The Effect of Covert Auditory Attention in Multiple Target Aiming: Kinematic Evidence

by

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ABSTRACT

The theories of attention and motor planning postulate that both process are tightly coupled. The present study examined these theories in covert auditory attention. In two experiments, participants (N=24) reached to four target locations in the presence of a no-cue, neutral cue, 50/50, and 80/20 auditory cue. In the first experiment the cue was presented at movement initiation, while in the second experiment it was presented 130ms following movement initiation. Neutral condition cues were presented from both piezoelectric buzzers (right and left). Predictive condition cues predicted the target location on 50% or 80% of the trials. Movement trajectories were collected using an Optotrak 3D investigator. Performance and kinematic variables were analyzed, including trajectory deviations. With lateralized cues, the point at which a deviation toward the target occurred earlier in both experiments. Therefore, the presence of a random lateralized sound affected action from both a crossmodal attentional and multisensory integration perspective.

Keywords: exogenous attention, endogenous attention, action-centred attention, spatial averaging, multiple targets aiming, movement trajectory, goal-directed aiming.

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CHAPTER 1:

Introduction

1.1 Introduction

Comprehension of thoughts or actions without paying attention is inherently difficult. It may explain the phrase; I need your attention! Attention can be regarded as an important component of human cognition, perceptual and motor performance, and has been linked to what we are aware of at a point in time (consciousness). The assertion of consciousness is evident by William James' definition of attention (1890) as, "the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or train of thoughts. Focalization, concentration, of consciousness is of its essence". That is, attending to one thought or action out of the numerous options exemplifies that the human capacity for information processing is limited. In other words, there is a limit to the amount of information the brain can handle at a given point in time. For instance, a student's attention to a lecture can be impaired if people are discussing or using laptops (Fried, 2008; Borbone, 2009) around them. Another plausible example is the human's insatiable appetite for advanced designs and technologies with automobiles that has resulted in competing sensory information due to several auditory, vibrotactile, and visual cues in today's vehicles. For instance, visual and auditory beeps on the right side of the dashboard are used to alert drivers when another vehicle is too close. In spite of this advancement, we are somewhat ignoring that what is meant to create comfort can be an overlooked attentional load. For instance, driving in itself, which is primarily a visual and complex limb coordination task, requires a great amount of attention. An important question is: Does the presence of these additional stimuli affect the limited attentional capacity mentioned

earlier? For instance, a sudden beeping sound from right side of the dashboard elicited while driving. Does that sound compete for the limited information processing capacity if it captures attention reflexively or voluntarily? And if it does, can it impact the limbs coordination in a way that may result in swerving the car toward the location of the sound unknowingly? The last question brings into light the notion of covert spatial attention (James, 1890), which is attending to a location as a result of perceived (reflexively or voluntarily) sensory stimuli in that location. Based on the above premise, therefore, this thesis explored the possibility that the presence of random and predictive auditory stimuli might impair complex motor coordination, such as making the decision between reaching to point A or point B.

Over the past three decades, covert spatial attention has been the focus of many researchers, inspired by the findings of James (1890) in which he introduced "active" and "passive" attention as the two main mechanisms whereby attention is selected (Green and Mckeown, 2001). This was later conceptualized by Posner (1980) as endogenous and exogenous attention in his study using a cue-target paradigm (Jones and Forster, 2014) and is largely known as the Posnerian paradigm (Chica and Lupianez, 2009). In the Posnerian paradigm, participants were required to fixate on the center of a screen after which a cue appears. In the endogenous "condition" of the paradigm, a cue (usually an arrow) indicates the likely position of a visual target, that way the subject is prompted to voluntarily direct covert attention to the cued side. In the exogenous "condition" of the paradigm, a salient, non-informative cue (Indovina and Macaluso, 2007) is provided at peripheral locations, either at the same position of the upcoming target or an invalid position (Indovina and Macaluso, 2007). Participants were to respond as fast as possible to the target, which may or may not appear at the cued location. Posner found that participants typically respond faster when the target appeared at the cued location compared to

an un-cued location. By definition, therefore, endogenous attention or sustained attention is a voluntary control of attention (Blurton et al., 2015) that relates to our ability to consciously monitor information at a location or position. On the other hand, exogenous or transient attention is reflexive or involuntary and relates to an automatic response orientation to a location where sudden stimulation has occurred (Blurton et al., 2015). Exogenous and endogenous attention can occur crossmodally (Spence and Driver, 1997). That is, between two different stimuli irrespective of direction. In other words, a secondary auditory cue can capture attention toward or away from the location of a primary visual task and vice-versa.

This type of interaction between sensory modalities, in the absence of crossmodal covert selective attention, can also occur at the level of multisensory integration (Stein and Stanford, 2008). It has been consistently shown that multisensory integration enhances decision making about the relevant object if the different senses are temporally and spatially congruent (Molholm, Ritter, and Foxe, 2004; Donohue, Woldorff, and Mitroff, 2010; Van der Stoep, Van der Stigchel, and Nijboer, 2015). For instance, Molholm, Ritter, and Foxe (2004) had participants respond to a target animal that could be presented visually, auditorily, or audiovisually. They found that response times were faster when presented audiovisually compared to unimodal presentation (visually or auditorily). However, there is an ongoing debate as to whether there is an actual difference between cross-modal attention and multisensory integration in terms of their processes (Van der Stoep, Van der Stigchel, and Nijboer, 2015). Cross-modal attention occurs when a secondary stimulus captures attention in such a way that enhances the processing of another stimulus in that space or location (Van der Stoep, Van der Stigchel, and Nijboer, 2015). Because that definition can also explain multisensory integration, the conundrum is now to dissociate what process, or processes, drives the other. In other words, is multisensory integration a result

of attention to the secondary stimuli or is crossmodal attention as a result of multisensory integration?

In addition to the volume of sensory information that can act voluntarily or involuntarily capture attention and may be integrated to modulate behaviour, we are often faced with multiple objects presented simultaneously across space, but not all are relevant for behavior (Funes, Lupianez, and Milliken, 2005). As such, when interacting effectively in such complex visual environments an actor must select the appropriate object. For instance, to reach and grasp an object in an array of similar or dissimilar objects the subsequent action must be planned based on the selected object. To achieve this, there are concurrent processes of collecting information and creating a picture of the immediate environment that requires continuous interaction with the surroundings, and any deviation from what is being planned may result in movement inefficiencies (Cisek, 2007). In order to address limitations that may arise from inefficient movement planning, some investigators have suggested that potentially competing targets for an action are encoded in parallel (Cisek, 2007; Chapman et al., 2010), such that movement trajectories to competing targets reflects planning to a point that is between the targets (Chapman et al., 2010). This way, factors such as the amount of energy expended when a correction is made to the final target location, any additional movement time and trajectory deviations due to error corrections would have been minimized (Elliott and Khan, 2010).

However, according to the principle of attention, its processes are linked to movement planning and may therefore influence the planning processes (Rizzolatti, Riggio, Dascola, and Umilta, 1987; Tipper, Lortie, and Baylis, 1992; Cisek, 2007). This link has been demonstrated in experiments involving three dimensional reaching (Tipper, Lortie, and Baylis, 1992), multiple target aiming (Welsh, Neyedli, and Tremblay, 2013) and in the presence of a non-target stimulus

(Welsh and Elliott, 2004). If the prediction that attention and movement planning are linked holds, an important consequence is that an action plan can be modulated if attention is reoriented. In other words, what captures attention can predict or influence the decision making processes or how the planned action unfolds. While many studies have provided evidence to support this claim, a significant number have focused mainly on the effect of visual attention and to some extent, auditory attention when reaching to a target. It appears that the functional role of audition in reorienting attention is yet to be fully acknowledged, despite an obvious limitation in the forward facing eyes by extreme peripheral vision (Spence and Driver, 1994). That is, in cases where an object is located at the extreme of or outside the visual angle, the auditory system may provide additional or useful information that is required for a response. More so, in cases where its effect has been tested experimentally, the experiments involved arbitrary key-press responses. For instance, Spence and Driver (1994) required participants to respond to upper or lower visual targets by pressing the farther and nearer buttons respectively. Similarly, Van der Stigchel, and Nijboer (2015) examined reaction time (RT) intervals in participants that were required to make button presses to visual, auditory and audiovisual targets in response to an auditory exogenous cue.

A critical limitation of object detection tasks that have primarily been used in the literature is that detection tasks account for task situations that are rarely encountered in normal human interaction with the environment. For instance, we rarely respond to picking up a cup of coffee by pressing a button. Thus, these studies have not considered ecologically valid, complex actions, typically required during human interactions. Therefore, an important question arises as to whether the same mechanism for covert cross-modal auditory attention is involved in object detection (keypress) or identification and target location (reaching tasks).

1.2 Purpose and Hypothesis

The purpose of the current study was to examine the effects of cross-modal auditory attention when planning a reaching movement to multiple competing targets. This was done through the evaluation of not just the chronometric measures (reaction and movement time), but also kinematic variables such as movement trajectories. In addition to what has been learned from previous studies on auditory attention, the present study explored the tight coupling of attention and action, by strategically isolating the planning and execution phases of a typical reaching movement in the first experiment. A second experiment was done to investigate if the outcome of the first experiment was due to multisensory integration or covert cross-modal attention. That is, since the interaction between two stimuli, visual and auditory stimuli for instance, can occur through cross-modal attention and/or multisensory integration processes.

In this study, the main hypothesis is that if attention and action are tightly coupled (Cisek, 2007), spatial averaging (Chapman et al., 2010) behavior will be significantly observed with uncued versus cued targets. That is, when the targets are cued there will be a significant deviation to the cued location regardless of target locations. On the other hand, if attention and action processes are independent, there will no significant difference between movement trajectories in uncued versus cued conditions.

CHAPTER 2:

Literature Review

2.1 Attention

The study of attention can be traced back to William James (1890) and stemmed from the argument between "*pure receptivity*" and "*reactive spontaneity*" (James, 1890) in neural development. Pure receptivity refers to how higher faculty of the mind is a product of experience that stems from what is "given". That is, human experiences can only occur if presented with the situation in which the experience occurred. Reactive spontaneity, on the other hand, refers to a sudden change in behavior that is stimulus driven. For instance, when an individual suddenly turns toward the glimpse of someone they thought was familiar. According to James, most researchers were more inclined to study neural development as a function of experience. However, what was not acknowledged is the fact that experience is a product of attention and as pointed out by James (1890), "My experience is what I agree to attend to". That is, what captures attention shapes human behavior regardless of current or future interaction with environment.

If critically analyzed, attention is a word with various meanings that depend on the context and is applicable to a wide range of phenomena (Moray, 1969). Importantly, many of these concepts are central to understanding human and animal behavior. Some of the subcategories of attention according to Moray include;

- "Mental concentration: refers to concentrating on a particular task while preventing interference from others.
- Vigilance: refers to process of observation with the hope of finding something.

- Search: refers to the process of isolating and object or signal out of a subset or others.
- Activation: refers to the daily version of reflexive orientation. That is, getting ready to deal with future occurrence.
- Selective attention: refers to the process of selecting an action out of several presented actions".

The significance of these subdivisions cannot be overemphasized. The current thesis focuses solely on selective attention, in particularly, selective attention in audition.

2.1.1 Attention as a selective process

One of the earliest empirical descriptions of selective attention was provided by Helmholtz in 1867 in his classic wooden box pinholes experiment. The apparatus which was similar to a tachistoscope could light up several letters for a fraction of a second. He observed that after the brief illumination of the printed page of a sheet by a spark of light that he was able to perceive letters in certain regions while his eyes were still fixated on a spot through the hole. The experiment demonstrated that humans have the ability to selectively attend to certain locations without eye movements. The process of selectively attending to a location while ignoring other locations has been attributed to limitations in human's capacity to hold excessive information (Schmidt and Lee, 2011). Conversely, the limit can be attributed to the fixed amount of energy available to the brain and the metabolic cost of neuronal computation (Carrasco, 2011; Attwell and Laughlin, 2001). The consequence of fixed energy supply is that only specific neurons are recruited for efficient behavioral computation for the task at hand (attending to a location while ignoring others) as opposed to a generalized neuronal activation (attending to all locations at will). For instance, when multiple stimuli are presented simultaneously in close

proximity at distinct peripheral locations in the visual field, neurons elicit a weaker response compared to when the same multiple stimuli are presented sequentially (Beck and Kastner, 2005; Chelazzi, et al., 1998). The latter results are also in accordance with the fMRI findings of Beck and Kastner (2005) who compared simultaneous and sequential presentation of four Gabour patches (visual cues) and measured retinotropic-signal using 3-T head scanner. They found that retinotopically-signal reduction was found in an area that was initially signal-enhanced when attention was diverted by simultaneous visual cue presentation compared to sequential presentation. In a similar study, Smith et al. (2000) found significant widespread reduction in baseline activity in non-foveal visual cortex when attention was directed to the fovea. Such findings are consistent with the notion that selective attention results in greater resource allocation (signal enhancement) to attended locations at the detriment of resource allocation to unattended locations (Carrasco, 2011).

While we may think of attention as being crucial in a complex or cluttered environment, evidence from psychophysical studies have shown that even in simple environments, attention is pertinent in order to distribute resources to the most crucial space or object. In line with this notion, behavioral studies on visual attention, for example, have shown that when a larger area of the visual field is captured by attention, there is associated reduction in spatial resolution and efficient processing for a given subregion of the visual field (Castiello and Umilta, 1990;1992). In conclusion, it does appear that the selective nature of attention optimizes performance of the task at hand while overcoming human's limited capacity to process excessive information. That is, by allowing representation of relevant information whilst diminishing attention to less relevant information when interacting with the environment, humans are able to fully optimize the inherent limitation to attend to several processes (e.g. several locations or objects) at the

same time. For instance, if I chose to listen to my professor during class and the person next to me decided to pay attention to social media, it is not because I detest the latter nor does he dislike the professor, it is our inability to respond to both processes at the same time.

2.2 Covert spatial attention

Attention can be directed overtly or covertly. When attentional allocation is overt then attention to a location is accomplished by eye movements toward the location. Therefore, attention can only be deployed to a single location. That is, overt attention can only be done sequentially (Carrasco, 2011). However, in covert attention, environmental monitoring is accomplished without gazing, and can inform subsequent eye movements (Carrasco, 2011). That way, simultaneous locations can be analyzed before the process is shifted or attention is directed overtly.

This type of attention is particularly important in everyday situations, such as dancing, driving, riding, and various sports. For instance, eye movements in board games can inform an opponent about one's intention or serve as cue that the individual aimed at concealing. Such cue or prediction can be addressed or solved covertly. In other words, humans can voluntarily initiate covert attention without concurrent eye movement. The absence of gazing inherent to covert attention is important in designing studies associated with attention. That is, experimenters must ensure consistent fixation (usually a cross) at a single location in order to ensure the task remains constant throughout the experiment (Carrasco, 2011).

2.2.1 Types of covert attention

An increasing body of behavioral studies have provided evidence that demonstrates unequivocally, that there are two types of covert attention; one is "endogenous" which is also

called voluntary or goal-driven attention involving purposeful or intent oriented process (Macaluso, 2010), and the other is "exogenous". The latter involves involuntary or stimulus driven attention, corresponding to an automatic orienting response to a location where salient or sudden sensory events have occurred (Hopfinger and West, 2006). In terms of the temporal characteristics, it appears to take about 300ms to deploy endogenous attention, thereby giving an actor a considerable amount of time to engage the voluntary deployment of attention to a particular location. On the other hand, involuntary deployment of attention tends to peak at about 200ms and decay quickly afterward (Spence and Driver, 1994). A delay duration beyond this (>300ms) has been shown to result in "inhibition of return" (Posner and Cohen, 1984), a term used to describe the longer response time to a target in the same location as the preceding cue (Schmitt, Postma, and Haan, 2000). Based on the temporal differences, some have suggested that exogenous mechanisms maybe phylogenetically older (Carrasco, 2011), allowing human to interact quickly in order to modulate behavior relevant for environmental interaction.

Apart from the temporal differences that exist between exogenous and endogenous attention, there is evidence to show some unique perceptual effects. For example, the effect of attention on conjunction search (objects separated by one or more common features, e.g. identifying smaller black box in a pool of larger red boxes) has been shown to be larger compared to feature search (objects separated by a distinct feature, e.g. identifying letter "B" from a pool of letter "As") with a peripheral cue, but not with central cues (Suzuki and Cavanagh, 1997). More so, while endogenous attention improves performance at all eccentricities in a texture segmentation task (Yashurun, Montagna, and Carrasco, 2008), exogenous attention improves it at peripheral locations and impairs it at central locations (Yeshurun and Corrasco,1998; Talgar and Carrasco, 2002). Other studies have revealed that, for

instance, while exogenous attention improves temporal order judgment, endogenous attention impairs it (Hein, Rolke, and Ulrich, 2006). In addition to previous studies, Giordano, McElree, and Carrasco (2009) examined how validity effect may impair automaticity in exogenous attention by requiring participants to perform a discriminatory task involving target orientation. Participants responded if one of the eight targets on a screen is tilted right or left. Tilted target was preceded with a central directional endogenous cue or a random exogenous cue with validity of 12, 33, 50, 66, and 100%. They revealed that the cost and benefit of exogenous attention in discriminability and temporal dynamics were not pronounced with cues associated with higher validity, whereas the benefit of endogenous attention increased with cue validity.

2.3 Covert spatial attention in audition

Earlier studies in covert auditory attention were inspired by the numerous studies on visual attention using the cue-target paradigm (Posner, 1980). The very few studies that aimed to demonstrate a covert shift of auditory attention using the same paradigm used with visual cues proved unsuccessful. For instance, Scharf et al. (1987) reported no significant change in response latency to sounds coming from expected compared to an unexpected direction. A similar report was made by Buchtel and Butter (1988). They used both informative visual and auditory cues and measured the detection latency (reaction time) for auditory and visual targets. Buchtel and Butter initially found improved response latency when the target was visual; however, there was no effect of auditory cue with an auditory target. The latter led the authors to attribute the initial finding to a general alerting effect. Even studies that used uninformative cues provided evidence that auditory detection was not modulated by visual cues; however, auditory cues did influence visual detection by improving the response latency to the visual target (Klein, Brennan, and Gilani, 1987).

The null effects found with auditory attention were attributed to differences that exist between audition and other stimulus modalities. For instance, Buchtel and Butter (1988) pointed out that there are sensitive regions in the receptor arrays in both vision (fovea) and touch (palmer surface of the hand and soles of the feet) that are capable of selectively directing attention to the task at hand. That said, there seems to be no auditory equivalent of fovea and cutaneous receptors to act in that capacity. Another important factor that was highlighted by researchers in understanding covert attention in audition was that, unlike vision that is inherently spatial and able to detect a separation of 1min of arc or 1/60 of a degree (Spence and Driver, 1994; Ward, 1994), auditory information from different locations are initially represented tonotopically, without any preference to where the sound is located in space. Such disparity between spatiotopic arrangement in vision and tonotopical in auditory has led some investigators to suggest that the most appropriate auditory analog of vision may not be its location, but its frequency (Spence and Driver, 1994).

That said, Ward (1994), required participants to make speeded spatial discrimination responses to visual and auditory targets following the peripheral presentation of a spatially non-predictive visual cue, auditory cue, combined cues or no cue at stimulus onset asynchronies (SOA) ranging from 100, 200, 550, or 1050ms. He reported that while a non-predictive visual cue was able to facilitate response to ipsilateral auditory target at shorter SOAs, non-predictive auditory cues had no influence on ipsilateral visual targets. However, there was a corresponding influence of auditory cues on auditory target detection when the cue was on the same side at the shortest SOA. The findings of Ward (1994) were attributed to response priming or stimulus-response compatibility effects or the Simon effect (Simon, 1990). That is, the presentation of a

lateralized cue may have prompted a response to the ipsilateral side as the cue compared to targets contralateral to it.

It is possible that the earlier findings of Farah and colleagues (1989) may provide some support to that of Ward (1994). Farah et al. (1989) carried out similar experiments on patients with a unilateral parietal lesion and found similar results. Because parietal lesion leads to impaired ability to disengage attention from stimuli presented on the side of their lesion, the patient had longer RT to valid cues presented on the opposite side of their lesion. Therefore, if it was just stimulus response compatibility only there would not have been any sort of valid cue difference based on the side it was presented. However, the methodology in the Farah et al. study raised certain doubts. For instance, fixation was not monitored in the patients, therefore, they may have overtly responded to the peripheral sound as opposed to being orienting covertly.

Various ambiguities in the earlier studies in auditory attention prompted the development of a modified version of the cue-target paradigm by Spence and Driver (1994). In a series of experiments the authors presented 2000Hz spatially predictive and nonpredictive auditory cues from left or right of the fixation point. On the other hand, the auditory targets were located above or below the location of the cues on both sides. As such, the speeded spatial discrimination task of the experiment required participants to identify target locations orthogonally, regardless of laterality and the sensory modality. That is, participants were cued toward the right or left, but were required to discriminate front and back targets or upper and lower targets. The manipulation enabled the authors to eliminate a priming effect (predicting target location with a cue on the ipsilateral side compared to the contralateral side) that could occur otherwise. Surprisingly, they found that regardless of the manipulation in the experiments, exogenous and endogenous auditory cues led to faster responses to target location if the cue was from the same

side as the target (Spence and Driver, 1994). The findings provided evidence that addressed some of the limitations in covert auditory attention such as the priming effect (Duncan, 1980) that may have occurred otherwise, since the auditory cue always predicted the target location in previous studies. As such, the authors were able to argue that the secondary stimulus did capture attention. Also, Spence and Driver used a large separation between the sources of the auditory cue and high frequency auditory cue (2000Hz) to improve detection of spatial location of the sound source. Lastly, the argument that there are no equivalent sensitive receptors in audition compared to vision (Butchtel and Butter, 1988) was disconfirmed by the results of Spence and Driver. That is, the effect of auditory attention was found despite the fact that cue-target manipulation was done orthogonally, which could not have been explained by priming effect as previously argued. In addition, the observable head movement by infant in response to peripheral sounds further support the latter argument that covert attention is present in audition as it is found in vision (Spence and Driver, 1994). The argument was based on the proposal that overt visual attention is preceded by covert visual attention (Rizzolatti et al., 1987). In other words, when attention is diverted to a location in space, it is followed by corresponding ocular movement. Therefore, if a peripheral sound causes observable head movement, there must have been a corresponding covert auditory attention.

In summary, the findings from the Spence and Driver study addressed the limitations that marred the previous reports in covert auditory attention. As pointed out by Spence and Driver (1994), covert auditory attention appears to influence both auditory target localization and pitch discrimination endogenously, and only target location in the case of exogenous attention. Following the series of studies done to investigate the presence of covert auditory attention,

researchers went on to investigate the presence of cross-modal links in covert attention between sensory modalities.

2.4 Cross-modal attention

Early-on in the study of spatial covert attention, there was a greater focus on unimodal sensory stimuli. However, considering human evolution and interaction with the environment, an important factor in the study of auditory attention is that our senses do not rely on unimodal processes or better still, do not work independently and what is perceived with any one of vision, audition, or tactile senses will have an effect that is either negative or positive on the other senses. For instance, visual information processing at a location can be facilitated when a sound attracts attention to that location of visual search (Driver and Spence, 1998; McDonald and Ward, 2000). Similarly, Soto-Faraco et al. (2002) studied cross-modal attention using visual and tactile stimuli. In the study, participants were required to depress four pedals that were placed beneath the right and left toes and heels. They also held a cube that was comprised of nine yellow LEDs and four vibrators attached to it sides (two on each sides). Participants responded to visual and tactile stimulation by releasing the pedal that corresponded to the right and left upper or lower targets. They found that the presentation of a visual cue before the tactile stimulus (visuotactile condition) facilitated the accuracy of pedal release whereas a reduction in accuracy was reported when the tactile cue was produced first (tactovisual condition). Kennett et al. (2002) took a step further using the same experimental approach as Soto-Faraco et al., but now the participants' posture was reoriented (crossed hands) and made invisible (no-vision of the hands). Despite the latter manipulation, they authors reported the same results as the former. That is, the direction of facilitation was dependent on visual cue-tactile target as opposed to tactile cue-visual target. Despite the presence of cross-modal attention between vision and other

stimuli, the bias toward presentation of vision before tactile stimulus could be due to the dominance of visual stimulus (spatial accuracy) over other sensory modalities (Shamojo and Sham, 2001).

McDonald and Ward (1999) studied crossmodal attention using an implicit spatial discrimination task. In the task, participants were required to respond to targets at one spatial location while ignoring targets at other locations. Participants responded to targets presented on either side of the fixation rather than targets presented concurrently with the fixation. They found that while the presentation of an auditory cue had no effect on the response latency for visual targets, visual cue presentation had a significant effect on responses to auditory targets, despite controlling for overt shifts of attention and target priming. Another study by McDonald et al. (2001) asked participants to discriminate between high-frequency and low-frequency auditory targets presented from the right or left speaker, and to ignore the sound from the central speaker following the presentation of visual cues at varying SOAs (100ms-300ms). Again, they found shorter response latencies with valid compared to invalid cues.

The previously discussed studies in cross-modal attention provided evidence measuring behavioural changes (e.g. RT) that occurs due to stimuli interaction (vision, touch and audition). However, they failed to show the corresponding neural link that may account for cross-modal attention considering the fact that such effects cannot be exclusively resolved on the basis of behavioural changes. That is, the former has been very informative, but the underlying cortical processes can provide further insight into how the neural processes shapes behaviour. In line with this notion, Eimer and Schröger (1998) required participants to respond with a button press to a 100ms visual or auditory target, following the presentation of a 200ms cue (an arrow pointing to right or left of the fixation point). The results of their encephalograph (EEG) study

showed increased (enhanced) intermodal negativities for stimuli in the valid compared to invalid cue-target condition. Similarly, Jones and Forster (2014) used intramodal tactile stimuli to access neural correlates of endogenous and exogenous attention in ten participants. In the experiment, participants were required to respond to a 50ms tactile target by saying the word 'pa' into a microphone following the presentation of the target. Using an electroencephalogram (EEG) to record event-related potentials (ERPs), they found that the behavioural measure (RT) correlates well with early modulation in N80 when participants were exogenously cued and late modulation in N140 and Nd in the case of endogenous cues. Again, the difference in the area of the brain modulated due to attention may explain the difference in duration (SOAs) that triggers exogenous and endogenous attention effects. As it was stated earlier in the discussion, the former takes about 200ms to be elicited while the latter takes about 300ms to be observed.

In summary, behavioral and electrophysiological findings from the various experiments lend support or evidence for the presence of cross-modal attention mechanisms between stimuli of different modalities. Particularly, cross-modal links have been reported to affect not just top-to-down attention, but also, bottom-to-top attention mechanisms. At this point, attention will be shifted to the mechanism that underlies attentional processes.

2.5 Mechanism of attention

The effect of covert attention on performance is well-established. Although, the mechanism and the stages of information processing it affects remain unresolved among researchers in the field. Some of the theories proposed to explain the mechanism of covert attention include, reduction in spatial uncertainty (Cameron, Tai, Eckstein, and Carrasco, 2004), external noise reduction, and signal enhancement (Lu and Dosher, 1998, 2000). Firstly, diverting

attention to a certain location helps to isolate distractors at other locations. With distractor suppression, neural processes can be tailored toward the attended location as opposed to attending to several locations, thereby reducing spatial uncertainty. The external noise reduction theory proposed that reducing the amount of external noise such as spatial uncertainty and the amount of distractors will facilitate larger attention allocation that is required to adequately interact with the environment (Lu and Dosher, 1998, 2000). Lastly, by reducing uncertainty and external noise through attention, the processing of the stimuli can be enhanced within the locus of attentional selection (Ling and Carrasco, 2006). Regardless of the proposal, each tends to propose efficient computation processes by improved performance through selective attention.

2.5.1 Neural evidence

Another fundamental question is whether exogenous and endogenous mechanisms are facilitated by similar or different neural systems based on the fact that they both modulate behavior. As stated earlier exogenous modulation is faster and more transient than endogenous modulation (Busse et al., 2008). Through the years, there have been basically two robust lines of evidence that identified separate neural systems. The first are studies done before the advent of advanced functional neuroimaging that studied patients who have brain injuries. For instance, in patients with progressive supranuclear palsy (PSP), exogenous spatial orientation was found to be slow (Posner, Cohen, and Rafal, 1982; Rafal and Grimm, 1981; Rafal, Posner, Friedman, Inhoff, and Bernstein, 1988). This line of evidence was based on the fact that cells in the superior colliculi that are impaired in PSP respond reflexively to exogenous orientation but are suppressed with endogenous orientation (Robinson and Kertzman, 1995). On the other hand, patients with lesions to the temporoparietal junction (TPJ), and the superior and inferior parietal lobes (Posner et al., 1987) are typically impaired engaging endogenous cues but not exogenous

cues. Other areas that are thought to be important in endogenous cueing include frontal eye field (Henik, Rafal, and Rhodes, 1997) and intraparietal sulcus (Robinson, Bowman, and Kertzman, 1995).

Recent evidence from fMRI studies has also demonstrated the activation of intraparietal sulcus and frontal eye field with endogenous attentional cues and TPJ and inferior frontal gyrus with stimulus-driven attention orientation (exogenous cue). Kincade et al. (2005) for instance, found activation in the fronto-parietal region, bilateral frontal eye field, intraparietal sulcus, and the occipital lobe with endogenous cues, while exogenous cues resulted in activation in the dorsal frontoparietal region and less activation in the TPJ.

2.6 Multisensory Integration

Due to large amount of sensory input that humans receive on a daily basis, sensory integration is paramount in order to perceive or recognize different types of sensory input as belonging to the same object or to truly recognize and interact with the world around us (Diedrich and Colonius, 1987). Generally, there is clear evidence that the outcome of multisensory integration (MSI) is reduced time required for motor planning (Colonius and Diederich, 2010; Glazebrook, Welsh, and Tremblay, 2015). However, for MSI to occur, unimodal stimuli are required to be spatiotemporally congruent (Diederich and Colonius, 2004).

Diederich and Colonius (2004, 2008, and 2015) proposed a model known as the time window for integration model (TWIN model) that explains the process of MSI. According to the updated version of the model (Diederich and Colonius, 2008), two separate processes are responsible for the decreased RT seen in MSI: a spatially non-specific warning signal and a subsequent spatially specific stimulus, and specifically, the possibility of the latter being able to

fall within the "time window for integration" (Diederich and Colonius, 2004). The precept of this model holds that, for effective integration to occur in the central nervous system, it is dependent on temporal and spatial bimodal proximity. For instance, Staufenbiel et al. (2011) found that when participants were required to make a button press in response to an abrupt change in visual stimulus (random moving white dot), performance improved when the visual stimulus was presented at the same time with a 1000 Hz tone pip. Also, Glazebrook et al. (2016) reported stimuli integration when participants were required to reach to a visual or an auditory target, despite the fact that the participants were told to ignore the secondary stimulus (visual or auditory). It should be noted, however, greater accuracy was achieved with visual targets compared to auditory target.

Studies done investigating the neural correlation of multisensory integration have found activity in the superior temporal sulcus, superior colliculus, primary visual and auditory cortices, superior temporal sulcus, and intraparietal area (Meredith, Nemitz, and Stein, 1987; Shams, Kamitani, and Shimojo, 2000; Van der Burg et al., 2008). Given that the neural processes of attention share similar cortical activated regions with sensory stimuli integration has led many authors to suggest the basis for interaction between attention and MSI (Cisek, 2007; Tipper, Lortie, and Baylis, 1992).

2.7 Goal-Directed movement

At this point, it is important to discuss how selective attention and stimuli integration from different modalities contribute to movement performance. As reported by Henry and Rogers (1960), an increase in movement complexity requires additional neural processes to prepare the movement as opposed to simple movements. The additional processes are observed

as an increase in the time it takes an actor to initiate a response if required to move from point A to point B, and back to point A as opposed to move to point A. The increase in preparation time is known as Reaction Time (RT). The increased RT that is observed with movement complexity is not restricted to just planning but also, the cascade of processes that unfold during response execution (MT). However, we cannot consider MT as one entity because researchers have proposed that it is composed of an initial primary movement that is followed by a corrective phase (Woodworth, 1899; Keele and Posner, 1968; Meyer, Abrams Kornblum, Wright, and Smith, 1988; Elliott, Helsen, and Chua, 2001; Elliott et al., 2010). Considering this line of evidence that the initial segment of the movement is programmed in advance, it can be argued that the segment will be a function of the sensory stimuli present before movement initiation and unmodifiable until the preprogrammed movement is executed. In contrast, the later segment of an aiming movement relies on sensory feedback from vision and proprioception (limb position in space with respect to the target location) in order to make necessary adjustments or corrections that brings the limb to the appropriate target location.

While the previous models have been very informative, current models of limb control for goal-directed movement has shifted from just the duration and displacement of aiming movements, but to a critical analysis of aiming movements in terms of movement velocity, acceleration and termination or discontinuities. The latter analyses provide important insight into movement planning and limb control (Elliott and Khan, 2010). Together, the latency preceding movement initiation (RT) and the initial segment of the trajectory (peak acceleration and peak velocity) reflect movement planning, while the later segment of the trajectory reflects online control.

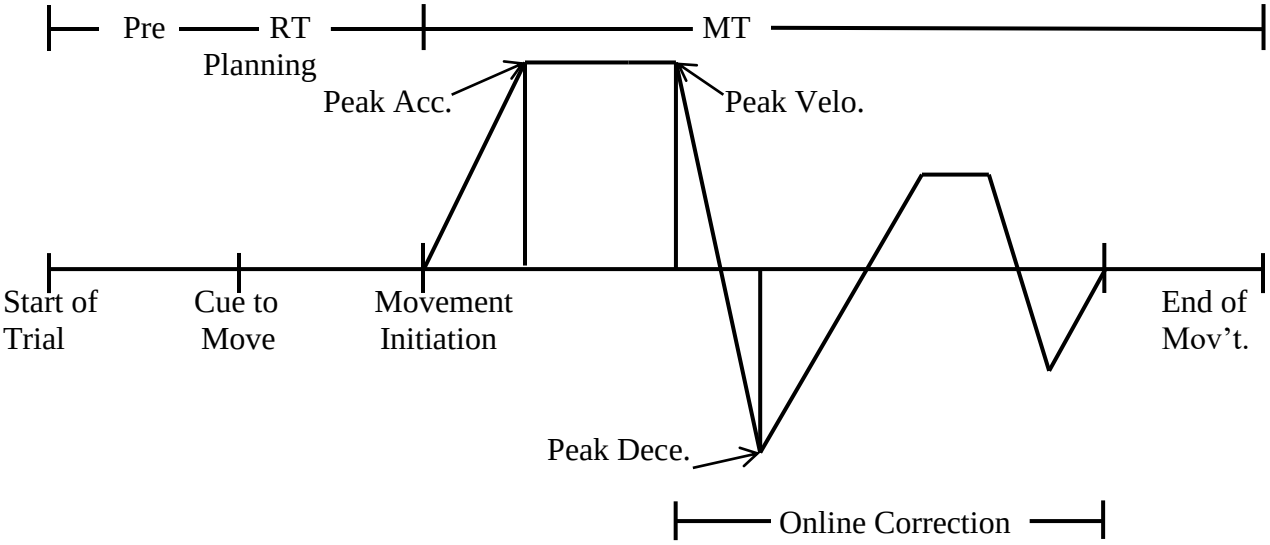

Figure 1.Movement Event (Adapted from Elliott et al. 2010)

Studies in the last two decades have investigated the effect of available information before movement onset on RT and the initial segment of the limb's trajectory. They have reported, in the case of vision versus no-vision, shorter RTs and less time spent to reach peak velocity when vision was available compared to when vision was not. For instance, Hansen and colleagues (2006) compared the effect of advance knowledge of vision compared to no-vision. In the experiment, they asked participants to reach to the center of one of the cued targets with a stylus held on their dominant hand. They found that when participants knew in advance that vision will be available, they spent less time planning their movement (faster RT), reached peak velocity earlier and spent more time after peak velocity compared to when vision was uncertain or not available. Similar findings have been reported with visual and auditory information prior to movement initiation (Glazebrook, Welsh, and Tremblay, 2016). That is, when participants knew in advance they were reaching to visual targets, they reached higher peak velocity at

shorter durations and spent more time making online correction compared to when they reached to auditory targets.

In summary, from an information processing perspective, information from different senses can influence or determine the strategies employed in motor programming and subsequent execution. In particular, analysis of trajectories can provide an insight into how the process is being shaped (Song and Nakayama, 2009). Therefore, in light of the current thesis, we will be investigating how auditory attention may influence planning or control processes when reaching to multiple competing targets.

2.8 Multiple target processing

As pointed out earlier, in a natural environment humans are rarely presented with a single object or act on isolated targets. Instead the typical environment is a visually cluttered environment, containing many targets toward which an action could be selected. While traditional cognitive theories (Cisek, 2007) revolve around object identification before response selection to a single target, it has been eloquently argued that the same process is employed regardless of the complexity of the environment (Cisek, 2007). To achieve this, researchers have proposed when there are competing targets for an action, all possible action plans are encoded in parallel such that neuronal activities creates overlapping hills until inhibition of neurons for those activities that are not required falls below baseline (Cisek, 2007; Cisek and Kalaska, 2005). Thus, the process of selecting a particular object reflects the strength of the vector sum of neuronal activities encoding a response to the selected object. This evidence has been behaviorally and electrophysiologically observed in human and nonhuman primates. For instance, the experiment of Cisek and Kalaska (2005), two male monkeys were required to reach

to a single target in one condition, and one of the two targets in another condition. They measured neuronal activities in the dorsal premotor areas (PMd) and the primary motor cortex (M1) in both animals using microelectrodes. They found that the presentation of two competing targets led to widespread activation of cells in the PMd. Moreover, the activation level of the cells were stronger when the targets were closer together compared to being further apart. Interestingly, the corresponding directional signal increased in the PMd when one of the two targets were cued as the goal for reaching, whereas directionally tuned cells to the targets to be ignored were suppressed.

Spatial averaging of eye gaze has also been reported where activity in the neuronal cells of the superior colliculus were found to be most intense at a location between the two targets. For instance, Sparks, Rohrer, and Lee (1990) used a scleral search-coil technique to monitor eye movement in three monkeys in relation to eccentric targets that were displayed on a computer screen, and extracellular recording technique for neuronal activities in the superior colliculus. They found intense firing in the population cells after which fewer neuronal activities were recorded for saccades to specific spatial locations. That is, they observed an initial generalized (baseline) response from neurons and subsequently, specific directional tuned cells excitation increased with a concurrent inhibition in other cells. Behavioural evidence from human participants have also revealed reaching patterns that denotes parallel planning of irrelevant objects when reaching within an array of targets. For example, in a series of experiments by Tipper et al. (1997), participants were required to reach and grasp a target in the presence of a target distractor, and their trajectories was recorded by two infra-red video cameras. They reported that movement time was longer in the distractor condition compared to the single target condition. Also, trajectory analysis revealed deviations toward a non-target compared to reaching

to a single object. Thus, it appears that the evidence from neuronal activity recording corresponds with behavioural outcomes (trajectory) observed with both human and nonhuman primates.

In light of the behavioural evidence presented above, it appears that neural processes responsible for decision-making are embedded in the planning stage of action and observed as the movement unfolds. From this, it may be argued that the experimental manipulation in previous studies may have indirectly measured parallel planning of multiple actions (Chapman et al., 2010). Rather than assuming non-target information leaks into target reaching processes, Chapman et al. (2010) merged the planning processes to multiple equally probable targets, by forcing participants to initiate their movements before the target was cued. Therefore, the target was cued inflight or online. Similar to previous findings, the trajectory analyses revealed reaching behavior that was aimed toward the middle of the targets before participants made the decision to reach to the cued target inflight. That is, participants initiated movement trajectories that mirror the vector sum of the potential targets or a probabilistic weighted average as a factor of location and number of potential targets (Chapman et al., 2010). In another experiment Stewart et al. (2014) had participants use the handle of a robotic manipulandum to control the cursor on a computer screen. Specifically, the cursor being controlled by the robotic hand was used to reach to one of the two targets separated by 30^0 from the origin (-30^0 and $+30^0$). In addition, the target was cued after movement initiation. Consistent with previous findings, participants reached toward the midpoint of the two targets before correcting their movement to the cued target. Again, this finding demonstrated spatial averaging behavior, termed global effect, that is usually observed when planning an action in the presence of multiple competing objects.

Finally, based on the evidence presented above it can be argued that neuronal activities in the sensorimotor area reflect initial global averaging (Godijn and Theeuwes, 2002; Chapman et al., 2011) of potentially competing targets, and not a simple visual spatial averaging behavior (Stewart et al., 2014). The experimental procedure in the current thesis will build on the procedure of Chapman et al. (2011) by cuing one of the four competing targets after participants initiate their movement. The approach will allow us to fully assess the tight coupling of attention and action, particularly to multiple probable targets. In order to explore action-attention more fully, the models that have been proposed to explain attention-action processes will be the focus of the next discussion.

2.9 Models of attention and action

Building on the previously discussed multiple targets processing, it is imperative to discuss how the process is not just shaped by the mere presence of multiple competing objects, but to expand on the processes from the linkage between attention and action. As pointed out by von Hofsten (1987), successful interaction with the environment is a function of the dependency that exists between attention and action. Based on this principle, many theories have been proposed to explain the intimate link between attention and action.

Rizzolatti and colleagues (1987) proposed the premotor theory of attention due to the unresolved shifting of attention to a non-attended location. Based on Rosenbaum et al.'s (1984) premotor theory, the features of the movement to be performed are programmed independently and in series, such that emphasis is allocated to the most crucial component first. For instance, following the selection of an effector (e.g. in the case of wrist movement, selecting the right or left hand), the directional component of an arm movement would be specified before the distance

in which the arm will cover because the cost of changing direction is associated with changing muscle group, whereas a change in distance only requires additional force to the existing muscle group. Rizzolatti and colleagues (1987) reasoned that the theory also predicts attention to distractors in covert attention, being that one can argue the relationship between attention and ocular movement (overt) with respect to the constant interaction with the environment. That is, when attention is directed to a certain visual field there is a corresponding eye movement to that location in order to appropriately interact with the environment. Since covert attention occurs due to peripheral inhibition, it is thus plausible to insinuate that both covert and overt attention is modulated by a common neural mechanism. To test the hypothesis, Rizzolatti et al. (1987) required eight participants to respond to a highly probable target or equiprobable targets among four boxes that were arranged horizontally or vertically, by pressing letter 'B' on the computer keyboard. They found that within each hemifield, there was an increase in RT when the cue did not predict the location of target and an even greater cost when the cue was contralateral to the target.

Based on the findings, Rizzolatti and colleague argued that a change in direction required more time for reprograming compared to a change in distance. Therefore, the mechanism(s) involved in covert attention are intimately linked to ocular movement (motor response). Similarly, an earlier study by Posner, Cohen, and Rafal (1982) had found that individuals with severe deficits in vertical eye movement (progressive supranuclear palsy) had difficulty orienting covertly in the vertical dimension as opposed to the same requirement in the horizontal direction.

Tipper, Lortie, and Baylis (1992) proposed the action-centered model of attention following a series of experiments based on rapid three-dimensional manual aiming movements to target locations in the presence and absence of a nontarget stimulus (distractor). In the

experiment, they aimed to investigate the impact of interference on perception-action coupling by asking participants to depress the button with a red light while ignoring the yellow light (buttons were arranged in three rows and three columns). The results of the study showed that interference occurs only if the distractor exists within the path of the target and greater interference was observed when the distractor appeared on the same side as the responding hand. According to Tipper et al., this outcome suggests that attention to the distractor may have accessed the action-centered representations, giving rise to increased reaction time compared to when the distractor was not in the path of the target. Even when participants were required to reach and grasp an object, Tipper et al. (1997) found similar results except that distractor inference existed with both near and far non-targets.

Similarly, Welsh and Elliott (2004) proposed the response activation model. The model was based on the finding that non-targets or distractors may compete with activation only if attention to the distractor occurs during the planning stage of reaching, thereby affecting response programming and execution. This was in line with the prediction of Tipper and colleagues (1992), but the authors were able to elucidate the temporal characteristic of inhibition and activation of the non-target. In the study, Welsh and Elliott (2004) required two groups of participants to reach to an illuminated red target in the presence of an illuminated green distractor which may be presented before or after the target presentation (SOA of -750, -250,0,+250, and +750ms). Only distractors presented at negative SOA had an effect on movement planning. That is, when distractors were presented before target onset, attention to the object had an effect on the planning processes to the illuminated red target.

While many of these models may have been proposed from different methodologies, it appears that they all aimed to provide fundamental evidence for the crucial link between

attention and action. It is important to mention that, like the models, the studies that have provided evidence for the theories were done from a visual attention perspective. For example, Welsh and colleagues (2013) required participants to reach to one of the three targets that were displayed on a computer screen following the presentation of a 50ms non-predictive visual cue at five different CTOAs after cue offset. They found increased RT to cued targets at CTOA greater than 225ms compared to uncued targets and MT to cued targets were shorter compared to uncued targets. More importantly, participants' trajectories analysis indicated movement deviation toward cued location at shorter CTOA and away from the cued location at longer CTOA. Therefore, in the current study, the effect of covert auditory attention when reaching to multiple targets will be investigated in light of these models in order to provide more evidence regarding the tight link between attention and action, and in particular, investigate if a similar process is involved with audition. Specifically, if there is any difference between auditory exogenous and endogenous attentional processes in multiple targets aiming. The study was divided into two experiments and the experimental model of Chapman et al., (2010) was used in order to isolate the phases (movement planning and execution) involved with a typical reaching strategy. The details of the experiments are discussed in detail in the third chapter of the thesis proposal.

2.10 Objectives

The objective of the current thesis was to:

1. Examine the effect of covert auditory attention in multiple target aiming.
2. Examine any differences that may exist between covert exogenous and endogenous auditory attention in multiple target aiming.

2.11 Predictions

1. Based on the proposed models of attention, it is predicted that there will be no difference in RT between cued and uncued targets. However, there will be early trajectory deviations for cued compared to uncued targets. That is, global effect will be smaller for cued versus uncued targets.
2. It is predicted that a similar trajectory pattern will be observed in both valid and invalid auditory conditions in the early segment of the movement, despite the fact that the latter will be contralateral to the target location.
3. Due to the addition of endogenous attention in the endogenous + exogenous condition, it is predicted that a larger trajectory deviation will be observed in that condition compared to the exogenous condition.
4. Based on the evidence that attention and MSI share the same neural pathway for processing, it is predicted that there will be no difference in RT and the effect of the auditory cue will be observed late in the trajectory (MSI) for the exogenous and endogenous (+ exogenous) conditions compared to experiment one. The latter prediction was made due to the different time courses for MSI and cross-modal attention. In other words, since auditory cues were presented at a later time in the second experiment, we expected that the auditory cue would have a smaller or later influence on the subsequent movement trajectory.

CHAPTER 3

3.1 Experiment 1

3.1.1 Methods

3.1.1.1 *Participants*

Twelve right-handed typically developing young adults (M=22.2 year-old; Range= 18-29 years) from the University of Manitoba community were recruited for the study. Recruitment was done using posters at various visible poster boards throughout the campus. Also, the research opportunity was presented to students by the research assistants as approved by the Dean and faculty members of the Faculty of Kinesiology and Recreation Management. Participants completed a self-reported questionnaire indicating they are right-handed, free from any neurological disorder, orthopaedic conditions, as well as normal, or corrected-to-normal, vision and normal hearing. The decision for sample size was based on previous studies where they typically used between 12-20 participants (Van da Stoep et al., 2015; Spencer and Driver, 1994, 1997, Neyedli and Welsh, 2012). Ethical approval was obtained from the Educational/Nursing Research Ethics Board (ENREB) of the University of Manitoba. All participants consented by signing an informed consent form after they had read all the necessary information on the consent form.

3.1.1.2 *Apparatus and Stimuli*

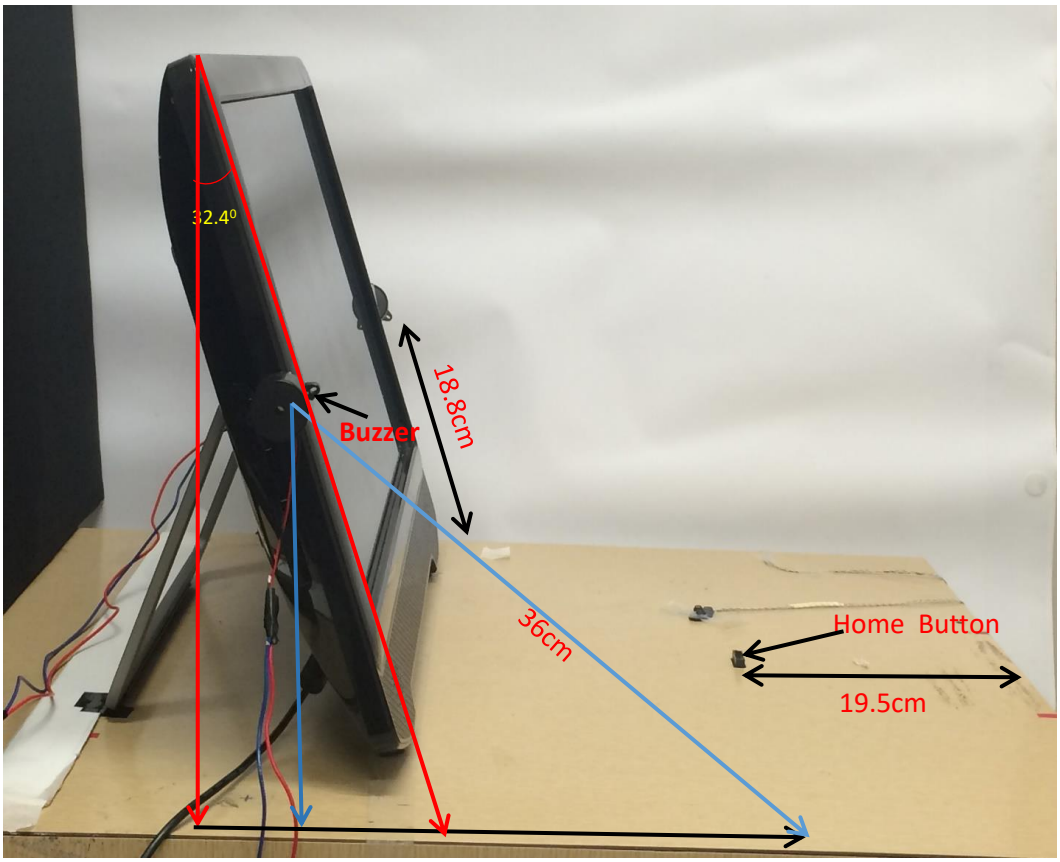

Figure 2. Experimental setup.

A touch screen computer monitor displaying 1920 x 108 pixels (Dell ST2220T, dimension of 37.99 x 52.81 x 5.84 cm) was tilted at 32.4^0 on a table that was 75cm above the floor. The home button was at a midpoint, 19.5cm from the edge of the table. On either side of the computer monitor, a 1000Hz piezoelectric buzzer (to present auditory stimuli) was placed 18.8cm above the lowest point on it vertical dimension. The monitor was used to present four different square targets (1 x 1cm) at a distance of 36cm from the home button. Participants were required to sit on an adjustable chair of which the distance varied from the edge of the table depending on the comfort level of the participant. The distance to the targets was consistently 36cm from the home button. An Optotrak 3D motion analysis system (3D investigator, Northern

Digital, Inc., Waterloo, ON) and infrared light emitting diodes that were tracked by the Optotrak cameras were used in the experiments. The infrared marker (IRED) was attached to the tip of the right index finger using medical tape and the 3D position was sampled at 500Hz (Optotrak system). E-prime software (version 2.0.8.74, Psychology Software Tools) was used to control all commands ranging from cue to target presentation, and to trigger the motion analysis system to recording the location of IRED for offline analysis.

Figure 3. Optotrak 3D motion analysis system (Northern Digital, Inc.)

3.1.1.3 *Procedure*

After the initial instructions regarding the procedure, participants were tested in a single session of about 60min. There were four different conditions namely: no-sound, neutral-sound, exogenous, and endogenous + exogenous. During the no-sound condition, there was no auditory cue in any trial. In the neutral condition, the auditory cue was presented bilaterally. In the last two conditions, the auditory cues were presented equally (50/50) from the right and left buzzers. However, the auditory cue predicted the target location during the exogenous + endogenous condition 80% of the time, whereas it was a 50% cue-target congruency during exogenous only condition. In addition, participants were aware of the cue predicting target location in the endogenous + exogenous condition but not in the exogenous condition. Given that the auditory cue does not have any semantic value, this manipulation meant that any attentional deviation during the 50/50 condition should be reflexive only, whereas during the 80/20 there should also be a contribution of voluntary or endogenous attention (due to the predictability of the auditory cue and the prior knowledge of this predictability) as well as exogenous attention (Spence and Driver, 1994).

Participants were instructed to begin each trial by placing their right index finger on the home position thereby depressing it. As illustrated in Figure 4, following the presentation of a "ready sign" on the screen (controlled by the experimenter), it was replaced by a "fixation cross" that lasted for 500ms. After a variable foreperiod (300-850ms), four equiprobable green outlined targets appeared on the screen. The presentation of the green outlined targets signaled the participants to initiate their movement (within 100-320ms) toward the targets. Simultaneously with movement initiation a 50ms auditory cue was presented from the buzzer(s). One hundred and fifty milliseconds following the presentation of the auditory cue, one of the targets (200ms

CTOA) in the display was filled-in. Participants were required to make necessary adjustments to their trajectory in flight to that location. Feedback was given to participants if they were too fast initiating their movement ("Too Fast, Calm down!"), if their movement was initiated within the set temporal measure ("Correct!), and lastly, if their movement was initiated after 320ms ("Too Slow!"). Participants were instructed to reach rapidly and naturally, and participants were able to see if they landed on the target correctly.

Each session consisted of 12 familiarization trials and 240 test trials (80 trials under the exogenous and exogenous + endogenous conditions (20 trials to each target) and 40 trials under each of no-sound and neutral-sound conditions (10 trials to each target)). For the exogenous condition 50% of the cues were valid and 50% were invalid (cue/target congruency) yielding 10 valid and 10 invalid cue-target trials to each target. With the endogenous + exogenous condition, 80% of the cues were valid and 20% were invalid yielding 16 valid and four invalid cue-target trials to each target. Participants always started with the baseline condition (no-sound and neutral sound), followed by a counterbalanced exogenous and endogenous + exogenous conditions between participants. Test trials were randomly ordered and then split into three blocks of 80 trials. Three-minute mandatory breaks were given to each participant following the completion of each condition and one minute breaks after 40 reaching trials.

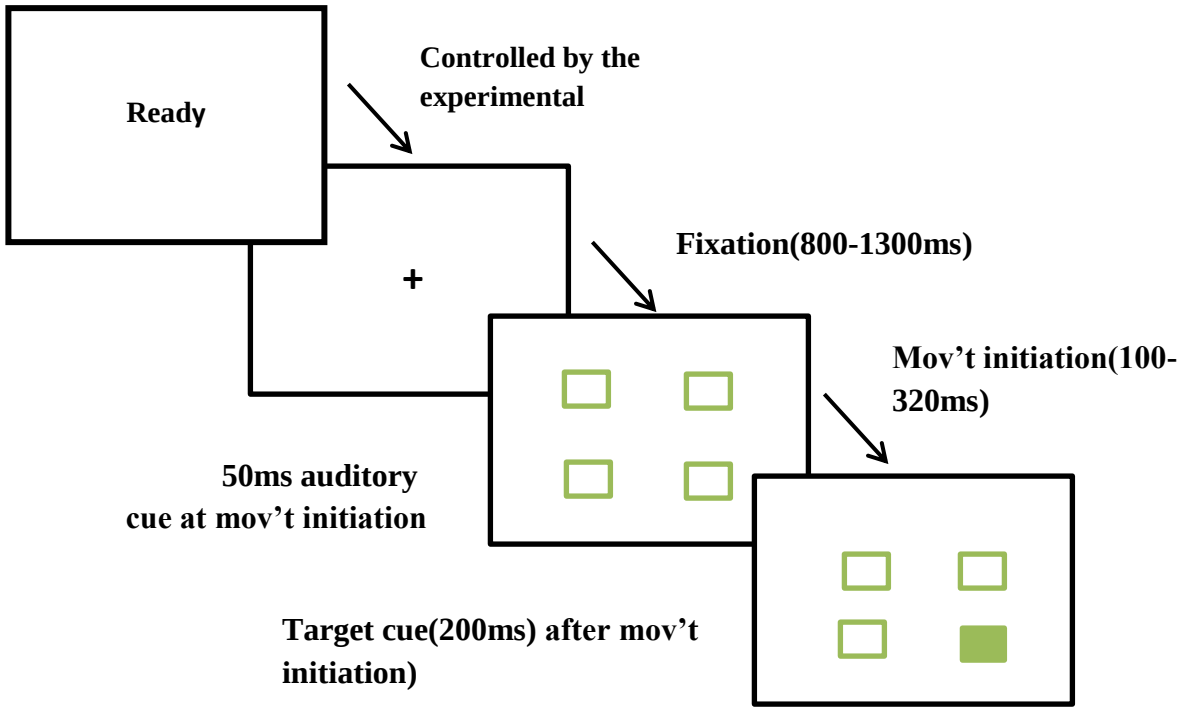

Figure 4. Schematic program of experiment one.

3.1.2 Data Analysis

Following the deletion of all blank files (files which no optotrak data was collected), the displacement data collected via the Optotrak system was processed using a custom program (MatLab, The Mathworks Inc.). To measure movement performance, the main dependent variables were reaction time (RT) and trajectory deviation. The secondary dependent measures were: Movement time (MT), time to peak velocity (ttPV), percent time to peak velocity (%ttPV), constant error (CE) and variable error (VE) in the horizontal (x) and vertical (z) axes. Within the analysis program, movement initiation was defined as the first sample in which the velocity of the movement exceeded 30mm/s for more than 15 frames (30ms). Correspondingly, movement termination was defined as the first sample in which the velocity fell below 30mm/s and remained below the threshold for at least 15 samples after movement initiation. To calculate RT,

therefore, sampling rate was multiplied by the number of samples recorded from the start of the cue to initiate movement to the actual movement initiation. RT measure will shed light on how sensory stimuli are being used or processed before participants initiate movement. Movement time (MT) was calculated by multiplying the sampling rate by the number of frames recorded between movement initiation and movement end. The MT measure helped to determine how sensory information after movement initiation may have been used. Constant error was calculated by computing the difference between end location of the movement and the stationary target location in each of the axes mentioned above. Variable error was calculated by computing the SD of the endpoint location of the IRED. Both CE and VE measures indicated endpoint performance, and they may be affected by how sensory feedback is being used when homing in on a target. A differential of the displacement data was used to compute time to peak limb velocity (ttPV) in the primary axis (z) while the %ttPV was a function of ttPV divided by the MT. Kinematic variables may provide insight into the tight coupling between attention and action. That is, how the presence of auditory attention may influence movement planning processes. For instance, the presence of a secondary stimulus may influence the time to attain peak velocity. For example, a shorter time to peak velocity signifies an actor would have had a considerable increase in movement variability at the early stage. On the other hand, they would have the greater portion of the MT to make online corrections.

Before statistical analysis, trials in which the RT fell below 100ms, as well as trials in which the RT and/or MT fell outside $\pm$2.5 standard deviations from the mean, were excluded from the data. A total of 25.4% (3.8% were excluded due to RT less than 100ms) of all the trials were removed. Due to the large number of excluded trials, we included trials with RT more than 320ms, provided that the RT fell within the $\pm$2.5 standard deviations from the mean. The large

number of excluded trials was not expected and may have been due to the rapid nature of the task. One participant was excluded from the data because the entire Optotrak file for the left lower target was blank. After the outliers were removed, the mean values for RT, MT, ttPV, %ttPV, CE and VE under baseline, exogenous and exogenous + endogenous conditions were further analyzed using a 3 Condition (baseline, endogenous + exogenous, exogenous) x 2 Target locations (right, left) repeated measures ANOVAs to examine the effect of cuing. That is, how the presence of a random cue could have potentially affected the strategy used by the participants. Therefore, only valid cues under endogenous + exogenous and exogenous conditions were used as the baseline cues were assumed to always be valid. To then assess if there was a difference between valid and invalid cues, the effect of cue validity under exogenous and exogenous+ endogenous conditions was submitted to a 2 Condition (endogenous + exogenous, exogenous) x 2 Validity (valid, invalid) x 2 Target location (right, left) repeated measures ANOVAs. It is worth pointing out that the baseline condition that consisted of the no-cue was not used in the ANOVA model because we were interested in ensuring that the neutral auditory cue was uninformative. That is, it was not different from a condition where no cue was presented. This was done to ensure that any effect of cuing was not as a result of an alerting effect (Spence and Driver, 1994). To this effect, a paired sample t-test was also done to compare the RT and MT under neutral cue and no-cue conditions.

To assess the effect of the auditory cue on movement trajectories in each of the conditions, movement displacement along the secondary axis (x-axis) was analyzed. The home button was used as the relative origin of all the coordinates (0, 0, 0) in determining the deviations. To measure the trajectory deviation, the average x-position of the IRED at a specified time in the entire course of the movement was calculated for each cue-target location in all of the

conditions. Specifically, the horizontal position of the IRED was identified at six points (5%, 15%, 30%, 45%, 60%, 75%) of the MT, and the average x-position was submitted to a 3 Condition (baseline, endogenous + exogenous, exogenous) x 2 Target location (right, left) x 5 Positions (15, 30, 45, 60, 75 % of MT) repeated measures ANOVAs for uncued versus valid-cue. To compare valid and invalid cues directly, a separate 2 Condition (endogenous + exogenous, exogenous) x 2 Target location (right, left) x 5 Positions (15, 30, 45, 60, 75 % of MT) repeated measures ANOVAs was conducted.

Significance level was set at $p < .05$ and significant interactions involving more than two means were further investigated using Turkey's HSD (post hoc analysis), $p < .05$.

3.2 Experiment 2

A follow-up experiment was conducted since sensory interaction can occur through cross-modal attention or multisensory integration. We conducted a second experiment in which the CTOA was 70ms in order to ensure the results of experiment one, particularly trajectory deviation, was not as a result of multisensory integration. It should be noted that experiment 2 was essentially the same as the first experiment and the duration at which the target was cued remained consistent (200ms after button release) except that, the CTOA was 70ms (50ms auditory cue at 130ms after button release compared to 0ms after button release in experiment 1). The delay in the presentation of the auditory cue separates processing of cross-modal attention and multisensory integration because it has been shown from previous studies that cross-modal attention is elicited at 200ms CTOA (Spence and Driver, 1994) and multisensory integration peaks at about 100ms CTOA (Stevenson et al., 2012).

3.2.1 Methods

3.2.1.1 *Participants*

A total of 12 right-handed typically developing young adults (M=21.3 year-old; Range= 18-31years) from the University of Manitoba community also participated in this experiment. Method of recruitment and informed consent were the same as the first experiment. None of the participants who completed experiment 2 had participated in experiment 1.

3.2.1.2 Apparatus and Stimuli

The same apparatus and stimuli were used for experiment 2. The difference was the timing of when the auditory cue was presented. Specifically, a 50ms auditory cue was presented at 130ms after button release compared to 0ms after button release in experiment 1

3.2.1.3 *Procedure*

The procedure was the same as the first experiment except that the CTOA was 70ms in this case (see Figure 4). Participants were instructed to begin each trial by placing their right index finger on the home position thereby depressing it. Following the presentation of a "ready sign" on the screen (controlled by the experimenter), it was replaced by a "fixation cross" that lasted for 500ms. After a variable foreperiod (300-850ms), four equiprobable green outlined targets appeared on the screen. The presentation of the green outlined targets signals the participants to initiate movement (within 100-320ms) toward the targets. One-hundred and thirty milliseconds following movement initiation, a 50ms auditory cue was presented from the buzzer(s). Twenty milliseconds following the presentation of the auditory cue, one of the targets (70ms CTOA) in the display was filled-in. Participants had to make necessary adjustments to their trajectory in flight to that location and feedbacks was provided. We specifically chose the

CTOA of 70ms in the second experiment in order to ensure that the auditory and visual stimuli are as close in time and space as possible (Stevenson et al., 2012).

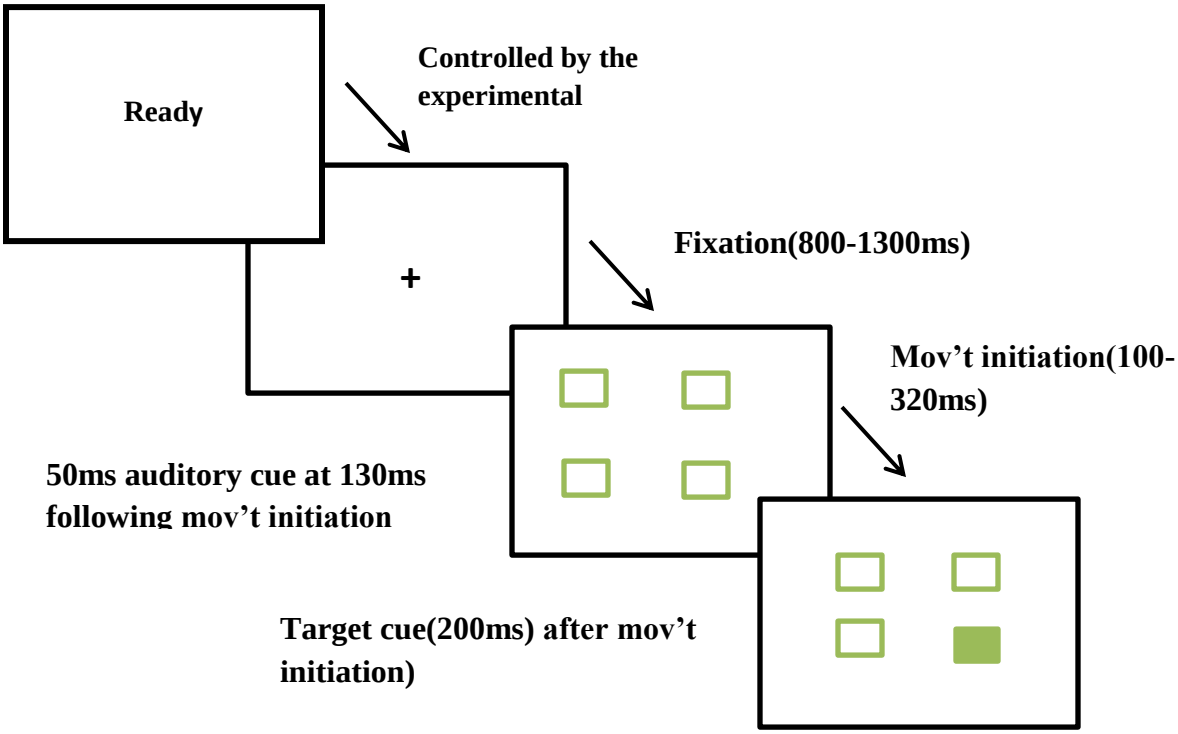

Figure 5. Schematic program of experiment two.

3.2.2 Data Analysis

Data processing was essentially the same as it was done in the first experiment. For experiment two, a total of 25.9% (9.2% were excluded due to RT less than 100ms) of all trials were removed in experiment 2. Again, due to the large number of excluded trials, we included

trials with RT more than 320ms, provided that the RT fell within the $\pm$2.5 standard deviations from the mean. The same ANOVA model was used for each variables mentioned above. Significance level was set at $p < .05$ and significant interactions involving more than two means were further investigated using Turkey's HSD (post hoc analysis), $p < .05$.

CHAPTER 4

4.1 Experiment 1

4.1.1 Results

The analysis of reaction time (RT) and movement time (MT) under no-cue was not significantly different from a neutral cue, $t(22) = 0.316$, $p=0.41$ and $t(22) = -0.084$, $p=0.96$ respectively. This result indicates that the presentation of the neutral auditory cue was the same as no cue. Therefore, an alerting effect of sound can be ruled out as an explanation for a significant effect of cuing in the following results.

4.1.1.1 *Temporal measures*

Reaction Time

The analysis of reaction time (RT) revealed no significant effect of condition for uncued (baseline) compared to cued targets (exogenous and exogenous + endogenous conditions) regardless of target locations to the right or left, $F(2, 20) = 2.04$, $p=0.15$. For valid and invalid cues, there was no effect of condition, validity or target location, Fs $(1, 10) < 2.5$, $p>0.05$, but there was a significant interaction between conditions and target location, $F(1, 10) = 16.26$, $p=0.002$ (Figure 6). Post hoc analysis revealed that RT was significantly longer to the left targets (229.5ms) compared to the right targets (221.8ms) in the exogenous condition while there was no difference between the right (221ms) and left (222ms) in the endogenous + exogenous condition regardless of cue validity.

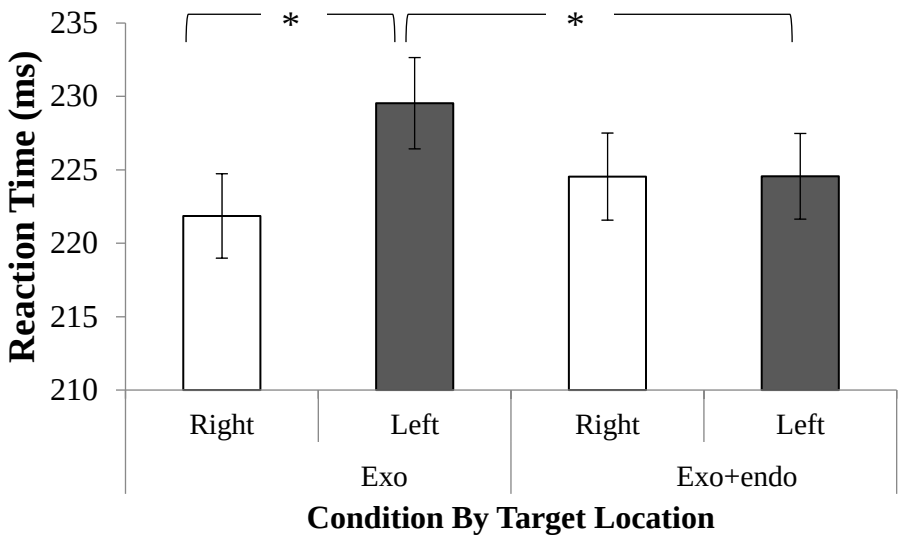

Figure 6. Mean reaction time (ms) as function of condition by target location. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$)

Movement Time

The only significant effect of movement time (MT) was a main effect of target location with cued versus uncued target locations, $F(1, 10) = 5.48$, $p=0.04$ (Figure 7). Regardless of cuing, there was a MT advantage to the right targets (849.5ms) and it took participants significantly longer to complete movements to the left targets (899.5ms). It is worth noting that there was a trending pattern with cue validity that did not reach the set level of significance, $F(1, 10) = 4.03$, $p = 0.07$. That is, with valid cues participants spent less time reaching to the targets regardless of target locations.

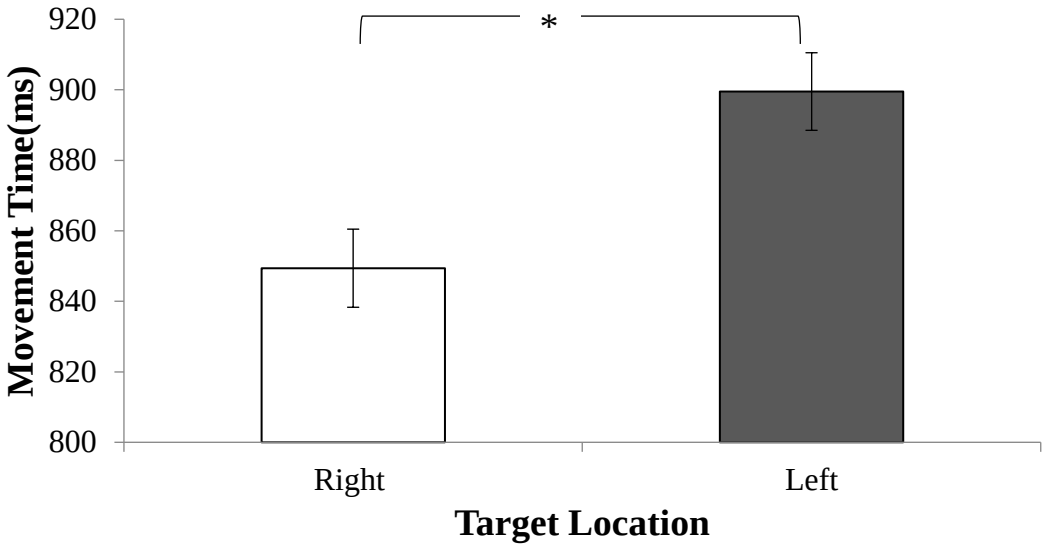

Figure 7. Mean movement time (ms) as a function of target location regardless of cuing. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$)

4.1.1.2 *Kinematic measures*

The analysis of the time to peak velocity (ttPV) was not significantly different between cued and uncued targets $F(2, 20) = 0.02$, $p=0.97$. Although, there was a trending pattern with target locations that did not reached the set level of significance, $F(1, 10) = 4.56$, $p =0.058$. That is, participants spent more time to peak velocity to the right targets (129ms) compared to the left targets (122ms) regardless of condition. It was also not significant for cue validity, $F(1, 10) =1.7$, $p=0.21$. On the other hand, the percentage of time to peak velocity was significant for cued and uncued for target locations, $F(1, 10) =9.64$, $p=0.01$ (Figure 8). Specifically, regardless of cuing the target or not, participants spent greater percentage of their time to peak velocity when reaching to the right (15.8%) compared to the left (14%). There was also a main effect of target location for cue validity, $F(1, 10) =8.47$, $p=0.01$ (Figure 9). That is, regardless of condition and validity, participants spent 15.1% of the MT to peak velocity to the right targets compared to 14.4% to the left target.

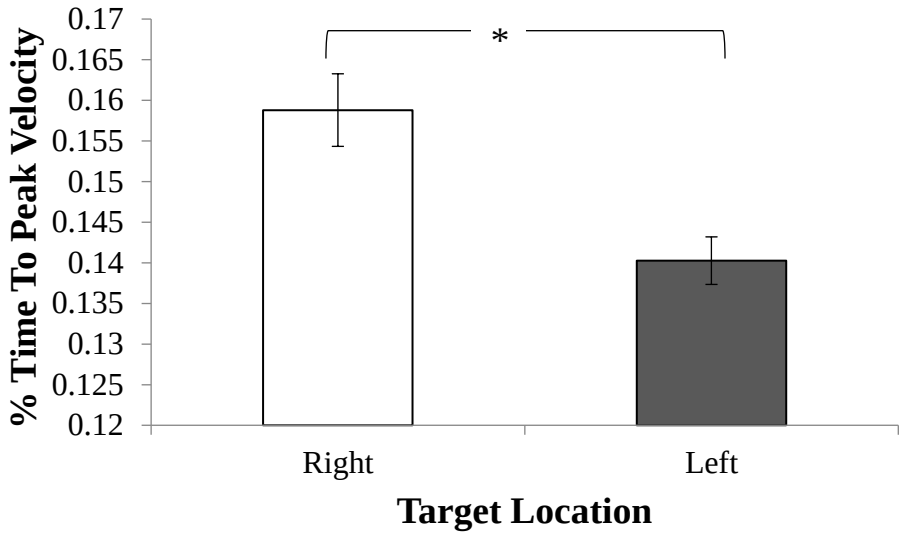

Figure 8. Mean percent time to peak velocity as a function of target location regardless of cuing. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

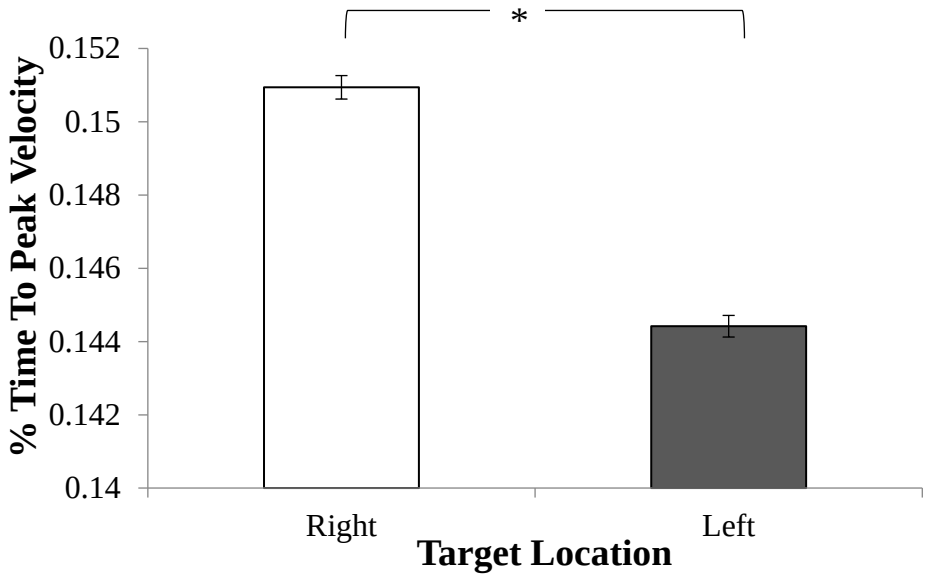

Figure 9. Mean percent time to peak velocity as function of cue validity by target location. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

4.1.1.3 *Endpoint performance measures*

Constant Error

Analysis of the constant error (CE) in the primary (z) and secondary axis (x) were not significantly different for cued versus uncued conditions and for valid versus invalid cues, Fs <1.6, p>0.05.

Variable Error

Variability (VE) in both z-axis and x-axis were not significantly different in terms of cued versus uncued targets, and cue validity, Fs <1.1, p>0.05.

4.1.1.4 *Movement trajectory analyses*

The analysis of uncued versus valid-cue targets revealed a main effect of target locations, $F(1, 10) = 65.02$, $p<0.0001$, percent MT points, $F(5, 50)= 14.62$, $p<0.0001$, a significant target location by movement time interaction, $F(5, 50)= 150.3$, $p<0.0001$, and a significant condition by target locations by percent MT points interaction, $F(10, 100)= 2.83$, $p<0.05$. Post hoc analysis of the interaction revealed that uncued right and left target trajectories were different from 60% of the MT, while for right and left valid cued trajectories were different from 45% of MT (Figure 10). The analysis of valid cue versus invalid cue revealed only significant effect of percent of MT points, $F(1, 10)= 56.23$, $p<0.0001$. As such, there was no significant difference between valid and invalid cues.

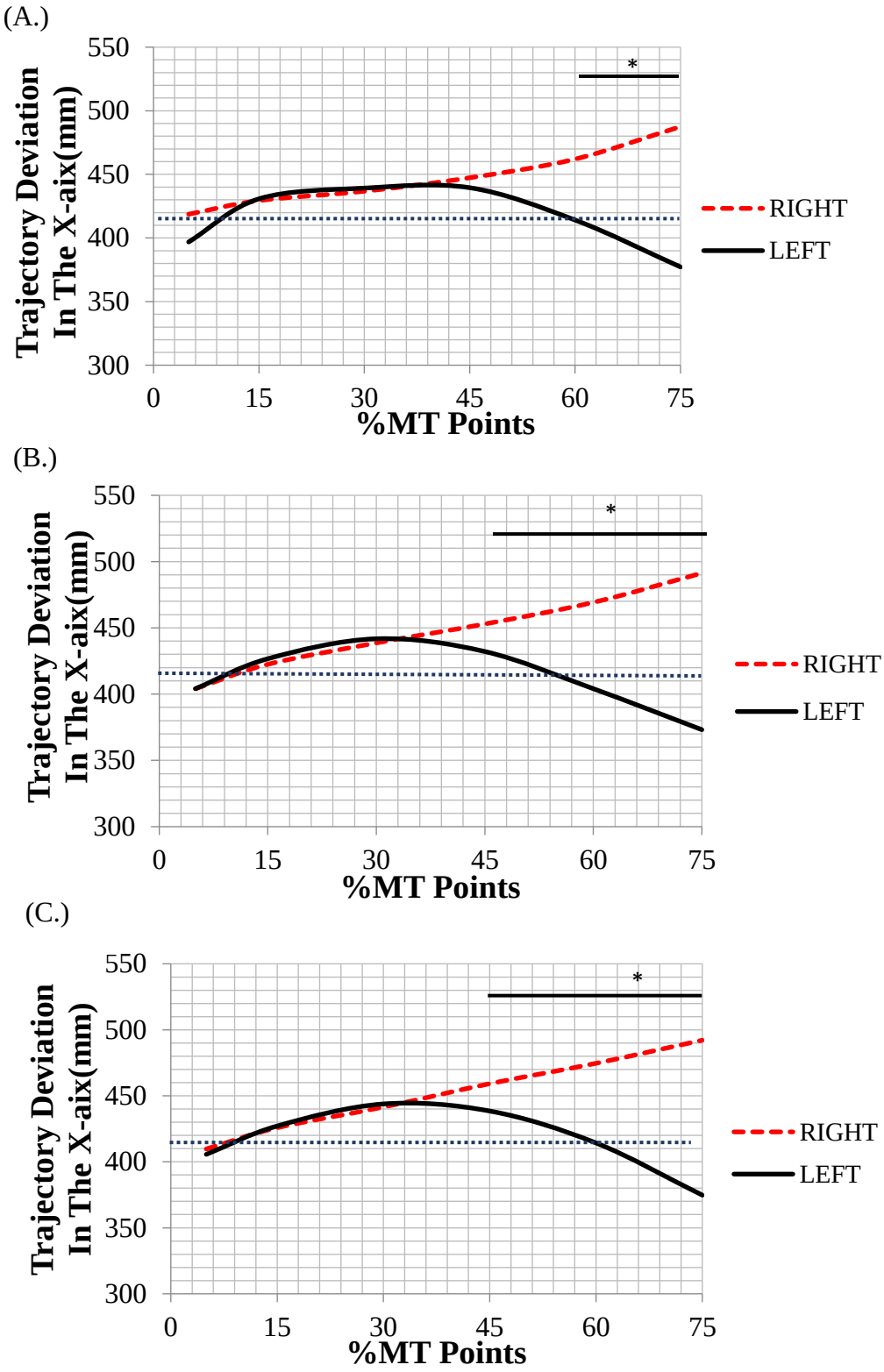

Figure 10. Mean trajectories deviations in the horizontal axis as function of percent movement time points.* indicates significant difference (α=0.05). (A) Trajectory path with neutral cue. (B) and (C) Trajectory path with lateralized valid auditory cue under endogenous + endogenous and

exogenous conditions respectively. In all conditions, the average starting position (midline position) was at 419mm (±5mm) in relation to the displacement in the x-axis.

4.1.1.5 *Discussion*

The general purpose of the first experiment was to assess the impact of covert auditory attention in multiple targets-aiming. Many studies have addressed the issue of covert auditory attention (Farah et al., 1989; Spence and Driver,1994, 1997; McDonald and Ward, 1999; Van der Stoep, Van der Stigchel, and Nijboer, 2015), but they have ignored a typical human environment, where tasks or interactions are not usually performed with a single target.

Firstly, the absence of a RT advantage in any of the conditions is consistent with the prediction that there will be no difference in RT since the target location was unknown for 200ms following movement initiation. The result is consistent with what has been reported in previous studies that looked at human motor decision making when presented with multiple potential targets (Chapman et al., 2010; Gallivan et al., 2011). For instance, in the study of Chapman et al. (2010), participants were forced to initiate very fast movements to competing targets within 320ms without knowing the final location until movement initiation. It was evident in their results that participants made similar movement planning processes based on the reported RT to multiple targets, except when a single target was presented on the screen. This was not surprising as it would be efficient to take into consideration, the uncertainty associated with what the actual target will be, (considering four targets were displayed) and the location of the potential target.

However, there was a right target advantage that was reinforced by the shorter MT. The finding is consistent with previous studies and maybe associated with biomechanical factors of reaching to the left side of the body (Carey, Hargreaves, and Goodale, 1996; Chapman et al.,

2010). In other words, biomechanical consequences or constraints such as muscle group recruited and displacement of the center of mass (COM) in the opposite direction is usually larger than the ipsilateral direction (Carey, Hargreaves, and Goodale, 1996). For instance, movements done on the ipsilateral side are largely a function of shoulder flexion and elbow extension. On the other hand, movement that crosses the mid-sagittal line involves a significant amount of horizontal shoulder adduction. As such, greater muscle recruitment is needed in the latter case. Alternatively, it could have been as a result of interhemispheric relaying of sensory information (Fisk and Goodale, 1985; Carnahan, 1998). Since the targets were located in the right and left visual fields because participants had to maintain fixation until movement initiation, it could have been that target advantage emanated as a result of the processing of object in the right visual field in the same hemisphere that is largely responsible for organization and control of voluntary movement (Mieschke et al., 2001). On the other hand, targets in the left visual field are first processed in the right primary visual cortex, after which the information is then used for motor output in the left hemisphere. Such patterns of communication may have resulted in longer time to complete a task. Moreover, participants spending more time to reach peak velocity and an even larger percentage of their MT to do so to the right targets would be an indication of efficient planning processes. Contrary to this explanation, we did not find any significant effect of RT to either the left or right targets regardless of cuing. Consistent with the nonsignificant difference in RT that we found in our study, Mieschke et al. (2001) in their study required participants to perform goal-directed reaching movements to one of four targets (two on each side) with either the right or the hand. In either case, targets can appear on the right or the left side. They reported a difference of 9ms between reaches made to the right and left hemispaces with the right hand. However, the MT to the right hemispace was significantly

shorter than to the left hemispace using the right hand. Therefore, in accordance with our results, the likely argument is that right target advantage may be due to the added effect of both the biomechanical and interhemispheric factors.

Also, as mentioned in the results, there was tendency toward spending more time reaching to targets with invalid cues compared to the valid cues. This would not have been surprising because of the cost of correcting movements away from the cued location would have added to the time spent to reach to the appropriate target. Several studies have reported similar finding with invalid cues compared to valid cues in auditory attention (Spence and Driver, 1994, 1997; Van der Stoep, Van der Stigchel, and Nijboer, 2015) visual attention (Posner, 1980; Guzman-Martinez et al., 2011; Neyedli and Welsh 2012), as well as in vibrotactile attention (Soto-Faraco et al., 2002). For instance, in the study of Guzman-Martinez et al. (2011), participants were instructed to press a response key when presented with two rectangular boxes and one is a potential target. The target was preceded by valid or invalid exogenous and endogenous visual cues. They reported faster RT with valid cue trials compared to invalid cue trials. Thus, the results of the current thesis provide evidence that the auditory cue affected participants' movements outcome.

Surprisingly, there was no evidence of bias in terms of end point performance to the right or left targets as it would have been expected to provide a clue as to whether the findings in the current thesis support the biomechanical or the interhemispheric argument. If the right target advantage was interhemispherically mediated as opposed to biomechanical factors, the ability of the participants to make necessary adjustments online would have been difficult with targets on the left. On the other hand, they would have done better with the targets on the right which would have been manifested in their endpoint performance. In other words, if the argument of

Fisk and Goodale (1985) was accurate, participants' ability to make adjustment from online feedback would have taken longer because of relaying information between hemispheres. The latter assertion was not the case in the present study. Alternatively, since participants spent only about 15% of total time to peak velocity, the extra time could have been sufficient enough to make necessary adjustments to reaches made to the right or left targets, thereby resulting in similar endpoint performance.

In terms of trajectory deviations, it was evident that the presence of localized sound resulted in participants making early decisions toward the direction of the target, compared to when sound was presented bilaterally. That is, spatial averaging behavior was more pronounced with bilateral cues compared to localized auditory cues. As proposed in previous studies (Sparks et al., 1990; Chapman et al., 2011), the initial direction of movement toward competing objects is a function of the vector sum of their corresponding activation. In other words, when presented with multiple competing objects, humans plan their movements toward the middle of the objects to account for the uncertainty to the final position. For instance, a recent study by Steward et al. (2014) demonstrated that when participants were presented with competing objects, they initially displayed spatial averaging behavior before making necessary corrections to the cue target. This way, factors such as the amount of energy expended when a correction was made to the final target location and any additional movement time and trajectory deviations due to error corrections would have be minimized (Elliott and Khan, 2010). However, the presence of a lateralized auditory cue reduced the magnitude of this behavior as seen in our results showing trajectory deviations early in the movement. The trajectory finding is consistent with previous studies, such as those investigating the presence of non-targets while reaching to a target (Welsh and Elliott, 2004), predictive visual cues to competing targets (Neyedli and Welsh, 2012), and

even in saccadic trajectories to targets in the presence of non-targets (McSorley et al., 2006). For instance, in the study of Neyedli and Welsh (2012), participants reached to one of the three targets on a screen in the presence of non-predictive visual cue at CTOA of 150ms, 400ms, 900ms, and 1150ms. Movement trajectory deviations in the horizontal axis relative to the vertical axis were analyzed at different CTOAs. Their behavioral pattern was such that they deviated toward the direction of the cue at the shortest CTOA and away from the cue at CTOA of 900ms. This type of behavior suggests that attention may have leaked into the action center with subsequent alteration in the motor response that was also observed in the present study; ultimately supporting the notion that attention and action are intricately linked (Rizzolatti, Riggio, Dascola, and Umilta, 1987; Tipper, Lortie, and Baylis, 1992; Cisek, 2007).

While one would expect the trajectory to deviate earlier than what we have seen in the present study, it is possible that the inhibition of the motoric response aimed toward the middle of the targets took longer to develop, or the excitatory response to the auditory cue (attention) had lapsed in the attention system but was still competing in the motor system (Neyedli and Welsh, 2012). The latter explanation is consistent with neurophysiological basis of the affordance competition hypothesis (Cisek, 2007). That is, there is a correlation between sensory and motor variables, and neural activities in the fronto-parietal region that are involved in specifying potential actions based on sensory information. This same region, according to Cisek (2007), can be modulated by attention. Specifically, the process of action selection in the presence of attention is interconnected and flows through the posterior parietal region to the dorsal premotor area and lastly, to the motor cortex (Cisek, 2007).

Taken together, in the present study, it was evident that reflexive or voluntary lateralized auditory cue did influence the trajectory pattern of participants despite the fact that it was

presented at movement initiation. The result is generally consistent with previously proposed models of attention and action (Rizzolatti, Riggio, Dascola, and Umilta, 1987; Tipper, Lortie, and Baylis, 1992; Cisek, 2007), providing support for intimately linked attention and action.

4.2 Experiment 2

4.2.1 Results

The analysis of reaction time (RT) and movement time (MT) under no-cue was not significantly different from neutral cue, $t(22) = -0.299$, $p=0.55$ and $t(22) = 0.029$, $p=0.57$. Similarly, this result indicates that the presentation of the neutral auditory cue was the same as no cue. Therefore, an alerting effect of sound can be ruled out as an explanation for a significant effect of cuing in the following results.

4.2.1.1 *Temporal measures*

Reaction Time

The analysis of RT revealed no significant difference between cued versus uncued targets, $F(2, 22) = 2.4$, $p > 0.05$, as well as cue validity, $F(1, 11) = 0.52$, $p > 0.05$.

Movement Time

The analysis of MT for cued versus uncued targets was significant for target location, $F(1, 11)=6.26$, $p=0.02$. There was also condition by target location interaction, $F(2, 22)= 5.56$, $p=0.01$ (Figure 11). Post hoc analysis showed that it took longer to reach to the right target with neutral cues (776ms) compared to right targets with endogenous +exogenous cues (745ms), while the former was not different from right targets with exogenous cues (751ms). Generally,

however, participants spent more to targets on the left (802ms) compared to targets on the right (757ms) regardless of condition.

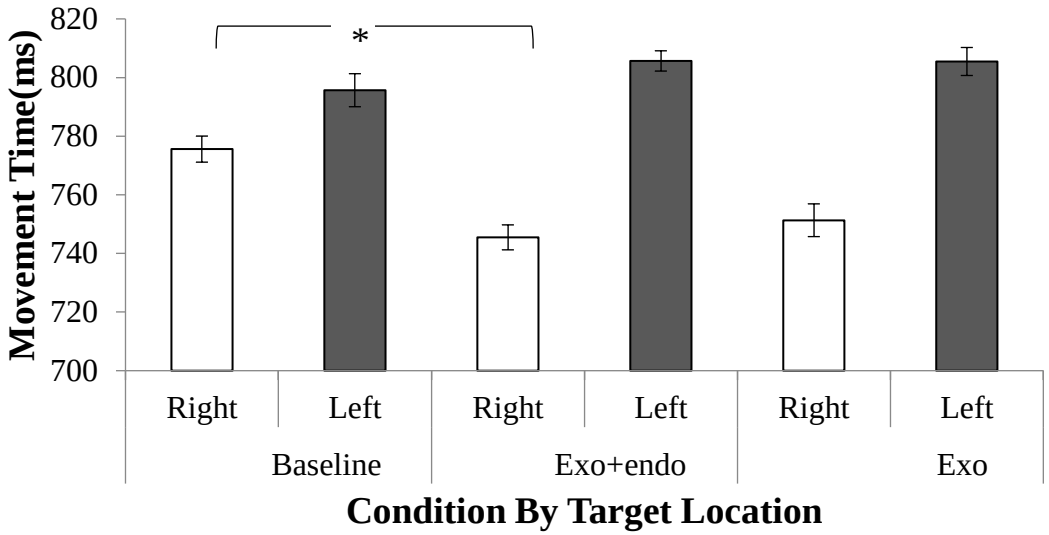

Figure 11. Mean movement time (ms) as a function of uncued versus cued condition by target location. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

Also, with cue validity, there was a main effect of condition, $F(1, 11) = 39.4$, $p<0.001$ (Figure 12), and target locations, $F(1, 11) = 9.84$, $p<0.001$ (Figure 13). Participants spent more time reaching to targets when exogenously cued (796ms) compared to exogenous +endogenous cue (792ms). Also, it took participants less time to reach to the right targets (763ms) compared to the left targets (862ms)

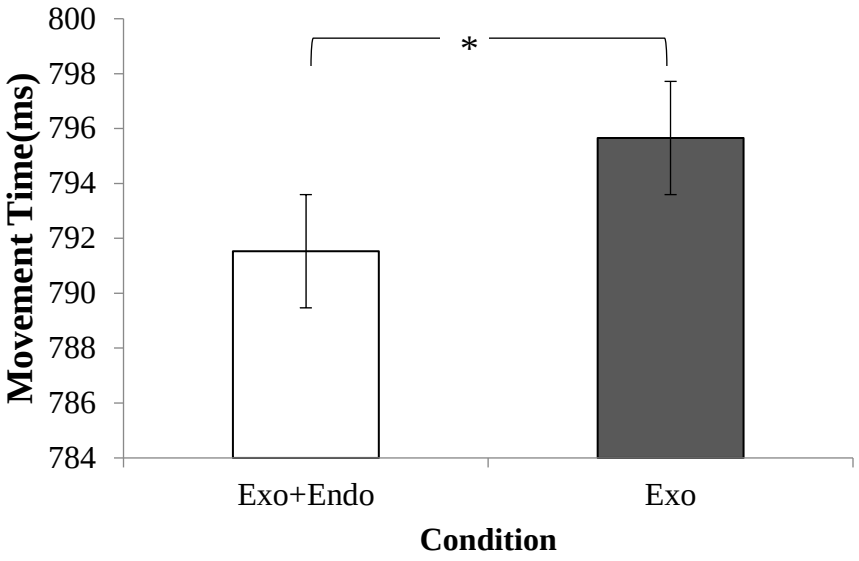

Figure 12. Mean movement time (ms) as function of cue validity. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

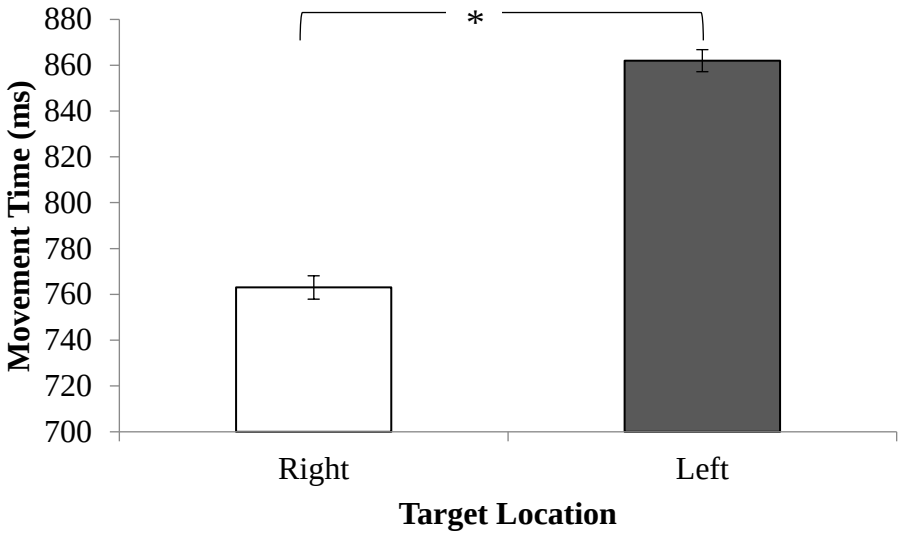

Figure 13. Mean movement time (ms) as function of target locations. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

4.2.1.2 *Kinematic measures*

The analysis of ttPV was significant for cued versus uncued targets location, $F(1, 11)= 6.0$, $p=0.03$ (Figure 14). That is, participants spent more time to reach peak velocity to the right

targets (164ms) compared to the left targets (149ms). There was a trending pattern for cue validity that did not reach the set level of significance regardless of condition or targets location , $F(1, 11) = 4.0$, $p=0.07$ (Figure 14). That is, participants tend to spend more time to peak velocity with valid cues (161ms) compared to invalid cues (128ms).

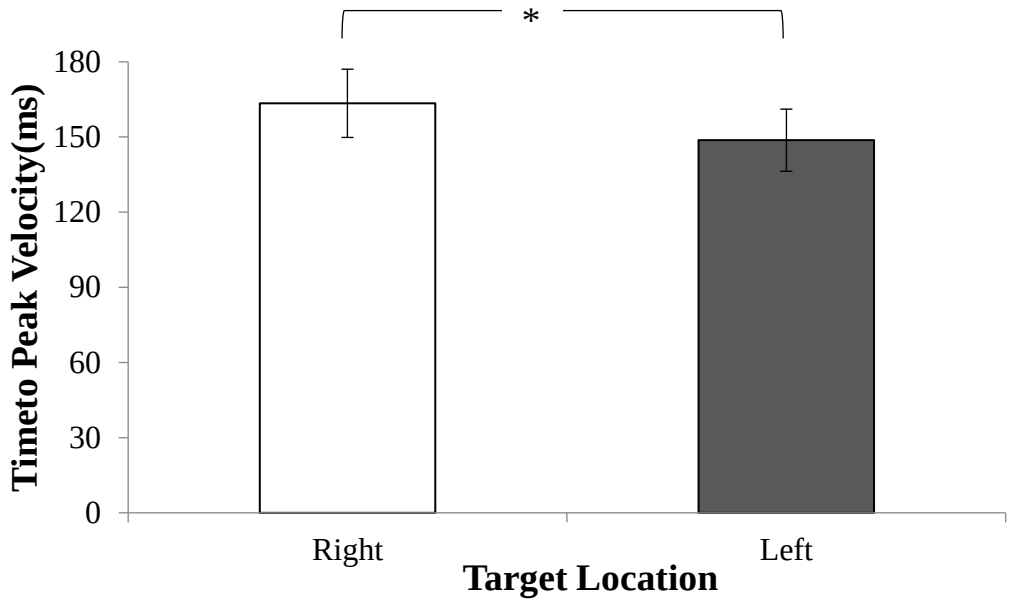

Figure 14. Mean time to peak velocity as function of right and left target locations irrespective of cuing. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

On the other hand, percent movement time to peak velocity revealed a significant effect of target location for cued versus uncued targets location, $F(1, 11) = 11.8$, $p=0.005$, and a significant condition by targets location interaction, $F(2, 22) = 3.62$, $p=0.04$ (Figure 15). Post hoc analysis indicated that the percentage of time spent to peak velocity with neutral cue was not different between the right and left targets. However, it was significantly different for right and left targets with cued conditions. Also, there was a significant effect of target location with cue validity, $F(1, 11) = 9.2$, $p=0.01$ (Figure 16), with participants using a lesser percentage of the MT to peak velocity to the left targets (18.9%) compared to the right targets (22.2%) regardless of the cue validity.

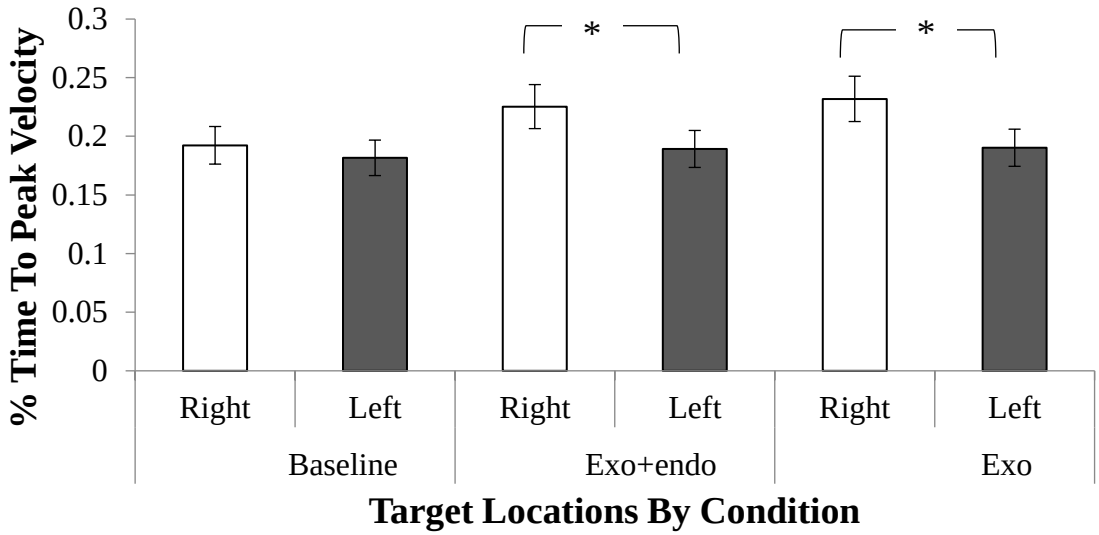

Figure 15. Mean percent time to peak velocity as function of conditions by target locations. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

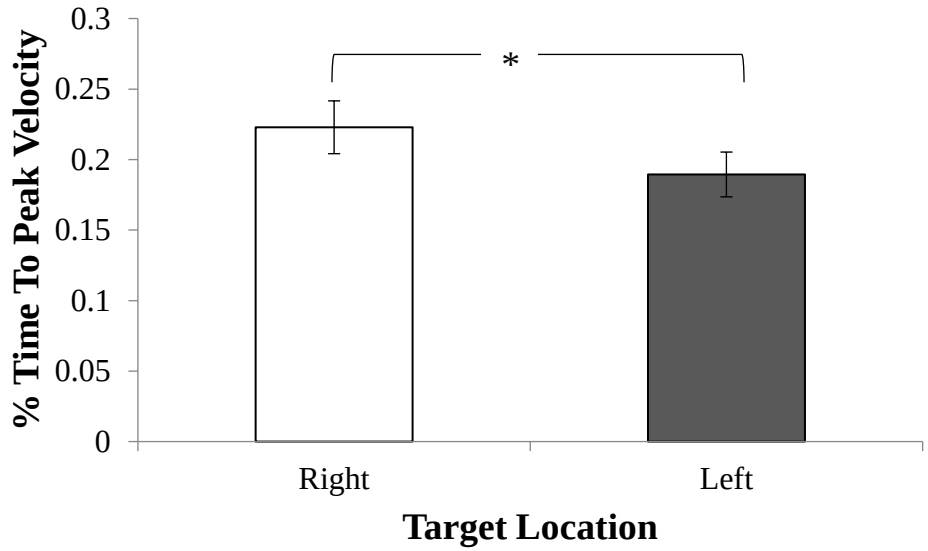

Figure 16. Mean percent time to peak velocity as function of target location irrespective of cue validity. Error bars shows SEM. * indicates significant difference ($\alpha<0.05$).

4.2.1.3 *Endpoint performance measures*

Constant Error

The analysis of the CE in the x-axis and z-axis was significant for target location for uncued versus cued targets, $F(1, 11)=24.7$, $p=0.0004$ and $F(1, 11)=23.5$, $p=0.0005$ respectively.

In this case, participants were aiming closer to the mid-point of the right target compared to the left target. (Figure 17). For cued validity in the z-axis, there was a significant effect target location, $F(1, 11)=5.65$, $p=0.03$ (Figure 18). In this case, participants were closer to the left target centre compared to the right target centre. Also, there was trending pattern in the x-axis for condition and cue validity that did not reach the set level of significance, $F(1, 11)=4.49$, $p=0.057$ and $F(1, 11)=4.42$, $p=0.059$, respectively.

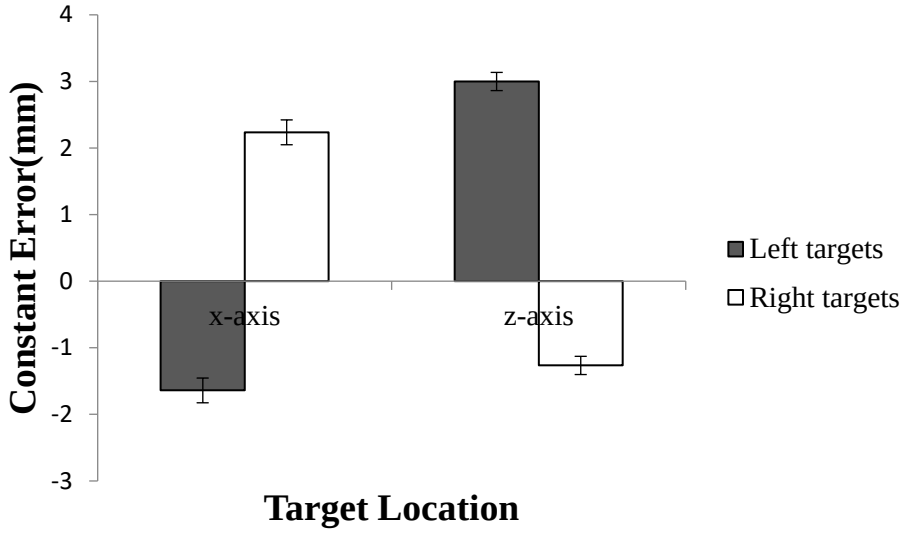

Figure 17. Mean constant error(mm) as a function of target location for cued versus uncued targets in the x-axis and z-axis. Error bars shows SEM.

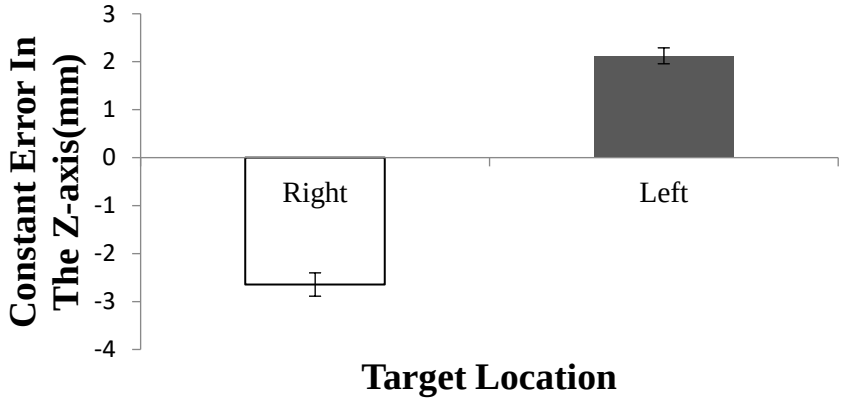

Figure 18. Mean constant error(mm) as a function of target location for cue validity in the z-axis. Error bars shows SEM.

Variable Error

The measure of endpoint variability (VE) in the x-axis revealed a trending pattern between condition, validity, and target locations that did not reach the set level of significance, $F(1, 11)= 4.36$, $p=0.06$. In the z-axis, there was also a trending pattern for validity that did not reach the set level of significance and $F(1, 11)= 4.09$, $p=0.067$

4.2.1.4 *Movement trajectory analyses*

The analysis of valid cue versus invalid cue revealed only a significant effect of percent of MT points, $F(5, 50)= 17.29$, $p<0.0001$. Again, this was expected as participants moved from one point to the other as opposed to a stationary object. As such, there was no significant difference between valid and invalid cues. The analysis of uncued targets versus valid-cue target was significant for target locations, $F(1, 11) = 129.2$, $p<0.0001$, percent MT points, $F(5, 55)= 16.02$, $p<0.0001$, target location by movement time interaction, $F(5, 55)= 375.9$, $p<0.0001$, and condition by target locations by percent MT points interaction, $F(10, 110)= 5.34$, $p<0.0001$ (Figure 16). Post hoc analysis of the interaction revealed that uncued right and left target trajectories were different from 60% of the MT, while for right and left valid cued (exogenous+ endogenous and exogenous) trajectories were different from 30% of MT as seen in Figure 19.

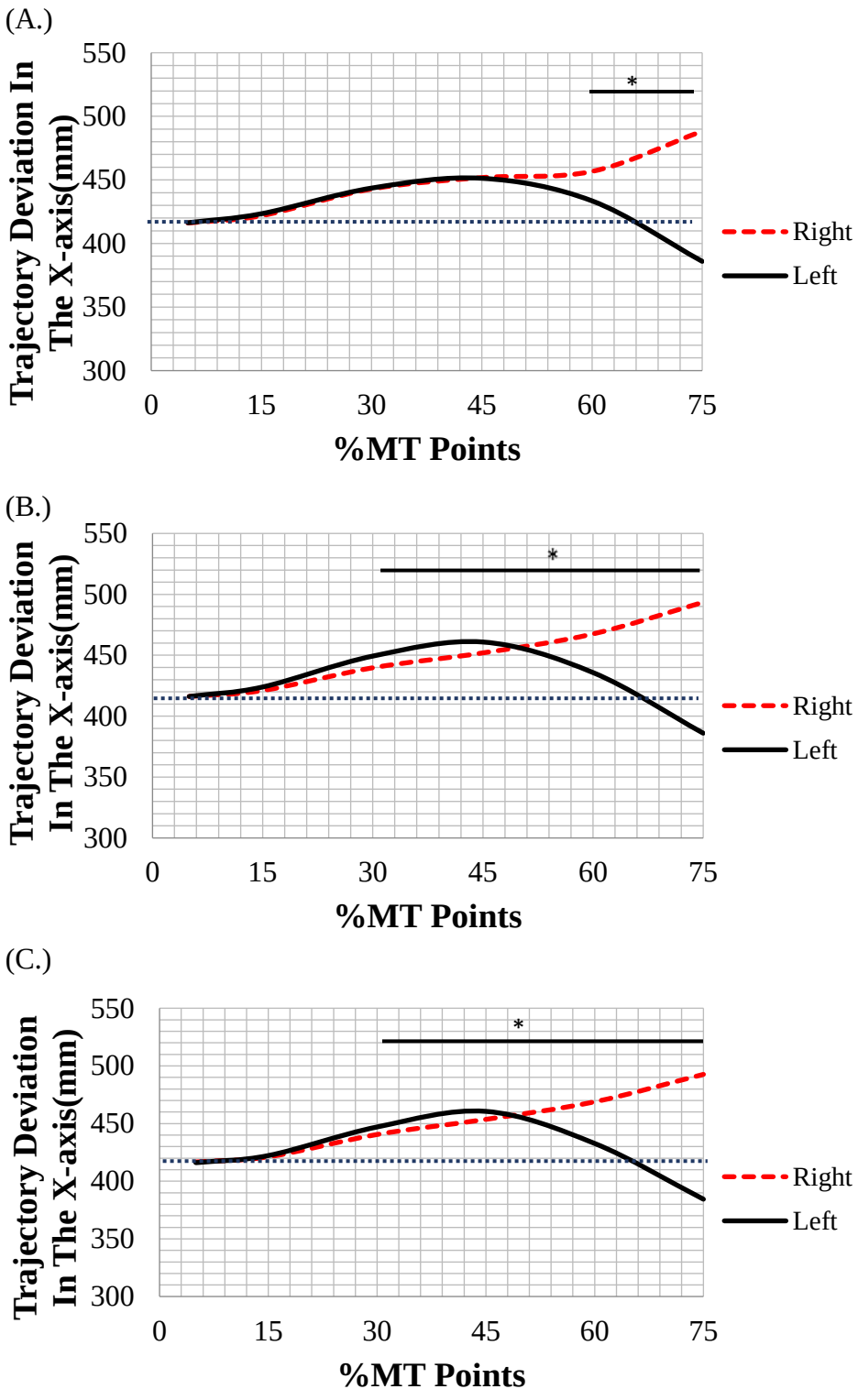

Figure 19. Mean trajectories deviations in the horizontal axis as function of percent movement time points.* indicates significant difference (α=0.05).(A) Trajectory path with neutral cue. (B) and (C) Trajectory path with lateralized valid auditory cue under endogenous + endogenous and

exogenous conditions respectively. In all conditions, the average starting (midline position) position was at 417mm (±4mm) in relation to the displacement in the x-axis.

4.2.1.5 *Discussion*

As was stated earlier, the goal of the second experiment was to investigate if the pattern of behaviour observed in the first experiment was solely due to cross-modal attention. As was predicted, there was no difference in RT regardless of condition and target locations signifying that participants used a similar movement planning strategy since they were forced to initiate their movement before the final position was unknown for 200ms after movement initiation. It would, as was observed in the first experiment, be strategically efficient to plan the movement in a way that would be less costly when making online corrections. That is, the presence of partially encoded motor plans (Chapman et al., 2010) to each location in space makes switching of the movement goal to be highly rapid and efficient. Again, this finding is consistent with previous evidence provided by researchers that have looked at the behavioral outcome such as reaching (Chapman et al., 2010) and eye movement (Arai, McPeek, and Keller 2004) and neuronal region (subcortical region), such as the superior colliculus, (McPeek and Keller, 2004) in decision making when confronted with multiple targets. For instance, in the study of Arai and colleagues, they recorded saccade movements in two male rhesus monkeys that were presented with a single target, or multiple targets. The authors reported that that there was an increase in curvature when presented with multiple distractors compared to a single target. In other words, the trajectory deviation may have reflected partial planned action to the distractors that were presented with the actual target. However, that effect decreased when distractors were eight and sixteen. The latter finding is consistent with what was reported in the study by Gallivan and colleagues (2011), in which participants were required to reach as opposed to perform eye movements to a target in the

presence of distractors ranging from ratio 2:0, 2:4, 2:5, and 2:8 on the right and left side respectively. They found that participants were biased toward the location of four targets and the bias diminished beyond this number. Meaning that,the bias found in both studies when limited numbers of distractors were presented could be as a result of the total number of competing motor plans that can be processed at a point in time (capacity limit).

A right target advantage in terms of MT was observed regardless of cuing in the present experiment. The magnitude of the advantage (right target) was greater with lateralized cues compared to bilateral cues. Again, according to previous research, there is tendency for rightward bias that is biomechanically mediated (Carey, Hargreaves, and Goodale, 1996; Chapman et al., 2011) as explained in the previous session. On the other hand, less time was spent to peak velocity to left targets. A smaller percentage of MT that was used to achieve peak velocity could be an indication of inefficient planning process. Based on these points, it would be contrary to the argument that biomechanical factors are responsible for the right hemispace advantage that is seen in manual asymmetry. In other words, if the left cerebral hemisphere is not at advantage (efficient planning), then we should not have observed more time to peak velocity and a larger percentage of MT to reach to the right target compared to the left target. Again, in accordance with our results, the likely argument is that right target advantage may be due to the added effect of both the biomechanical and interhemispheric factors. Although, a slight difference in end-point performance was seen between the right and the left targets. The observed difference did not provide meaningful information as participants always landed within the target (10mm x 10mm), but were few millimeters short of the target centre.

Lastly, the trajectory data provided evidence that the presence of the lateralized auditory cues caused participants to deviate toward the direction of the cue compared to reaches made to

targets in the presence of bilateral cues. This was expected as a result of the auditory cue being spatiotemporally congruent with the presentation of the visual target. The finding is consistent with the multisensory integration literatures, where it has been established that when unimodal sensory information are integrated, the outcome is sensory enhancement, defined as an increase in performance in terms of shorter RTs (Van der Burg et al., 2008; Keetels and Vroomen, 2011; Van der Stoep, Van der Stigchel, and Nijboer, 2015) and smaller error in endpoint performance compared to unimodal stimulus (Khanafer and Cressman, 2014). For instance, in the study by Van der Stoep and colleague (2015), for instance, participants had to detect auditory, visual and audiovisual targets presented to the right and left of a fixation cross and in response to the cues they were required to press a button as quickly as possible. As hypothesized, responses were faster to audiovisual targets compared to unisensory targets. With that said, despite the fact that the secondary stimulus was presented after movement initiation in the present study, participants still responded by deviating as early as 30% of MT compared to 60% of MT that was observed with bilateral cues. The possible argument would be that participant knew the bilateral cue was uninformative such that the strategy used was to rely on vision alone. Thus, early trajectory deviations (30% of MT) seen in this experiment indicated that the presentation of a random auditory cue influenced spatial averaging behaviour that was seen in the absence of a neutral cue. In addition, deviations occurred earlier than what was observed in the first experiment. The importance of the latter finding is that the same process could not have been responsible for different outcomes (trajectory patterns). In other words, multisensory integration could not have been responsible for what was observed in the first experiment.

CHAPTER 5

5.1 General Discussion

The main purpose of this thesis was to examine the effect of covert auditory attention in a complex environment that humans are typically presented with. Strategically, we looked at how the presence of an auditory stimulus affects spatial averaging behaviour. In other words, based on what has been reported in the literature (Chapman et al., 2010), whenever we are confronted with multiple objects and we are yet to make a decision about what to reach for, we do so by reaching to the midpoint of all the possible options. We do this to ensure that the final decision to any of the objects can be made rapidly and efficiently. As well, previous studies have shown that the process of making that decision can be affected by attention (Rizzolatti, Riggio, Dascola, and Umilta, 1987; Tipper, Lortie, and Baylis, 1992; Cisek, 2007). Therefore, an important question was how the presence of a random sound would influence or capture attention in a way that reduces spatial averaging behaviour. In the first experiment, since the target location was unknown for 200ms following movement initiation, we predicted that RT would be the same regardless of cuing. In addition, we predicted that if attention and action are linked, the presence of the lateralized (exogenous and endogenous + exogenous) cues would reduce spatial averaging behavior in a way that trajectory deviation would be observed early in the movement compared to the presence of a neutral cue. We also predicted that there would be no difference between valid lateralized cues compared to invalid lateralized cues in terms of trajectory deviations because we were only interested in the initial stage of the deviation and not the entire trajectory. Due to addition of exogenous to the endogenous condition, we predicted that trajectory deviations would be earlier compared to the exogenous condition alone. On the other hand, in the

second experiment, on the other, we predicted similar outcomes except that the trajectory deviation in the second experiment would be observed later compared to the trajectory deviation in the first experiment. With a few notable exceptions, such as the insignificant effect of lateralized endogenous+ exogenous compared to the exogenous cues; overall the results of the current study were consistent with our predictions.

Variables	Experiment 1	Experiment 2
1. RT(ms)	Endo+exo vs exo	None
2. MT(ms)	Faster to the right targets	Faster to the right targets and Endo+exo condition.
3. ttPV(ms)	None	To the right targets
4. %ttPV	Greater % to the right targets	Greater % to the right targets
5. Movement Trajectory	Spatial averaging and deviation as early as 45% of MT	Spatial averaging and deviation as early as 30% of MT

Table 1: Dependent variables: Experiments one and two.

Despite the consistency in the amount of information provided before movement initiation), a longer RT in the first experiment was observed for movements to the left target in the endo+exo condition (regardless of validity; see Table 1.). Apart from this result, in general, our first prediction was supported by the consistency observed in RT regardless of the conditions. In other words, participants used a similar planning strategy regardless of the presence of a neutral cue or predictive and non-predictive lateralized cues. Considering the fact that two critical factors for a successful execution of the goal were unknown (actual target and its location) by the participants, it made sense that they were always using the same strategy, at least

before any other sensory stimuli that could be informative was presented or available. Unequivocally, evidence from various studies over the years have shown that the initial stage of the movement is preprogrammed in advance of movement initiation and is dependent on the sensory information presented at that point in time (Woodworth, 1899; Keele and Posner, 1968; Mieschke et al., 2001; Hansen et al., 2006; Glazebrook et al., 2016). In other words, sensory input present or presented before any muscle contraction will determine the RT and the initial stage of the movement. For example, in the study of Glazebrook et al. (2016), participants were required to reach to the location of either an auditory or visual target and their RT was recorded. They found that reaches made to visual targets were faster (shorter RT), attained higher peak velocity, and spent less time doing so compared to those made toward the auditory targets. Meaning that the participants engaged in more efficient planning processes not just because they knew where the target was but also, vision provided superior information for movement planning than audition. Similarly, studies that looked at the presence or absence of vision have found that humans tend to spend more time planning movements (longer RT) in the absence of vision compared to when vision was available (Hansen et al., 2006). Intuitively, if we think about sudden loss of light while walking, we slow down the pace of our movements and critically think about the next step to make. Therefore, since the cues were presented at movement initiation regardless of the condition in our study, such information would not be of any significance for premotor planning processes, despite the fact that they were aware of it. In addition, it was a very rapid movement task and four targets were presented without knowing the final location until 200ms following movement initiation. Thus, it would be efficient to plan their movement in such a way that takes the uncertainty into consideration.

Moreover, in both experiments, there was right target advantage as participants spend lesser time reaching to the right targets compared to the left targets, regardless of condition. What is responsible for the right hemispace advantage over the left hemispace is still an ongoing debate. Some researchers attributed it to biomechanically consequences (such as muscle group recruitment and the displacement of the COM) of reaching to the contralateral space (Carey, Hargreaves, and Goodale, 1996; Chapman et al., 2010), some have argued that it is due to interhemispheric processing of objects in the contralateral space (Fisk and Goodale, 1985; Carnahan, 1998). In the current study, even if we assume they were always planning toward the right targets, the absence of RT advantage to any of the targets regardless of location that was seen in both experiments provides a plausible explanation for the former. That is, if the right target advantage was a function of interhemispheric processing due to the fact that the left hemisphere play a significant role in the organization and control of voluntary movement (Mieschke et al., 2001), then we should have observed RT differences. As explained in the previous sessions, on the other hand, the location of the left targets in our study might have required some level of horizontal shoulder adduction in addition to shoulder and elbow extension that would have been required to the right target. Alternatively, the larger percentage of time to peak velocity that was observed to the right targets in both experiments would be an indication of more efficient planning processes. This is, of course, contrary to the biomechanical theory and more consistent with the interhemispheric theory. Therefore, our observation can be explained by both hypotheses. Whichever the case, more research will be required to distinguish the process that is responsible for the right hemispace advantage.

The presentation of both bilateral and lateralized cues did not influence spatial averaging behavior as participants aimed toward the middle of the targets until they made the decision to

reach to the appropriate target. The spatial averaging behavior was supported by the similarity in RT that was evident regardless of condition. That is, the initial planned process was to aim toward the middle of the target and later make necessary adjustments since the final goal of the movement was unknown for 200ms. The finding is consistent with what has been reported in previous studies (Chapman et al., 2010, Arai, McPeek, and Keller 2004; Gallivan et al., 2011), and provides support for the idea that the visuomotor system can create parallel processing of multiple motor programs (Cisek, 2007), and the suppression of an unwanted motor program being a function of time (Chapman et al., 2010). In other words, if there was enough time to completely suppress motor programs to distractors, spatial averaging will not be observed. In the case of the current study, there was no time to suppress other motor plans as the participants lacked the most crucial information (targets' relative and absolute locations for 200ms) needed to efficiently execute the action. Therefore, in order to efficiently home-in on the correct target, it would be strategically imperative to aim toward the middle of the four targets. Such strategy would have ensured that the magnitude of error corrections toward the location of the target is minimized, because a consistent distance is travelled to any of the targets and the corresponding amount of energy used by the muscle is also minimized (Elliott and Khan, 2010).

More importantly and as was expected, the trajectory pattern in the two experiments (Table 1.) was consistent with our prediction that the magnitude of spatial averaging behavior would be less in the presence of lateralized cues compared to the neutral cue. We did observe that the participants deviated earlier toward the direction of the lateralized cues in both cases. Moreover, we did not observe any differences between the trajectories of the valid and invalid lateralized cues in both experiments as was predicted. Based on the above, there are two important points to be noted in both experiments; in one instance, participants displayed spatial

averaging behaviour until appropriate information was received, which could have been from the auditory cue, visual cuing of the target, or both. In another case, the presence of the lateralized auditory cues caused the participants to deviate early compared to when the cue was neutral.

To the second point, in the first experiment, I argued that the deviation seen was due to the intimate link between attention and action. That is, the presence of the random cue did capture attention toward the location of the cue, thereby affecting the action. Interestingly, the pathway that is involved in visual guidance of action (posterior parietal cortex), according to Goodale and Milner (1992), has also been shown to be modulated by attention (Colby and Goldberg, 1999; Bisley and Goldberg, 2003). For instance, in the study of Bisley and Goldberg (2003), two monkeys were required to make saccadic eye movement to the location of a target in the presence of a cue that was presented at the location of the target (valid cue) or contralateral to the target (invalid cue). They then measured the activity of 41 neurons in the lateral intraparietal region of the posterior parietal cortex (PPC). The authors found a correlation between activityin those cells with improved saccade performance when a cue preceded the target. Therefore, the double (action and attention) function performed by the PPC may explain the early trajectory deviation with lateralized cues compared to the informative bilateral cues in the current study. In addition to our argument, the 200ms CTOA that was used in the current study is consistent with the temporal interval used in previous studies that have reported presence of covert intramodal attention in audition (Spence and Driver, 1994) and cross-modal attention between audition and vision (Spence and Drive, 1997; Farah et al., 1989; McDonald and Ward, 2000). For instance, in one of the series of experiments by Spence and Driver (1997), twenty subjects were required to respond to a visual target at one of four locations (two visual targets on each side) by pressing the farthest key for upper target position regardless of side, and nearest key for targets from

either of the lower positions regardless of side. The auditory cue was presented for 100ms after which the target was presented at 0ms, 100ms, and 600ms (SOA of 100ms, 200ms, and 700ms). In terms of RT, the results showed that visual target elevation judgement was faster if the target was preceded by the auditory cue, particularly at SOA of 100ms and 200ms.

In the second experiment, however, I argue that the trajectory deviation that was observed was due to the presentation of the lateralized auditory cues in close proximity with the target. As such, audiovisual integration would have taken place. In other words, the 70ms CTOA that was used in the current study is consistent with the study of Stevenson et al. (2012) who examined the temporal and spatial factors that could affect audiovisual integration. In their study, the authors required participants to detect if visual, auditory or audiovisual targets were synchronous, asynchronous, visual only, auditory only, or there was no stimulus. In the audiovisual condition, auditory and visual target temporal offset were parametrically varied at 0, 70, 120, and 220ms. They found that response time (ms) was fastest at 0ms, followed by 70ms and slowest at 220ms. Therefore, in the current study, the presentation of lateralized auditory cues would have fallen into the time window for integration (Diedrich and Colonius, 2004, 2008) resulting in the modulation of the extent of spatial averaging behavior that would have been observed otherwise. The latter argument is extensively supported by several studies that have looked at the facilitation of responses with audiovisual integration as opposed to unimodal stimuli (Staufenbiel et al., 2011; Glazebrook, Welsh, and Tremblay, 2016; Molholm, Ritter, and Foxe, 2004). For instance, in the study Staufenbiel et al. (2011) found that when participants were required to make a button press in response to an abrupt change in a visual stimulus (random moving white dot), performance improved when the visual stimulus was presented at the same time with 1000 Hz tone pip. Similarly, Molholm and colleague (2004) had participants respond to a target

animal that could be presented visually, auditorily, or audiovisually. They found that response times were faster when presented audiovisually compared to unimodal presentation (visually or auditorily).

Contrary to our last prediction that trajectory deviations would be observed later in the second experiment compared to the first experiment, the deviations were in fact observed earlier. This finding is surprising because the time at which the cue was presented in the first experiment was 130ms earlier than when the cue was presented in the second experiment. Despite the fact that the time at which the target was presented remained constant (200ms after movement initiation). Logically, we thought the former cue should have been used earlier as the only informative stimulus about the direction of the target that was still unknown. This was not the case as the cue that was produced 130ms into movement initiation resulted in earlier deviations than the cue produced at zero milliseconds into movement initiation. While it was not what was expected, it is interesting because it may provide some clue or disentangle the argument concerning the difference between multisensory integration and selective attention. Specifically, does it mean that multisensory integration does occur preattentively (Spence and Driver, 2000)? That is, the brain would have already processed the perception of two stimuli as one before attention was captured. Based on the results of this study, if cross-modal attention and multisensory integration were to be the same process, at least, there should not have been any obvious differences between the trajectories across the two experiments. However, the late trajectory seen with cross-modal attention compared to multisensory integration is indicative of the amount of time (about 200ms) needed for crossmodal attention to be shifted (Spence and Driver, 1994) to the cue location in order to facilitate the processing of the visual target. On the other hand, consistent with previous studies, multisensory integration had occurred with

subsequent trajectories that had taken place before crossmodal attentional shift (McDonald et al., 2001; Vroomen, Bertelson, and de Gelder, 2001; Soto-Faraco, Navarra and Alsius, 2004). For instance, in the study of Mcdonald et al. (2001), participants were required to detect auditory targets (right or left) that were presented from one of four speakers (two each on the right and left). Before the auditory target, a multimodal (audiovisual) cue was presented at 100ms, 200ms, and 700ms. Participants were faster in localizing the direction of the target if preceded by the multimodal cue at 100ms. This suggests that spatial attention was reflexively oriented to the location of the target following audiovisual integration. Thus, results from the current study and previous studies provide evidence that multisensory integration, in this case audiovisual integration, can occur preattentively and as such, are two different processes.

5.2 Limitations of the Study

In the current thesis, we identified some limitations that could have had a potential effect on the results of this study. First, our manipulation of endogenous+exogenous might have not been sensitive enough to get the beneficial effect of the two processes in one condition. Such that the CTOA (200ms) used in the current study was not long enough to engage endogenous attention, despite the fact that participants knew in advance about the predictability of the cue in the endogenous +exogenous condition. For instance, in some of the series of studies carried out by Spence and Driver (1994), they found that engaging exogenous and endogenous by highly predictive cue (75% chance) resulted in cuing effect with valid cues. However, when it was changed to highly no-predictive cues (75% chance), there was no effect of cuing with invalid cues. This may explain why we have not found a significant difference between the conditions in almost all of our variables. Secondly, the number of trials (240) is a large number of similar trials.

As such, there is a possibility that the participants became bored and their attention was not engaged.

Lastly, we did not monitor gaze behaviour directly. Therefore, we cannot objectively determine if participants did engage overt attention (eye movement). However, studies that have compared two groups of participants did not find any difference between those whose gaze were monitored compared to those that were told to maintain centre fixation on the computer screen throughout the trials (Butchel and Butter 1987; Spence and Driver, 1994).

5.3 Future Directions

Based on limitations I observed in the current study, future studies should examine the absolute difference between exogenous and endogenous auditory attention by a longer CTOA should be used in order to ensure that the voluntary attention is captured as opposed to the possible short CTOA that was used in the current research. This will provide further support for the distinction that exists between exogenous and endogenous auditory attention.

Furthermore, future studies should examine how covert auditory attention may affect more complex processes such as reaching to grasp movement in multiple target aiming. This is important because reaching to grasping in laboratory experiments is a complex task this related to the ecological component of daily activities. How attention may affect these processes is paramount in understanding some of the limitation humans face on a daily basis.

In addition, future studies should examine the possible changes in covert auditory attention throughout the life span by comparing different age groups. Again, this may provide a window into how attention changes with age. For instance, would changes in attentional span

affect postural adjustment in older adults? Since some of the sensory stimuli that may capture attention will likely inform (sensory integration) postural adjustment to perturbations.

Lastly, due to the availability of more sophisticated eye tracking devices, future studies should examine a possible contribution of overt attention in covert auditory attentional studies. For instance, some of the studies that have looked at this factor were done about two decades ago and so were the instruments used. Newer gaze trackers allow for reaching movements to be performed while the gaze is being tracked. This will provide more robust support for the presence of covert auditory attention in humans.

5.4 Conclusions

One of the objectives of this study was to examine if covert auditory attention can influence complex human behaviour. Based on the results of the current thesis, the effect of cuing manifested in the participants' movement trajectory pattern, as deviations occurred with lateralized cues. Meaning that, we were able to show that the presence of covert auditory attention can influence action. This finding is important if we think about the current level of automobile technology and the perceived need for highly sophisticated in-car technology such as navigation systems, and the resulting constant inundation of auditory and visual information. The importance of knowing more about how this stream of information may affect driving performance, which is primarily a visual task, cannot be over emphasized. In addition, with classroom laptop use, could there have been a long standing effect of keypads sound on the ability of another student picking up necessary information from a lecture? That question may be true based on the survey report of Fried (2008). In the study, students reported that "other students' computer use' accounted for the greatest distractor during lecture. Interestingly, in

another survey study (Borbone, 2009); students reported that the distractions caused by "other students' laptop use" were equally due to "keyboard tapping" and "curiosity". It is worth noting that this studies were surveys and did not provide the underlying mechanism responsible for the distraction, neither did they provide an objective measure of the distraction. Contrary to the second objective of this thesis, the results obtained from the exogenous plus endogenous compared to the exogenous covert auditory attention conditions did not show any difference in terms of the effect on complex human behavior, such as goal-directed movement. As explained in the limitations section, it may be that our manipulation of endogenous covert attention was not sensitive enough to direct voluntary attention. On the other hand, it brings into question if there is an actual difference between covert exogenous and endogenous attention (Spence and Driver, 1994).

Irrespective of what may be the difference between endogenous and exogenous covert attention, the rapid reaching paradigm (Chapman et al., 2010) used in this thesis provided a unique window into online decision making in the visuomotor system. Of interest is that the presence of covert auditory attention modulated the behavioural outcome of the visuomotor system. Specifically, the trajectory deviations occurred earlier compared to the baseline conditions, and with the specific timing depending on the relative time of the auditory cue.

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APPENDIX 1

INFORMED CONSENT -

The Effect of Cross-Modal Auditory Attention in Multiple Target Aiming: Kinematic Evidence

Principal Investigator: Dr. Cheryl Glazebrook
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oladokub@myumanitoba.ca

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

PURPOSE: We are interested in learning how auditory attention affects movement planning processes when reaching to multiple targets.

DESCRIPTION: During the study, you will be asked to make a series of pointing movements to target in front of you. An OPTOTRAK 3-D motion analysis system will be used to record your hand movement. Prior to this task, you will be asked to fill out a brief demographics questionnaire that inquires about your age, gender, handedness, whether or not

your vision and hearing are corrected (glasses, contact lenses, hearing aids). The whole procedure will take 60minutes to complete.

RISKS AND BENEFITS: There are no evident risks inherent in the tasks you will perform but some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in your arms. While this may be frustrating, the investigator with you will provide breaks throughout and you may request a break at any time.

Your participation in this study will help us to investigate the role or impact of auditory attention when planning movement to potentially competing targets.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. However, you will receive a small honorarium for your participation.

CONFIDENTIALITY: Your information will be kept confidential. Once you begin the study your name, information, and results will be referred to by a code number. All files containing identifying information will be stored in a locked cabinet separate from data with your code number. Your files will only be accessible by the investigators and will be destroyed by Dr. Glazebrook seven years after the completion of the study (approximately June, 2024). All papers containing personal information will be shredded. All electronic files will be deleted. Any CDs or DVDs containing data will be physically destroyed. Only Dr. Cheryl Glazebrook and the student research assistants listed will have access to any lists that contain identifying information.

DEBRIEFING: Upon completion of the study the experimenter will describe the research questions being considered. If the participant would like to know the results of the study please indicate 'yes' on the consent form where indicated and the student research assistant will contact you with a summary of the findings in approximately 4 months.

VOLUNTARY CONSENT: If the participant *does not wish to participate* in the study or wishes withdraw from the study, you are free to leave without consequence at any point in time and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial

consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you will still receive compensation for the time you have participated. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

A copy of this consent form has been given to you to keep for your records and reference.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca.

INFORMED CONSENT

Research Study: The Effects of Cross-Modal Auditory Attention in Multiple Target Aiming: Kinematic Evidence

Participant's Name_____

Signature of Participant_____ Date _____

Researcher/ Delegate's Signature _____Date _____

SUMMARY OF FINDINGS: Would you like to be contacted by a student research assistant with a summary of the overall findings of this study? □ YES □ NO

If yes, please complete the following:

Name: _____

Phone Number: _____

Email Address: _____

APPENDIX 2

UNIVERSITY OF MANITOBA | Research Ethics and Compliance
Office of the Vice-President (Research and International)

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AMENDMENT APPROVAL

October 14, 2016

TO: **Cheryl M. Glazebrook**
Principal Investigator

FROM: **Zana Lutfiyya, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2012:075 (HS15612)**
"Multisensory-motor Integration: the Impact of Sight and Sound on Reaching Movements"

This will acknowledge your Amendment Request dated October 14, 2016, requesting amendment to your above-noted protocol.

Approval is given for this amendment. Any further changes to the protocol must be reported to the Human Ethics Coordinator in advance of implementation.

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RENEWAL APPROVAL

October 14, 2016

TO: **Cheryl M. Glazebrook**
Principal Investigator

FROM: **Zana Lutfiyya, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2012:075 (HS15612)**
"Multisensory-motor Integration: the Impact of Sight and Sound on Reaching Movements"

Please be advised that your above-referenced protocol has received approval for renewal by the Education/Nursing Research Ethics Board. **This approval is valid for one year and will expire on October 18, 2017.**

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Coordinator in advance of implementation of such changes.

APPENDIX 3

Demographics Questionnaire

Participant Number: _____

Age of Participant: _____ Gender (check one): Male ☐ Female ☐

Dominant Hand (check one): Right ☐ Left ☐

Vision (check one): Normal ☐ Corrected to Normal (contact lenses/eye glasses) ☐

Hearing (check one): Normal ☐ Corrected to Normal (hearing device) ☐

Is there any history of neurological or orthopedic injury in the last year? Yes ☐ No ☐

Is there any history of neurological or orthopedic surgeries in the last year?

Yes ☐ No ☐

Participant #	Age	Gender	Handedness	Vision- Normal or Corrected	Experiment
P001					
P002					
P003					
P004					
P005					
P006					
P007					
P008					
P009					
P010					
P011					
P012					
P013					
P014					
P015					
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P018					
P019					
P020					
P021					
P022					
P023					
P024					
P025					
P026					
P027					
P028					

APPENDIX 4

Research Study:

The Effect of Crossmodal Auditory Attention in Multiple Target Aiming:

VOLUNTEERS NEEDED

Purpose of Study:

To explore movements made to multiple targets in the presence of auditory information.

Study Details:

For this task you will point to targets on a computer monitor. We will measure hand movements using small sensors placed on your right index finger. The study should take 60minutes of your time. A small honorarium will be provided.

Testing will take place in room 238, Investors Group Athletic Centre, Fort Garry Campus, University of Manitoba.

Seeking males and females between 18 and 40 yrs old

How will your participation help?

Your participation in this study will help us to better understand how attention may influence movement planning process when making the decision to reach to competing targets

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@myumanitoba.ca

Contact Information:

Contact: Bayonle Oladokun
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Research Study
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