayed reaction was categorized as a trial that had a RT outside of $\pm$ 2.5 standard deviation units of the mean for that participant (Glazebrook et al., 2006).

4.2.5 STATISTICAL ANALYSES

Using R, factorial repeated measures analysis of variance (ANOVA) was used as there are four independent variables: audition, velocity, vision and stimulus origin. The

four variables completely crossed over, producing 48 experimental conditions, and the participants in the study participated in all of the conditions. The dependent measures were movement time, end position, peak velocity, time to peak velocity, peak acceleration, time to peak acceleration and peak deceleration, with the significance set at $p < 0.05$. Mauchly's tests were used to test for sphericity and a Greenhouse-Geisser correction factor was applied to the degrees of freedom and test statistic when the data violated assumptions of sphericity. Bonferonni's post hoc comparisons were conducted to determine the exact location of significant differences, as it is the most robust of the univariate techniques that controls for the Type I error rate (when a true null hypothesis is incorrectly rejected). Effect sizes were calculated using eta squared (η^2) and interpreted using the magnitude of the effect: small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$) and large ($\eta^2 = 0.14$) (Cohen, 1988).

4.3: RESULTS

MOVEMENT TIME

A main effect for audition, $F(2,30) = 3.99$, $p < 0.05$, $\eta^2 = 0.009$ suggests that participants had a longer MT when responding to a louder sound in comparison to when no sound accompanied the visual stimulus ($p = 0.018$) (see Figure 4.4). A main effect of origin of the visual stimulus, $F(3,45) = 16.56$, $p < 0.001$, $\eta^2 = 0.06$, suggests that participants had longer MTs when the stimuli originated from the top part of the screen as opposed to the bottom part of the screen (see Figure 4.5). A main effect of velocity $F(1,15) = 32.87$, $p < 0.001$, $\eta^2 = 0.3$, suggests that participants had a longer MT when the

stimulus was moving slow (see Figure 4.6). An interaction between vision and velocity $F(1,15)= 10.5, p < 0.01$, was also found to be significant. As seen in Figure 4.7, participants had an overall longer MT when the stimulus was travelling at a slow velocity, in comparison to when the stimulus was travelling at a fast velocity. This relationship is displayed when 33% of the stimulus movement trajectory is shown to the participants, however the difference in MT between slow velocity and fast velocity further increases when 66% of the stimulus movement trajectory is shown to the participants. More specifically, when the stimulus is travelling at a fast velocity, participants' MT decreases when they are provided with more vision (66%). Additionally, when the stimulus is travelling at a slow velocity, participants' MT increases when they are provided with more vision (66%).

END POSITION

A main effect for stimuli origin was found, $F(3, 45)= 178.8, p < 0.001, \eta^2= 0.71$ (see Figure 4.8), more specifically, the participants had a further end position when the stimuli originated from the top part of the screen ($M = 130$ mm, $SD = 21.05$) compared to the bottom part of the screen ($M= 80$ mm, $SD = 32.35$). Additionally, a main effect for vision was found, $F(1,15)= 8.01, p < 0.05, \eta^2= 0.009$ (see Figure 4.9).

PEAK VELOCITY

A main effect was found for stimulus origin, $F(3, 45) = 14.34, p < 0.001, \eta^2= 0.12$ (see Figure 4.10), wherein participants' PV was higher when the stimuli originated

from the top part of the screen. Additionally, PV was higher when more vision was provided to the participants compared to when there was less vision provided, $F(1,15) = 4.64$, $p < 0.05$, $\eta^2 = 0.02$ (see Figure 4.11). Lastly, PV was higher when the stimuli was moving at a fast velocity compared to when the stimuli was moving at a slow velocity $F(1,15) = 14.75$, $p < 0.01$, $\eta^2 = 0.08$ (see Figure 4.12).

TIME TO PEAK VELOCITY (TPV)

A significant main effect of time to peak velocity, $F(1,15) = 10.92$, $p < 0.01$, $\eta^2 = 0.06$ suggests that participants reached PV later in the movement when the stimulus was moving at a slow velocity (M = 716.63 ms, SD = 650) (see Figure 4.13) compared to when the stimulus was moving at a fast velocity (M = 504.62 ms, SD = 405.2). A significant three way interaction between position, audition and vision $F(6, 90) = 2.62$, $p < 0.05$, $\eta^2 = 0.02$ was also found. However, after conducting a Bonferonni post hoc test, no significant differences were found.

PEAK ACCELERATION (PA)

Similar to PV, a main effect for stimuli origin $F(3.45) = 7.05$, $p < 0.001$, $\eta^2 = 0.05$, showed that participants had a higher PA when the stimuli originated from the top part of the screen compared to when the stimuli originated from the bottom (see Figure 4.14). A main effect of stimuli velocity, $F(1,15) = 13.47$, $p < 0.01$, $\eta^2 = 0.04$, demonstrated greater PA when the stimulus was moving at a fast velocity (M = 2100 mm/ms^2, SD = 1159)

compared to when it was moving at a slower velocity (M = 1763 mm/ms ^2, SD = 1059.6) (see Figure 4.15).

TIME TO PEAK ACCELERATION (TPA)

No main effects were found to be significant with stimuli origin ($p < 0.05$), vision ($p < 0.05$), audition ($p < 0.05$) and velocity ($p < 0.05$).

PEAK DECELERATION (PD)

Similar to PA and PV, a main effect for stimuli origin $F(3, 45) = 5.47$, $p < 0.01$, $\eta^2 = 0.03$, was found as participants had a higher PD when the stimuli originated from the top part of the screen (see Figure 4.16). Moreover, PD was higher when stimuli was moving at a faster velocity (M = -1650.1 mm/ms^2, SD = 1116.3) compared to a slower velocity (M = -1362.5 mm/ms, SD = 1050.6), $F(1,15) = 11.5$, $p < 0.01$, $\eta^2 = 0.03$ (see Figure 4.17). An interaction was also found between vision and stimuli origin $F(3, 45) = 3.06$, $p < 0.05$, $\eta^2 = 0.01$ (Figure 4.18). After running a Bonferonni post hoc test, differences were found when the stimuli originated from the top left position in comparison to the bottom left and bottom right position whenever less vision was provided (33%). Additionally, significant differences were found when the stimuli originated from the top right position when provided with 66% vision, in comparison to stimuli that originated from the bottom right and bottom left position when less vision was provided (33%).

4.4: DISCUSSION

It was observed that participants had a longer MT, further EP, higher PA and higher PD whenever the stimuli originated from the top portion of the computer monitor. These findings were expected as the participants had to move the stylus a longer distance. Similar results were also observed between PV, PA and PD, as they all were significantly higher whenever the stimulus was moving at a fast velocity – a pattern seen in the study by Zelaznik et al., (1986). These findings may be a result of participants' generalized motor program producing a change in scale. On trials when the stimulus was travelling at a fast velocity, the participants had to intercept the target at a faster rate, and therefore the acceleration-time function would double the amplitude at every point in time throughout the movement, in hopes of intercepting the target correctly.

Other results of this study provided further evidence of the general impact of loud sounds on reaching/interceptive responses. For example, participants had a longer MT when a loud sound accompanied the stimulus, as opposed to when no sound accompanied the stimulus. This result counteracted the results of Fletcher & Munson (1933) that correlated high intensity sounds to faster RT and more impulse movements. Additionally, this finding also counteracts the study conducted by Farhead and Punt (2015) that measured accuracy and response times when they observed participants watching video trials of tennis serves that sometimes accompanied a grunting noise and sometimes did not. The study by Farhead and Punt (2015) observed that participants tend to associate a loud sound with a higher velocity (i.e., shorter MT). A finding that is in opposition of

what was observed for this study. Perhaps the randomization of the sound trials throughout the study could be the reason for the counteracting results to the past studies. As the participants were randomly presented with three sound conditions (no sound, soft sound and loud sound), whenever the loud sound would arise, it would serve as an additional obstacle that participants had to overcome, leading to a longer planning and control phase, and ultimately leading to a longer MT.

Another finding observed was that participants increased their PV when they were provided with more vision. This is an interesting observation as it counteracts the finding in the study by Elliott, Chua, Pollock & Lyons (1995), as they saw participants adapt a strategy to adjust their movement by increasing their PV when they were provided with less visual feedback. One possible reason for this occurrence could be due to the additional multimodal sensory stimuli that was provided to the participants. For example, as seen on Figure 4.12, PV also increased when the stimulus was travelling at a fast velocity in comparison to when it was travelling at a slow velocity. Therefore, although more vision was provided (66%), it was still required from the participants to adjust their movements as the stimulus would travel at varying velocities, and was also accompanied with varying sound volumes, ultimately leading to participants increasing their PV.

Despite the findings that were observed, the kinematic and performance data must, however, be viewed with some caution. In all of the conditions, the participants performed the task with a very low rate of accuracy, as shown through the proportion of low successful interceptions. It is important to consider that kinematic measures of performance are useful only when the task is being successfully completed on a relatively

high proportion of trials. However, the low level of accuracy is an interesting finding in and of itself. This finding is similar to past studies that have observed older individuals completing interceptive tasks while receiving incompatible multimodal sensory cues (De Dieuleveult, Brouwer, Siemonsma, Van Erp & Brenner, 2018; De Dieuleveult, 2019). Due to the inaccuracy, it was suggested that older adults may have more difficulty overall ignoring irrelevant sensory information, however, the reliability on vision is heightened because of the less reliable proprioceptive and vestibular information that they have.
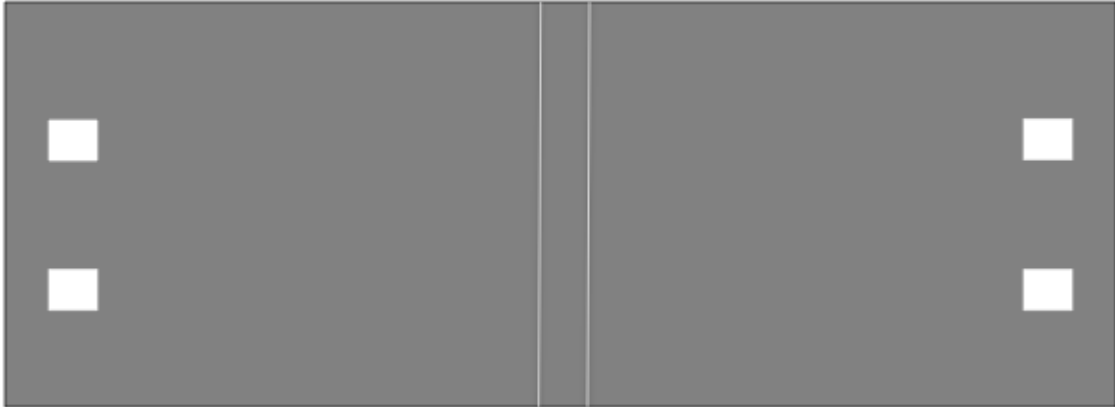
Figure 4. 1

Diagram of Experimental Setup for Study 3
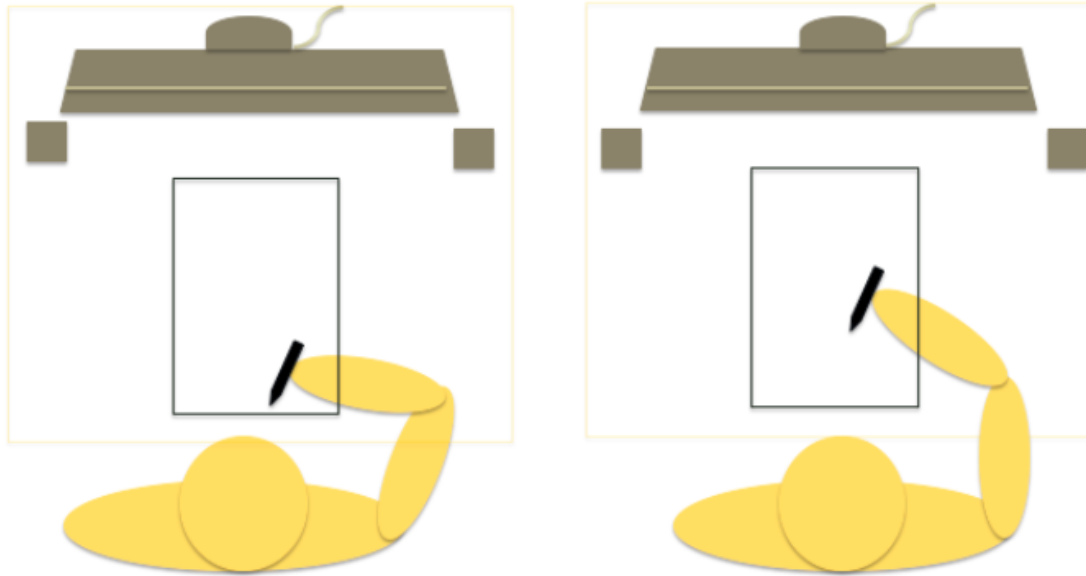
Note. Diagram of the experimental setup displaying the participant sitting across the computer monitor and speakers on each side of the computer monitor. Participants are holding a stylus and using it on a graphics tablet in order to make a movement response.
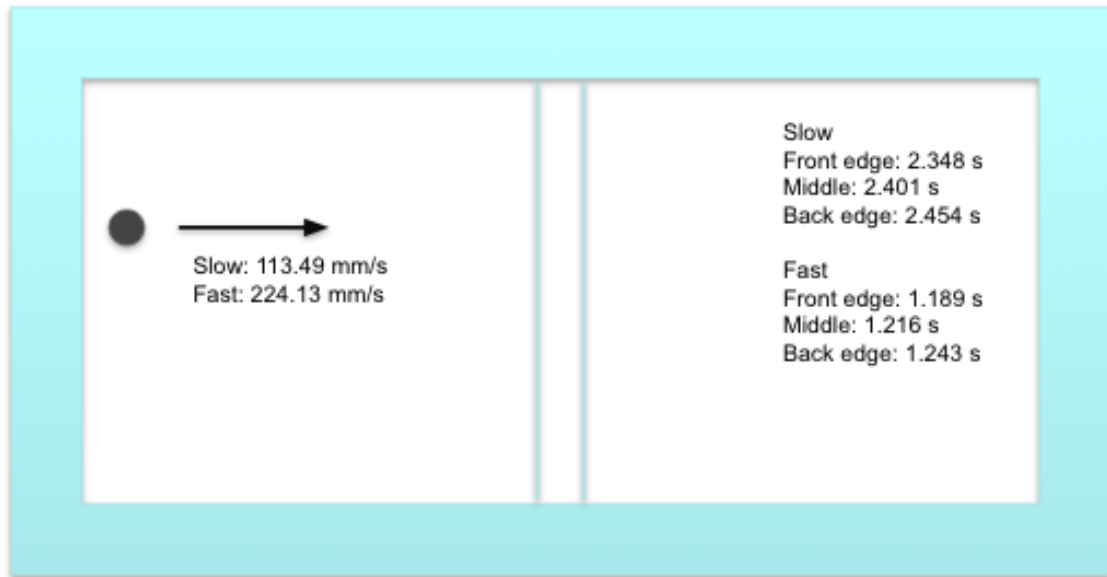
Figure 4. 2

Visual Stimulus Origin

Note. Layout of the possible visual stimulus origin, and target zone. The visual stimulus can originate from the top left, top right, bottom left and bottom right position.
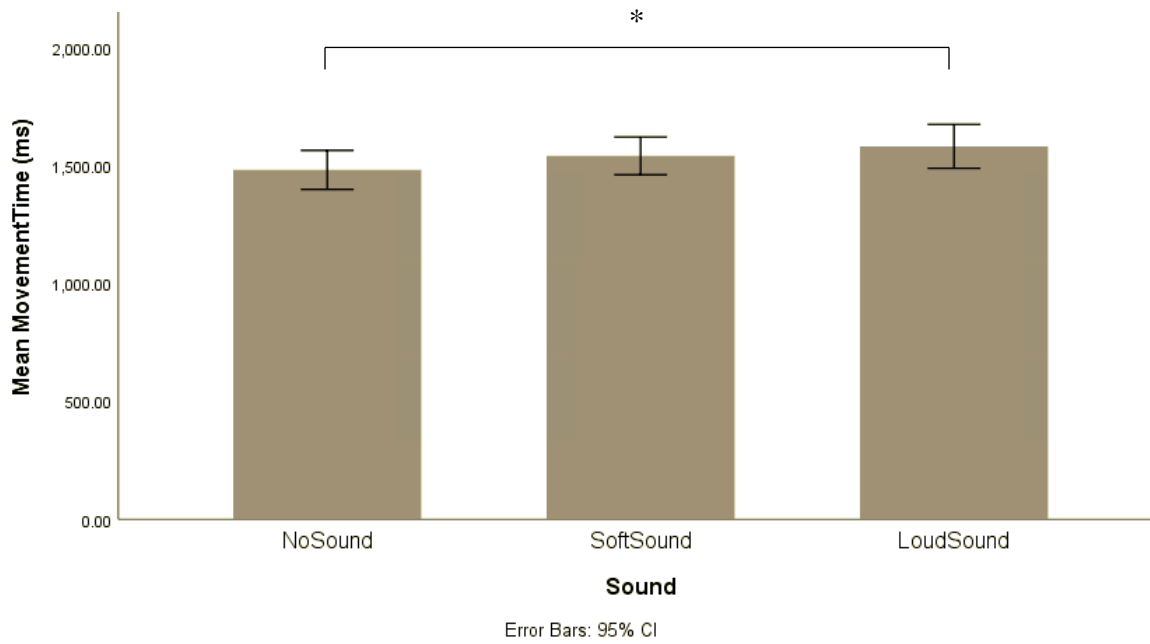
Figure 4. 3

Visual Stimulus Measurements

Note. The velocity of the visual stimulus is indicated whether the stimulus is moving at a fast or slow velocity. As well as the timing of when the stimulus enters the front edge, middle and back edge of the target zone, in accordance to the velocity of the visual stimulus.
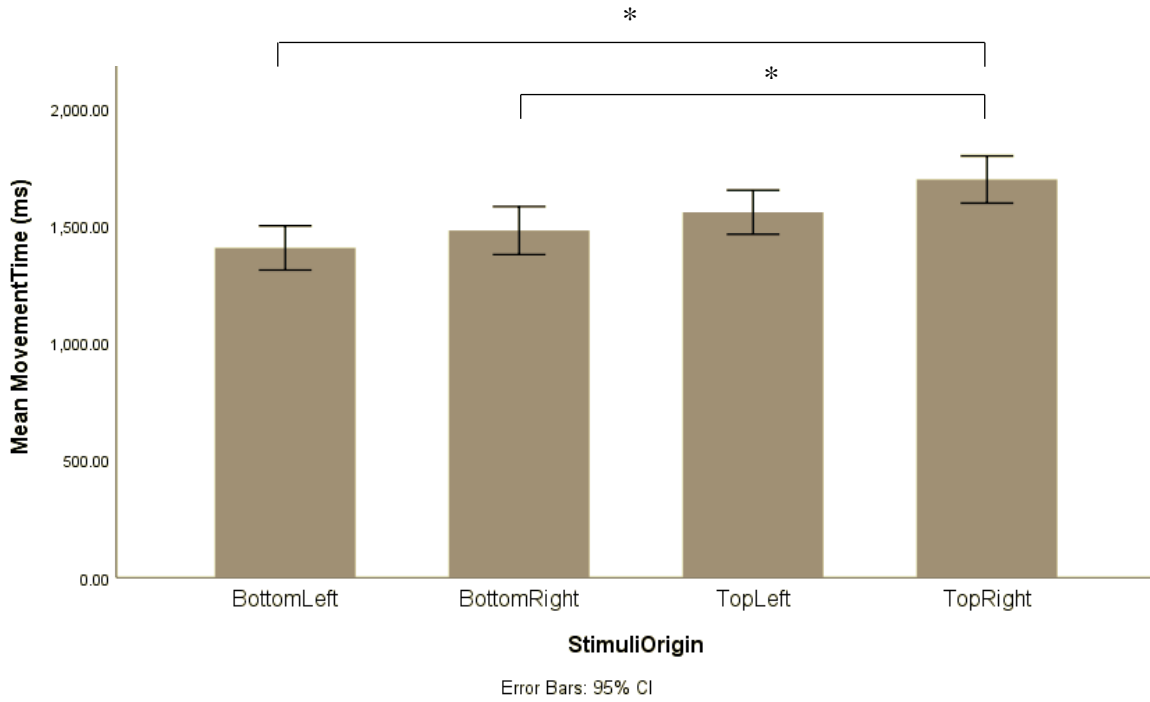
Figure 4. 4

Mean MT (ms) as a Function of Auditory Stimulus

Note. Mean MT results are shown for when a stimulus is accompanied with no sound, soft sound or loud sound. Error bars show 95% confidence interval.
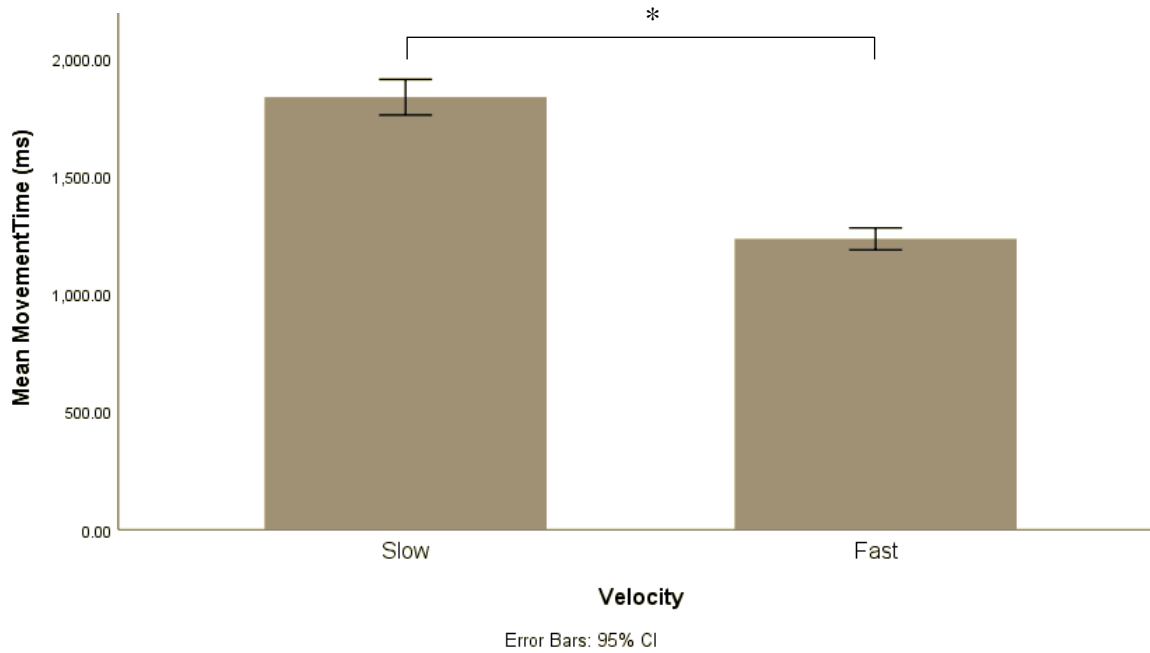
Figure 4. 5

Mean MT (ms) as a Function of Stimuli Origin

Error Bars: 95% CI

Note. Mean MT results are shown for the origin of the stimulus. Participants had a longer MT when the stimulus originated from the top right location, in comparison to when the stimulus originated from the bottom locations. Error bars show 95% confidence interval.
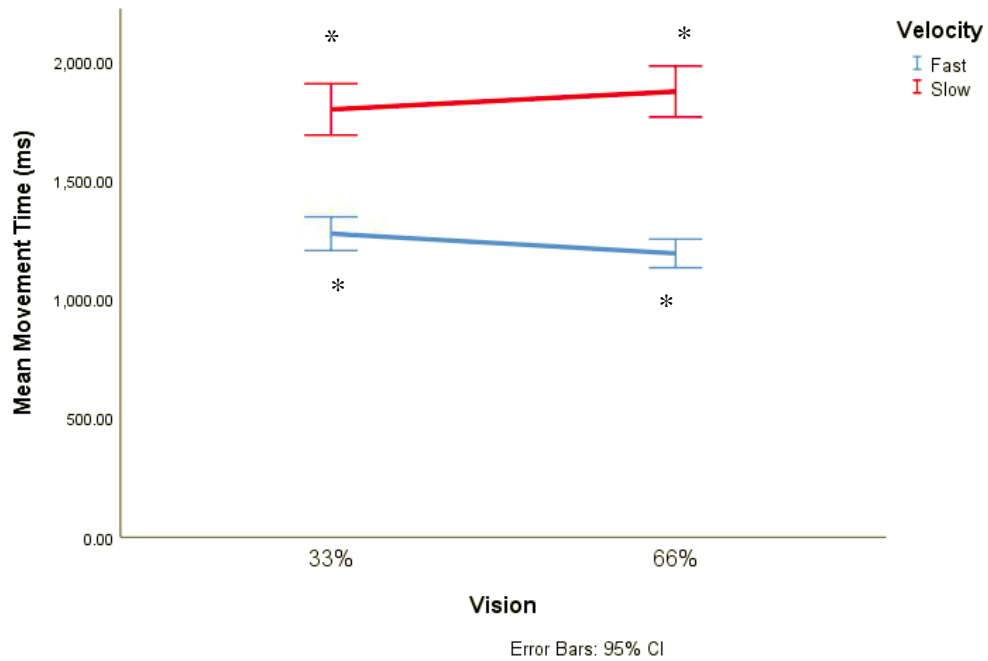
Figure 4. 6

Mean MT (ms) as a Function of Velocity

Note. Mean MT results are shown for when the stimulus is traveling at a fast or slow velocity. Participants generally had a longer MT when the stimulus was traveling at a slow velocity.
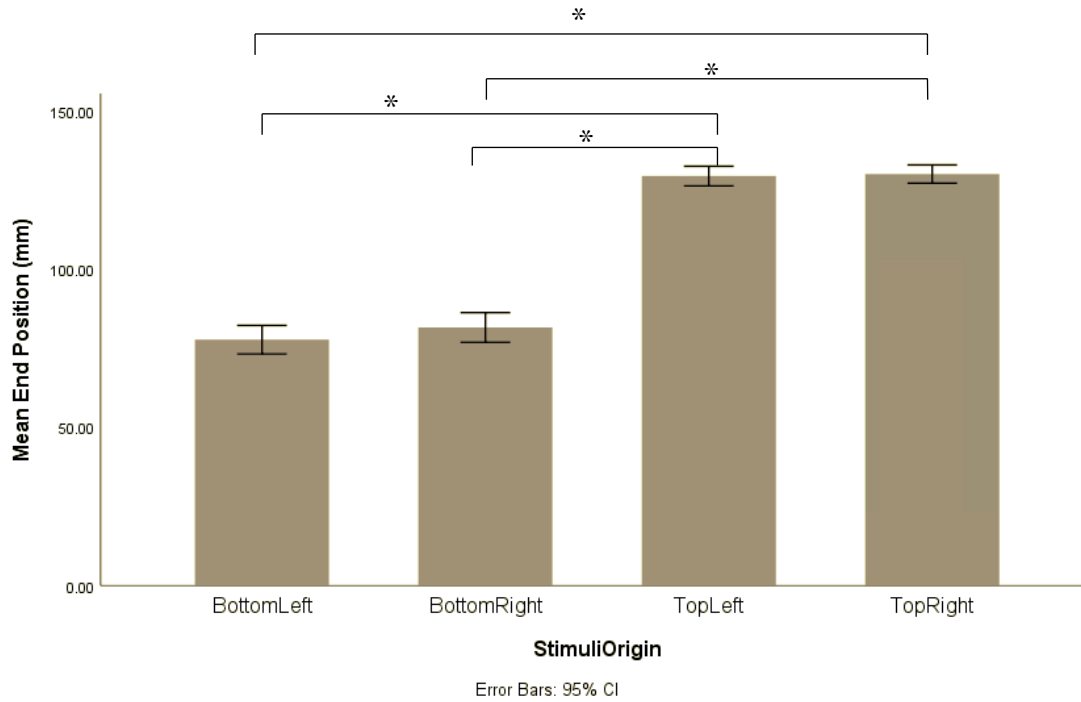
Figure 4. 7

Mean MT (ms) as a Function of Vision and Velocity

Note. An interaction between vision and velocity of the stimulus is shown. Participants generally have a longer MT when the stimulus is traveling at a slow velocity. Error bars show 95% confidence interval.

Figure 4. 8

Mean EP (mm) as a Function of Stimuli Origin

Error Bars: 95% CI

Note. Mean EP results are shown for the origin of the stimulus. Overall, the participants generally had a further end position whenever the stimulus would originate from the top portion of the computer monitor, in comparison to when the stimulus originated from the bottom portion.

Figure 4. 9

Mean EP (mm) as a Function of Vision

Note. Mean EP results are shown for when the participants had more or less vision of the stimulus movement trajectory. Error bars show 95% confidence interval.
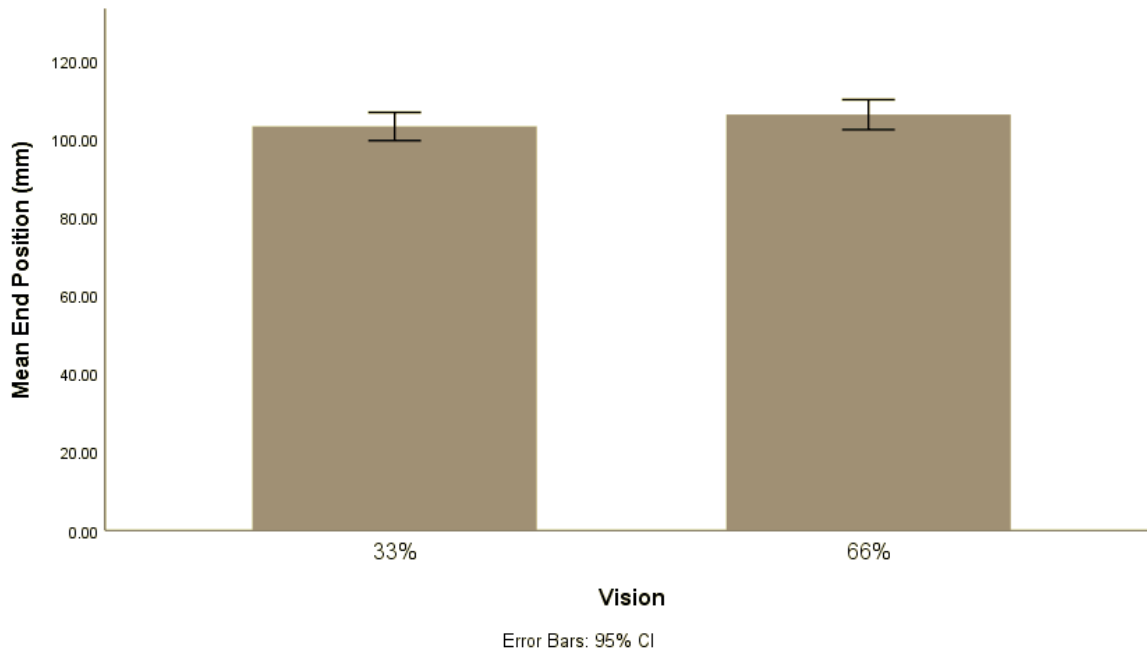
Figure 4. 10

Mean PV (mm/ms) as a Function of Stimuli Origin

Note. Mean PV results are shown for the origin of the stimulus. Participants had a higher mean peak velocity when the stimulus originated from the top portion of the computer monitor, in comparison to when the stimulus originated from the bottom portion. Error bars show 95% confidence interval.
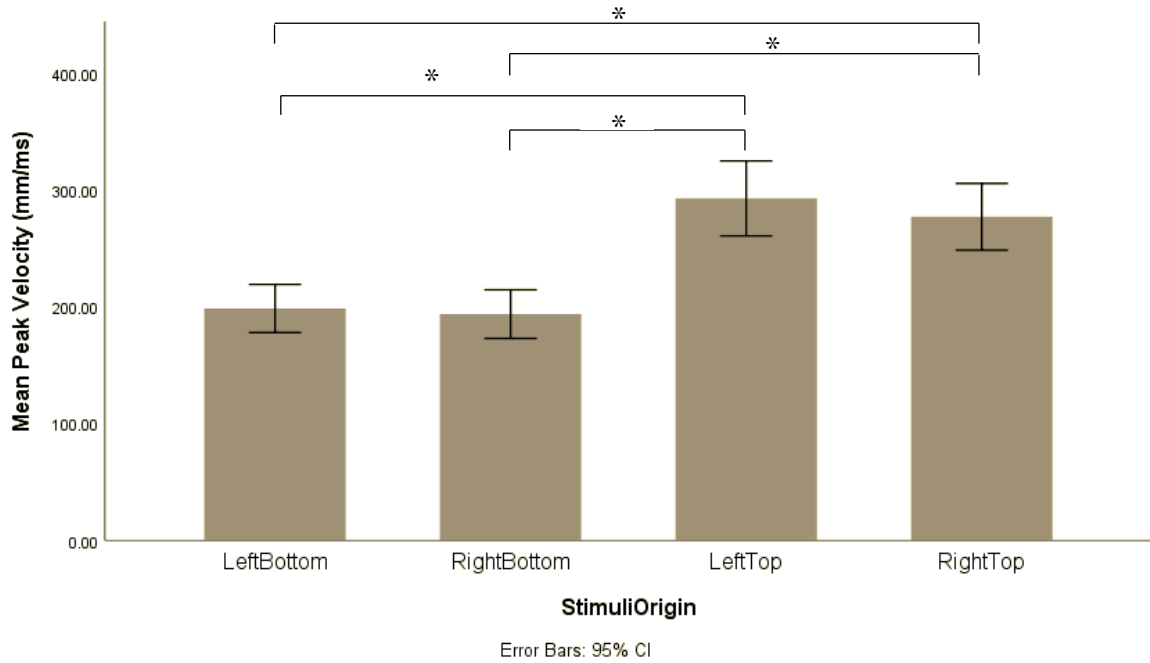
Figure 4. 11

Mean PV (mm/ms) as a Function of Vision
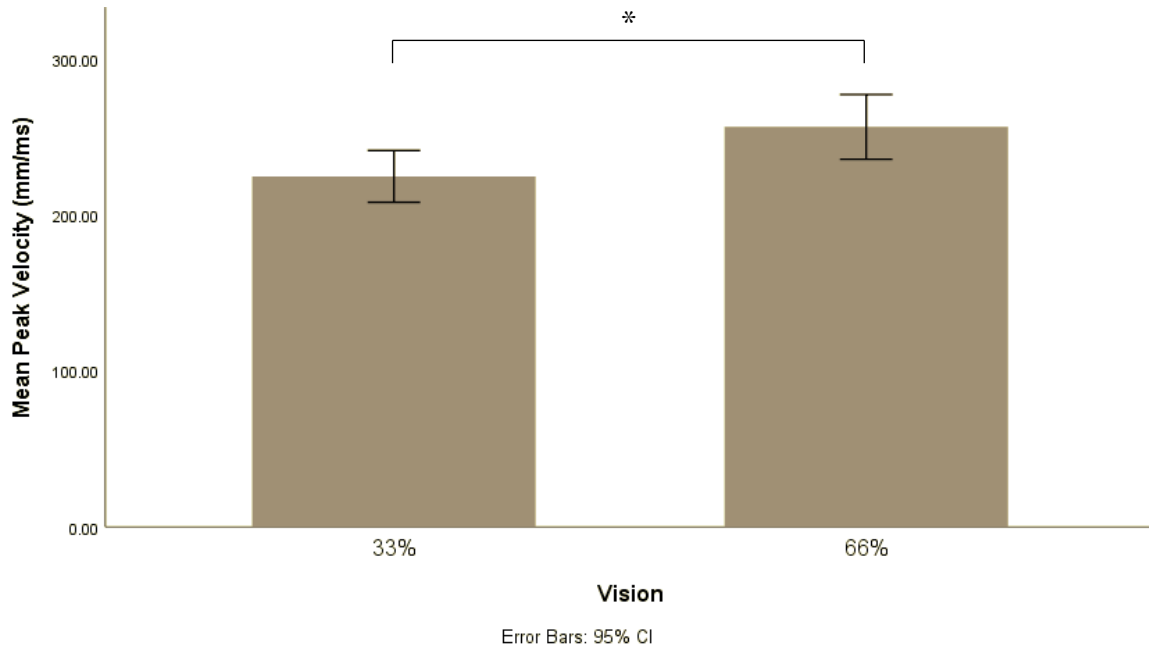
Note. Mean PV results are shown for when participants had more or less vision of the stimulus movement trajectory. Participants generally reached higher peak velocity whenever they had more vision of the stimulus movement trajectory. Error bars show 95% confidence interval.

Figure 4. 12

Mean PV (mm/ms) as a Function of Velocity
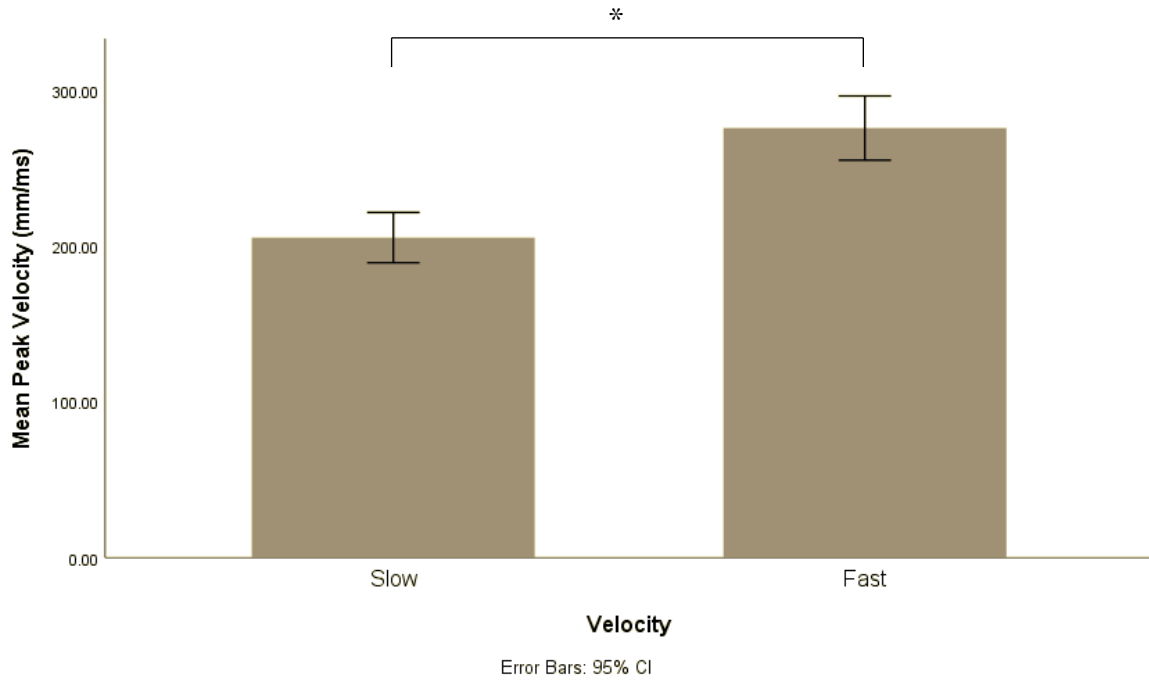
Note. Mean PV results are shown for when the stimulus was traveling at a fast or slow velocity. Participants reached higher PV whenever the stimulus was traveling at a fast velocity, in comparison to when it was traveling at a slow velocity. Error bars show 95% confidence interval.

Figure 4. 13

Mean TPV (ms) as a Function of Velocity

Note. Mean TPV results are shown for when a stimulus is traveling at a fast or slow velocity. Participants reached peak velocity sooner whenever the stimulus was traveling at a fast velocity. Error bars show 95% confidence interval.

Figure 4. 14

Mean PA (mm/ms^2) as a Function of Stimuli Origin

Figure 4. 15

Mean PA (mm/ms^2) as a Function of Velocity
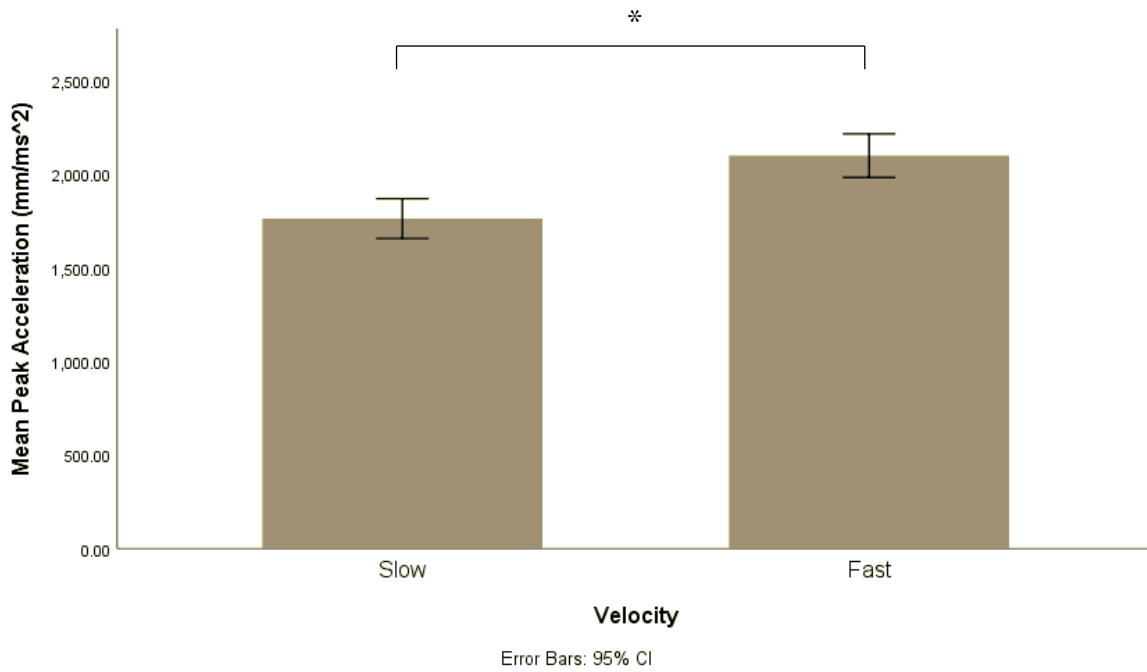
Note. Mean PA results are shown for when a stimulus is traveling at a fast or slow velocity. Participants had a higher peak acceleration whenever the stimulus was traveling at a fast velocity. Error bars show 95% confidence interval.

Figure 4. 16

Mean PD (mm/ms^2) as a Function of Stimuli Origin
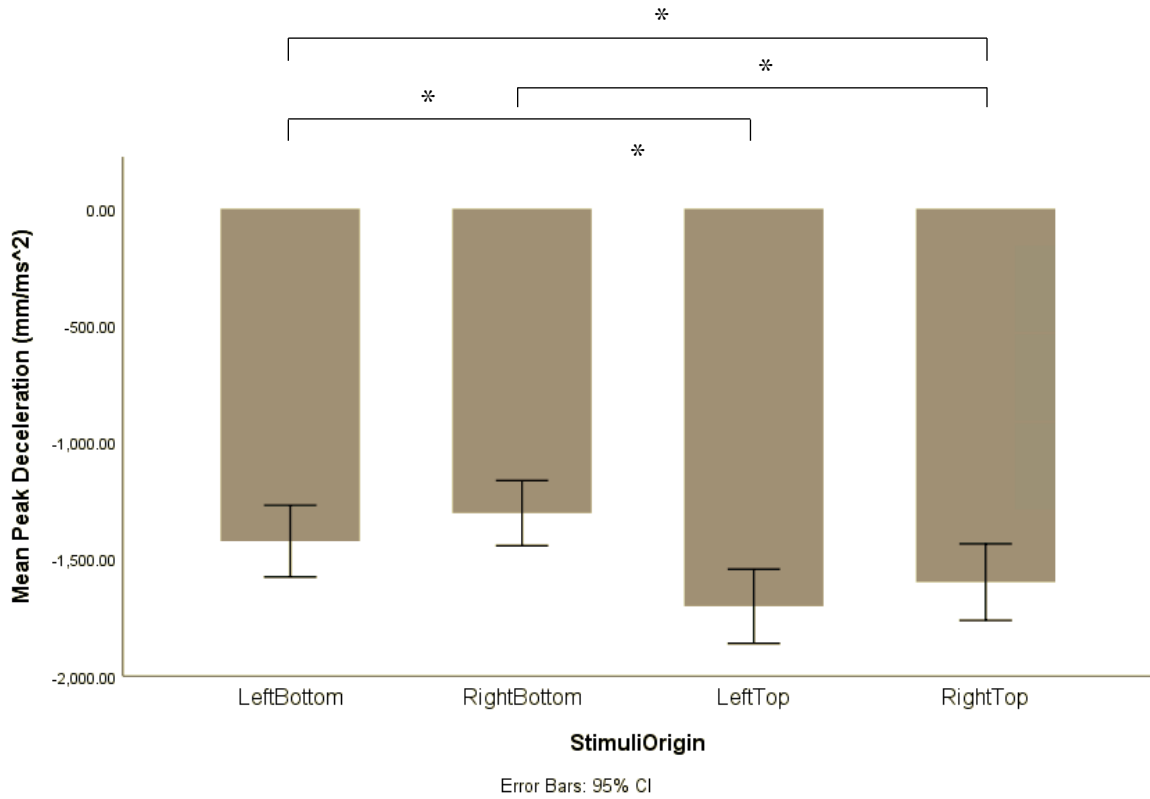
Note. Mean PD results are shown for the origin of the stimulus. Participants had a greater PD whenever the stimulus originated from the top portion of the computer monitor, in comparison to when the stimulus originated from the bottom portion. Error bars show 95% confidence interval.
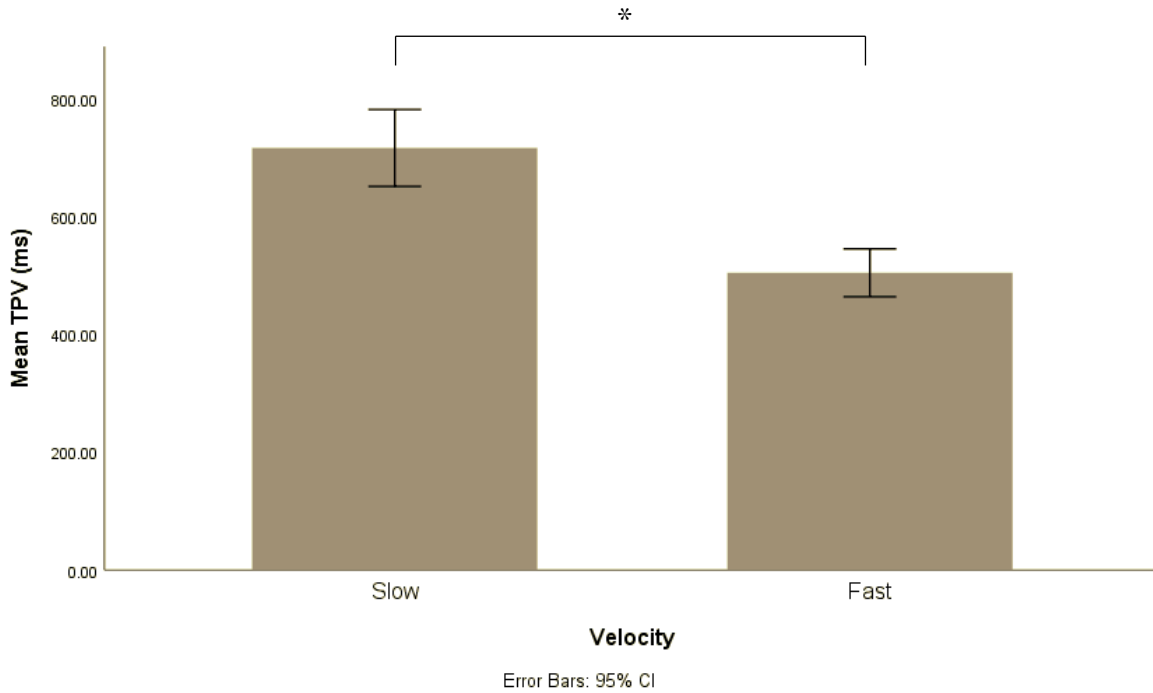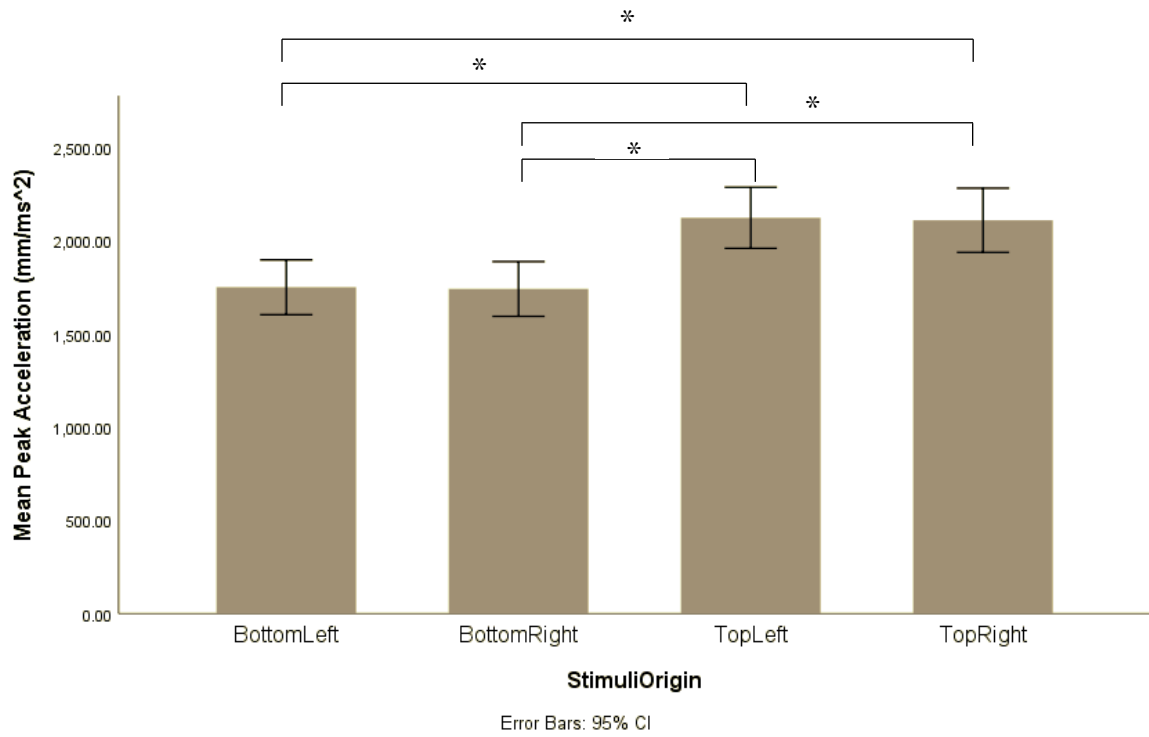
Figure 4. 17

Mean PD (mm/ms^2) as a Function of Velocity
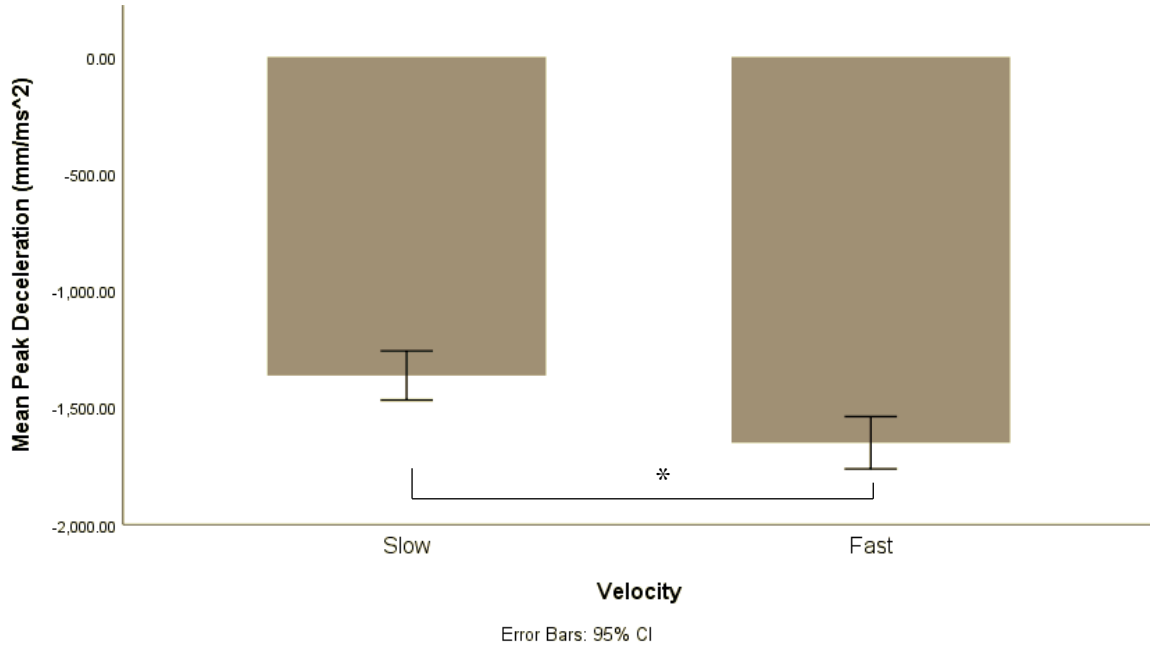
Note. Mean PD results are shown for when the stimulus is traveling at a fast or slow velocity. Participants had a higher PV whenever the stimulus was traveling at a fast velocity, in comparison to when the stimulus was traveling at a slow velocity. Error bars shown 95% confidence interval.

Figure 4. 18

Mean PD (mm/ms^2) as a Function of Stimuli Origin and Vision
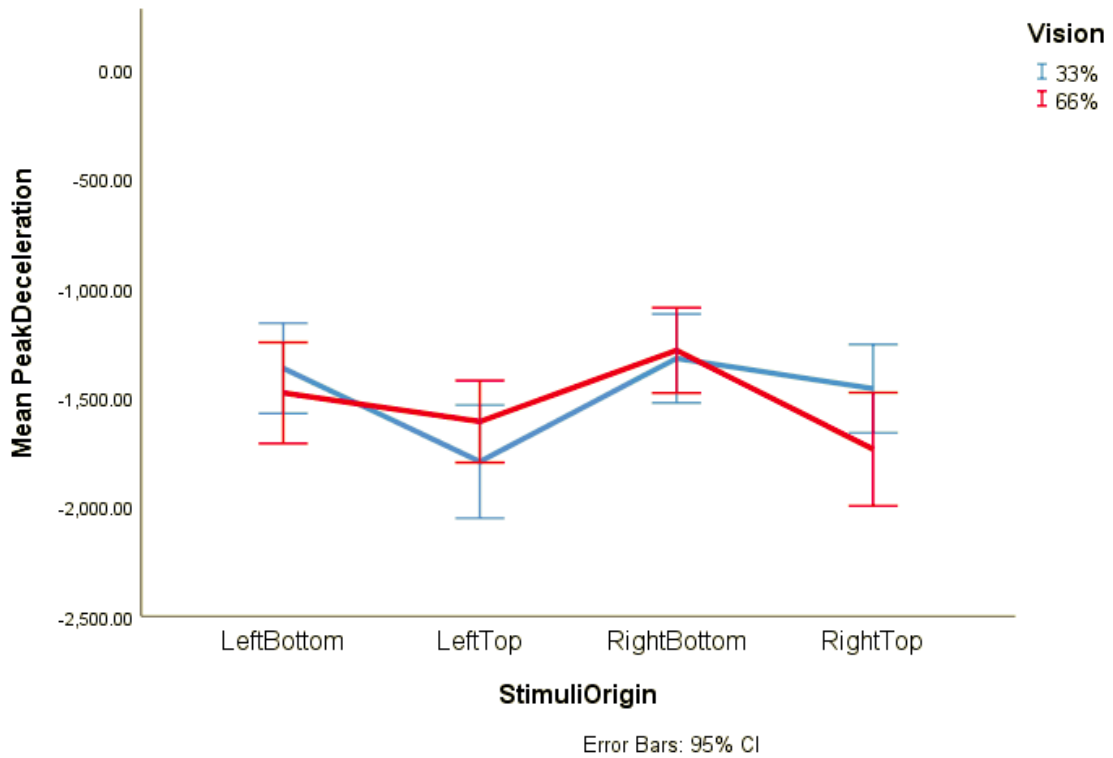

Note. An interaction between stimuli origin and vision of the stimulus movement trajectory is shown. Error bars show 95% confidence interval.

CHAPTER 5: GENERAL DISCUSSION

This work advances the understanding of how humans perceptually integrate and act upon compatible and incompatible multimodal information. To further comprehend the integration of perceptual information, the studies comprising this thesis study presented auditory and visual stimuli in an incompatible and compatible design, as well as having the auditory and visual stimuli originate from differing hemifields. Furthermore, the basis of this work is rooted in two opposing theories of perception-action, which include the perception-action dissociation theory (Milner & Goodale 1995) and the planning-control model (Glover & Dixon, 2001). The results from this study align with past studies (Burr, Banks & Morrone, 2009; Shams, Kamitani & Shimojo, 2000) that indicate that visual stimuli tend to dominate auditory stimuli when presented with spatially related tasks, and incompatible sensory information did have an effect on multisensory integration as cross-modal competition was observed. Moreover, when comparing the perceptual and action responses of the participants, the data provides more evidence to support the planning-control model, as the participants' action responses were impacted by salient multimodal information.

5.1: VISION AND AUDITION INTERACTION

The interactions between vision and audition in Study 1 showed that participants were more accurate and had less directional bias in the perceptual task when provided with less vision of the stimulus trajectory and accompanied with a loud sound. However, participants were less accurate, and had greater directional bias when provided with more vision of the stimulus trajectory and accompanied with the same loud sound. This

interaction was not expected. One reason this interaction could have occurred could be due to the nature of how and where one focuses attention when provided with auditory and visual stimuli. As mentioned earlier, the visual system naturally has poor alerting abilities (Posner et al., 1976), and it could be that the loud sound accompanying the visual stimulus (when less vision was provided) served as a helpful substitute to aid in the participants' high accuracy results. Ironically, the factors that manifest a loud sound stimulus are the same factors that one would expect not to serve as a helpful substitute when completing a perceptual task. With the knowledge of perceived loud sounds typically creating a large physiological response (Fletcher & Munson, 1933), it is of interest that the auditory stimulus did not serve as a hindrance, but in fact increased the participants' accuracy. Drawing back on the alerting abilities of the visual system, the low alerting nature has led individuals to deliberately focus their attention on the visual modality (Posner et al., 1976). However, when more visual information was provided, such as when the visual stimulus would disappear after travelling 66% along the travel trajectory, the participants did not have to focus or draw as much attention to the visual modality, a task that humans may have become accustomed to because of the low alerting abilities of the visual system. Therefore, the combination of more vision and a loud sound resulted in the participants being bombarded with salient multimodal stimuli, ultimately resulting in participants being less accurate and having greater directional bias when performing the task. This is a result of how sensory stimuli are interdependent, as the loud sound had an effect on the processing of the visual stimulus. As cross-modal competition does not have to be symmetrical (Robinson & Sloutsky, 2012), perhaps the loud sound

that was simultaneously presented with the visual stimulus was conflicting with the visual stimulus and weakened the process of the visual stimulus.

5.2: VISUAL STIMULI AND AUDITORY STIMULI

Past studies have indicated the dominating features of an auditory stimulus when compared to a visual stimulus in a temporal task, such as in the temporal ventriloquism phenomenon (Burr et al., 2009), the illusory flash effect (Shams et al., 2000), and in early development (Robinson & Sloutsky, 2013). This thesis measured participants' RT to calculate accuracy, directional bias and variability when completing a task that required them to press a button whenever they predicted the stimulus presented on the computer monitor would enter the specified target zone. Therefore, the task required participants to use visual-spatial skills. According to past literature, there is a pattern of visual stimuli dominating over auditory stimuli in spatial related tasks (Posner et al., 1976; Andersen et al., 2004; Stekelenburg & Vroomen, 2009; Colavita 1974); a pattern that was also observed in the perceptual studies (Study 1 and Study 2).

Although our results align with past studies, there are other factors that made us question why these results occurred. For example, acoustic transduction (approximately 1 ms) is a faster process than visual transduction (approximately 50 ms). Secondly, the speakers and headphones that provided the sound stimulus were placed equidistant from participants in all studies and at distances that were less than 10 m, indicating that the auditory signals likely reached the brain before the visual signals (Navarra et al., 2009). Lastly, when the participants were provided with a soft or loud sound, the sounds were

above the threshold of 10 dB, reducing the possibility of the visual stimulus to dominate over the auditory stimulus (Andersen et al., 2004). Therefore, it is assumed that not only did the auditory stimulus travel to the participants at a faster rate, but the participants in this study also processed the auditory stimulus at a faster rate in comparison to the visual stimulus.

In spite of this, there were no significant main effects with sound, and only saw main effects with the conditions that included visual processing, such as the velocity of the visual stimulus, as well as when more vision was provided to the participants. The result of having no main effects for sound is an indication that the intensity of the sound (whether it be no sound, soft sound or loud sound) – as presented in the first perceptual study, or directionality of the sound as presented in the second perceptual study – had no influence on the participants' accuracy, directional bias or within-participant variability.

These results are incosistent with the study by Navarra et al. (2009), as they found that exposure to audiovisual asynchrony only affected the speed of the participants' responses to auditory stimuli, and not to visual stimuli. Drawing from the results, the spatial features provided by the task override the fast properties of acoustic transduction. The participants' responses to providing more attention to the spatial features of the task could be a result of the poor alerting abilities that is natural to the visual system (Posner et al., 1976). The decreased alertness nature of the visual system led the participants to bias their responses to favour the visual stimulus. These results further support our ability as humans to develop; as infants and young children often fail to encode visual stimuli when

presented with auditory and visual stimuli simultaneously, humans have strategically found efficient ways to favour visual integration (Robinson & Sloutsky, 2013).

5.3: EXOGENOUS VERSUS ENDOGENOUS CUES

With the added component of sound localization for the second perceptual study, it is predicted that if the sound stimulus originated from the same hemifield as where the visual stimulus would originate from, then it would result in higher accuracy and less directional bias from the participants. However, there was no relationship between the origin of the sound and visual stimulus. The result of no significant interaction between the origin of the sound stimulus and visual stimulus could be due to the relationship of endogenous and exogenous orienting. Approximately over 500 ms is required for endogenous orienting to respond to incompatible information to overcome exogenous control of visual attention by localizable auditory stimulation (Klein, 2018). In other words, any stimulus presented in less than 500 ms would most likely result in exogenous orienting, while anything presented over 500 ms may result in endogenous orienting. Keeping this in mind, in addition to the fact that the minimum times for the stimulus to arrive at the target zone is 1189 ms (when travelling at a slow velocity) and 301 ms (when travelling at a fast velocity), it was observed that participants' RT did not scatter too far away from the 500 ms estimate threshold that borders between auditory stimuli being exogenous or endogenous in nature. To account for RT responses that were not over 500 ms, it is possible that exogenous control of visual attention may have been involved. Through exogenous control, the following scenario would not be expected: A loud sound originating from the left hemifield, causing participants' attention to be drawn towards

the left hemifield. However, when the visual stimulus originates from the opposite hemifield (right), the participants would have to disengage their attention from the left, and attend to the right hemifield, resulting in attention disorienting. Therefore, as the auditory stimulus in this study was more exogenous in nature, an interaction between sound and visual stimuli origin was not observed. Perhaps, future studies can look to further extend the period of auditory and visual orienting to ensure that the auditory stimulus is truly endogenous in nature (i.e., over 500 ms).

Despite the auditory stimulus being exogenous in nature (through the traditional definition), variability of the participants' RT (presented through VE) was observed as a result of velocity. The traditional definition of exogenous control refers to attention that is automatically drawn towards a stimulus and is referred to as overt orienting, while endogenous control on the other hand refers to attention voluntarily being directed toward a stimulus and is also referred to as covert orienting. The variability could have been a result of the fact that the participants did not have any knowledge of the result/condition (Donchin & Linsley, 1966), and that the trials were randomized and not sorted into blocks, therefore not allowing the participants to practice or become accustomed to the trials. Within-participant variability was observed when more vision was paired with a loud sound, compared to less vision paired with a soft sound, a similar conflict that was observed in the first study regarding cross-modal competition between two stimuli.

5.4: PERCEPTION-ACTION DISSOCIATION THEORY & PLANNING CONTROL MODEL

According to the perception-action dissociation theory, differences are expected between a perception and an action task as there are two streams that process and transmit visual information – a ventral stream that inputs the perceptual information, and the dorsal stream that is responsible for incorporating the visual control of actions (Milner & Goodale, 1995). More specifically, evidence shows that since the perceptual ventral stream uses an allocentric frame of reference, the illusion effects on perception are greater in comparison to the action dorsal stream that uses an egocentric frame. As illusions typically distort how the human brain organizes and interprets sensory information – a similar effect that occurs when humans are presented with asynchronous stimuli – it was of interest to see whether the asynchronous stimuli presented in the studies would have an effect on participants incorporating perceptual information and visually controlling their actions. If the perception-action dissociation theory were to be supported, incompatible sensory information should have no influence on action, however, the results of this study counteract this theory as the salient sensory information did have a great impact on the participants' action responses. One factor that was taken into consideration was whether perception and action interacted prior to the participants initiating their movement, as this could have an effect on the participants' movement responses. However, the information related to the targets' identity was not a required source of information for the participants to complete the action.

These conclusions lead us to another hypothesis for the third study, which predicts that to support the planning control model, incompatible sensory information would influence action (MT, end position, PA, PV, TPA, TPV and PD). The planning-control

model divides action into two stages, the premovement planning of the action response and the subsequent control of the action (see also Woodworth 1899). In this study, end position, MT, PV, PA, and PD all increase as the target distance increased. Additionally, an increase in PA, PV, and PD were observed as the required speed of the movement increased. The results of these kinematic measures illustrate the association with impulse control, as the participants had to move the stylus a further distance and accommodate when the stimulus was moving at a faster velocity.

Further examination of corrective submovements before the end of the movement can further provide evidence for the online control phase, and how the kinematic characteristics of a movement adapt to meet demands and information constraints (Elliott, Binsted & Heath, 1999). For this study, it is expected that the time between TPV and movement termination (as well as TPA and movement termination) is designed to use vision and other sources of feedback to regulate deceleration or make discrete error-reducing adjustments to intercept the target correctly (i.e., arrive at the right location spatially and temporally). As more vision is provided to the participants, the more precision is expected due to the online control that occurs during movement execution (Elliott & Hansen, 2010). Therefore, as seen in the study by Elliott, Dutoy, Andrew, Burkitt, Grierson, Lyons and Bennett (2014), it is expected that more trials with corrective submovements would occur when more vision (66%) is provided to the participants, in comparison to less vision (33%). Additionally, when participants are provided with less vision (33%) it is expected that there would be a higher amplitude of the corrective phase and more variability of the participants' end position.

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The results of this study align with past studies that have observed shorter RT responses to bimodal signals (Diederich & Colonius, 2004; Diederich et al., 2008). However, the results also counteract past studies showing improvements in human performances when participants incorporated multimodal sensory stimuli to complete movement tasks (Welch & Warren, 1986). When comparing RT responses in Study 1 (perception only) to the same participants' MT responses in Study 3 (perception and action), shorter MT responses were observed, however, improvements were not seen in participants' accuracy, as participants were less accurate in the task when completing Study 3, providing evidence of the initial ballistic portion of action that occurs throughout the premovement planning of action (Grierson & Elliott, 2009).

Participants were highly inaccurate in completing the action task (Study 3) compared to the perception task (Study 1). This could have been due to the action task being more complex compared to the perception task. That is, the action task not only required participants to predict when the stimulus would enter the target zone, but also physically intercept the stimulus. Another reason could simply be due to possible asynchrony in the presentation of the visual and auditory stimuli. According to the study by Harra et al., (2017), even if the participants perceived the stimuli to be in synchrony, multisensory facilitation of RTs would only occur if the stimuli were physically synchronous with each other. Additionally, characteristics of the visual environment were changed, such as the change in the velocity and the disappearance of the visual stimulus – both factors that could have had an effect on the participants' limb regulation (Grierson & Elliott, 2009).

5.5: CONCLUSION

Overall, the results from these studies demonstrate that the presentation of incompatible and compatible multimodal information impact perceptive and active responses. In particular, it was observed the consequences of a poor alerting nature of the visual system when presented with asynchronous multisensory stimuli (i.e., loud sound paired with a visual stimulus moving at a slow velocity, or visual stimulus originating from the left hemifield and auditory stimulus originating from the right hemifield), and that the nature of the task serves as a main contributor to how auditory and visual stimuli will compete with one another. In particular, the current results display that participants' responses (RT) do not differ if the auditory and visual stimuli originate from the same hemifield, whereas they tend to differ (RT) if they originated from differing hemifields. Lastly, this work provides further evidence of the planning-control model, such that results of the movement kinematics displayed associations with impulse control (i.e., increase in PV, PA and PD when the stimulus was travelling at a fast velocity) and online control (i.e., TPV and TPA occurring before the end of MT).

5.6: LIMITATIONS

A limitation to this study is that extensive corrective submovement calculations on the kinematic measures of Study 3 were not conducted. These calculations would provide more evidence to support the planning control model. The submovement calculations would mirror the calculations conducted in the study by Elliott et al., (2014). More specifically to criteria would include, "(a) zero crossing in velocity between peak velocity and movement end (i.e., movement reversal), (b) zero crossing in acceleration between

peak deceleration and movement end, and (c) zero crossing in jerk between peak deceleration and movement end".

Another limitation is that a control condition was not included individually for each of the independent variables: sound, vision and visual stimulus velocity. Individual control conditions for vision (33% and 66% disappearance) and visual stimulus velocity (slow, fast), would allow us to truly determine if the independent variables have an effect on the participants' reaction and movement performance on the task. However, this would result in a significantly increased amount of trials for the participants to complete.

5.7: FUTURE DIRECTIONS

Future work should consider recording the frequency of the sound stimulus and to test whether the frequency of the sounds had any effect on the participants' responses. According to past studies, high frequency sounds are correlated to being perceived as being louder, more salient, and having the ability to create a larger physiological response when compared to low frequency sounds (Fletcher & Munson, 1933), as well as have a larger influence on spatial perception (Deutsch, 1976).

Moreover, according to a study by Navarra et al., (2009), exposure to asynchronous stimuli for long periods of time have shown to influence temporal "aftereffects" in perception for subsequently presented stimuli. Future work should observe the aftereffects of the participants when exposed to incompatible sensory stimuli

for long periods of time, and thoroughly observe if the aftereffects contribute to

participants' subsequent trials.

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