LINKAGES BETWEEN AUDITORY PERCEPTION AND ACTION: ACOUSTICAL FACILITATION OF MOTOR RESPONSES.

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Summary

In our everyday lives we often have to respond quickly to events in the world around us. This thesis examined whether task-irrelevant, moving auditory stimuli facilitated context-appropriate motor responses. The experiments followed the same general methodology: participants responded to a visual target (a box on the screen) which was sometimes accompanied, or preceded, by a moving broadband auditory stimulus. For the experiments in Chapter 2 the auditory stimulus started in one hemifield and moved to the other. The results indicated motor responses were facilitated when the auditory stimulus was moving azimuthally, to a greater degree than when it was static, but only when the direction of the auditory stimulus was opposite to that of the response (incongruent) and only for Experiment 2. Chapter 3 further examined this facilitation, whilst restricting the movement of the auditory stimuli to either the left or right hemifield. The results indicated facilitation from bi-modal presentations, particularly when responses were towards the hemifield the auditory stimulus was presented in. Experiments 3 - 6 indicated responses were facilitated when the auditory stimulus and the required motor response moved in the same direction. Finally, Chapter 4 utilised looming auditory stimuli to test whether they led to greater facilitation than that observed in Chapter 3. The results indicated looming auditory stimuli facilitated responses relative to receding or static stimuli. There was also facilitation from bi-modal presentations over their uni-modal counterparts, particularly when the responses were towards the hemifield the auditory stimulus was presented in. There was facilitation when the auditory stimulus moved in the opposite direction to the required response, compared to static, though only in Experiments 7 and 11. This thesis suggests that motor responses can be facilitated by task-irrelevant, moving, particularly looming, auditory stimuli and may be of benefit in tasks that require quick responses.

CHAPTER ONE

1.0 INTRODUCTION

In a person's everyday life there are times in which they have to make a quick physical reaction to changes in their environment, such as a person driving a car having to react to the vehicle ahead of them braking sharply, or an air traffic controller responding to the warning of an imminent mid-air collision. Many factors can influence the time it takes a person to make these reactions. One such group of factors are the properties of the stimulus conveying the environmental change. For instance, if the tail lights of the car braking in front of the driver are dim it may take longer for the driver to see them come on than a bright set, which could lead to a crash. If the impending collision alarm for the air traffic controller was too quiet it may be missed if the controller was in an environment with large amounts of background noise. To improve the chances of a stimulus leading to faster responses, changes can be made to its properties, such as increasing the brightness of a light or increasing the volume of a sound. Another way in which reaction times can be improved is by presenting a stimulus with properties that facilitate the required motor response. ‘Facilitate’ in this sense would be to improve the ease and speed at which a motor response is executed. Thus if a stimulus naturally conveys the required motor response, this could lead to faster reaction times than a stimulus that does not contain this information.

Before going any further it may be helpful to outline this chapter's structure. First, a review of the literature on the facilitation of motor responses by visual stimuli is presented. From this the focus of attention will move to the automatic facilitation of motor responses by visual stimuli. The term ‘automatic’ is defined as a pre-attentive process, i.e., one that takes place before conscious attention has been directed at it. Therefore ‘automatic facilitation’ is the process in which a pre-attentive stimulus improves the ease and speed at which a motor response is executed.

From the visual domain the next section of this introduction will cover facilitation by auditory stimuli, as well as automatic auditory facilitation. There will be a review of the effects of bi-modal stimuli followed by task-irrelevant, bi-modal stimuli. Once these areas of previous research have been discussed the final section of the chapter will outline the experiments that will be reported in more detail in Chapters 2 to 4.

1.0.1 Visual Facilitation

Moving visual stimuli have been shown to facilitate motor movements in a choice task. Michaels (1988) had participants responding to a moving visual stimulus, a square, by manipulating two joysticks, one in each hand. The visual stimulus moved either from the left to the right of a computer screen or vice versa. Participants were required to move either the left or the right joystick depending on which visual stimulus was presented. The results suggested that participants were significantly faster to respond when the visual stimulus was moving towards the responding hand rather than away from it. This suggested that the moving visual stimulus facilitated a faster response in the hand that could be considered as interacting with the visual stimulus.

Other research investigating the use of visual stimuli to facilitate motor responses has been conducted using more ecologically valid stimuli to see if these also have a beneficial effect on motor responses. Tucker and Ellis (1998) asked participants to judge the orientation of objects that a person would likely interact with during a normal day, such as saucepans and teapots. These everyday objects were presented to the participant either in their normal orientation or in an inverted orientation, i.e., a teapot sitting on its base or inverted to be sitting on its lid. In each of these presentations the handle of the object was either pointing to the right or pointing to the left. Participants responded to the object with either their left or right hand depending on its orientation. The results showed that participants were faster when the task-irrelevant handle of the object was pointing towards the responding hand than if it was pointing in the opposite direction. This was taken to show that the congruency between hand and handle facilitated a participant's response to the object.

Phillips and Ward (2002) expanded upon these results and showed that facilitation was not limited to motor responses involving the hand. They had participants perform a left/right response task to a visual target, but before the presentation of the visual target the participants were exposed to a visual prime. This prime was a frying pan with its handle orientated to either the left or the right. The manner in which the participants responded was split between three different methods. In the first method the participants pressed a left or right button with the corresponding hand, i.e., the left button was pressed with the left hand. The second method required them to press the buttons with their hands crossed, i.e., the left hand pressed the right button. The final method involved them responding with their feet, i.e., a left response required the left foot to press a left foot pedal. The results showed that the participants were faster to respond to the visual target if the handle on the visual prime pointed towards the side of the body that was making the response, irrespective of the manner in which the participants responded. This indicated that the facilitation acted as a lateral response facilitation, rather than facilitation to a specific limb. Also, this showed that the facilitatory stimulus did not need to be the stimulus to which the response was required. This indicates that a facilitatory stimulus need not be limited to a specific motor response, and that it does not need to be part of the stimulus that requires the motor response.

Motor response facilitation by visual stimuli does not appear to be limited to just one side of the body either: there is evidence that visual stimuli can be used to facilitate whole body motor movements as well. In a navigation experiment Warren and Whang (1987) created 'doorways' of variable width between two movable partitions that could be moved closer or further away from each other depending on the desired width of the 'doorway'. Participants were then placed in front of the partitions at a distance of no less than 2.2 meters and asked if the doorway in front of them was wide enough to allow them passage without having to turn their shoulders. The results indicated that participants were capable of making such width judgements and this was taken to suggest that the participants could indeed perceive the width that visual stimuli conveyed and thus the suited motor movement. This result indicated that facilitation arising from visual stimuli is not limited to just a single appendage or a single side of the body, these facilitatory effects can be used to guide movements involving the whole human body if necessary.

1.0.2 Automatic Visual Facilitation

In some of the research discussed above it has been shown that the feature of a stimulus that leads to a motor facilitation may be task-irrelevant. This is useful in a real-world context as it means it could be possible to present a stimulus that facilitates a response yet not need specific attention be paid to the stimulus. For example, a pilot of an aircraft that has to perform a specific directional manoeuvre. To perform the manoeuvre the pilot could be presented with visual, auditory or haptic cues informing them which direction the aircraft needs to go. If this information could be presented in a manner in which the pilot did not need to attend to it, yet still be facilitated by it, this would be a desirable effect. This facilitation of task-irrelevant stimuli would be even more useful if the facilitation provided by the stimuli arose automatically. However, there is evidence that this task-irrelevant facilitation may not always arise, automatically.

Tipper, Paul and Hayes (2006) presented participants with pictures of door handles to which they had to respond either to the shape or to the colour of the door handle. The handles were, as with Tucker and Ellis (1998) and Phillips and Ward (2002), either orientated to the left or the right. Participants made their response to the visual target by pressing either the 'a' or the 'l' key on a keyboard depending on the properties of the target they were to monitor. Thus some participants pressed the 'a' key if the handle was square shaped and the 'l' key if it was round shaped. Other participants pressed the 'a' key if the handle was green and the 'l' key if it was blue. In the shape task participants were faster to respond to the visual target when the handle was pointing in the direction of the responding hand while in the colour task there was no effect of handle orientation. This was taken to mean that a visual stimulus conveying motor movements did not always lead to automatic facilitation, but rather facilitation was determined by which aspects of the stimulus the participants were attending to.

There are other studies that have indicated that the facilitating component of a stimulus may still have an effect even if it is task-irrelevant. Grèzes and Decety (2002) recorded participants' neurological activity using a Positron Emission Tomography (PET) scanner while they were shown a series of everyday objects, such as a stove-top espresso maker, colander or frying pan. There were five tasks that the participants were required to perform. The first required indicating whether the object's orientation was up or down. The second involved mentally simulating grasping the object, before indicating if the orientation of the object was to the left or the right. The third task involved silently naming the object before deciding left/right orientation, and the fourth task required silently saying the use of the object before indicating its orientation. The final task involved being shown a non-object for baseline comparisons to the other four tasks; in this task the participant stated whether the non-object was larger on the left- or the right-hand side. It should be noted that in the training section of the experiment the behavioural data replicated the findings of Tucker and Ellis (1998). The main result of the experiment revealed a common pattern of neurological activity in the parietal and pre-motor regions of the brain in all the tasks involving the everyday objects. This is evidence that objects activate the relevant actions they facilitate even if the part of the object is task-irrelevant.

This was supported by Fischer and Dahl (2007) who had participants respond to the change in colour of a visual target with a left- or right-hand motor response. During this task participants were presented with a continually rotating cup with a single handle. The results indicated that when the handle was pointing in the direction of the responding hand participants were faster to respond to the colour change than if the handle was pointing to the opposite hand. This indicates that the handle of the cup was facilitating motor responses even though the cup was task-irrelevant.

On a final note regarding facilitation via task-irrelevant visual stimuli there is evidence that the stimuli may not even need to be perceived to still have an effect. Fellows, Tabaza, Heumann, Klotz, Neumann et al. (2002) had participants perform a lifting task involving an object whose weight could be changed between light and heavy. Prior to lifting, participants were cued as to the weight of the object. When this cue was masked so participants were unable to perceive it, participants still adjusted the amount of force needed to lift the object as dictated by the masked cue. This finding is supported by Mattler and Fendrich (2007) who had participants perform a task in which they had to discriminate the direction of rotation of a moving ring of dots. Before participants were presented with the visual task they were flashed a rotating ring whose speed of rotation was so great they only perceived a solid static ring with no rotation. However, if this rapidly rotating ring was rotating in the same direction as the ring the participants had to make a discrimination about, they were faster to respond than if the ring was rotating in the opposite direction. Both of these studies indicate that a stimulus can be presented subliminally, yet still facilitate a motor response.

So far, it has been shown that visual stimuli can contain information that facilitates an observer's motor responses, be this navigating a passage (Warren and Whang, 1987) or responding to simple moving stimuli (Michaels, 1988) or everyday objects (Tucker and Ellis, 1998). These sensory-motor facilitations have also been shown to take place when the facilitating stimuli are task-irrelevant (Fischer and Dahl, 2007).

1.0.3 Auditory Facilitation

From the day a person is born they are surrounded by sounds, and these sounds can be used to understand and interact with the environment on many different levels. These can range from the sound of a kettle's whistle indicating that the water is boiled and the kettle needs to be taken off the heat, to the sound of a telephone ringing. Both of these sounds help the listener to decide what their next course of action may be: whether to remove the kettle from the hob, or deciding to answer the caller or not. So while auditory information can inform listeners about the environment it can also illuminate possible ways in which to interact with it.

It is possible to extract from sound alone the size (Grassi, 2005), speed (Houben, Kohlraush and Hermes, 2004), length (Carello, Anderson and Kunkler-Peck, 1998), composition (Giordano and McAdams, 2006) and texture of an object (Lederman, 1979). This information is useful from the point of view of facilitation as by knowing these properties of an object it can help a person decide what actions are possible. For example being able to tell the speed of an object might help the listener to decide if it is possible to safely interact with the object or if it would be safer to get out of its way. An example would be the textural auditory warning used to warn a driver they are wandering from their lane on a motorway, i.e., the sound of the road changes from a smooth sounding surface to a rough sounding one as they cross the rumble strip.

Grassi (2005) tested whether it was possible to use the sound of one object impacting on another to estimate the size of the first object. This was accomplished by having participants listen to the sound of various sized wooden balls dropped onto a baked clay plate. The participants' task was to listen to the ball striking the plate then make a size judgement from only the sound it made. It was shown that the participants were able to supply reasonable estimates of the size of the ball just from the sound of its impact.

As well as size, sound has been shown to convey the speed of an object. Houben et al. (2004) presented to participants pairs of recordings of wooden balls rolled across wooden plates. The size and speed of the balls were varied to give pairs that were either different in size, or different in speed, depending on which property was being tested. The results indicated that participants were able to indicate which of the two balls was larger in the size task, and which of the two balls was faster in the speed task.

Carello et al. (1998) produced evidence to show that an object's length can also be inferred from the sound it makes when impacting another object. They achieved this by having participants listen to the sound of wooden dowels of differing lengths being dropped onto the floor. Participants were able to estimate the length of the wooden dowel from its impact sound alone.

Giordano and McAdams (2006) showed that it was possible to identify the material from which an object was constructed by the sound it made when struck. Participants were presented with the sound of either a piece of plexiglass, soda-lime glass, steel or Tanganyika walnut being struck with a pendulum. The participants' task was to state whether the struck object was made of plastic, glass, steel or wood. The results indicated that participants could perfectly identify the material of the struck object.

Along with sound being able to convey the material of an object, it can also be used to communicate the texture of an object. Lederman (1979) presented participants with the sound of a finger running back and forth across metal plates that had grooves cut into them that were positioned at varying distances from each other. The greater the distance between the grooves the smoother the perception of the plate. Participants were able to use the sound alone to make judgements about the roughness of the plate indicating they were able to extract the textural information without coming into contact with the actual object.

Along with judging the properties of an object from the sounds it emits, it is also possible to judge whether an object is within a distance that would allow a listener to interact with it, i.e., the sound conveys whether a physical interaction is possible with the source of the sound. Rosenblum, Wuestefeld and Anderson (1996) had participants judge whether a box that produced a rattling sound could be reached by the participant if they stretched their arm out from where they sat. Participants could not see the box, thus had only the acoustical information to rely upon. Participants were tested with the box at varying distances from their seated position, some reachable others not, and the results indicated that using only the sound of the rattling they could accurately judge reachability.

As mentioned previously it is possible to use visual stimuli to facilitate navigation of the environment (Warren and Whang, 1987) and it appears that auditory stimuli may allow the same motor facilitation. Hughes (2001) conducted a similar study to that of Warren and Whang (1987) in which participants were asked to pass through two panels that could be adjusted to make a passage of variable width. Unlike the visual task, however, participants were blindfolded so they never saw the two panels. Participants were fitted with an echolocation device which they had to use to determine whether the passage in front of them was passable or not. The results indicated that the participants were able to use the acoustical information alone to judge passage passability. This indicates that stimuli do indeed exist in the auditory domain that can facilitate motor movements, and people are able to act upon them accordingly. Adding support to this is a study by Gordon and Rosenblum (2004) similar to that of Hughes (2001). Again participants were brought blindfolded into a room that contained a passage of adjustable width. However, instead of having participants use an echolocation system, a noise-producing loudspeaker was placed behind the passage. Participants were to use the acoustical shadow generated by the panels to judge passage passability. The results suggested that participants were indeed able to use this acoustical information to judge whether the passage was passable or not. Russel and Turvey (1999) showed similar results, however instead of using two panels they used a loudspeaker and a wall. This loudspeaker was placed at varying distances from the wall and blindfolded participants had to judge if they could walk between the speaker and the wall. The results showed that participants could reliably use the auditory stimulus to judge whether this action was possible. It appears that this use of sound to navigate an environment is not limited to only adult participants. Van der Meer, Ramstad and Van der Weel (2008) conducted a study using six to nine month old infants. In their task, infants were presented with an auditory stimulus at four different locations, and the researchers monitored how the infants went about orientating themselves to the sounds.

The results showed that the infants would move their bodies in the manner that required the least amount of motor movement to orientate themselves towards the location of the sound source. This indicates that even from an early age people are able to utilise auditory stimuli to facilitate motor responses.

In relation to being able to use sound to navigate the environment there is research that shows it is also possible to use sound to perform other motor tasks such as the adjustment of a person's gait. Studies by both Fernandez de Olmo and Cudeiro (2003) and Baram and Miller (2007) indicated that participants with neurological disorders leading to walking difficulties could improve their walking ability through the use of auditory stimuli. This was done by providing participants with a steady rhythm to walk to (Fernandez de Olmo and Cudeiro, 2003) or by feeding back the participants' walking pattern as an auditory stimulus (Baram and Miller, 2007). Both of these manipulations allowed the participants to adjust their gaits in a beneficial manner.

Other compelling evidence that auditory stimuli can facilitate motor responses comes from Cabe and Pittenger (2000). Participants were required to fill vessels of different sizes with water while blindfolded. Participants were able to complete this task again using only the acoustical information of the water filling the vessel. It could be stated that the facilitation here was the participants being able to extract the properties of the remaining air space in the vessel and act accordingly to stop it from overflowing.

So far it has been shown how auditory stimuli can be used to facilitate such motor tasks as navigating an environment, or judging whether an object is within reach or not. However, when looking at the literature regarding visual stimuli facilitating motor movements there appears to be evidence indicating that facilitatory effects in certain situations may arise automatically from the stimuli. If there is indeed a form of automatic facilitation by visual stimuli there might be a similar effect in the auditory domain.

1.0.4 Automatic Auditory Facilitation

Evidence supporting the possibility that there may be automatic facilitation from auditory stimuli comes from a variety of sources. Firstly, there is the neuronal evidence that indicates there are direct inter-cortical connections between the primary auditory areas and the motor cortex in a cat's brain (Ermolaeva and Borgest, 1980). While this study was limited to cats, if a similar pattern of connections exists in humans this could indicate that the human auditory system may have direct access to the motor system.

This is supported by examples of auditory stimuli that may use these possible pathways, for example the acoustic startle reflex (Yeomans and Frankland, 1995). The startle reflex is where the body stiffens to protect itself, and loud sudden onset auditory stimuli have been shown to produce this effect. As the startle reflex appears to be generated in an automatic manner, it could be taken as an indication of a direct link between an auditory stimulus and the motor system. This startle effect has also been shown to facilitate reaction times in a motor response task in a study by Walsh and Haggard (2008), in which participants' reaction times to simple visual targets were recorded. On some of the trials the visual target was preceded by a loud auditory stimulus. The results indicated that when the visual target was preceded by the startle stimulus participants were faster to respond than if the visual target was presented on its own.

While the auditory startle reflex is an interesting effect, it is easy to see how this would not be the preferred manner of facilitating a person's motor responses. The auditory stimuli used to generate the startle response are loud, over 100 dB, and constant exposure would be detrimental to a person's hearing. However it appears that it is not only loud and sudden onset auditory stimuli that interact with the motor system. Chen, Penhune and Zatorre (2008) conducted a functional Magnetic Resonance Imaging (fMRI) study in which they played participants a series of musical rhythms. Participants were unaware that they would later be asked to tap in time to these rhythms. The results showed that there were similar areas of activation in the motor cortices when participants listened to the rhythms and when they tapped in time. These findings indicate that there could be a link between the auditory and motor systems, at least for rhythmic sounds.

In this section it has been shown that, as in the visual modality, the auditory modality appears to facilitate motor responses. These facilitatory effects range from helping people to navigate their environment to informing them if possible motor actions will be successful, such as reaching for an object. These facilitations by auditory stimuli appear to work at a similar neurological level as for visual facilitation, and there is evidence that some auditory stimuli may work in an automatic manner as with some visual stimuli.

However it is rare that information is presented to a person in only a single modality. The human body has a number of senses available to it, including vision, hearing, touch, olfaction, etc. Many things in the environment will have a presence in more than one of these modalities. It may be that facilitating stimuli could also be cross-modal. Therefore, in the next section the focus will be on bi-modal stimuli and their facilitatory effect on people's reaction times.

1.0.5 Bi-modal Facilitation

It has been shown that bi-modal stimuli reduce reaction times compared to uni-modal stimuli (Hershenson, 1962; Bernstein, Clark and Edelstein, 1969; Hecht, Reiner and Karni, 2008). The general paradigm of these studies is that participants had to respond as quickly as possible to auditory only, visual only or combined auditory/visual targets. Overall the results indicated that participants were significantly faster to respond to the bi-modal audio/visual targets than the uni-modal, auditory or visual only targets.

It has been suggested that this facilitation effect arises from the reduction in time taken for bi-modal stimuli to be processed compared to uni-modal stimuli. Alpert, Hein, Tsai, Naumer and Knight (2008) conducted an experiment where participants' neurological activity was monitored via fMRI while they were passively presented with visual, auditory or audio/visual stimuli. The activity that these three sets of stimuli generated in the participants' brains was then compared against each other. The results revealed that the audio/visual trials led to shorter latencies in the blood-oxygen-level dependent (BOLD) response than either of the visual or auditory trials on their own. This was taken as an indication that the bi-modal stimuli had facilitated early sensory processing.

1.0.6 Task-irrelevant Bi-modal Facilitation

One finding that has arisen from research into multi-modal stimuli is the suggestion that when there is more than one channel of incoming information, other channels can be treated as task-irrelevant yet still appear to have an effect on responses. This is a beneficial finding as it means that a participant's attention can be kept on a single modality, thus not requiring attentional shifts, yet information presented in that modality can still facilitate responses.

This facilitation by a task-irrelevant stimulus in a modality different to the one where a target stimulus is being presented has been shown in a study by Miller, Franz and Ulrich (1999). Participants performed either a go/no-go or a choice task in response to a set of visual targets. In the go/no-go task they responded to the presentation of one visual target with a key press while the other target required no response. In the choice task both targets required a response and the response, a left or right key press, was determined by the visual target. During both tasks the participants were also presented with a task-irrelevant auditory stimulus. The results indicated that when the visual targets were presented in conjunction with the task-irrelevant auditory stimulus the participants responded with greater force than when the visual targets were presented on their own.

Task-irrelevant auditory stimuli have also been shown to have an effect on reaction times. Doyle and Snowden (2001) reported a series of experiments they conducted in which participants had to respond to a visual target that pointed either left or right. On some trials the visual target was accompanied by a task-irrelevant auditory stimulus. Participants were faster to respond to the visual targets when they were presented in conjunction with the auditory stimulus. This facilitation also appeared to be present irrespective of the location of the auditory stimulus in relation to the visual target. This is useful from the point of view that facilitation may still occur when the location of a task-irrelevant auditory stimulus is incongruent to the position of the target requiring the response.

These findings were supported by a similar set of results in an experiment conducted by Kiesel and Miller (2007). In their task participants were required to perform a simple go/no-go task in which they had to respond to any presentation of a visual target. On some of the trials where a response was required, i.e., a target was present, as well as in some trials where a response was not, the participants were presented with a task-irrelevant auditory stimulus. The results indicated that participants were faster to respond to the visual target if it was presented in conjunction with the auditory stimulus than if it was presented on its own. There was also a replication of the increase in the force of the response that was seen in Miller et al. (1999).

A way in which task-irrelevant auditory stimuli could lead to this effect is reflected in the body of research indicating that these stimuli may work via exogenous attentional capture. This is an automatic process in which a participant's attention is drawn or pushed to an area of interest (Posner, 1980). It has been shown that even in a focused state, task-irrelevant auditory cues can still have an exogenous attentional effect. Van der Lubbe and Postma (2005) performed an experiment using three displays side by side in which participants were required to respond to a visual target as fast and as accurately as possible. The participants were instructed to keep their eyes focused on the central display throughout each trial; this was tracked, and the results of any trials where the participants moved their eyes were removed. Each trial started with the presentation of either a symbolic cue or a warning, indicating the location of the upcoming visual target. This cue or warning was presented to the central display of the set of three. On some trials this was followed by a visual or auditory stimulus that was presented equiprobably to the left or right displays; participants were told to ignore these presentations. The participant was then presented with the visual target, to either the left or right display, which was a triangle that pointed either up or down. Depending on its orientation the participant pressed either a left or a right button. The main finding was that the auditory stimuli showed exogenous orientating effects, as trials in which the auditory stimulus was presented at the same location as the visual target led to faster responses than if it was presented to the opposite location. However, the results also indicated that participants were faster to respond to the visual target if it was preceded by an auditory stimulus than if it wasn't.

This indicates that even if participants are focusing on another task their attention can be shifted using task-irrelevant auditory stimuli. This has positive connotations for use in such contexts as warning systems where participants can have their attention reliably drawn to an urgent situation when they are possibly engrossed in another task. This appears to be the case even when participants are performing tasks that are considered to have a high perceptual load (Santangelo, Ho and Spence, 2008).

As well as facilitating hand-based motor responses, task-irrelevant auditory stimuli have been shown to facilitate eye saccades towards a visual target (Arndt and

Colonius, 2003). It has been suggested that this effect, at least in regard to eye saccades, facilitates responses at the motor level rather than at the stimulus processing level (Khan, Heinen and McPeek, 2010). This would parallel nicely the other research discussed here relating to motor response facilitation.

1.1 CONCLUSION AND THESIS INTENTIONS

It has been shown that motor responses can be effectively facilitated by changing the properties of the stimulus. This ranges from making it so that stimuli convey the required motor response, to presenting stimuli to more than one modality. It has also been shown that a stimulus that facilitates motor responses does not need to be the stimulus that is being responded to, i.e., stimuli can still facilitate responses even though they are task-irrelevant. Participants have been shown to be able to perform a range of motor responses from these manipulations to the stimuli, from making simple button presses to navigating unknown environments. It has previously been shown that responses can be facilitated by auditory stimuli when they indicate what motor responses are possible, even when the stimuli are task-irrelevant, as detailed above.

The aim of the first experimental chapter of this thesis, Chapter 2, is to test the hypothesis that task-irrelevant, moving auditory stimuli can facilitate a participant's motor response to a visual target. This will be accomplished by having the participant respond to the location of a visual target that appears to either the left or right of a central fixation cross. On some trials the visual target will be accompanied by a moving auditory stimulus that crosses both of the participant's hemifields, while on others the auditory stimulus will be static directly in front of the participant.

Chapter 3 will be a continuation of Chapter 2 with a change to the auditory stimuli, limiting the moving auditory stimuli to a single hemifield.

The final experimental chapter, Chapter 4, will change the auditory stimuli again so while they still move they should be perceived as either laterally looming or receding. The aim for Chapter 4 is the same as for the other two experimental chapters: to determine whether a task-irrelevant, laterally looming or receding auditory stimulus can facilitate a participant's motor response to a visual target.

CHAPTER TWO

2.0 INTRODUCTION

The aim of the two experiments described in Chapter 2 was to test the hypothesis that a task-irrelevant, moving auditory stimulus could facilitate a participant's motor response to a visual target. The methods for the two experiments were very similar; see below for further details. The participants performed motor responses with either hand, according to the location of a visual stimulus. On some trials the visual target was accompanied by an auditory stimulus that was either moving or static; the hypothesis tested was that the response latency would be shorter when the auditory stimulus was moving towards the responding hand than when it was stationary.

As discussed in Chapter 1, auditory stimuli have been shown to facilitate motor responses. Hughes (2001) showed that it is possible for participants to navigate a passage using sound only while Rosenblum et al. (1996) indicated that participants were able to use sound to detect if an object was reachable or not. Both of these can be considered examples of sensory-motor facilitations arising from auditory stimuli.

It has also been shown, at least in the visual domain, that moving stimuli may facilitate motor responses. Michaels (1988) showed that a moving visual target facilitated making responses with two joysticks. Participants were significantly faster to respond with a left hand joystick movement if a visual target was moving towards their left hand than if it was moving towards their right hand. This indicated that the moving visual stimulus was facilitating a motor response in the hand towards which the visual stimulus moved towards.

One of the features of these experiments is that they required the participants to pay attention to the facilitating stimuli. However there is evidence that participants are not required to attend to a stimulus for it to have an effect on subsequent motor responses. Miller et al. (1999) showed that in a simple reaction time task, participants' responses to a visual target were significantly affected by a task-irrelevant auditory stimulus. This ties in with the evidence that bi-modal stimuli generate faster responses than uni-modal stimuli (Hershenson, 1962), even when one of the stimuli in the bi-modal pairs is task-irrelevant. Taking into account that auditory, visual, bi-modal, moving and task-irrelevant stimuli can facilitate motor responses, it seems likely that a task-irrelevant, moving auditory stimulus may facilitate participants' motor responses to a visual target.

The hypothesis of the first experiment reported in this chapter was that participants' responses to a static visual target would be facilitated by a task irrelevant, moving auditory stimulus. The expected results would be that when the auditory stimulus was moving towards the responding hand participants should respond faster than when the auditory stimulus was moving away.

2.1 EXPERIMENT ONE

2.1.1 Method

2.1.1.1 Participants

Thirty students participated in the experiment, of whom 23 were female. The mean age of the participants was 23.4 years (SD 3.9 years). No participants were left-handed, and all participants had normal hearing with normal or corrected to normal vision. All participants gave their informed consent. They were paid £5 for their participation and were unaware of the purpose of the experiment except that they would be performing a left/right visual localisation task. The experiment was approved by and conducted under the guidelines of Cardiff University: School of Psychology Ethics Committee, the QinetiQ Ethics Committee and the MoD Research Ethics Committee (MoDREC).

2.1.1.2 Materials & Design

Stimuli, both visual and auditory, were presented to the participants using a computer running Visual Basic; participants' responses were collected via a keyboard. Auditory stimuli were delivered to the participants over a pair of Sennheiser HD 280 Pro headphones driven by a Yamaha DS1x native sound card. Visual target presentation was via a GNR TG700H 17” TFT Screen running at a resolution of 1280 x 1024.

The auditory stimuli were created using AUDIS and PipeWave (|WAVE) (Culling, 1996). AUDIS is a multi-purpose auditory display for 3-D hearing applications; it can generate 3-D sound sequences using parameters specified by the user. |WAVE is a Unix program which is used for manipulating sounds. For this experiment AUDIS was used to create a set of auditory clicks at azimuth points 45º, 35º, 25º, 15º, 5º, 355º, 345º, 335º, 325º, 315º around the head, all at elevation 0º with each click being 5 milliseconds (ms) in duration. When these ten separate clicks were linked together using |WAVE they created a click train that was 365 ms long. Some of these trains were designed to give rise to the perception of starting on the left-hand side of the listener. They then proceeded to move to the right-hand side passing in front of the listener's face. If the order of the clicks was reversed then listeners perceived the sound moving from their right-hand side to their left. For the static stimulus a single click was generated at azimuth position 0º; |WAVE was then used to create ten repetitions of this single click. The auditory stimuli were tested on five participants to see if they could correctly distinguish between the three different auditory stimuli and, for the moving auditory stimuli, correctly identify the direction of movement. The participants could always correctly identify which sound they were listening to.

The visual target used was a light grey box that was presented at a visual angle of 6.65º to the left or the right of a central fixation cross depending on the trial condition. This visual angle was measured from the centre of the box to the centre of the fixation cross. These boxes were presented against a slightly different grey background; thus there was a low contrast difference between the visual target and the background. This was done with the aim of making the participant focus more on performing the visual task so they were less likely to pay attention to the auditory stimuli.

2.1.1.3 Procedure

The participant started the experiment by pressing a 'start' button that appeared on the screen. There was a 250 ms interval between the start of each trial and the presentation of the auditory stimulus and (if not a catch trial in which there was only an auditory stimulus) the visual target. This meant that there was a stimulus onset asynchrony (SOA) of 0 ms between the auditory stimulus and the visual target. The auditory stimulus was presented for 365 ms, while the visual target lasted for 1000 ms. From the start of the target presentation the participant had 1000 ms to make a response; after 2000 ms the next trial automatically began.

The participant was asked to fixate on the cross during the presentation of the auditory stimulus and visual target; this fixation cross was present on the screen for the whole of the experiment. The participant's task was to indicate on which side of the fixation cross the visual target appeared and to make a response via the keyboard. The participant was asked to press the 'Z' key if the box appeared to the left of the cross and to press the '2' key on the numeric keypad if the box appeared to the right of the cross. The participant was asked to make this judgement as quickly as possible, and to ignore the auditory stimuli during the task and respond only to the boxes.

The experiment consisted of 360 randomised trials for each participant which included breaks every 50 trials for the participant to have a rest. Of these 360 trials, there were 108 trials in which an auditory stimulus moved from the participant's left-hand side to their right-hand side; 108 trials in which the auditory stimulus moved from the participant's right-hand side to their left-handed side, and 108 trials where the auditory stimulus was static. Within each set of 108 trials the visual target was presented half the time to the left and half the time to the right of the central fixation cross. Finally there were 36 catch trials in which there was only an auditory stimulus, 12 each of left, right and static, but no visual target. This was to ensure that the participant was responding to the visual target and not the auditory stimulus. The first 30 trials were practice trials, which consisted of 8 with left to right auditory stimuli, 8 right to left auditory stimuli and 8 with static auditory stimuli, plus 6 catch trials.

2.1.2 Results

Reaction Times (RTs) that were faster than 150 ms or slower than 1000 ms, and responses that were incorrect, were removed before data analysis was performed. Responses faster than 150 ms were classified as anticipatory and those slower than 1000 ms were classified as misses. On average participants responded correctly 98.4% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The results were obtained by running a Repeated Measures Analysis of Variance (ANOVA) utilising Bonferroni-corrected Pairwise Comparisons.

The analysis focused on participants' RTs to the visual target as a function of the direction of movement of the auditory stimulus. In this analysis, Congruent Trials were those in which the auditory stimulus moved towards the responding hand, Incongruent Trials were those in which the auditory stimulus moved in the opposite direction to the responding hand, and Static Trials were those in which the auditory stimulus was perceived as being directly in front of the participant. A Repeated Measures ANOVA using Trial Type (Incongruent, Congruent and Static) as the within-subjects factor indicated that there was not a significant effect of Trial Type, $F(2, 58) = 1.966$, $p > 0.05$. Figure 1 shows the mean RTs for each trial type with error bars.

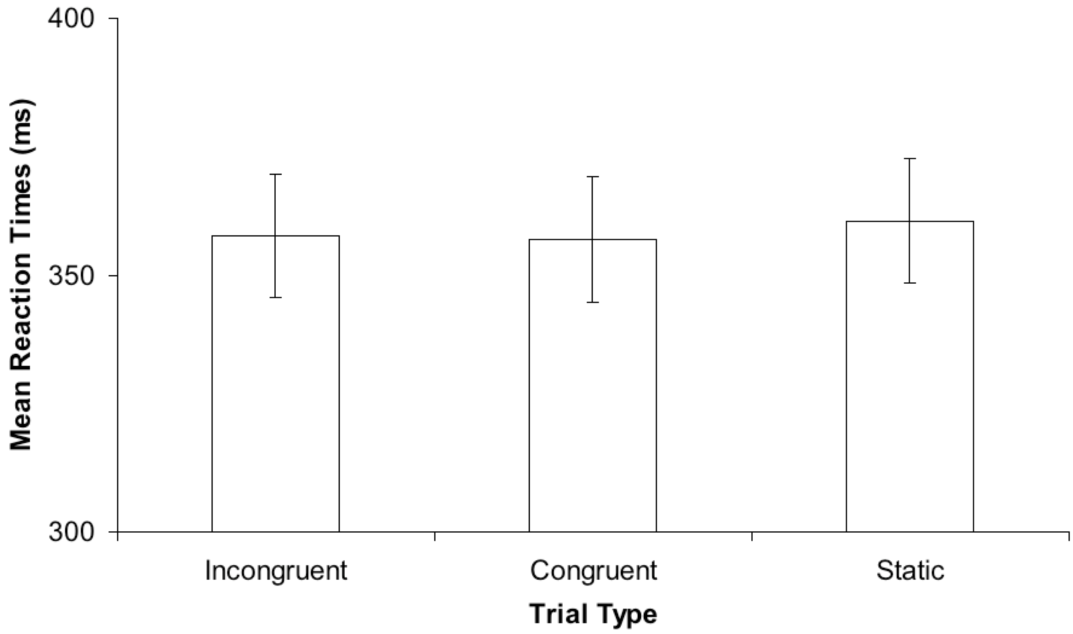

Figure 1. Mean Reaction Times for ‘Incongruent', ‘Congruent' and ‘Static' trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error.

2.1.3 Discussion

The results of Experiment 1 did not support the hypothesis that task-irrelevant, moving auditory stimuli facilitated motor responses, as there was no significant effect of Trial Type. Several issues were identified with Experiment 1 that Experiment 2 was designed to address, such as the possibility that participants had already made their left/right choice before the auditory stimulus had finished being presented. Thus Experiment 2 reduced the overall time of the auditory stimulus. It also incorporated multiple levels of SOA to test if presenting the auditory stimulus at varying times before the visual target had any effect on the participants' RTs. Also, due to the nature of the response method used in Experiment 1, participants did not have to make any movement greater than a finger press. This movement may have been too small for any facilitation to significantly improve RTs. This was addressed in Experiment 2 by using a custom keyboard that forced the participants to move their whole lower arm, either to the left or the right, when making their response to the visual target.

2.2 EXPERIMENT TWO

Experiment 2 made several changes to the method used in Experiment 1. These were the manner in which the participants responded to the visual target, the duration of the auditory stimulus, the introduction of multiple levels of SOA, and the visual angle between the fixation cross and visual target. In Experiment 1 the participants pressed either one of two keys, upon which their fingers were always resting, depending on the location of the visual target. To make the required motor response larger, a custom keyboard was used for Experiment 2 that required participants to move their whole lower arm when responding to the visual target. The new keyboard had only four keys, two centrally and two peripherally located, all arranged on the same axis. The distance between each centre key and its corresponding peripheral key was 16.5cm.

The change to a custom keyboard and participants' response method allowed the RTs collected to be divided into two types. Instead of recording merely the time from visual presentation to the participants pressing the 'Z' or '2' key, the interval between the visual target being presented and participants lifting their fingers off the two central keys was recorded, this was defined as the 'Lift' RT. The second reaction time recorded was the time between lifting off the central keys and the pressing of either the left or right peripheral key, which was defined as the 'Move' RT.

The length of the auditory stimulus was reduced from 365 ms to 265 ms to investigate whether faster moving stimuli had a greater effect. Also three levels of audio/visual SOA, 0, 60 and 100 ms, were introduced to see what effect changing the times between the onset of the auditory stimulus and visual target had. These levels of SOA were chosen so participants were exposed to varying levels of the auditory stimulus before the onset of the visual target. This was unlike Experiment 1, where the onset of both the auditory stimulus and the visual target, were at exactly the same time. There was also an increase in the visual angle between the central fixation cross and the visual target to mirror the increase in distance of the motor movement.

The hypothesis was that with the change in response method, participants would now be faster in trials where the auditory stimulus moved in the same direction as the motor response.

2.2.1 Method

2.2.1.1 Participants

Thirty students participated in the experiment, of whom 27 were female. The mean age of the participants was 19.5 years (SD 2.2 years), and no participants were left-handed. All other details were as for Experiment 1.

2.2.1.2 Materials & Design

Stimuli, both visual and auditory, were presented to the participants in the same manner and using the same systems as utilised in Experiment 1. However there was a change in presentation software from Visual Basic to E-prime (version 1.2). Participants' responses were also no longer collected using a standard keyboard; instead a custom keyboard was employed, as described above.

The auditory stimuli were the same as Experiment 1 with the exception of a reduction in their length from 365 ms to 265 ms. This was accomplished by shortening the periods of silence between each click. The auditory stimuli were tested on five participants as they were in Experiment 1 with the same results (all participants being able to successfully distinguish between the different auditory stimuli). The angle of the visual target from the central fixation cross was 12.23º.

2.2.1.3 Procedure

The participant performed the same task that was used in the Experiment 1, making a left/right decision as to where a box appeared in relation to the fixation cross. The participant started each trial by pressing and holding the two central keys on the custom keyboard; after a random interval of between 1 and 2 seconds, the auditory stimulus was presented, followed by the visual target if it was not a catch trial. The timing of the visual presentation depended upon the SOA used. If a visual target was presented, the participant released the two central keys and made their response according to where the box had appeared. If the box appeared to the left the participant was to press the left-hand peripheral key on the keyboard; if the box appeared to the right the participant was to press the right-hand peripheral key. If no box appeared (in a catch trial), the participant was instructed to keep the two central keys pressed down until a message on the screen prompted them to release the central keys and press and hold them again, starting the next trial.

The experiment consisted of 465 randomised trials for each participant. There were breaks every 50 trials for the participant to have a rest. Of these 465 trials, there were 150 trials including an auditory stimulus that moved from the participant's left-hand side to their right-hand side; 150 trials in which the auditory stimulus moved from the participant's right-hand side to their left-handed side; and 150 trials where the auditory stimulus was static. There were also 15 catch trials in which there was only an auditory stimulus, 5 each of left, right and static, but no visual target. Within each set of 150 trials the visual target was presented half the time to the left and half the time to the right of the central fixation cross. Unlike Experiment 1, which had only a single SOA of 0 ms, Experiment 2 had three levels of SOA: 0 ms as in Experiment 1, 60 ms (the auditory stimulus presented 60 ms before the visual target), and 100 ms (the auditory stimulus presented 100 ms before the visual target). Within the set of 150 trials for each auditory stimulus there were equal numbers of the three SOAs.

2.2.2 Results

Data preparation and analysis were essentially the same as for Experiment 1, with the removal of incorrect responses and responses faster than 150 ms or slower than 1000 ms. However due to the design of the custom keyboard and its ability to collect two different types of RTs this culling of responses below 150 ms and above 1000 ms was only applied to the Lift RTs. This was due to the fact that anticipatory responses and misses should only affect the participants' Lift RTs; they should have not had an effect on the Move RTs. On average, participants responded correctly 98.4% of the time, thus there was no analysis of participants' errors. Of the 30 participants tested, five were removed for responding over 50% of the time to catch trials.

As with Experiment 1 the analysis focused on participants' RTs to the visual target as a function of the direction of movement of the auditory stimulus. In this analysis, Congruent Trials were again those in which the auditory stimulus moved towards the responding hand, Incongruent Trials were those in which the auditory stimulus moved in the opposite direction to the responding hand, and Static Trials were those in which the auditory stimulus was perceived as being directly in front of the participant. All results were obtained by running a 3 x 3 Repeated Measures ANOVA with Bonferroni-corrected Pairwise Comparisons with SOA (0, 60 and 100 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors.

For Lift RTs the results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 6.523$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.604, 38.495) = 92.849$, $p < 0.01$, Trial Type, $F(2, 48) = 13.207$, $p < 0.01$ and a significant interaction between SOA and Trial Type, $F(4, 96) = 4.155$, $p < 0.01$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 100 ms than at 60 ms or 0 ms, they were also faster at SOA 60 ms than at 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Incongruent Trials than Congruent or Static Trials, $p < 0.05$. Pairwise comparisons for the interaction between SOA and Trial Type indicated that for SOA 0 ms participants were significantly faster to respond to the visual target when the auditory stimulus was Incongruent or Static than when it was Congruent, $p < 0.05$. For SOA 60 ms participants were significantly faster to respond to the visual target when the auditory stimulus was Incongruent than when it was Congruent, $p < 0.05$. At SOA 100 ms there was no significant effect of Trial Type, $p > 0.05$. Figure 2 shows the mean RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

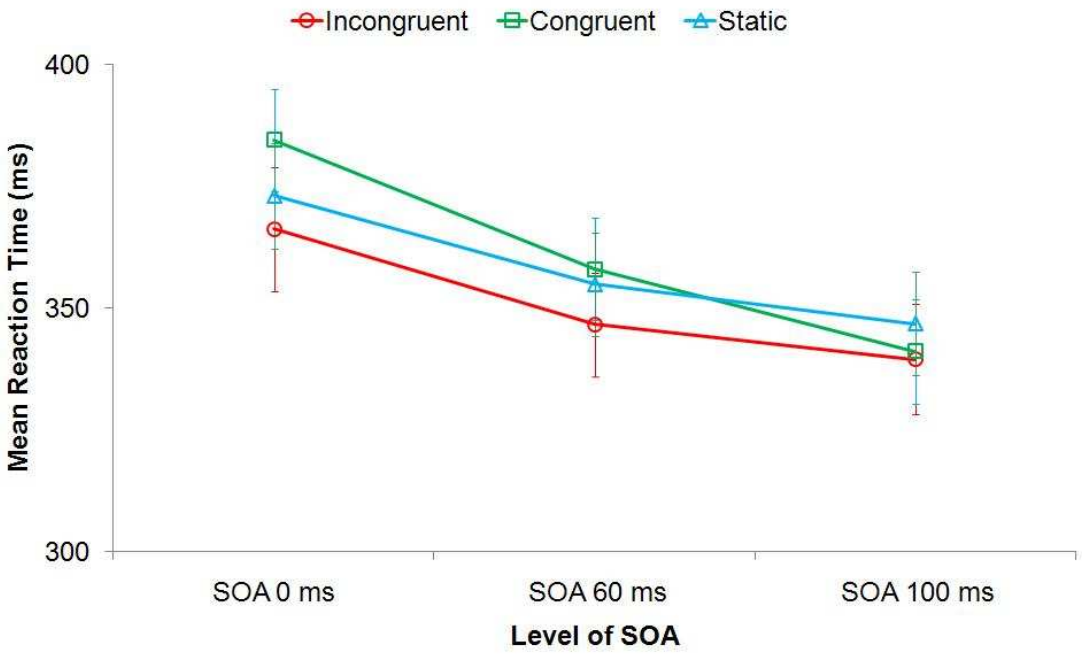

Figure 2. Mean Lift Reaction Times for ‘Incongruent', ‘Congruent' and ‘Static trials for SOA 0, 60 and 100 ms when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error.

The analysis for Move RTs indicated there were no significant main effects of SOA or Trial Type and no significant interactions, $p > 0.05$.

In summary the results of Experiment 2 indicated that participants were fastest to respond at SOA 100 ms, i.e., when the auditory stimulus had started 100 ms before the onset of the visual target. Participants were also generally faster to respond in trials where the direction of the auditory stimulus was moving away from the responding hand, i.e., incongruent, than when it was either moving towards the responding hand, i.e., congruent, or static. This indicates that the moving auditory stimuli may have facilitated the participants' motor responses but only when the auditory stimuli were moving in the opposite direction.

2.2.3 Discussion

The results of Experiment 2 indicated that, unlike Experiment 1, there appeared to be an effect of task-irrelevant, moving auditory stimuli on the participants' motor response times. While this was partially in line with the hypothesis outlined at the start of the experiment, the direction of the effect was opposite to that which had been predicted. Participants were not faster when the auditory stimulus was moving in the same direction as the responding hand; the opposite was in fact true: participants were faster when the auditory stimulus was moving in the opposite direction. Regarding the facilitation by the moving auditory stimuli, it may have been that rather than the facilitation arising from the movement of the stimulus, it may have been the stimulus position of onset that was leading to the observed results. This is discussed in more detail in the general discussion section of this chapter.

The results indicated that there was also an effect of the manipulations made to the level of SOA between the auditory stimulus and the visual target. Participants were faster to respond to the visual target the greater the time between the onset of the auditory stimulus and the onset of the visual target. It may have been that the onset of the auditory stimulus was acting as some form of warning that a visual target was going to appear. As participants were told to ignore the auditory stimuli, as well as there being trials where there were auditory stimuli followed by no visual target, this should have acted as a counterbalance to the auditory stimulus working as a warning.

Finally, while there was an effect of the experimental manipulations on the Lift RTs there appeared to be no effect on the Move RTs. This indicates that facilitation was occurring between the onset of the auditory stimulus and participants lifting their fingers from the central keys rather than facilitating any process that started when the participants lifted off the central keys to press a peripheral key.

2.3 GENERAL DISCUSSION

The results of Experiment 1 showed no differences between any of the Trial Types indicating that the task-irrelevant, moving auditory stimuli in this experiment did not facilitate motor responses. Several changes were made to the methodology used in Experiment 1 for Experiment 2. These changes led to participants being faster when the auditory stimuli were moving in the opposite direction to the responding hand. Participants were also faster the greater the time between the onset of the auditory stimulus and the onset of the visual target. While the results could be taken to indicate that moving stimuli facilitated the participants' motor responses there is an alternative explanation that the results were a product of the Simon effect (Simon and Rudell, 1967; Craft and Simon, 1970). The Simon effect is where the congruency between a task-irrelevant feature of a stimulus and the response to the stimulus has an effect on RTs, i.e., if a participant responds to an auditory stimulus with either a left- or right-hand response, depending on whether it is low or high frequency, they will be faster responding to the side of the body the stimulus is delivered to even though its location is task-irrelevant. In Experiment 2 it may have been the onset location of the auditory stimulus the participants were being facilitated by rather than its direction of movement. This would explain why responses were faster when the auditory stimulus was moving in the opposite direction to the response, as its position of onset was on the same side of the body as the motor response.

As it stands even though there appeared to be a difference between moving and static auditory stimuli the level of the facilitation effect was only an improvement in the order of approximately 10 ms. While the results were significant, an increase in the magnitude of the facilitation effect would be beneficial to applying the results in real-world applications. Therefore the next Chapter in this thesis describes experiments that attempted to improve upon this facilitation while controlling for possible issues with the Simon effect.

CHAPTER THREE

3.0 INTRODUCTION

The results of Experiment 2 showed that a task-irrelevant, moving auditory stimulus may have facilitated participants' motor responses, although the facilitation appeared to go in the opposite direction to that predicted. Participants were faster when the auditory stimulus moved in the opposite direction to the motion of the responding hand, though the effect amounted to a difference of only 10 ms. A possible explanation for the results of Experiment 2 was that facilitation arose from the Simon effect rather than from the movement of the auditory stimulus. The Simon effect (Simon and Rudell, 1967) occurs when a task-irrelevant feature of a stimulus and the corresponding response to the stimulus are congruent, thus facilitating faster reaction times (RTs) than if the feature of the stimulus and response are incongruent. In Simon and Rudell's (1967) experiment participants responded to an auditory stimulus presented to either their left or right ear. The auditory stimulus was the word 'left' or 'right', and depending on which word was spoken the participant had to press a left or right button, i.e., the word 'left' required a left button press, the word 'right' a right button press. The results showed that when the verbal command was delivered to the side of the body on which the participant was to make the button response, i.e., the word 'left' to the left ear, the participant was significantly faster to respond than if the auditory stimulus was presented to the opposite ear, i.e., the word 'left' to the right ear. This was the case even though the ear to which the verbal command was delivered was task-irrelevant. In Experiment 2 the starting position of the auditory stimulus in the Incongruent Trials was presented to the same side of the body as the response that the participants had to make to the visual target. Therefore there was congruency between the position of onset of the auditory stimulus and participants' responses, which may have been the factor leading to faster RTs.

The aim of the series of experiments reported in this chapter was to continue to test for facilitation by task-irrelevant, moving auditory stimuli, while controlling for the possible influence on the results of the Simon effect. To achieve this it was necessary to change the properties of the auditory stimuli. In the previous experiments the auditory stimulus, when moving, always crossed the participant's mid-line, so the sound moved fully from one auditory hemifield to the other. The auditory stimuli used in the following experiments, while still moving, were limited to one hemifield, thus not crossing the participant's mid-line. This meant that unlike the previous experiments where there were two different moving auditory stimuli and one static stimulus, there were now four moving auditory stimuli, two for each hemifield, and one static stimulus.

3.1 EXPERIMENT THREE

There were several significant changes between Experiments 2 and 3, the first being a substantial change in the auditory stimuli used. Unlike the previous two experiments where the moving auditory stimuli crossed the participants' mid-line, the auditory stimuli for Experiment 3 did not. This change to the auditory stimuli was to address the possibility that any significant effects of auditory motion may have been due to the Simon effect rather than facilitation by movement. The auditory stimuli were also changed in length from 265 ms to 250 ms. A new No Sound Trial was also included in the experiment, where only the visual target was presented. This was so a comparison could be made between RTs from presenting both an auditory stimulus and visual target against the presentation of a visual target only. Participants were now individually tested to see if they could correctly distinguish between the five different auditory stimuli and, for the moving auditory stimuli, correctly identify their direction of movement. The auditory stimuli were delivered over loudspeakers instead of headphones, this was done to enforce the externalisation of the auditory stimulus so they would not be perceived as being localised in the participants head. Finally there was a change to the levels of stimulus onset asynchrony (SOA), from 0, 60 and 100 ms to 0, 125 and 250 ms. In other words, the onset of the visual target was at the same time as the auditory stimulus, the target's onset was halfway through the presentation of the auditory stimulus, or it was presented at the termination of the auditory stimulus respectively.

3.1.1 Method

3.1.1.1 Participants

Twenty-six students participated in the experiment, of whom 18 were female. The mean age of the participants was 22.0 years (SD 3.3 years). Three participants were left-handed, and all participants had normal hearing with normal or corrected to normal vision. All participants gave their informed consent. They were paid £5 for their participation and were unaware of the purpose of the experiment except that they would be performing a left/right visual localisation task. The experiment was approved by and conducted under the guidelines of Cardiff University: School of Psychology Ethics Committee, the QinetiQ Ethics Committee and the MoD Research Ethics Committee (MoDREC).

3.1.1.2 Materials and Design

The experiment took place in a sound attenuated booth of which the height, width and length were 198 cm, 193 cm and 183 cm respectively. Stimuli, both visual and auditory, were presented to the participant using a computer running Eprime (version 1.2); the participant's responses were collected via the custom keyboard used in Experiment 2. The visual targets were presented using a 19” VideoSeven L19PS TFT Screen running at a resolution of 1280 x 1024. Auditory stimuli were presented over two loudspeakers positioned 57 cm in front of the participant and 97 cm to the left and right. The participant used a custom chin rest designed with only a resting cup for the chin. The chin rest therefore did not have bars extending over the participant's ears, which might have interfered with the presentation of the auditory stimuli.

The auditory stimuli were created using Cool Edit 96 and |Wave (Culling, 1996). Cool Edit 96 was used to create a series of 10 ms broadband clicks; these were then edited into five different click trains by |Wave. The amplitude of the left and right channel of each click was adjusted so the participant perceived the click as either being located to left of their mid-line, right of their mid-line or directly in front of them. Each click train was 250 ms long and contained a total of eleven clicks.

The separate clicks when combined in a specific order were designed to be perceived in one of three ways; a) moving from the participant's mid-line to either the left or right of them; b) from the participant's left or right to their mid-line or c) stationary at the participant's mid-line

The visual target was a black box that was presented at a visual angle of 11.96° to the left or right of a central fixation cross.

3.1.1.3 Procedure

The participant started the experiment by pressing and holding down the two central keys on the custom keyboard; they used their left hand index finger to hold down the left key while the right hand index finger was used to hold down the right key. After a random interval of between one and two seconds, the participant was presented with an auditory stimulus plus visual target pair, a lone visual target or a lone auditory stimulus. The participant's task was to respond to only the visual target.

In a trial where a visual target was presented, either alone or paired with an auditory stimulus, the participant was instructed to lift both of their index fingers off the central keys and make a response via one of the peripheral keys depending on where the visual target was located. If the visual target was located to the left of the fixation cross then the participant pressed the peripheral key on the left hand side of the keyboard with their left hand. If its location was to the right of the fixation cross the participant pressed the peripheral key on the right hand side of the keyboard with their right hand. Once the participant had made a left or right key peripheral response they started the next trial by pressing and holding down both the central keys again.

Trials in which only an auditory stimulus was presented to the participant were defined as Catch Trials. These were used to test whether the participant was responding to only the visual target and not responding to the onset of the auditory stimulus. In a Catch Trial the participant kept the central keys pressed down until a message was displayed on the screen that prompted them to release the central keys and press and hold them again. This started the next trial.

When the trial consisted of an auditory stimulus and a visual target, the auditory stimulus was either static or one of the four moving stimuli. For the audio stimulus plus visual target trials there were three levels of SOA. These were SOA 0, 125 and 250 ms: for SOA 0 ms the audio and visual targets were presented concurrently; for SOA 125 ms and 250 ms the onset of the auditory stimulus preceded the visual target. This meant that for SOA 125 ms the participant had heard half of the auditory stimulus before being presented with the visual target. At SOA 250 ms, the participant had heard the auditory stimulus fully before being presented with the visual target.

There were a total of 747 trials for each participant. In 168 of the trials only the visual target was presented; there was a 50/50 split between left side presentations and right side presentations of the target. There were 75 trials in which only an auditory stimulus was presented, 15 of each sound type. These were used as Catch Trials to test whether the participant was waiting for the visual target to appear before making a response, as instructed, rather than responding to the auditory stimulus.

The remaining 504 trials were evenly split between the three levels of SOA, with each level having 168 trials. Of these 168 trials, 56 contained a static auditory stimulus. The other 112 trials were evenly distributed between the four moving auditory stimuli, meaning that there were 28 of each moving auditory stimulus. For each level of SOA there was an equal number of left- and right-hand side presentations of the visual target. Hence the auditory stimulus was not predictive as to the location of the visual target.

After the participant had completed all 747 trials they were tested on their ability to distinguish between the five different types of auditory stimulus using a five alternative forced choice (5-AFC) test. The participant was presented 50 randomised presentations of the auditory stimuli, 10 of each type, mid-line to left, left to mid-line, mid-line to right, right to mid-line and static. The participant's task was to indicate after each presentation which of the five auditory stimuli they thought they had heard.

3.1.2 Results

Lift RTs that were faster than 150 ms or slower than 1000 ms, and responses that were incorrect, were removed before data analysis was performed. Responses faster than 150 ms were classified as anticipatory and those slower than 1000 ms were classified as misses. This removal procedure was not applied to Move RTs as anticipatory responses and misses should not have affected these RTs. On average, participants responded correctly 97.9% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over

50% of the time to catch trials. The results of the 5-AFC test revealed that participants were able to correctly identify which auditory stimulus they heard 87% of the time. Two different sets of analyses were conducted: facilitation by hemifield location of the auditory stimulus, and facilitation by direction of movement of the auditory stimulus.

3.1.2.1 Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented, irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield corresponding to the responding hand, i.e., left hemifield presentation - left hand response; Incongruent were those in which the hemifield and responding hand were on opposite sides of the participant, i.e., left hemifield presentation - right hand response; and Static when the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were when only the visual target was presented.

A Repeated Measures ANOVA of Lift RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor showed that the assumptions of sphericity had been violated, $\chi^2(5) = 32.791$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.607, 40.181) = 109.888$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in the Incongruent, Congruent and Static Trials than the No Sound Trials, $p < 0.05$. Participants were also significantly faster in the Static Trials than in the Incongruent and Congruent Trials, $p < 0.05$. Figure 3 shows the mean Lift RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

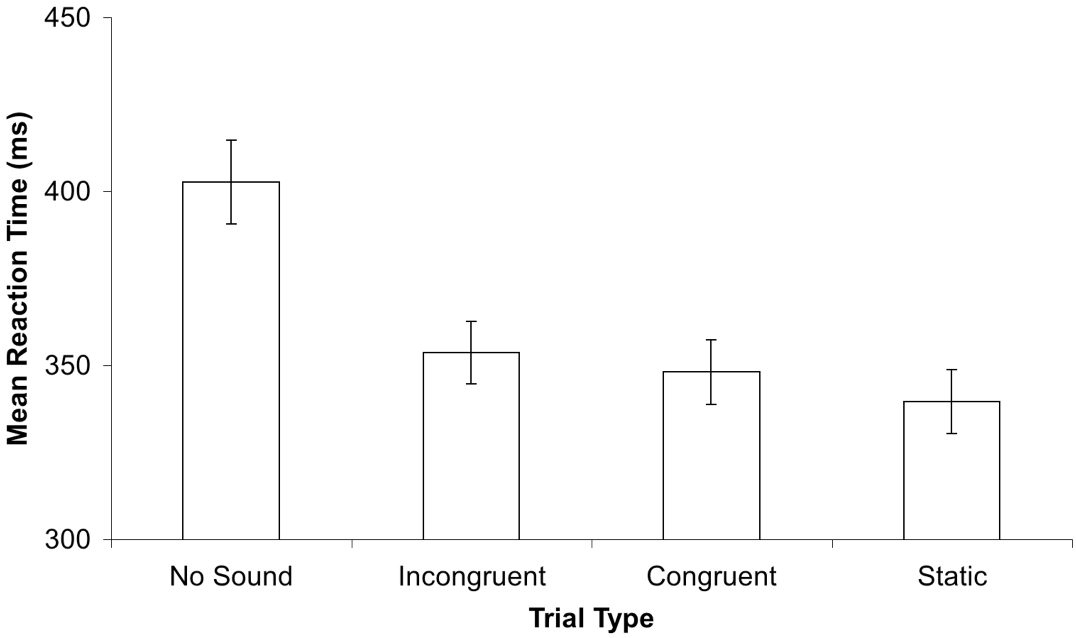

Figure 3. Mean Lift Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Lift RT was further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA $\chi^2(2) = 7.256$, $p < 0.05$, Trial Type $\chi^2(2) = 7.229$, $p < 0.05$ and SOA and Trial Type $\chi^2(9) = 22.299$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, F(1.586, 39.654) = 27.848, $p < 0.01$, Trial Type F(1.587, 39.680) = 17.345, $p < 0.01$ and a significant interaction between SOA and Trial Type, F(2.632, 65.807) = 11.965, $p < 0.01$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms and 125 ms than 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Congruent and Static Trials than Incongruent Trials, $p < 0.05$. Pairwise comparison for the interaction between SOA and Trial Type indicated at SOA 0 ms participants were significantly faster in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. For SOA 125 ms participants were significantly faster in Static Trials than Incongruent and Congruent Trials, $p < 0.05$. At SOA 250 ms participants were significantly faster in Static Trials than the Incongruent or Congruent Trials, $p < 0.05$. Figure 4 shows the mean Lift RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

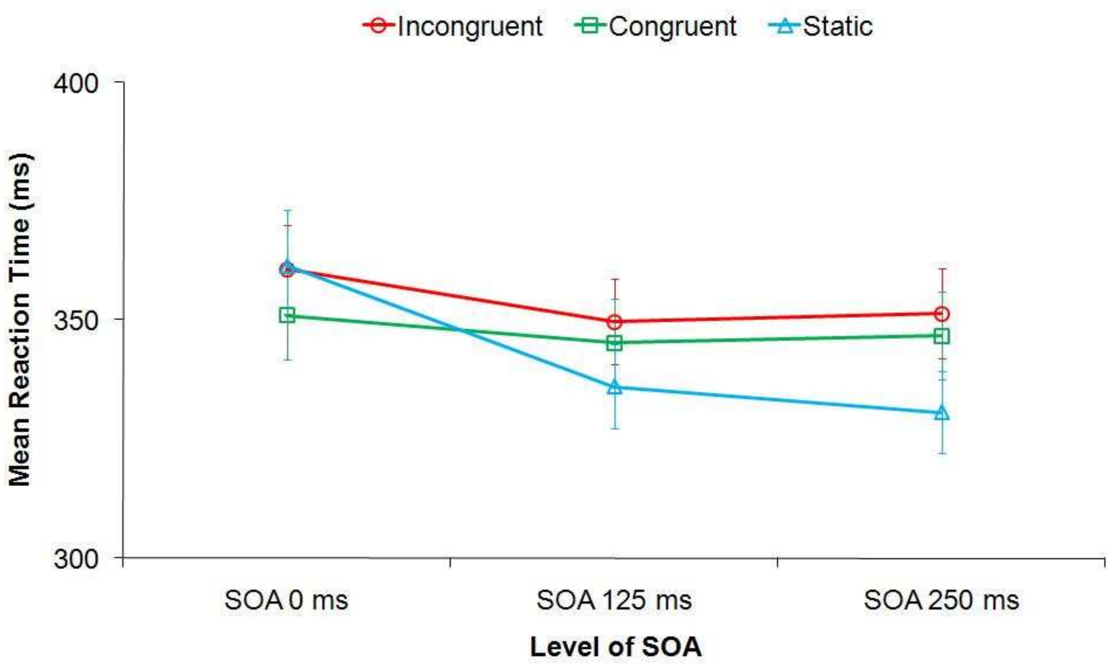

Figure 4. Mean Lift Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

A Repeated Measures ANOVA of Move RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 12.278$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.354, 58.844) = 11.306$, $p < 0.01$. The Pairwise comparison indicated that participants were significantly faster in the No Sound Trials than they were in the Incongruent, Congruent and Static Trials, $p < 0.05$. Figure 5 shows the mean Move RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

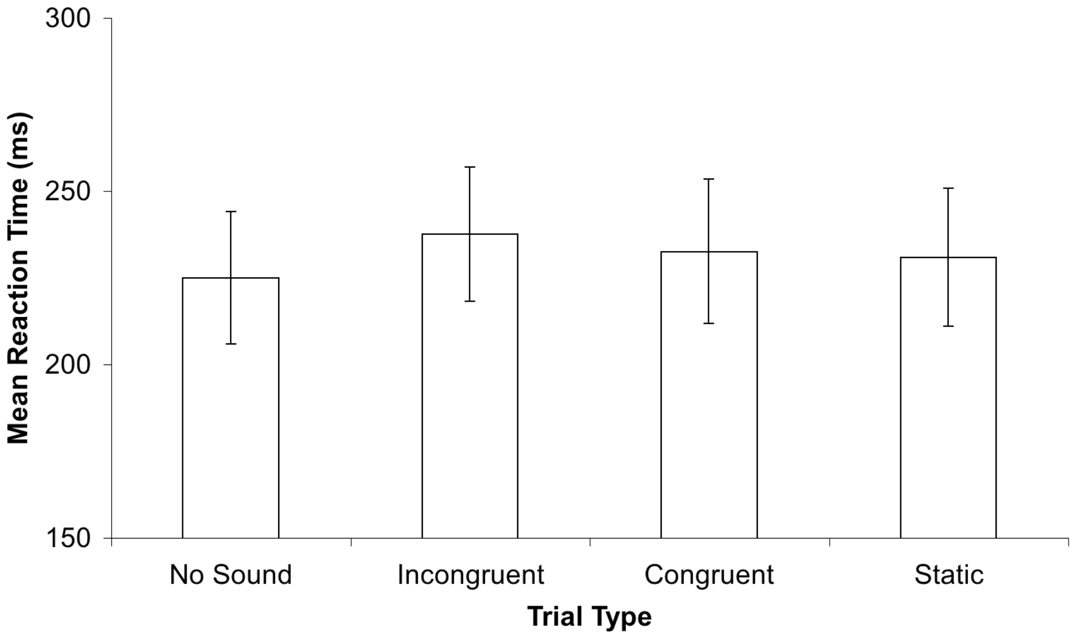

Figure 5. Mean Move Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

A 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors for Move RTs indicated there were no significant effects, $p > 0.05$.

Thus when congruency was defined by hemifield, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs but the opposite was true for Move RTs. Furthermore the analysis of Lift RTs revealed that participants were also faster when the auditory stimulus was static or presented to the same side of the body to which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

3.1.2.2 Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target in relation to the direction of movement of the auditory stimulus. This was irrespective of the hemifield to which the auditory stimulus was presented. Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant had to make in relation to the position of the visual target, i.e., a leftward moving auditory stimulus with a left hand key press. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant had to make, i.e., a leftward moving auditory stimulus with a right hand key press. Static Trials were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were where only the visual target was presented.

A Repeated Measures ANOVA of Lift RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 39.631$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.492, 37.291) = 105.310$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in the Static Trials than the Incongruent or Congruent Trials, $p < 0.05$. Figure 6 shows the mean Lift RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

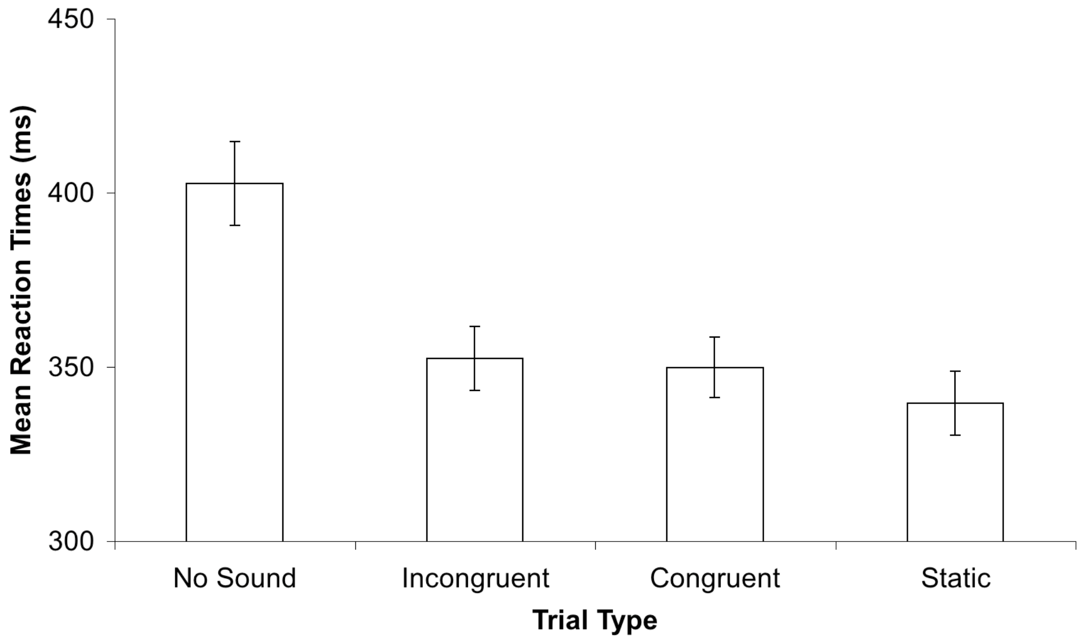

Figure 6. Mean Lift Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

Lift RT was further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated a main effect of SOA, $F(2, 50) = 35.872$, $p < 0.01$, Trial Type, $F(2, 50) = 14.250$, $p < 0.01$ and a significant interaction between SOA and Trial Type, $F(4, 100) = 11.427$, $p < 0.01$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms and 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Static Trials than Incongruent or Congruent Trials, $p < 0.05$. Pairwise comparison for the SOA and Trial Type interaction indicated at SOA 0 ms no significant differences, $p > 0.05$. At SOA 125 ms participants were significantly faster in Static Trials than Incongruent or Congruent Trials, $p < 0.05$. For SOA 250 ms participants were significantly faster in Static Trials than Incongruent and Congruent Trials, $p < 0.05$. Participants were also significantly faster in Congruent Trials than Incongruent Trials, $p < 0.05$. Figure 7 shows the mean Lift RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the direction of the auditory stimulus.

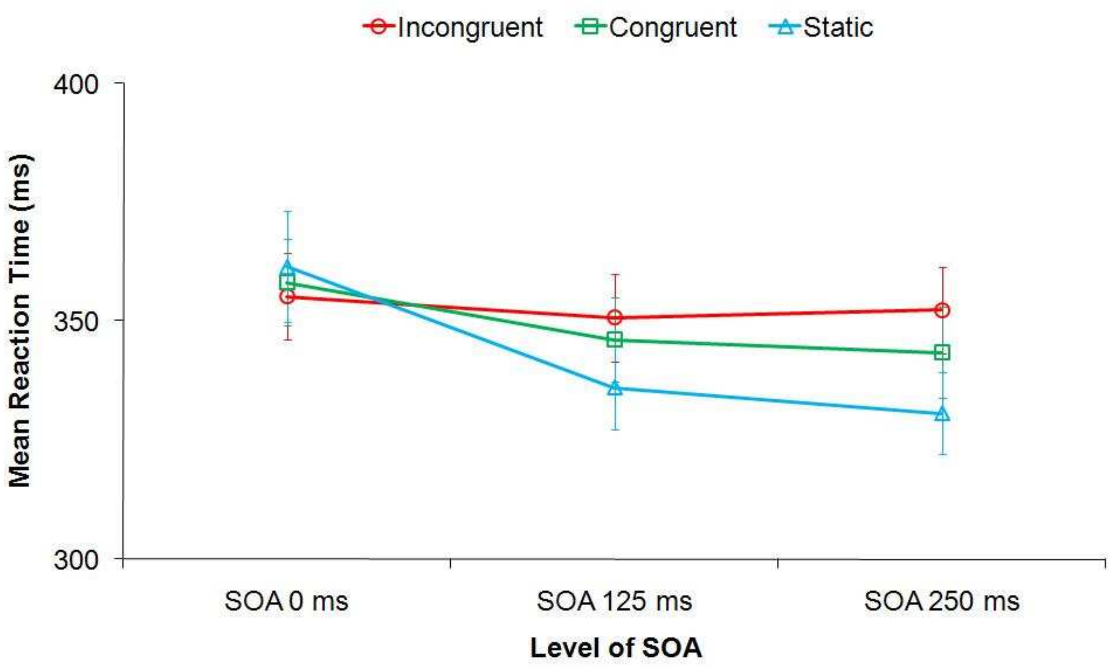

Figure 7. Mean Lift Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

A Repeated Measures ANOVA of Move RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 15.019$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.326, 58.146) = 11.025$, $p < 0.01$. The Pairwise comparison indicated that participants were significantly faster in No Sound Trials than Incongruent, Congruent and Static Trials, $p < 0.05$. Figure 8 shows the mean Move RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

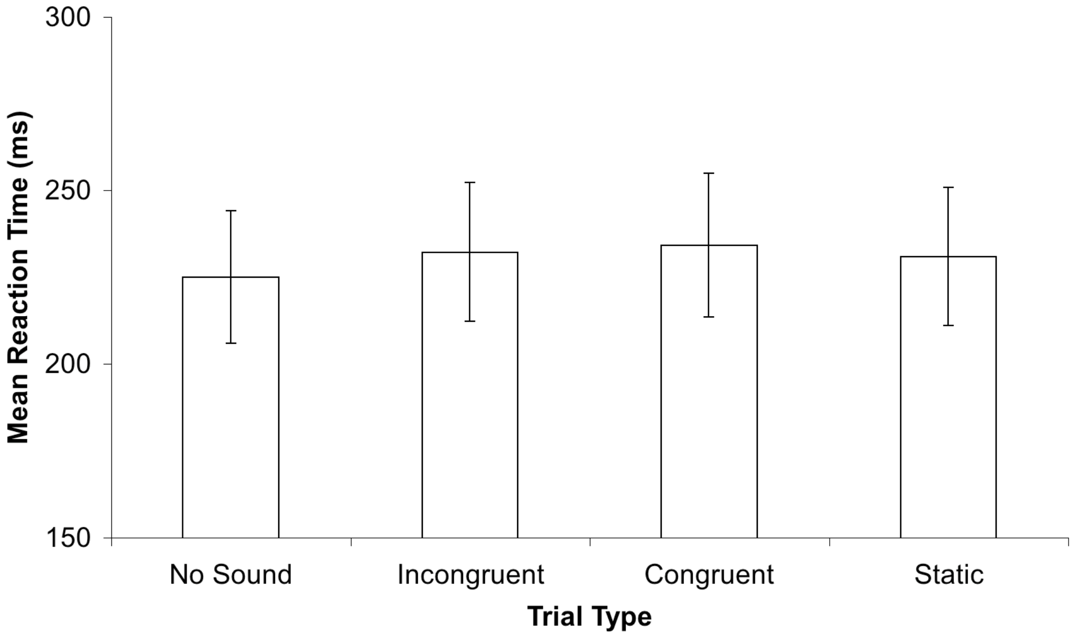

Figure 8. Mean Move Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

A 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors for Move RTs indicated there were no significant differences, $p > 0.05$.

In summary, when congruency was defined by hemifield, the analysis revealed that participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs, but the opposite was true for Move RTs. Furthermore the analysis of Lift RTs revealed that participants were also faster when the auditory stimulus was static or presented to the same side of the body to which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

When congruency was defined by direction, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs but the opposite was true for Move RTs. Further analysis of the Lift RTs indicated that the participants were faster in trials containing a static auditory stimulus than either of the moving auditory stimuli. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target. These findings indicate that bi-modal presentations facilitated motor responses with respect to uni-modal, though only for the Lift response. Facilitation of response also appeared to be present when the auditory stimulus was on the same side of the body as the motor response. There appeared to be facilitation for congruently moving auditory stimuli over their incongruent counterparts, but this was only after the auditory stimulus had been fully presented before the onset of the visual target. Finally participants' responses appeared to be facilitated to a greater degree the greater the period of time between the onset of the auditory stimulus and the onset of the visual target.

3.1.3 Discussion

The aim of Experiment 3 was to test whether task-irrelevant, moving auditory stimuli facilitated motor responses to a visual target, while controlling for possible facilitation from the Simon effect (Simon and Rudell, 1967). The employed methodology allowed participants' RTs to be analysed in two different dimensions, hemifield and direction. If the previous results from Experiment 2 were indeed due to the Simon effect it would be expected that there would only be significant differences between Trial Types when congruency was defined by hemifield and no significant differences when defined by direction. If however the directionality of the auditory stimuli were having an effect on participants' RTs there would be significant differences between Trial Types when congruency was defined by direction. The first set of analyses, in which congruency was by hemifield, revealed that participants were indeed faster in Congruent Trials than Incongruent. This meant that participants were faster to respond to the visual target when the auditory stimulus and the required motor response were on the same side of the body. This leads to the conclusion that the results may indeed have been a product of the Simon effect. This interpretation of the results is supported by the fact that when congruency was defined by direction there were no consistent facilitatory effects, as the observed facilitation arose at only a single level of SOA.

This was also the first experiment in which there were trials in which only the visual target was presented, unlike Experiments 1 and 2 which contained only trials where the visual target was accompanied by an auditory stimulus. This inclusion of the No Sound Trials meant that it was now possible to compare bi-modal stimulus presentations to uni-modal stimulus presentations. In Chapter 1 it was reported that bi-modal presentations have often been shown to reduce participants' RTs in comparison to uni-modal presentations (Hershenson, 1962; Bernstein et al., 1969; Hecht et al., 2008). The results of Experiment 3 indicated that, in line with this previous research, participants' RTs to the visual targets were facilitated by the presence of the auditory stimuli. However this only appeared to be the case for the participants' Lift RTs. For the Move RTs the reverse was true, participants were faster in the uni-modal trials than they were in the bi-modal trials. It could be that the lift section of the experiment involved some component of decision making that the move section did not, though it should be noted that the difference between the uni-modal and bi-modal trials was on average only 10 ms for the Move RTs compared the average of 50 ms for the Lift RTs. In other words, the bi-modal stimuli led to a faster initial reaction (Lift RT), but the uni-modal stimuli, while having a slower initial reaction (Lift RT) led to slightly faster movement in then making the response (Move RT). However, the bi-modal stimuli led to an overall improvement in total RT (Lift RT plus Move RT) from presentation of the visual target to pressing one of the response keys.

An issue with the design of Experiment 3 was the manner in which participants responded to the visual target. The experiment was designed in such a way that each trial began with the participant pressing and holding down the two central keys on the custom keyboard. To respond to the visual target they had to lift both hands from the central keys even though only one hand had to push a peripheral key. By having the participant lift both hands they were in effect making a dual motor response to the presentation of the target. To address this possible issue Experiment 4 was designed so only the responding hand was lifted off the central keys during a trial.

3.2 EXPERIMENT FOUR

Experiment 4 followed the same basic methodology as Experiment 3, however there was a change to how the participants' responses were executed. In the previous experiments the participant had to lift both their hands off the central keys when responding. Experiment 4 was changed so that the participant lifted only a single hand to respond to the visual target, leaving their non-responding hand resting on one of the central keys.

3.2.1 Method

3.2.1.1 Participants

Forty-seven students participated in the experiment, of whom 32 were female. The mean age of the participants was 21.4 years (SD 4.3 years) and three participants were left-handed. All other details were as for Experiment 3.

3.2.1.2 Materials and Design

The experiment took place in the same sound-attenuated booth as used for Experiment 3. Stimuli, both visual and auditory, were presented in the same manner and using the same systems as utilised in Experiment 3, except that visual presentation was no longer via a TFT screen; instead visual targets were presented using a Sanyo PLC XU75 projector, which displayed onto a matt screen. The participants' responses were collected via the custom keyboard from Experiment 3.

Two loudspeakers were placed 84cm in front of the participant and 65cm to the left or right of the participant's mid-line This meant that there was an angle of 37.7 degrees between the participant's mid-line and each speaker.

The visual target was a 2 cm^2 black box that appeared to either the left or the right of the central fixation cross. The visual angle between the central fixation cross and the visual target was 18.12 degrees. The auditory stimuli were the same as used in Experiment 3. The participant used a chin rest to keep their head in a fixed location in relation to the speakers for the duration of the experiment.

3.2.1.3 Procedure

The participant followed the same procedure as in Experiment 3 except for the change in how they responded to the visual target. In trials containing a visual target where its location was to the left, the participant was instructed to lift their left hand off the left-hand central key and press the left-hand peripheral key. If the target was located to the right, the participant was instructed to lift their right hand from the right-hand central key and press the right-hand peripheral key. After making their response to the location of the visual target, the participant returned their responding hand to the central key, and pressed and held it to start the next trial.

3.2.2 Results

RTs were prepared for analysis using the same method as utilised in Experiment 3. On average, participants responded correctly 98.2% of the time, thus there was no analysis of participants' errors. Of the 47 participants tested one was removed for responding over 50% of the time to the Catch Trials. The results of the 5-AFC test revealed that participants were able to correctly identify which auditory stimulus they heard 82% of the time. Two different sets of analyses were conducted: facilitation by hemifield location of the auditory stimulus and facilitation by direction of movement of the auditory stimulus.

3.2.2.1 Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented, irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield consistent with the responding hand, i.e., left hemifield presentation - left hand response; Incongruent were those in which the hemifield and responding hand were inconsistent, i.e., left hemifield presentation - right hand response; and Static when the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were when only the visual target was presented.

A Repeated Measures ANOVA of Lift RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 66.302$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.541, 69.323) = 420.957$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in the Congruent Trials than Incongruent and Static Trials, $p < 0.05$. Participants' responses in Static Trials were also significantly faster than Incongruent Trials, $p < 0.05$. Figure 9 shows the mean Lift RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

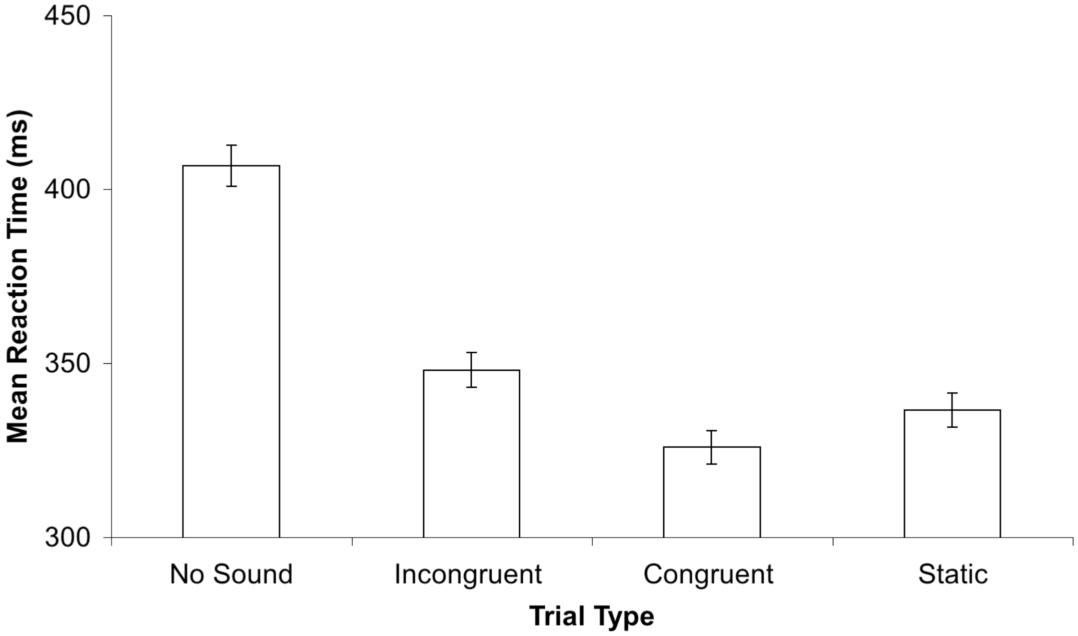

Figure 9. Mean Lift Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Lift RT was further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 19.201$, $p < 0.01$, and Trial Type, $\chi^2(2) = 6.762$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.478, 66.488) = 219.836$, $p <$

0.01, Trial Type F(1.751, 78.778) = 175.410, $p < 0.01$ and a significant interaction between SOA and Trial Type, F(4, 180) = 15.129, $p < 0.01$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms than SOA 125 ms and 0 ms, $p < 0.05$. Participants were also significantly faster at SOA 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Congruent Trials than Static or Incongruent Trials, $p < 0.05$. Participants were also significantly faster in Static than Incongruent Trials, $p < 0.05$. Pairwise comparison for the SOA and Trial Type interaction indicated that at SOA 0 ms participants were significantly faster in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. Also Static Trials were significantly faster than Incongruent Trials, $p < 0.05$. For SOA 125 ms participants were significantly faster in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. Also Static Trials were significantly faster than Incongruent Trials, $p < 0.05$. At SOA 250 ms participants were significantly faster in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. Also Static Trials were significantly faster than Incongruent Trials, $p < 0.05$. Figure 10 shows the mean Lift RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

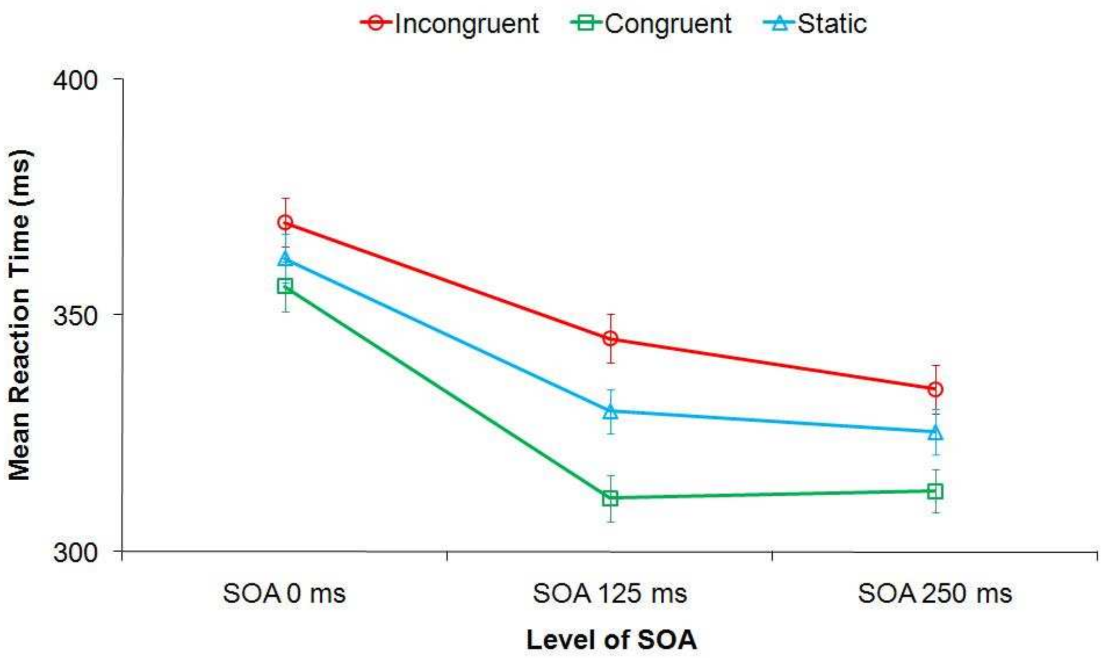

Figure 10. Mean Lift Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

A Repeated Measures ANOVA of Move RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 23.551$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.252, 101.326) = 12.445$, $p < 0.01$. The Pairwise comparison indicated that participants were significantly faster in No Sound Trials than Incongruent, Congruent and Static Trials, $p < 0.05$. Figure 11 shows the mean Move RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

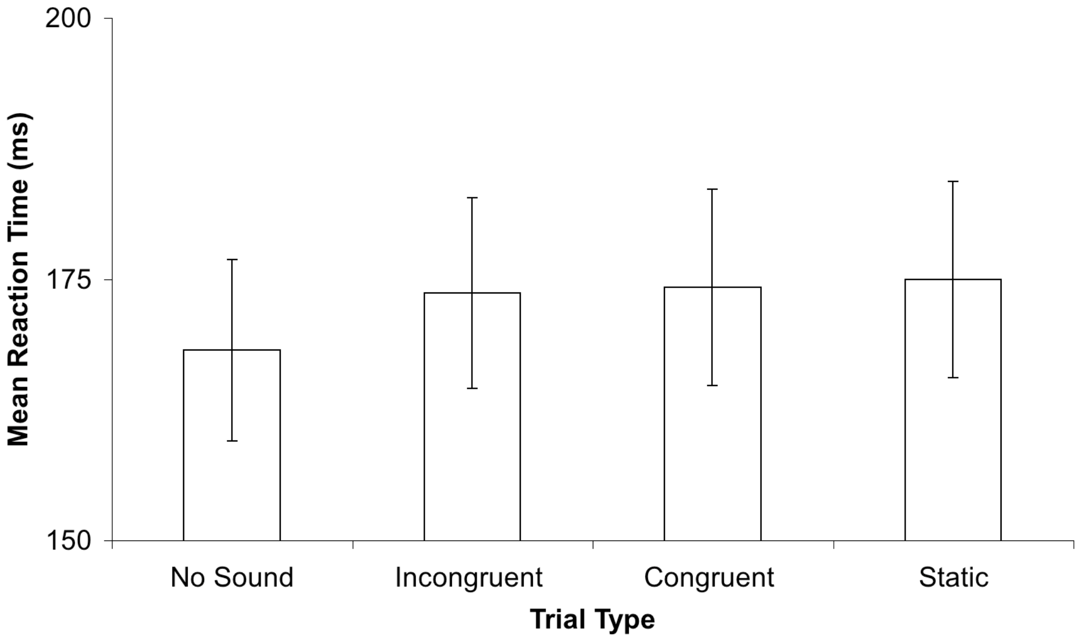

Figure 11. Mean Move Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

A 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors for Move RTs indicated there were no significant differences, $p > 0.05$.

Thus when congruency was defined by hemifield, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs but the opposite was true for Move RTs. Furthermore the analysis of Lift RTs revealed that participants were also faster when the auditory stimulus was presented to the same side of the body on which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been presented fully before the visual target was presented.

3.2.2.2 Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target in relation to the direction of movement of the auditory stimulus. This was irrespective of the hemifield to which the auditory stimulus was presented. Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant had to make in response to the location of the visual target, i.e., a leftward moving auditory stimulus with a left hand key press. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant had to make, i.e., a leftward moving auditory stimulus with a right hand key press. Static Trials were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were where only the visual target was presented.

A Repeated Measures ANOVA of Lift RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 71.527$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.482, 66.697) = 361.669$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials then the No Sound Trials, $p < 0.05$. Figure 12 shows the mean Lift RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

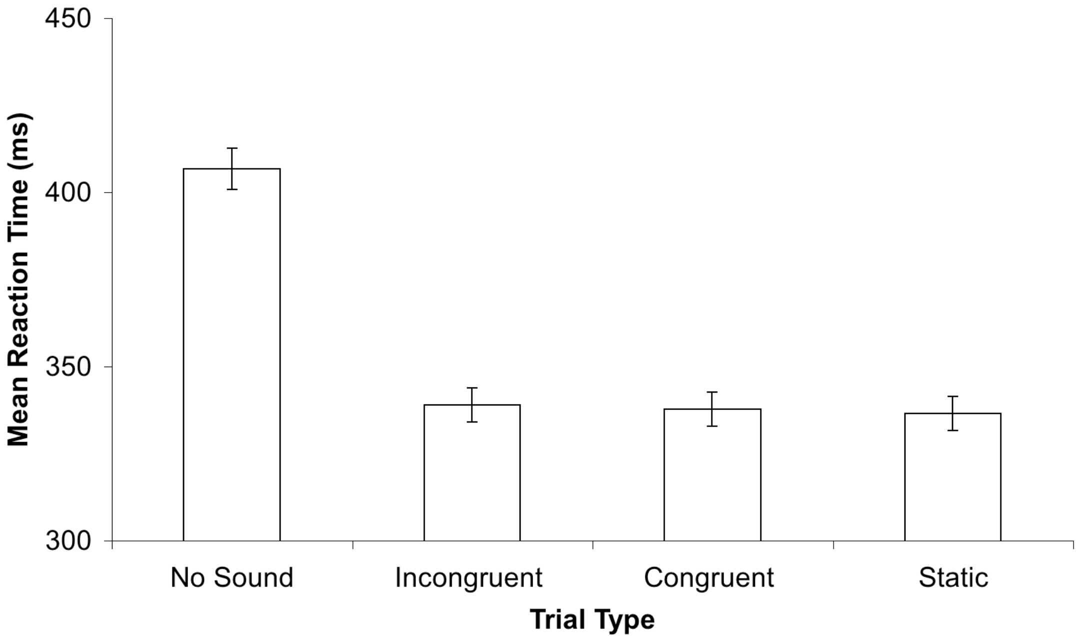

Figure 12. Mean Lift Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

Lift RT was further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 29.536$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.343, 60.446) = 236.716$, $p < 0.01$ and a significant interaction between SOA and Trial Type, $F(4, 180) = 32.596$, $p < 0.01$. There was no significant main effect of Trial Type, $p > 0.05$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms than SOA 125 ms and SOA 0 ms, $p < 0.05$. Participants were also significantly faster at SOA 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for the SOA and Trial Type interaction indicated that at SOA 0 ms participants were significantly faster in Incongruent and Static Trials than Congruent Trials, $p < 0.05$. At SOA 125 ms participants were significantly faster in Incongruent than Congruent Trials, $p < 0.05$. For SOA 250 ms participants were significantly faster in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. Participants were also significantly faster in Static Trials than Incongruent Trials, $p < 0.05$. Figure 13 shows the mean Lift RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the direction of the auditory stimulus.

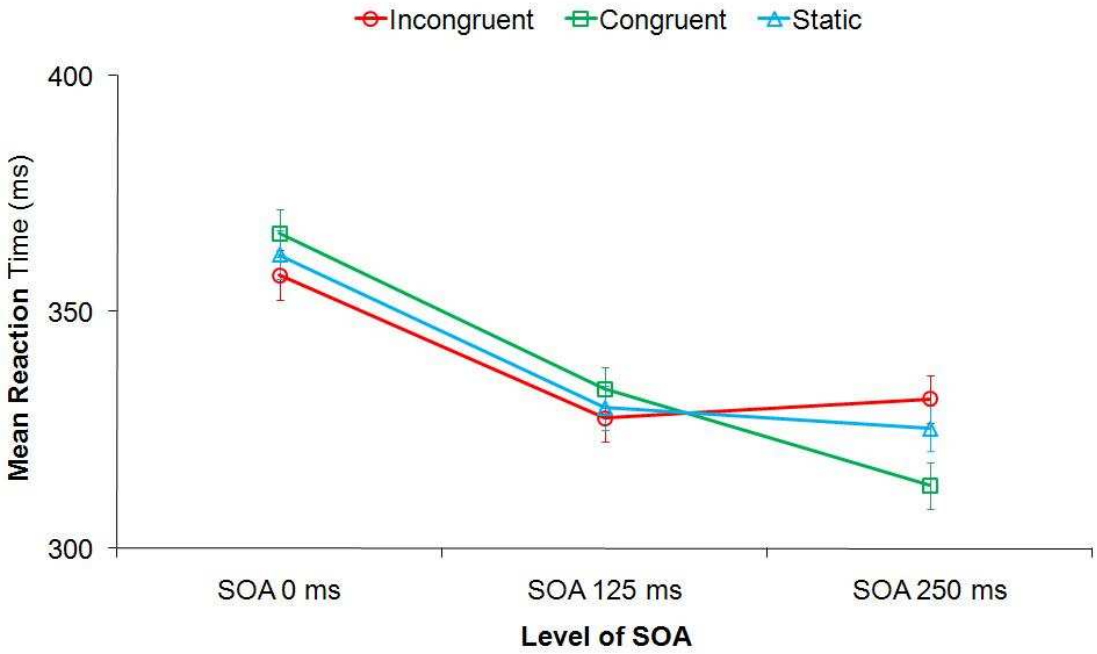

Figure 13. Mean Lift Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

A Repeated Measures ANOVA of Move RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 26.825$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.088, 93.972) = 13.786$, $p < 0.01$. The Pairwise comparison indicated that participants were significantly faster in the No Sound Trials than the Incongruent, Congruent or Static Trials, $p < 0.05$. Figure 14 shows the mean Move RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

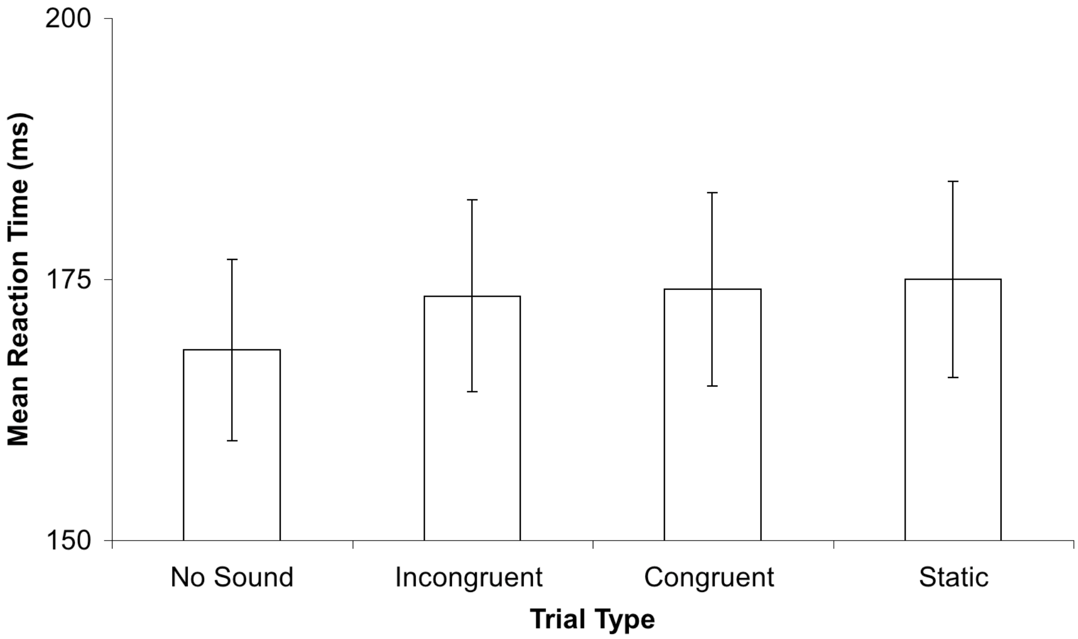

Figure 14. Mean Move Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

A 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors for Move RTs indicated there were no significant effects, $p > 0.05$.

In summary, when congruency was defined by hemifield the results indicated that participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs but the opposite was true for Move RTs. Furthermore the analysis of Lift RTs revealed that participants were also faster when the auditory stimulus was presented to the same side of the body on which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been presented fully before the onset of the visual target.

When congruency was defined by direction, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs but the opposite was true for Move RTs. Further analysis of the Lift RTs indicated that the participants were generally faster when the auditory stimulus moved in the opposite direction to the responding hand, though this pattern reversed itself when the auditory stimulus had been fully presented before the onset of the visual target. Participants were also at their fastest when the auditory stimulus had been fully presented before the visual target. These findings indicate that bi-modal presentations facilitated motor responses in comparison to uni-modal, though only for the Lift response. Facilitation of response appeared to be present when the auditory stimulus was on the same side of the body as the motor response. There also appeared to be facilitation for moving auditory stimuli over their static counterparts, though this was with slight caveats. Finally participants' responses appeared to be facilitated to a greater degree the longer the period of time between the onset of the auditory stimulus and the onset of the visual target.

3.2.3 Discussion

Experiment 4 aimed to address the possible issue identified in Experiment 3 of participants having to lift both their responding and non-responding hand when indicating the location of the visual target. As with Experiment 3 participants' RTs were recorded and analysed in two different ways: Lift/Move RTs and congruency defined by both hemifield and direction. Again if there was a Simon effect it would be expected for there to be differences between trial types when congruency was defined by hemifield. If there was a facilitatory effect of directionality there would be significant differences when congruency was defined by direction. As with Experiment 3 the analysis by hemifield showed that participants were faster in Congruent Trials than Incongruent Trials. When congruency was defined by direction there were mixed results with participants being faster in Incongruent Trials at SOA 0 and 125 ms, while they were faster in Congruent Trials at SOA 250 ms. This supports the hypothesis that there is facilitation arising from the Simon effect and inconsistent facilitation by the direction of movement of the auditory stimulus.

The analysis of bi-modal trials compared to uni-modal trials, for congruency by both hemifield and direction, for Lift and Move RTs followed the same pattern as in Experiment 3. For Lift RTs this meant that participants were significantly faster in the bi-modal trials (Incongruent, Congruent and Static) than the uni-modal trials (No Sound). For Move RTs the reverse was true as participants were significantly faster in uni-modal trials than bi-modal trials. The results of the Lift RTs analysis support the previous bi-modal facilitation results while the reverse of these results for Move RTs seems once again to go against previous findings regarding bi-modal facilitation (Hershenson, 1962). As with Experiment 3 it could be that the lift section of the experiment involved some component of decision making that the move section did not. Also as for Experiment 3 the differences between the trials for Lift RTs compared to those of Move RTs were markedly different. For Lift RTs the difference between uni-modal trials and bi-modal trials was around 70 ms while the difference for Move RTs was only 5 ms. In other words, as for Experiment 3, the bi-modal stimuli led to an overall improvement in total RT (Lift RT plus Move RT) from presentation of the visual target to pressing one of the response keys.

However the interaction for when congruency was defined by direction indicates that there might have also been some form of facilitatory effect of directionality. At SOA 0 ms and 125 ms participants were faster in Incongruent Trials than Congruent Trials, indicating that participants were faster when the auditory stimulus was moving in the opposite direction to the motor response participants made. However at SOA 250 ms participants were faster in the Congruent Trials than the Incongruent Trials. This pattern of results would suggest that there is some form of facilitation of moving auditory stimuli on participants' responses. However it may also be possible to explain this pattern of results using the Simon effect. For SOA 0 ms and 125 ms the short period of time between the presentation of the auditory stimulus in relation to the visual target might have meant that the most salient feature of the auditory stimulus was its onset position. For Incongruent Trials the onset position of the auditory stimulus was near the position of both the visual target and the location of the response the participant had to make. Conversely at SOA 250 ms, as the participant had heard the auditory stimulus in its entirety the most salient feature might have been the position of the termination of the auditory stimulus. For Congruent Trials the position of the termination of the auditory stimulus was near the position of both the visual target and the location of the response the participant had to make. If participants were using the onset and termination positions of the auditory stimuli in this manner it would produce the pattern of results noted here.

While Experiment 4 addressed the possible issue of the participants making dual motor responses there may have also been an issue with how the visual target was presented. In Experiments 1 to 4 the visual target was randomly presented to the left or right of the central fixation point. There is evidence that eye saccades affect the perception of auditory stimuli. Pavani, Husain and Driver (2008) conducted an experiment where participants were presented with a 250 ms auditory stimulus over an array of loudspeakers, followed 2.5 seconds later by another 250 ms auditory stimulus. The participant was then required to state whether the two auditory stimuli came from the same or different locations. On some of the trials the participant was required to keep their eyes static throughout each trial while on others they were required to move their eyes between the presentation of the first and second auditory stimulus. The results showed that when the participants moved their eyes between the presentation of the two auditory stimuli they were significantly worse at judging location than when their eyes were static. This was taken as an indication that eye movements could significantly affect the perceived location of an auditory stimulus. In order to mitigate any influence of this effect, Experiment 5 changed the manner in which the visual target was presented: instead of appearing randomly to the left or right of the fixation cross the visual target now appeared in the same position as the fixation cross. This controlled for both eye saccades and the possible issue of the onset/termination of the auditory stimulus interacting with the position of the visual target.

3.3 EXPERIMENT FIVE

Experiment 5 followed the same general methodology as Experiment 4, however there was a change to the position of the visual targets. In the previous experiments the visual target was a box that appeared randomly either to the left or right of a central fixation cross. This meant participants might have moved their eyes from the central fixation point which in turn could have affected the perception of the auditory stimulus. To control for this the visual targets for Experiment 5 were presented at the position of the central fixation point. The visual target was one of two different colours and dependent on the colour of the visual target participants made either a leftward or rightward motor response.

3.3.1 Method

3.3.1.1 Participants

Thirty-seven students participated in the experiment, of whom 33 were female. The mean age of the participants was 19.3 years (SD 2.4 years) and one participant was left-handed. They were informed they would be performing a visual discrimination task. All other details were as for Experiment 4.

3.3.1.2 Materials and Design

The experiment was conducted in the same sound-attenuated booth that was used in Experiment 4. Presentation of the visual and auditory stimuli was the same as before and the participant's responses were collected using the same custom keyboard. Again, each participant used the chin rest throughout the entirety of the experiment.

The auditory stimuli were the same as used in Experiments 3 and 4. The only change was to the visual target to which the participant responded. The visual target was a green or red coloured box that appeared at the position of the central fixation point. The luminance levels of the coloured boxes were matched to control for possible confounds of differences in luminance levels.

3.3.1.3 Procedure

The participant followed the same procedure as in Experiment 4 except for the change in how they responded to the visual target. In a trial where a visual target was presented the participant had to make a response dependent on its colour. The response was counterbalanced across participants: for half of the participants if the target was red, the participant was instructed to lift their left hand off the left-hand central key and press the left-hand peripheral key; a green target required them to lift their right hand from the right-hand central key and press the right-hand peripheral key. For the other half of the participants, this requirement was reversed. After making their response to the colour of the visual target, the participant returned their responding hand to the central key, and pressed and held it to start the next trial. Participants were randomly assigned to each group.

3.3.2 Results

RTs were prepared for analysis using the same method as utilised in Experiments 3 and 4. On average, participants responded correctly 96.3% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The results of the 5-AFC test revealed that participants were able to correctly identify which auditory stimulus they heard 80% of the time. Two different sets of analyses were conducted: facilitation by hemifield location of the auditory stimulus and facilitation by direction of movement of the auditory stimulus.

3.3.2.1 Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented, irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield consistent with the responding hand, i.e., left hemifield presentation - left hand response; Incongruent were those in which the hemifield and responding hand were inconsistent, i.e., left hemifield presentation - right hand response; and Static when the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were when only the visual target was presented.

A Repeated Measures ANOVA of Lift RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated the assumptions of sphericity had been violated, $\chi^2(5) = 14.961$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.483, 89.386) = 197.621$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster in the Congruent Trials than Incongruent and Static Trials, $p < 0.05$. Figure 15 shows the mean Lift RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

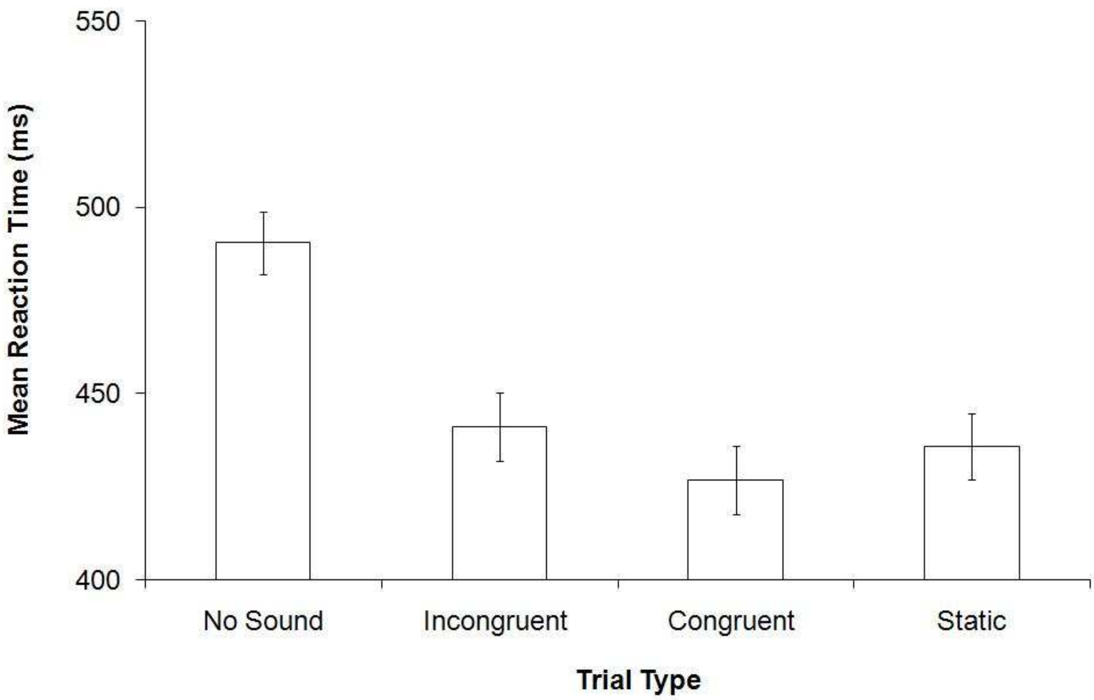

Figure 15. Mean Lift Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Lift RT was further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 9.601$, $p < 0.05$, and Trial Type, $\chi^2(2) = 25.228$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.613, 58.069) = 105.259$, $p < 0.01$, Trial Type, $F(1.321, 47.568) = 21.033$, $p < 0.01$, and a significant interaction between SOA and Trial Type, $F(4, 144) = 6.939$, $p < 0.01$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms and SOA 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Congruent Trials than Static or Incongruent Trials, $p < 0.05$. Participants were also significantly faster in Static than Incongruent Trials, $p < 0.05$. Pairwise comparison for the SOA and Trial Type interaction indicated that at SOA 0 ms participants were significantly faster in Congruent and Static Trials than Incongruent Trials, $p < 0.05$. For SOA 125 ms participants were significantly faster in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. At SOA 250 ms participants were significantly faster in Congruent Trials than Static Trials, $p < 0.05$. Figure 16 shows the mean Lift RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

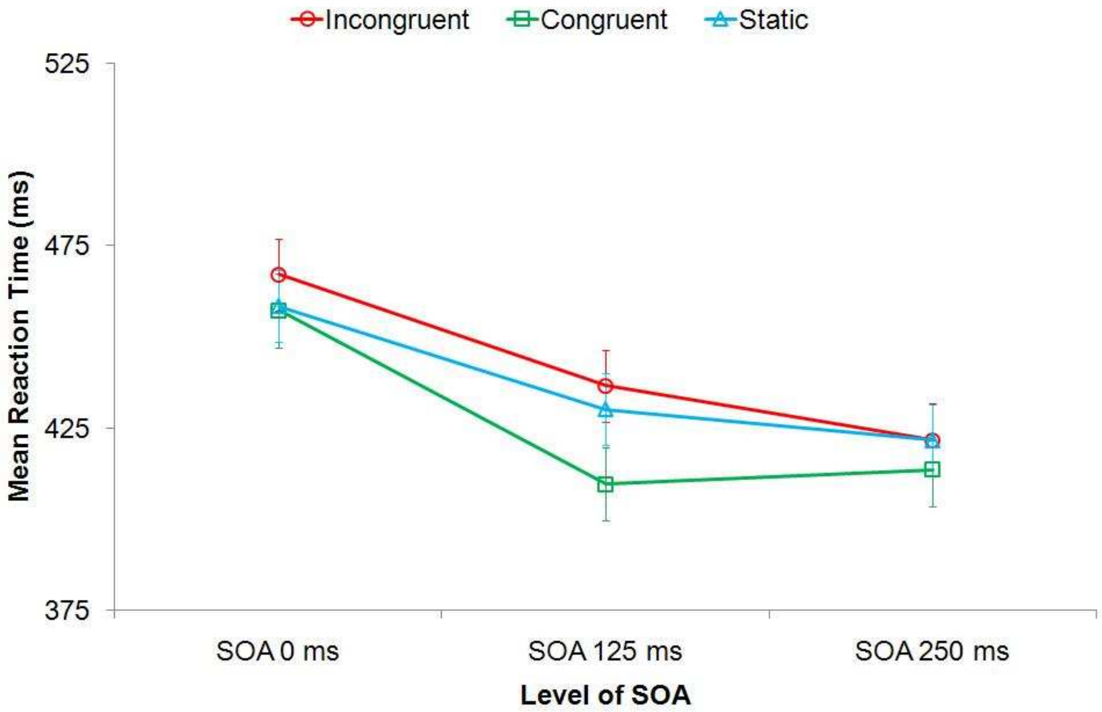

Figure 16. Mean Lift Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

A Repeated Measures ANOVA of Move RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated there was no significant effect of Trial Type, $p > 0.05$.

A 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors for Move RTs indicated there were no significant effects, $p > 0.05$.

Thus when congruency was defined by hemifield, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs. Furthermore the analysis of Lift RTs revealed that participants were also faster when the auditory stimulus was presented to the same side of the body on which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

3.3.2.2 Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target in relation to the direction of movement of the auditory stimulus. This was irrespective of the hemifield to which the auditory stimulus was presented. Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant had to make in relation to the colour of the visual target, i.e., a leftward moving auditory stimulus with a left hand key press. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant had to make, i.e., a leftward moving auditory stimulus with a right hand key press. Static Trials were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were where only the visual target was presented.

A Repeated Measures ANOVA of Lift RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated the assumptions of sphericity had been violated, $\chi^2(5) = 15.327$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.352, 84.669) = 222.830$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in Congruent Trials than Incongruent Trials, $p < 0.05$. Figure 17 shows the mean Lift RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

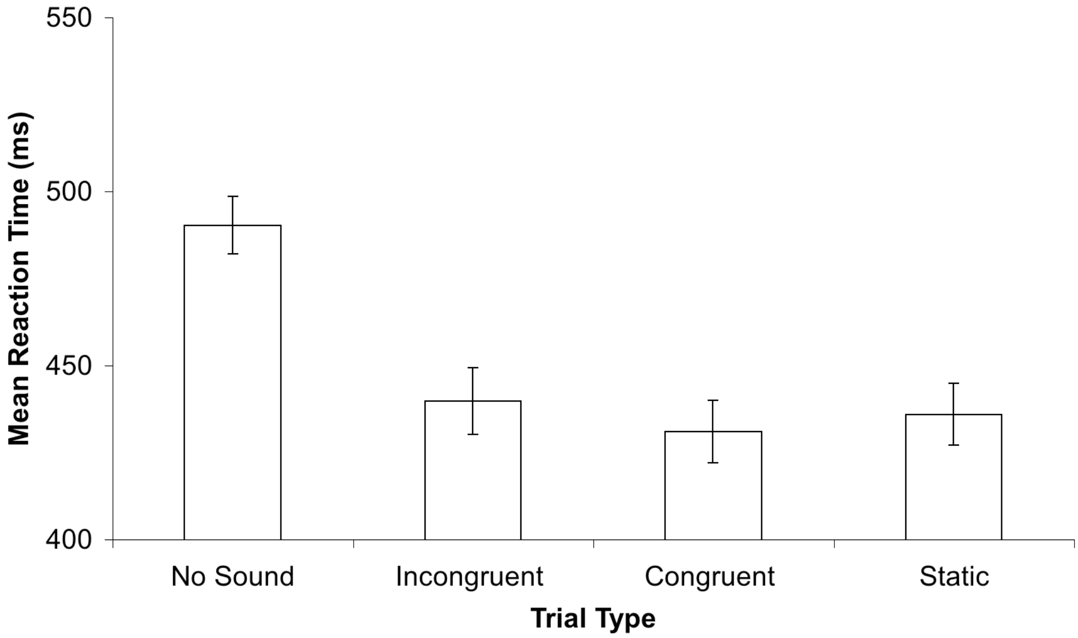

Figure 17. Mean Lift Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

Lift RT was further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 7.214$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.686, 60.695) = 96.807$, $p < 0.01$ and Trial Type, $F(2, 72) = 8.971$, $p < 0.01$. There was no significant interaction between SOA and Trial Type, $p > 0.05$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms than SOA 125 ms and SOA 0 ms, $p < 0.05$. Participants were also significantly faster at SOA 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Congruent and Static Trials than Incongruent Trials, $p < 0.05$. Figure 18 shows the mean Lift RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the direction of the auditory stimulus.

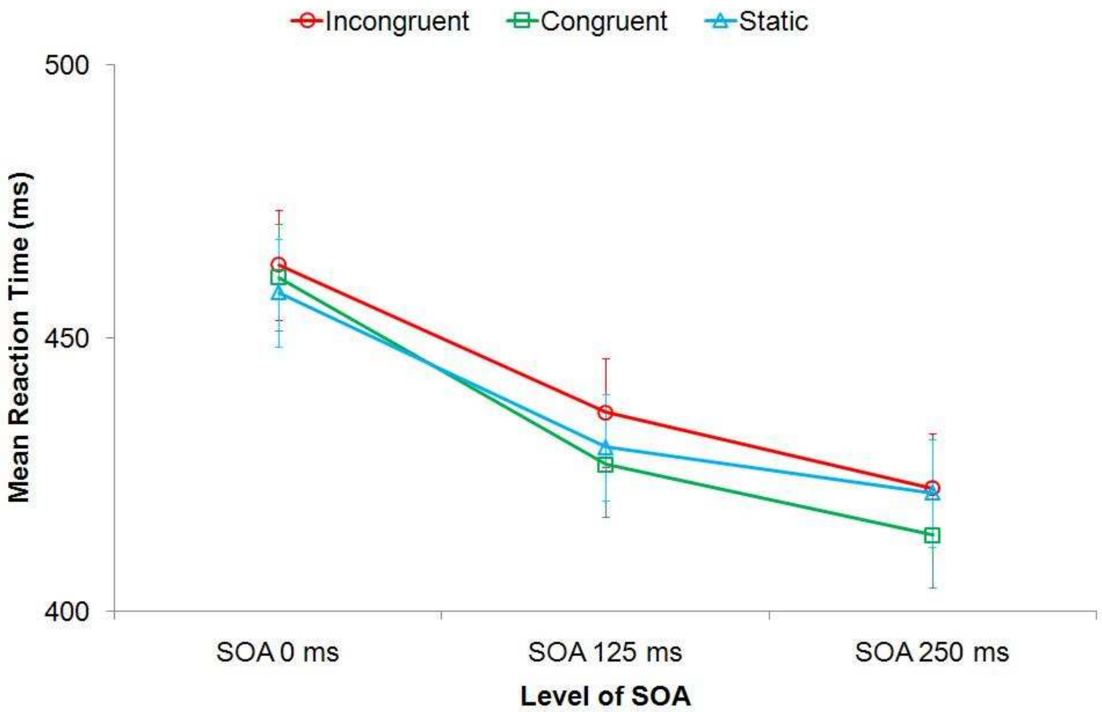

Figure 18. Mean Lift Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

A Repeated Measures ANOVA of Move RT using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated no significant effect of Trial Type, $p > 0.05$.

A 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors for Move RTs indicated no significant effects, $p > 0.05$.

In summary when congruency was defined by hemifield, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs. Furthermore the analysis of Lift RTs revealed that participants were also faster when the auditory stimulus was presented to the same side of the body on which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

When congruency was defined by direction, participants were faster when the visual target was presented in conjunction with an auditory stimulus for Lift RTs. Further analysis of the Lift RTs indicated that the participants were generally faster when the auditory stimulus moved in the same direction as the responding hand. Participants were also at their fastest when the auditory stimulus had been fully presented before the visual target. These findings indicate that bi-modal presentations facilitated motor responses in comparison to uni-modal stimuli. Facilitation of response also appeared to be present when the auditory stimulus was on the same side of the body as the motor response. There also appeared to be facilitation for congruently moving auditory stimuli over their incongruent counterparts. Finally participants' responses appeared to be facilitated to a greater degree the greater the period of time between the onset of the auditory stimulus and the onset of the visual target.

3.3.3 Discussion

The changes in methodology in Experiment 5 meant that the only movement participants needed to make during testing was of the hand that was responding to the visual target.

As with the previous experiments, when congruency was defined by hemifield there was a significant effect of Trial Type with Congruent Trials being faster than Incongruent. As with the previous results this is evidence that there was facilitation of motor response by the Simon effect. When congruency was defined by direction, participants were significantly faster to respond to the visual target when the auditory stimulus was moving in the direction of the required hand movement.

Again there was evidence of bi-modal facilitation with participants' Lift RTs being significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials for both definitions of congruency. Unlike Experiments 3 and 4, the reverse was no longer true for Move RTs.

While Experiment 5 indicated that there may have been facilitation of participants' responses when the auditory stimuli moved in the same direction as the required motor response, in reality this facilitation was small: around 7 ms. For the facilitation to be beneficial in a real-world context the size of the effect would need to be increased. To attempt to bring about this increase two changes were implemented for Experiment 6. The first was how the auditory stimuli was presented to the participant: this involved presenting the stimuli over headphones instead of loudspeakers. This change allowed for greater control over the apparent location of the auditory stimulus than could be obtained with the loudspeakers. This change was enacted on the basis of the findings of Rosenblum et al. (1996) that participants are able to deduce from sound alone whether or not an object is within their reach. It may have been that presenting the auditory stimuli over loudspeakers placed the position of the auditory stimuli outside the participants' perceived motor action area. It was hoped by moving the presentation of the auditory stimulus to headphones that even if the stimuli were now 'within the head' that they would be perceived as within the participant's motor action area. Also while participants were told to use the chin rest for the duration of the experiment they were not monitored throughout. Thus it is possible they may have moved their head during the experiment. As the auditory stimuli were being delivered over loudspeakers any movement of the head would have led to changes in the interaural level differences (ILD) and interaural time differences (ITD) of the stimuli. As ILDs and ITDs are used to determine the location of an auditory stimulus (Hartmann, 1999), changes in their properties from trial to trial may lead to changes in the perception of the location of the auditory stimulus.

Both of these possible issues were addressed by the presentation of the auditory stimulus over headphones for Experiment 6. Also while the issue of participants making dual motor responses had been addressed by allowing them to make responses with only one hand, they still had to prepare to make responses with either hand. So while they made only a single lift and move response they had to prepare responses for both hands. So that participants only had to plan responses for a single hand, Experiment 6 had participants responding to the visual target using a joystick.

3.4 EXPERIMENT SIX

Two fundamental changes were implemented in Experiment 6; these related to the presentation method of the auditory stimuli and the method by which participants responded to the visual target. Presentation of the auditory stimuli reverted to using the headphones from Experiments 1 and 2. This shift back to headphones allowed more control over the apparent location of the auditory stimuli by controlling the ILDs of the auditory stimuli. Secondly the participant's responses were no longer collected using the custom keyboard, instead the participant responded to the visual target using a joystick.

3.4.1 Method

3.4.1.1 Participants

Twenty-four students participated in the experiment, of whom 15 were female. The mean age of the participants was 20.7 years (SD 3.2 years) and no participants were left-handed. All other details were as for Experiment 5.

3.4.1.2 Materials and Design

The experiment was completed in the same sound-attenuated booth that was used in Experiments 3 to 5. Presentation of the auditory stimuli was once again over the headphones used for Experiments 1 and 2. The visual targets were also once again presented via the 19” VideoSeven L19PS TFT screen.

The participant's responses were no longer collected using the custom keyboard utilised in Experiments 2 to 5. Responses were instead collected using a Saitek X45 Joystick placed in front of the participant at their mid-line.

Due to the presentation of the auditory stimuli over headphones the participant was no longer required to use the chin rest employed in Experiments 3 to 5. There was no other change to the auditory stimuli apart from their method of presentation.

The visual target was a blue or yellow coloured box that appeared at the position of the central fixation point. The luminance levels of the coloured boxes were matched to control for possible effects of differences in luminance levels.

3.4.1.3 Procedure

The participant followed the same procedure as in Experiment 5 except for the change in how they responded to the visual target.

In Experiments 3 to 5 the participant started the experiment, and subsequently each trial, using the custom keyboard. As Experiment 6 utilised a joystick this required a different starting method. Thus the experiment began when a button on the top of the Joystick was pressed. In a trial where a visual target was presented the required response was counterbalanced across the participants: for half of the participants, a blue target required a leftward joystick movement, and a yellow target required a rightward joystick movement. For the other half of the participants, this requirement was reversed. Participants were randomly assigned to each group.

3.4.2 Results

RTs were prepared for analysis using the same method as utilised in Experiments 3 to 5. On average, participants responded correctly 97% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The results of the 5-AFC test revealed that participants were able to correctly identify which auditory stimulus they heard 88% of the time. Two different sets of analyses were conducted: facilitation by hemifield location of the auditory stimulus and facilitation by direction of movement of the auditory stimulus.

3.4.2.1 Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented in relation to the participants' response irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield consistent with the side of the body the joystick was moved towards, i.e., left hemifield auditory presentation - leftward joystick movement; Incongruent were those in which the hemifield and responding side were inconsistent, i.e., left hemifield auditory presentation - rightward joystick movement; and Static were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

A Repeated Measures ANOVA of hemifield RTs using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated a significant effect of Trial Type, $F(3, 69) = 75.355$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in the Congruent

Trials than Incongruent and Static Trials, $p < 0.05$. Figure 19 shows the mean hemifield RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

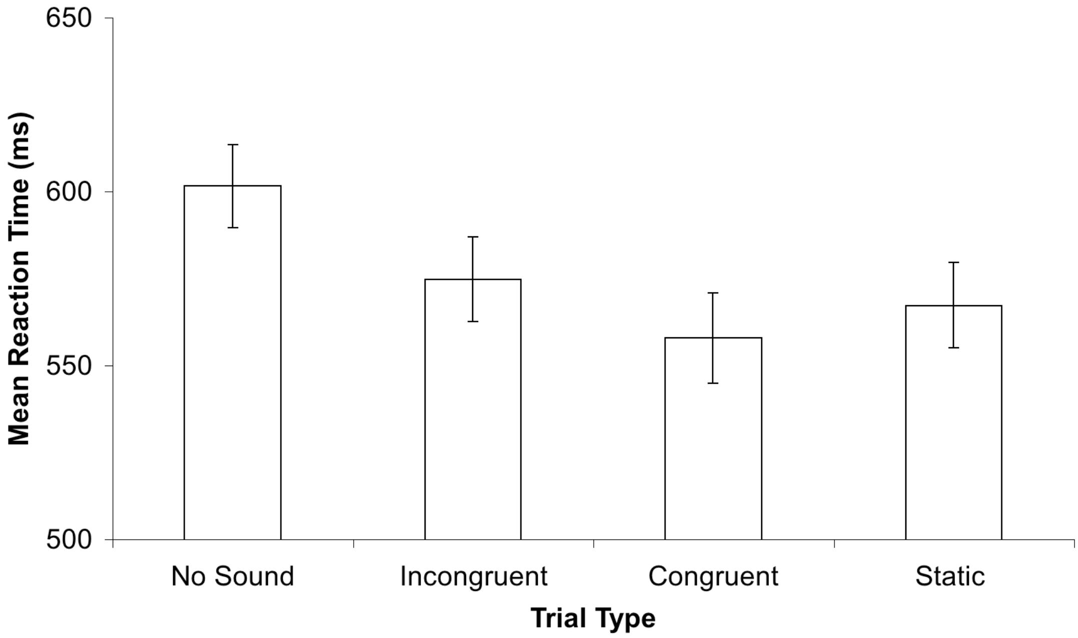

Figure 19. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Hemifield RTs were further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 10.274$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.457, 33.500) = 40.950$, $p < 0.01$ and Trial Type $F(2, 46) = 19.435$, $p < 0.01$. There was no significant interaction between SOA and Trial Type, $p > 0.05$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms and SOA 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for Trial Type indicated that participants were significantly faster in Congruent Trials than Static or Incongruent Trials, $p < 0.05$. Participants were also significantly faster in Static than Incongruent Trials, $p < 0.05$. Figure 20 shows the mean hemifield RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

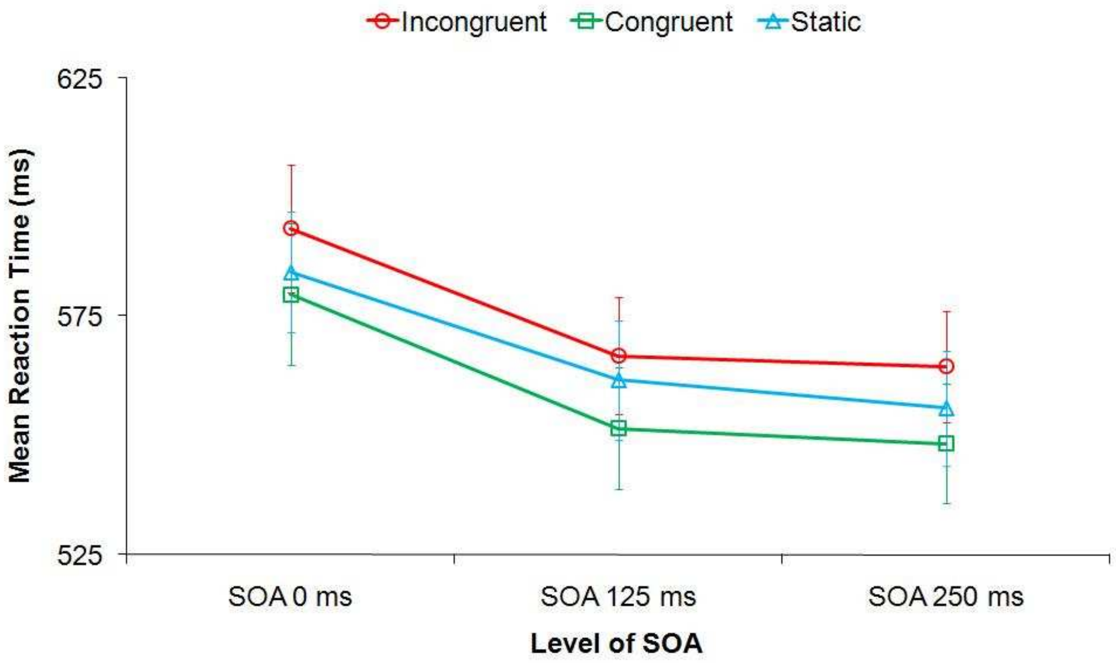

Figure 20. Mean Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Thus when congruency was defined by hemifield, participants were faster when the visual target was presented in conjunction with an auditory stimulus than when presented on its own. Furthermore participants were also faster when the auditory stimulus was presented to the same side of the body towards which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

3.4.2.2 Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target in relation to the auditory stimulus direction of movement. This was irrespective of the hemifield to which the auditory stimulus was presented. Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant had to make in relation to the colour of the visual target, i.e., a leftward moving auditory stimulus with a leftward joystick movement. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant had to make, i.e., a leftward moving auditory stimulus with a rightward joystick movement. Static Trials were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were where only the visual target was presented.

A Repeated Measures ANOVA of direction RTs using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated a significant effect of Trial Type, $F(3, 69) = 69.541$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Figure 21 shows the mean direction RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

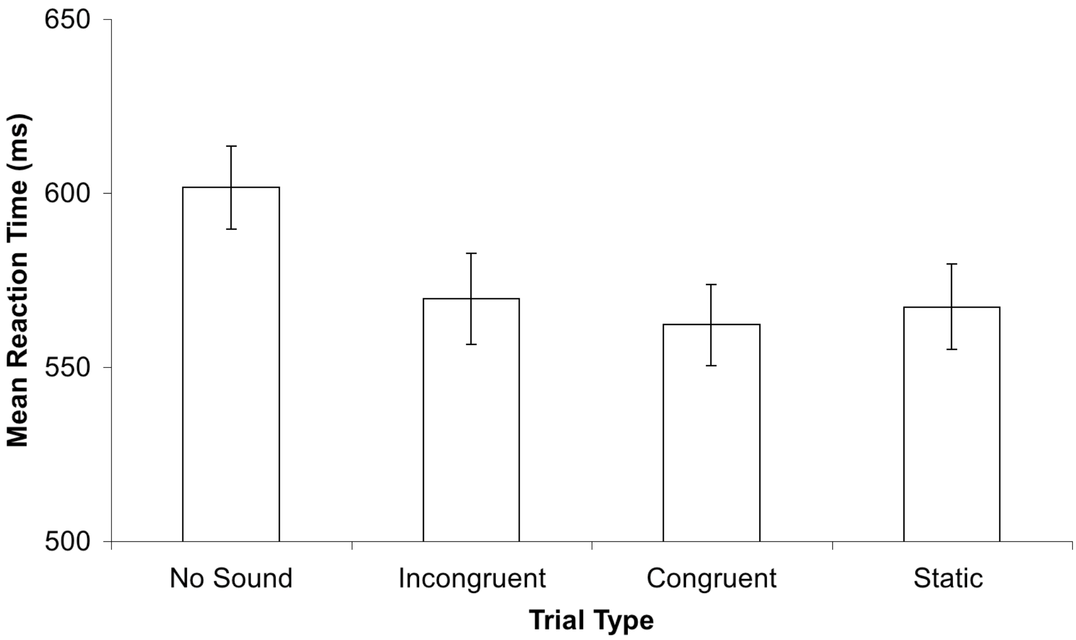

Figure 21. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

Direction RTs were further analysed using a 3 x 3 Repeated Measures ANOVA using SOA (0, 125 and 250 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated that the assumptions of sphericity had been violated for SOA, $\chi^2(2) = 6.441$, $p < 0.01$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of SOA, $F(1.595, 36.688) = 40.585$, $p < 0.01$ and significant interaction between SOA and Trial Type, $F(4, 92) = 3.398$, $p < 0.05$. There was no effect of Trial Type, $p > 0.05$. Pairwise comparison for SOA indicated that participants were significantly faster at SOA 250 ms and SOA 125 ms than SOA 0 ms, $p < 0.05$. Pairwise comparison for the SOA and Trial Type interaction indicated at SOA 0 ms and SOA 250 ms there were no significant differences, $p > 0.05$. At SOA 125 ms participants were significantly faster in Congruent Trials than Incongruent Trials. Figure 22 shows the mean direction RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the direction of the auditory stimulus.

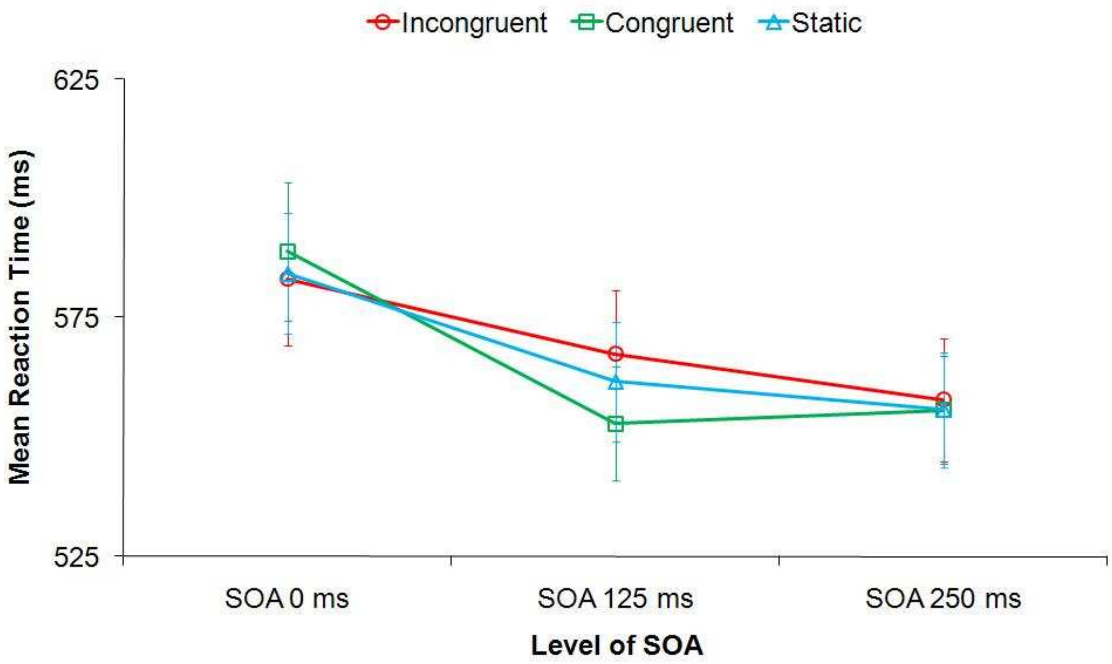

Figure 22. Mean Reaction Times for Incongruent, Congruent and Static Trials at SOA 0, 125 and 250 ms when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

In summary, when congruency was defined by hemifield, participants were faster when the visual target was presented in conjunction with an auditory stimulus than when presented on its own. Furthermore participants were faster when the auditory stimulus was presented to the same side of the body towards which the motor response had to be made. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

When congruency was defined by direction, participants were faster when the visual target was presented in conjunction with an auditory stimulus. Further analysis indicated that participants were faster when the auditory stimulus moved in the same direction as the responding hand, but this was true for only one level of SOA. Participants were also at their fastest when the auditory stimulus had been fully or partially presented before the visual target.

These findings indicated that bi-modal presentations facilitated motor responses in comparison to uni-modal stimuli. Facilitation of response also appeared to be present when the auditory stimulus was on the same side of the body as the motor response. There also appeared to be facilitation for congruently moving auditory stimuli over their incongruent counterparts, with slight caveats. Finally participants' responses appeared to be facilitated to a greater degree the longer the period of time between the onset of the auditory stimulus and the onset of the visual target.

3.4.3 Discussion

Experiment 6 made several changes to the design of Experiment 5, the first being the method of presentation of the auditory stimulus and the second being the method in which participants responded to the visual target.

As with Experiments 3 to 5, when congruency was defined by hemifield the results indicated that participants were significantly faster in Congruent Trials than Incongruent or Static Trials. This, as with the previous experiments, supports the presence of the Simon effect. As with Experiment 5 there appeared to be facilitatory effects of auditory motion, as participants were faster when the auditory stimulus moved in the same direction as the required motor response. However this facilitation only arose for a single level of SOA, 125 ms.

When comparing the uni-modal presentations to the bi-modal presentations the results were in line with Experiments 3 to 5 in relation to the Lift RTs. Participants were significantly faster in the Incongruent, Congruent and Static Trials than they were in the No Sound Trials. The difference between the No Sound Trials and the Incongruent, Congruent and Static Trials was on average 40 ms meaning that the RTs recorded in this experiment followed the same pattern as the Lift RTs of the previous experiments.

The results of Experiment 6 with its change to headphones and joystick did not produce any major changes from the results of the previous experiments. Participants still produced results that could be attributed to the Simon effect; they were faster with bi-modal presentations, faster to respond the greater the difference between onsets of the auditory stimulus and visual target but still did not show a consistent directional facilitation effect.

3.5 GENERAL DISCUSSION

The overall pattern of results for Experiments 3 to 6 indicated that there did not appear to be a consistent facilitatory effect of moving auditory stimuli on participants' motor responses. There were several changes made over the course of these four experiments to control for possible issues such as dual hand movements, position of the visual target, the method in which the auditory stimuli were presented and a major change in how participants responded to the visual target. However even with these changes in place there still appeared to be little to no facilitation from moving auditory stimuli. What effects were noted in the experiments reported in this chapter were relatively small and appeared not to be very consistent. There was however facilitation from other factors, with participants' responses being faster when the auditory stimulus was in the same hemifield as the side of the body to which the participant made a motor response. Participants were generally faster to respond to the visual target when it was accompanied by an auditory stimulus than when it was presented on its own. Also, in the bi-modal trials, participants were faster to respond the greater the period of time between the onset of the auditory stimulus and the onset of the visual target. These facilitatory effects were consistent across all the experiments discussed so far.

While this replication of previous findings indicates that the current methodology was working to produce significant results, it would seem that there needed to be a fundamental change if any consistent facilitation from moving auditory stimuli was to be observed. Thus for the next series of experiments there was a substantial change to the auditory stimulus: instead of using auditory stimuli that moved left to right and right to left, the auditory stimuli were changed to laterally looming or receding.

CHAPTER FOUR

4.0 INTRODUCTION

When a ball is thrown towards a person the image cast on their retina increases in size as the ball draws closer, this change in image size gives rise to the perception of the ball 'looming' or approaching the catcher. The perception of looming is not limited to the visual domain: the phenomenon also exists in the auditory domain. A common example of a looming auditory stimulus in a real-world environment could be the increasing intensity of the sound of a car or motorcycle approaching a person as they walk down the street. Thus looming stimuli could be seen as behaviourally important signals as they generally indicate that an object is approaching, to which some form of response may be needed (Graziano and Cooke, 2006).

Previous work has shown that neuronal cells in the brains of locusts, pigeons, monkeys and humans react specifically to, or give greater response to, looming stimuli than static or receding stimuli, in both the visual and auditory domain (Fotowat and Gabbiani, 2007; Sun and Frost, 1998; Lu, Liang and Wang, 2001; Maier and Ghazanfer 2007; Seifritz, Neuhoff, Bilecen, Sheffler, Mustovic, Schachinger et al., 2002). Lu et al. (2001) performed a series of single cell recordings in the auditory cortices of awake Marmoset monkeys. While recording the activity of these cells, the monkeys were presented with either ramped (looming) or damped (receding) auditory stimuli. The results from the recording sessions indicated that the majority of the cells from which they extracted data had a significant bias towards responding only to either the ramped auditory stimuli or the damped auditory stimuli. There also appeared to be more cells that responded to the ramped auditory stimuli than to the damped auditory stimuli.

Further evidence for the special properties of looming auditory stimuli in non-human primates can be seen in the work of Maier and Ghazanfer (2007). They presented looming auditory stimuli to Rhesus monkeys whose auditory cortices had been implanted with electrode recorders. The recordings indicated that there were cells in the monkey's auditory cortex that appeared to have a bias in response to the looming auditory stimuli over the receding auditory stimuli. Both of these primate studies show that for at least the non-human primates, there is a biological bias towards looming auditory stimuli.

There is also evidence that this bias is not restricted to non-human primates. Seifritz et al. (2002) conducted an fMRI experiment in which human participants were scanned while they were asked to judge the intensities of looming, receding and static auditory stimuli. The scans revealed that the participants' right temporal plane had a larger response to both the looming and receding auditory stimuli than it did to the static auditory stimuli. There was also a greater level of distributed neuronal activity, such as in the pre-motor cortices, when the participants were presented with looming rather than receding auditory stimuli.

A possible advantage of these special properties of looming stimuli can be seen in the behavioural responses to such stimuli, as exhibited by avoidance motor responses in primates (Schiff, Caviness and Gibson, 1962; Ball and Tronick, 1971; Freiberg, Tually and Crassini, 2001). Schiff et al. (1962) presented both looming and receding visual stimuli to Rhesus monkeys. This was accomplished by placing the monkey in front of a screen on which the shadow of a ball was projected. This shadow could be manipulated in such a fashion as to give the visual perception of an object rapidly looming towards the monkey or rapidly receding. During each trial the monkey's behaviour was monitored for any reactions to the visual stimulus. The behaviour exhibited by the monkeys to the looming stimuli was markedly different to the receding stimuli. When they were presented with a looming stimulus the monkeys would rapidly withdraw from it, while when presented with the receding stimulus, they showed an inquisitive behaviour by staying in place and observing it.

Similar patterns have also been shown in human infants. Ball and Tronick (1971) presented infants aged from two to eleven weeks old with a visual stimulus that either loomed or receded. As an extra dimension on some of the looming trials the visual stimulus was on a trajectory that would pass by the infant rather than make contact with it. As with the Rhesus monkeys the infants had distinctly different responses to the visual stimulus depending on whether it was on a collision or non-collision trajectory. When the stimulus was looming towards the infant on a collision trajectory they displayed characteristic defensive or avoidance behaviours such as stiffening, moving their head back or bringing their arms up in front of their face. When the visual stimulus was looming but on a non-collision trajectory or was receding the infant did not perform these defensive movements but rather appeared to track the visual stimulus with their head and eyes.

This defensive behaviour is not limited to looming visual stimuli, infants have also been shown to react defensively when presented with a looming auditory stimulus. Freiberg et al. (2001) conducted a similar experiment to Ball and Tronick (1971) in which infants, this time aged four to six months, were presented with a varying set of auditory stimuli with changing sound pressure levels (SPL). The stimuli's SPLs were manipulated to give rise to the perception of either a looming or receding object; they were also constructed to be perceived as either slow or fast moving. When these auditory stimuli were presented to the infants the results indicated that, as with looming visual stimuli, they induced evasive patterns of behaviour. The infants tried to move away from the auditory stimulus if it was looming but not when it was receding. There were also greater levels of attempted avoidance in the fast looming trials than the slow looming trials.

This defensive pattern of behaviour has also been shown to be present in adult humans when they are performing a distracting task. King, Dykeman, Redgrave and Dean (1992) tasked participants with playing a video game that required high levels of attention. While they were playing they were suddenly presented with a looming visual stimulus which approached from the edges of their peripheral vision. This looming stimulus had variable approaching speeds and stopping distances; being either fast or slow to move and stopping either close to the participant or far away. The looming stimulus also had a varied trajectory, either collision or non-collision. The findings indicated that when the participant's attention was engaged in playing the video game and they were presented with a fast looming visual stimulus on a collision trajectory they performed defensive head movements similar to those of the infants in the experiments of Ball and Tronick (1971) and Freiberg et al. (2001). This defensive response was absent when the looming stimulus was on a non-collision trajectory, and there were minimal defensive movements when the stimulus was fast looming but the stopping point was far from the participant.

The results of King et al. (1992) are of interest as they show that even when attention is directed to another task looming stimuli appear to have the ability to capture attention, allowing other motor movements to be performed not related to the original task. This is supported by the findings of Franconeri and Simons (2003) whose research indicated that task-irrelevant, looming visual stimuli capture attention. In their task participants performed a visual search task in which they looked for a target letter interspersed within several distracter letters. Before the search array was presented to participants the target letter, plus the distracters, were briefly masked. On some trials the mask over the target letter either loomed or receded before the target letter was presented. The results suggest that the looming mask was significantly more effective at capturing participants' attention than the receding mask.

There is a possibility that this capturing of attention can take place without the participant being aware of the looming stimulus. Lin, Murray and Boynton (2009) had participants perform a visual search task involving locating an oval target interspersed within circular distracters. The search array was preceded by a visual looming stimulus that was either on a collision trajectory with the participant or a non-collision trajectory. When the target was preceded by a looming visual stimulus on a collision trajectory the participant was significantly faster to respond to the following visual target than when the looming stimulus was on a non-collision trajectory. Participants were subsequently tested on their ability to differentiate between the collision and non-collision trajectory looming stimulus but were unable to do so. This can be taken to indicate that the looming stimuli on a collision trajectory were able to effectively facilitate responses without participants' awareness of it doing so.

Apart from the difference in the direction of motion of looming and receding auditory stimuli there are other special properties of looming auditory stimuli that may influence participants' responses. In a series of experiments by Neuhoff (2001) participants were asked to judge the relative loudness, onset, and termination positions of both looming and receding auditory stimuli. These stimuli were matched for changes in loudness and had the same onset and termination positions irrespective of whether they were looming or receding. However when participants were asked to make judgements on these properties they rated the looming stimuli as having both a greater change in loudness and closer onset and termination positions than the receding stimuli. This is a further example of the special properties of looming stimuli, which could be a factor in the behavioural responses that they generate.

Another reported special property of looming stimuli that differs to receding or static stimuli, and that may influence behavioural responses, is that looming auditory stimuli appear to be subjectively more unpleasant than other stimuli. Bach, Neuhoff, Perrig and Seifritz (2009) presented participants with both looming and receding auditory stimuli while recording their skin conductance reaction (SCR), which they used as a measure of autonomic orienting. After the presentation of the auditory stimulus the participant was asked to make ratings of its potency, arousal and intensity. Participants were further asked to judge how likely it was that the sound was going to be followed by a significant event, and how likely it was that the sound was going to be followed by a threatening event. When comparing the participants' SCR for the looming trials to the receding trials the data revealed that they were producing a significantly greater physiological response to the looming auditory stimuli than they were to the receding auditory stimuli. This indicated that looming auditory stimuli led to the mobilisation of energetic resources. The findings of the emotional ratings revealed that participants thought looming stimuli were more unpleasant, had greater potency, were more arousing, and of greater intensity than receding stimuli. The participants also reported that a looming auditory stimulus was more likely to be followed by a significant or threatening event. This indicates that as well as the purely biological responses to looming stimuli there is also a strong cognitive response to them as well which may feed into the behavioural responses observed in other studies.

The findings of Bach et al. (2009) are supported by Tajadura-Jimenez, Valjamae, Asutay and Vastjall (2010) who conducted a similar experiment and reported that looming auditory stimuli were considered as more unpleasant than receding stimuli as well as generating greater physiological responses in the participant.

As noted previously in Chapter 1, bi-modal stimulus presentations led to faster reaction times (RTs) than uni-modal stimulus presentations. This facilitatory effect of multi-sensory combinations is also present with looming visual and auditory stimuli. Moreover it appears that there is bias towards looming stimuli pairs over receding or static pairings. Cappe, Thut, Romei and Murray (2009) presented participants with uni-modal or bi-modal visual and auditory stimuli that could be looming, receding, static or, for bi-modal presentations, any combination of the three. Participants were asked to make judgements on the strength of movement on a 5-point Likert scale of each stimulus presentation. This was followed by a second experiment where the task was to respond as quickly as possible to indicate whether the presented stimulus was in motion or not. Unlike the first experiment the bi-modal stimulus presentations always contained pairs of stimuli that were moving in the same direction. In the judgement experiment participants rated the strength of movement to be greater for the looming stimulus pairs than for any of the other multi-sensory pairings. For the second experiment the results showed that participants were significantly faster to respond in the bi-modal stimulus trials when the stimuli were looming than when they were receding. Participants were also faster to respond in bi-modal trials than any of the uni-modal trials.

This apparent bias towards looming bi-modal stimuli is supported by a similar bias observed in Rhesus monkeys in a study by Maier, Neuhoff, Logothetis and Ghazanfar (2004). The monkeys were presented with two visual display screens, one to their left and the other to their right, one of which would present a looming visual stimulus while the other presented a receding stimulus. Behind each display screen was a speaker that played a looming or receding auditory stimulus. The results of the experiment showed that when presented with one screen-speaker pair playing looming stimuli and the other pair receding stimuli the monkey paid more attention to the looming presentation. If however both the speakers presented receding stimuli the monkey showed no preference to either the looming or receding visual display indicating that it was the combination of both a looming visual and auditory stimulus that was linked to where the monkey focused their attention.

In conclusion it has been shown that looming stimuli tend to engender stronger reactions compared to receding or static stimuli, and this appears to be true for both the visual and the auditory domain. This bias is evident in the behavioural reactions made by both humans and other animals in response to being presented with looming stimuli. Looming stimuli capture attention more effectively than receding or static stimuli and this capture of attention arises even when the looming stimuli are task-irrelevant, or in some situations not perceived.

The previous experimental chapters of this thesis, Chapters 2 and 3, tested the hypothesis that task-irrelevant, moving auditory stimuli would facilitate participants' motor responses to a visual target. The results of experiments in these two chapters were that while participants' motor responses were facilitated by the auditory stimuli, this facilitation arose from factors other than the stimulus movement. Participants' responses appeared to be facilitated by the location of the auditory stimuli, the presentation of bi-modal stimuli compared to uni-modal as well as audio stimulus/visual target stimulus onset asynchrony (SOA) greater than 0 ms. However there appeared to be no consistent results of the movement of the auditory stimulus facilitating motor responses. Given the special properties of looming stimuli, as discussed above, it may be that these properties could lead to the facilitation of responses.

Thus the aim of this final experimental chapter is to use the special properties of looming stimuli, specifically looming auditory stimuli, to test the hypothesis that task-irrelevant, looming auditory stimuli will facilitate motor movements when responding to a visual target.

4.1 EXPERIMENT SEVEN

The core difference between Experiment 6, from Chapter 3, and Experiment 7 was the change in the auditory stimuli presented to the participants. In Experiment 6 participants were presented with auditory stimuli that gave rise to the perception of movement from the participants' mid-line to either the left or right-hand side of their body or vice versa. A possible issue with how these stimuli were created and presented to the participants was that while there was movement in the auditory stimulus, participants may have localised this movement to inside their head. To control for this potential effect, Experiment 7 used laterally looming auditory stimuli which were designed to be perceived as being outside the head. The auditory stimuli were also changed from 250 ms to 1000 ms in length. Participants performed the same task that was utilised in Experiment 6, moving a joystick leftward or rightward depending on the colour of the visual target.

4.1.1 Method

4.1.1.1 Participants

Twenty-five students participated in the experiment, of whom 20 were female. The mean age of the participants was 21.1 years (SD 3.2 years). No participants were left-handed, and all participants had normal hearing with normal or corrected to normal vision. All participants gave their informed consent. They were paid £5 for their participation and were unaware of the purpose of the experiment except that they would be performing a visual discrimination task. The experiment was approved by and conducted under the guidelines of Cardiff University: School of Psychology Ethics Committee, the QinetiQ Ethics Committee and the MoD Research Ethics Committee (MoDREC).

4.1.1.2 Materials and Design

The experiment took place in a sound attenuated booth of which the height, width and length were 198 cm, 193 cm and 183 cm respectively. Stimuli, both visual and auditory, were presented to the participant using a computer running Eprime (version 1.2). Auditory stimuli were delivered to the participant over a pair of Sennheiser HD 280 Pro headphones driven by a Yamaha DS1x native sound card. The visual targets were presented using a 19” VideoSeven L19PS TFT Screen running at a resolution of 1280 x 1024.

The responses were collected using a Saitek X45 Joystick placed in front of the participant at their mid-line.

The auditory stimuli were created using |Wave (Culling, 1996), Matlab and Cool Edit 96. |Wave was used to create Impulse Responses (IRs) with sources at 300 cm and 25 cm, 90 degrees to the left of the mid-line, and included the effects of the head by using Head-related transfer functions (HRTFs), taken from the MIT measurements of a KEMAR mannequin (Gardner and Martin, 1994). All IRs were generated using an adapted version of the room impulse response program in |WAVE, which filtered each echo in the room impulse response by the HRTF corresponding to the direction of the incident ray. Matlab (Version R2008a) convolved a 1000 ms long broadband noise with those IRs to create auditory stimuli perceived to be at 300 cm and 25 cm to the left of the participant's head. Cool Edit 96 was then used to fade between the 300 cm and 25 cm auditory stimuli to create the perceptual effect of lateral looming. This was mirrored to create another auditory stimulus that was perceived to be laterally looming towards the right hand side of the head. Finally to create the receding sounds both looming auditory stimuli were reversed, while the static sound was a 1000 ms long broadband noise perceived as directly in front of the participant.

The visual target was a coloured box, blue or yellow, which appeared at the same location as the central fixation cross. The visual targets were matched on luminance to control for possible confounds that may have arisen from differences in luminance levels.

4.1.1.3 Procedure

The participant started each trial by focusing on the fixation cross. After a random interval of between one and two seconds, the participant was presented with either the visual target alone; the visual target and an auditory stimulus; or just an auditory stimulus.

In a trial where a visual target was presented, either alone or paired with an auditory stimulus, the participant made a response dependent on the colour of the visual target. The response to the visual target was counterbalanced across the participants: for half of the participants, a blue target required a leftward joystick movement, and a yellow target required a rightward joystick movement. For the other half of the participants, this requirement was reversed. Participants were randomly assigned to each group.

When the trial consisted of an auditory stimulus/visual target presentation, the auditory stimulus was either static or one of the four moving stimuli. For the auditory stimulus/visual target trials there was a single level of SOA of 1000 ms. This meant the participant heard the auditory stimulus fully before being presented with the visual target.

There were a total of 450 trials for each participant. In 100 of the trials only the visual target was presented; there was a 50/50 split between blue visual targets and yellow visual targets. There were 50 trials in which only an auditory stimulus was presented, 10 of each sound type. These were used as Catch Trials to test whether the participant was responding only to the visual target and not to the auditory stimulus.

The remaining 300 trials were distributed between the four moving and one static auditory stimuli. There were 50 of each of the moving auditory stimuli and 100 of the static auditory stimulus. For each auditory stimulus type, there was an equal number of blue and yellow presentations of the visual target. Hence the auditory stimulus was not predictive as to the colour of the visual target and thus the required motor response.

After the participant completed all 450 trials, they were tested on their ability to distinguish between the five different types of auditory stimulus using a five alternative forced choice (5-AFC) test. The participant was presented with 50 randomised presentations of the auditory stimuli, 10 of each type (looming from the left, receding to the left, looming from the right, receding to the right and static). The task was to indicate after each presentation which auditory stimulus they thought they had heard.

4.1.2 Results

RTs that were faster than 150 ms or slower than 1000 ms, and responses that were incorrect, were removed before data analysis was performed. Responses faster than 150 ms were classified as anticipatory and those slower than 1000 ms were classified as misses. On average, participants responded correctly 96% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The results of the 5-AFC test revealed that participants were able to correctly identify which auditory stimulus they heard 92% of the time. The same statistical analysis was applied to all the results reported here; this was a Repeated Measures Analysis of Variance (ANOVA) utilising Bonferroni-corrected Pairwise Comparisons. Three different sets of analyses were conducted: facilitation by hemifield location of the auditory stimulus, facilitation by direction of movement of the auditory stimulus and facilitation by looming of the auditory stimulus. The first two sets of analyses were conducted to integrate the findings across the experiments of Chapter 3 while the third analysis was to investigate the effects of looming auditory stimuli.

4.1.2.1 Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented in relation to the response, irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield consistent with the side of the body the joystick was moved towards, i.e., left hemifield auditory presentation - leftward joystick movement;

Incongruent were those in which the hemifield and responding side were inconsistent, i.e., left hemifield auditory presentation - rightward joystick movement; and Static were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

As in the experiments of Chapter 3 the effect of bi-modal presentations was compared to that of uni-modal trials. A Repeated Measures ANOVA of hemifield RTs using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated the assumptions of sphericity had been violated for Trial Type, $\chi^2(5) = 22.617$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of Trial Type, $F(1.900, 47.491) = 89.831$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in the Congruent Trials than Incongruent and Static Trials, $p < 0.05$. Figure 23 shows the mean RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

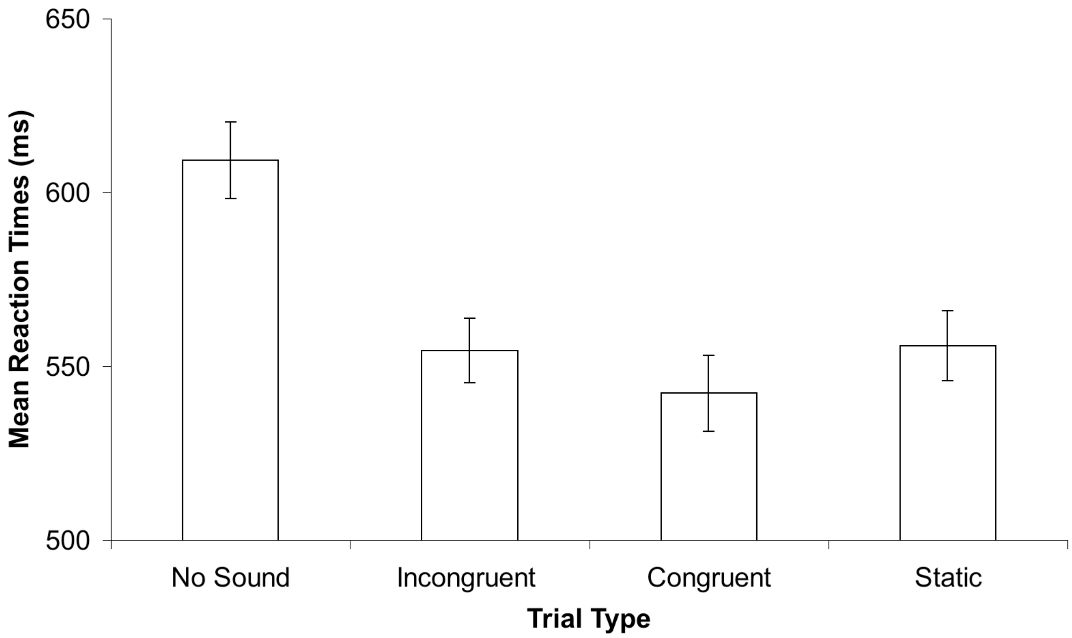

Figure 23. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

So for congruency defined by hemifield, RTs were faster when the visual target was preceded by an auditory stimulus than if the visual target was presented on its own. Participants were also faster when the auditory stimulus was presented to the same side of the body as the motor response was to be made towards.

4.1.2.2 Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target as a function of the direction of movement of the auditory stimulus irrespective of it looming or receding. This was also irrespective of the hemifield to which the auditory stimulus was presented. In this analysis, Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant made in relation to the colour of the visual target, i.e., a leftward moving auditory stimulus with a leftward joystick movement or a rightward moving auditory stimulus with a rightward joystick movement. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant made, i.e., a leftward moving auditory stimulus with a rightward joystick movement. Static Trials were those in which the auditory stimulus was perceived as being directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

A Repeated Measures ANOVA of directional RTs using Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated for Trial Type, $\chi^2(5) = 30.056$, $p < 0.05$. This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of Trial Type, $F(1.634, 40.856) = 103.785$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in Incongruent Trials than they were in Static Trials, $p < 0.05$. Figure 24 shows the mean direction RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

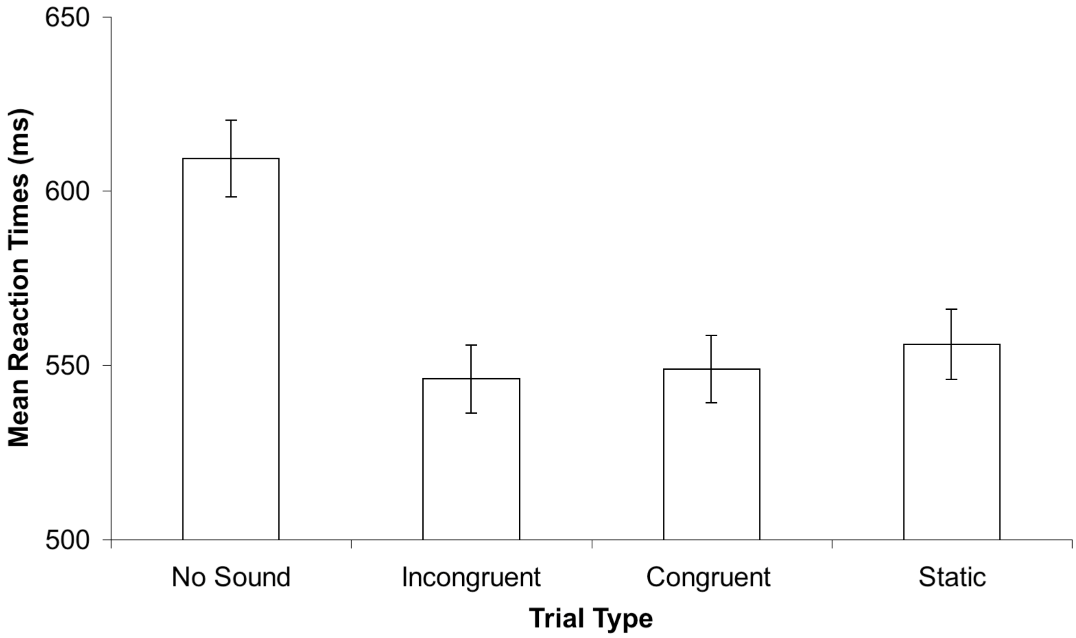

Figure 24. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

For congruency by direction, the results indicated that again RTs were faster when the visual target was preceded by an auditory stimulus than when the visual target was presented by itself. Participants were also faster in trials where the auditory stimulus direction of movement was Incongruent to the required motor response than when the auditory stimulus was Static.

4.1.2.3 Facilitation by looming of the auditory stimulus

The final analysis defined trials as Receding, Looming or Static dependent on the auditory stimulus in relation to the body. Receding Trials were those in which the auditory stimulus was laterally moving away from the body on either side of the participant's head; Looming Trials were those in which the auditory stimulus was laterally moving towards the body on either side of the head and Static Trials were those in which the auditory stimulus was presented directly in front of the participant.

A Repeated Measures ANOVA of Looming RTs using Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated for Trial Type, $\chi^2(5) = 21.056$, $p < 0.05$.

This was corrected for using Greenhouse–Geisser estimates of sphericity. The corrected results indicated that there was a main effect of Trial Type, $F(2.009, 50.214) = 82.037$, $p < 0.01$. Pairwise comparisons showed that participants were significantly faster in Receding, Looming and Static Trials than No Sound Trials, $p < 0.05$. Participants were also significantly faster in Looming Trials than they were in Receding and Static Trials, $p < 0.05$. Figure 25 shows the mean RTs for each Trial Type with error bars.

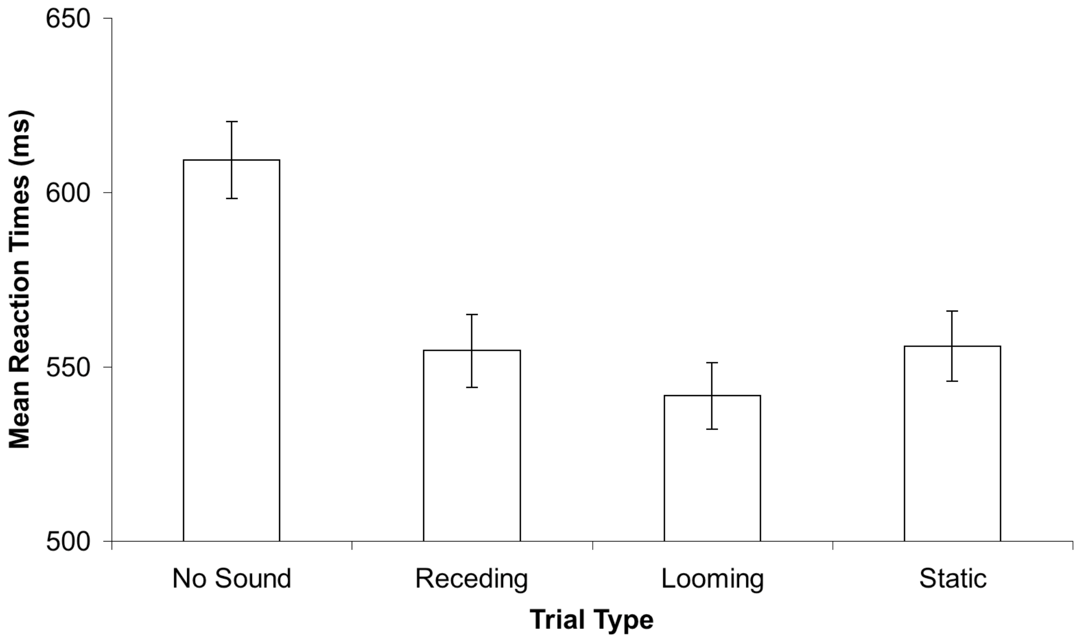

Figure 25. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

In summary for trials defined by whether the auditory stimulus was looming or not the results indicated that, as with the other two sets of analyses, when the visual target was preceded by any auditory stimulus participants were faster to respond than when the visual target was presented on its own. Also, participants were faster to respond when the auditory stimulus was looming than if it was receding or static. This indicated that the looming auditory stimuli facilitated participants' motor responses to a greater degree than receding or static auditory stimuli. The results of the other two analyses revealed that participants were also faster to respond to the visual target when the auditory stimulus was presented to the hemifield towards which the participants were required to make their motor response. Finally when the auditory stimulus was moving in the opposite direction to the required motor movement this facilitated the response to the visual target.

4.1.3 Discussion

The aim of Experiment 7 was to test the hypothesis that that motor responses can be facilitated by task-irrelevant, looming auditory stimuli. This hypothesis was based on previous research that looming stimuli, specifically looming auditory stimuli, appeared to have special properties compared to receding or static auditory stimuli. Such properties were defensive motor responses (Freiburg et al., 2001) and neurological activation bias towards looming stimuli (Maier and Ghazanfer, 2007).

The present experiment demonstrated the ability of task-irrelevant, looming auditory stimuli to facilitate participants' motor responses to visual targets. The main finding was that participants were significantly faster to respond in Looming Trials than Receding or Static. This supports the hypothesis that motor responses can be facilitated by looming auditory stimuli and that this facilitation occurs even where the stimulus is task-irrelevant.

In a complementary series of analyses to ones conducted in Chapter 3, the results were that participants were always faster in the bi-modal trials than they were in the uni-modal trials, and faster when the required motor response was to the same hemifield to which the auditory stimulus was presented.

As the previous experiments reported in this thesis have shown there were significant differences in participants' motor response times when SOA was manipulated, thus Experiment 8 re-introduced three levels of SOA. This was to investigate whether these significant differences were replicable when using looming auditory stimuli. Also by having varying levels of SOA it was possible to see if any one level was consistently more effective than another. Manipulations to SOA were important because by changing the time between the onset of the auditory stimulus and the onset of the visual target it was possible to change how much of the auditory stimulus was presented, and thus processed, by the listener before they made their motor response to the visual target.

4.2 EXPERIMENT EIGHT

Experiment 8 re-introduced multiple levels of SOA, in this case SOA 500, 1000 and 1500 ms. SOA 500 ms and 1000 ms were chosen to replicate the previous experiments in Chapter 3 where the visual target was presented half way through the presentation of the auditory stimulus and at the termination of the auditory stimulus. SOA 1500 ms was chosen because in the previous experiments of Chapter 3 participants' responses were at their fastest when the auditory stimulus had been heard in its entirety before the onset of the visual target. It was hypothesised that participants' responses would be faster the greater the time between onset of the auditory stimulus and the onset of the visual target.

4.2.1 Method

4.2.1.1 Participants

Thirty students participated in the experiment, of whom 19 were female. The mean age of the participants was 21.2 years (SD 1.8 years). All other details were as for Experiment 7.

4.2.1.2 Materials and Design

The experiment was conducted in the same sound-attenuated booth that was used for Experiment 7. The visual targets and auditory stimuli were the same as used in Experiment 7. Presentation of the visual and auditory stimuli was the same as before and the responses were collected using the same Joystick in the same position at the mid-line, as utilised in Experiment 7.

4.2.1.3 Procedure

The participant performed the same task as described in Experiment 7. However there was a change to three levels of SOA; 500, 1000 and 1500 ms in which the auditory stimulus always preceded the visual target. This meant that for SOA 500 ms the participant heard half of the auditory stimulus before being presented with the visual target. At SOA 1000 ms, the participant had heard the auditory stimulus fully before being presented with the visual target. At SOA 1500 ms, the participant had heard the auditory stimulus fully followed by 500 ms of silence before the visual target was presented.

There were a total of 747 trials for each participant. In 168 of the trials only the visual target was presented; there was a 50/50 split between blue visual targets and yellow visual targets. There were 75 trials in which only an auditory stimulus was presented, 15 of each sound type. These were used as Catch Trials to test whether the participant was waiting for the visual target to appear before making the response, as instructed, rather than responding to the auditory stimulus.

The remaining 504 trials were evenly split between the three levels of SOA, with each level having 168 trials. Of these 168 trials, 56 contained a static auditory stimulus. The other 112 trials were evenly distributed between the four moving auditory stimuli, meaning that there were 28 of each moving auditory stimulus. For each level of SOA there was an equal number of blue and yellow presentations of the visual target. Hence the auditory stimulus was not predictive as to the colour of the visual target and thus the response required.

4.2.2 Results

RTs were prepared for analysis using the same method as utilised in Experiment 7. On average, participants responded correctly 96.3% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The same statistical analysis was applied to all the results reported here; this was a Repeated Measures Analysis of Variance (ANOVA) utilising Bonferroni-corrected Pairwise Comparisons. Three different sets of analyses were conducted: facilitation by hemifield location of the auditory stimulus, facilitation by direction of movement of the auditory stimulus and facilitation by looming of the auditory stimulus. The first two sets of analyses were conducted to integrate the findings across the experiments of Chapter 3 while the third analysis was to investigate the effects of looming auditory stimuli.

4.2.2.1 Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented in relation to the response, irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield consistent with the side of the body the joystick was moved towards, i.e., left hemifield auditory presentation - leftward joystick movement; Incongruent were those in which the hemifield and responding side were inconsistent, i.e., left hemifield auditory presentation - rightward joystick movement; and Static were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

As with Experiment 7 the effect of bi-modal presentations was compared to that of uni-modal trials. A Repeated Measures ANOVA with Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that there was a significant effect of Trial Type, $F(3, 87) = 46.031$, $p < 0.01$. Pairwise comparisons indicated that participants were faster to respond to the visual target in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster in Congruent Trials than Incongruent Trials. Figure 26 shows the mean hemifield RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

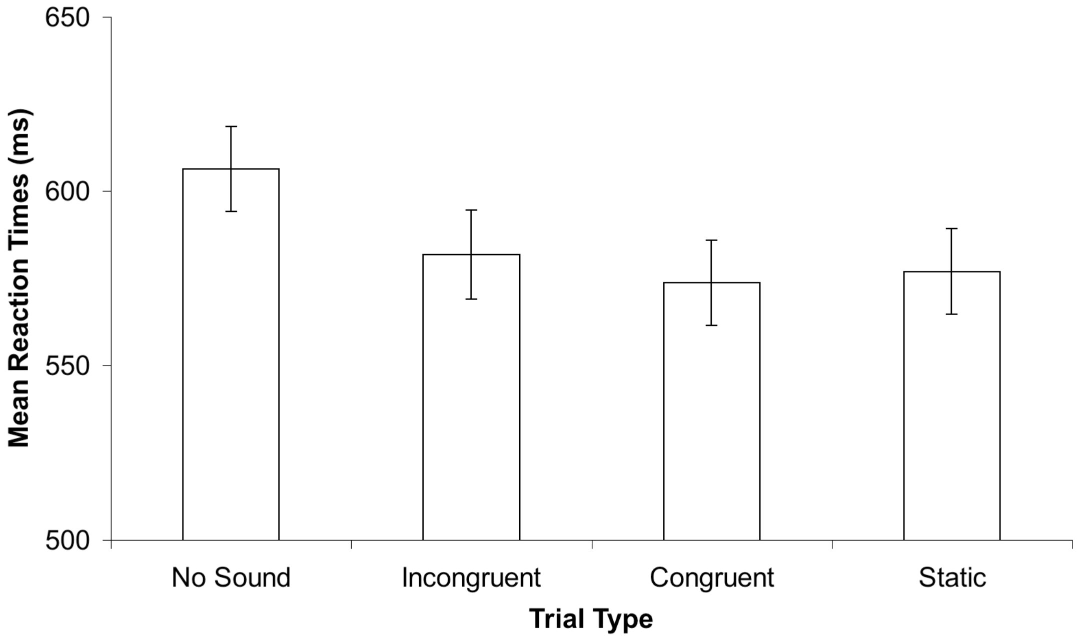

Figure 26. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Hemifield RTs were further analysed using a 3 x 3 Repeated Measures ANOVA with SOA (500, 1000 and 1500 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. The results indicated there was a significant effect of SOA, $F(2, 58) = 17.170$, $p < 0.01$ and Trial Type, $F(2, 58) = 6.156$, $p < 0.01$. There was no significant interaction between SOA and Trial Type, $p > 0.05$. Pairwise comparison for SOA showed that participants were significantly faster at SOA 1000 ms than SOA 500 ms or 1500 ms, $p < 0.01$. Pairwise comparisons for Trial Type indicated that participants were faster in Congruent Trials than Incongruent or Static Trials, $p < 0.01$. Figure 27 shows the mean hemifield RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

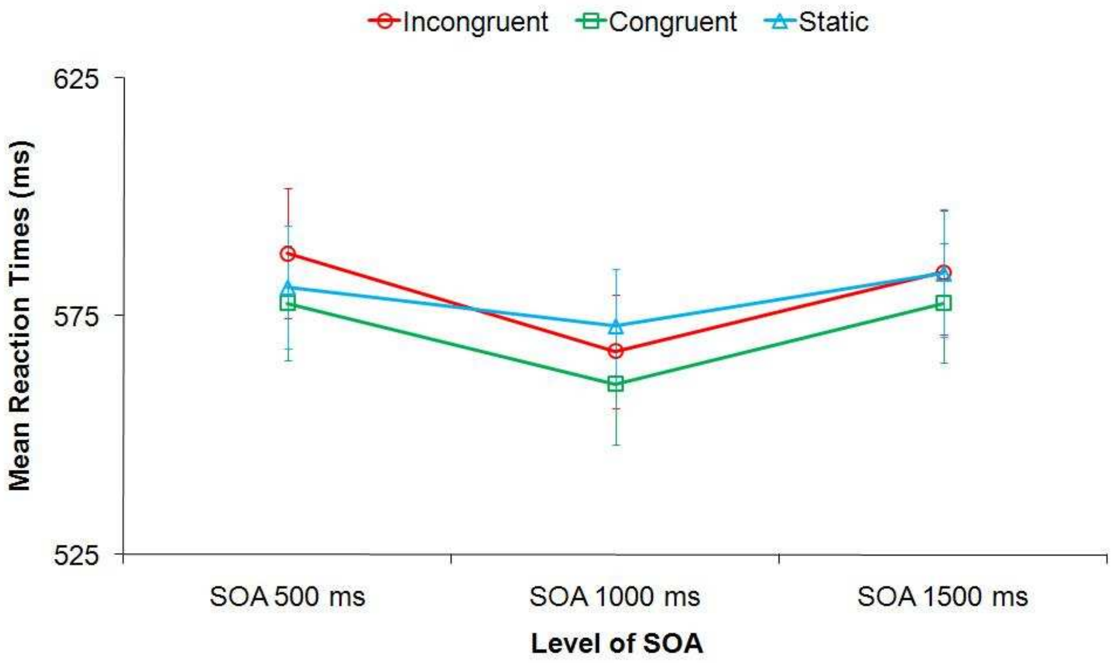

Figure 27. Mean Reaction Times for Incongruent, Congruent and Static Trials at SOA 500, 1000 and 1500 ms when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

Thus for congruency defined by hemifield, participants were at their fastest to respond when the onset of the visual target coincided with the termination of the auditory stimulus. Participants were also faster when the auditory stimulus was presented to the same side of the body towards which the motor response was made.

4.2.2.2 Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target as a function of the direction of movement of the auditory stimulus, irrespective of it looming or receding. This was irrespective of the hemifield to which the auditory stimulus was presented. In this analysis, Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant made in relation to the colour of the visual target, i.e., a leftward moving auditory stimulus with a leftward joystick movement. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant made, i.e., a leftward moving auditory stimulus with a rightward joystick movement. Static Trials were those in which the auditory stimulus was perceived as being directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

A Repeated Measures ANOVA with Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that there was a significant effect of Trial Type, $F(3, 87) = 41.989$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Figure 28 shows the mean RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

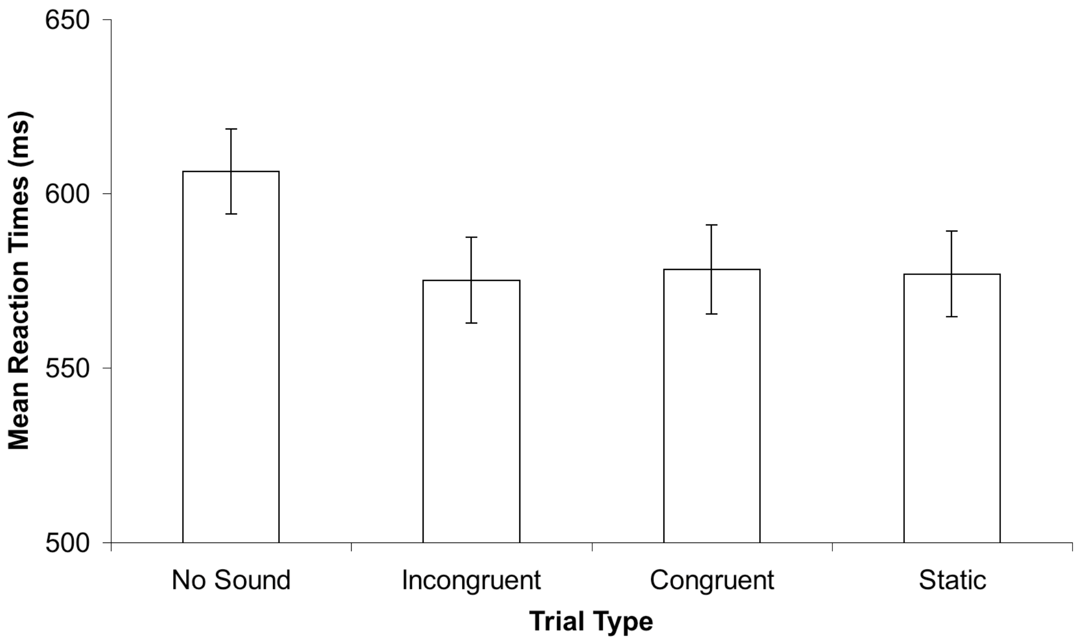

Figure 28. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

Directional RTs were further analysed by a 3 x 3 Repeated Measures ANOVA using SOA (500, 1000 and 1500 ms) and Trial Type (Incongruent, Congruent and Static) as the within-subjects factors. This indicated that there was a significant effect of SOA, $F(2, 58) = 14.586$, $p < 0.01$. There was no significant effect of Trial Type and no significant interaction between SOA and Trial Type, $p > 0.05$. Pairwise comparison for SOA showed that participants were significantly faster at SOA 1000 ms than SOA 500 ms or 1500 ms, $p < 0.01$. Figure 29 shows the mean RTs for each Trial Type at each level of SOA with error bars when congruency was defined by the direction of the auditory stimulus.

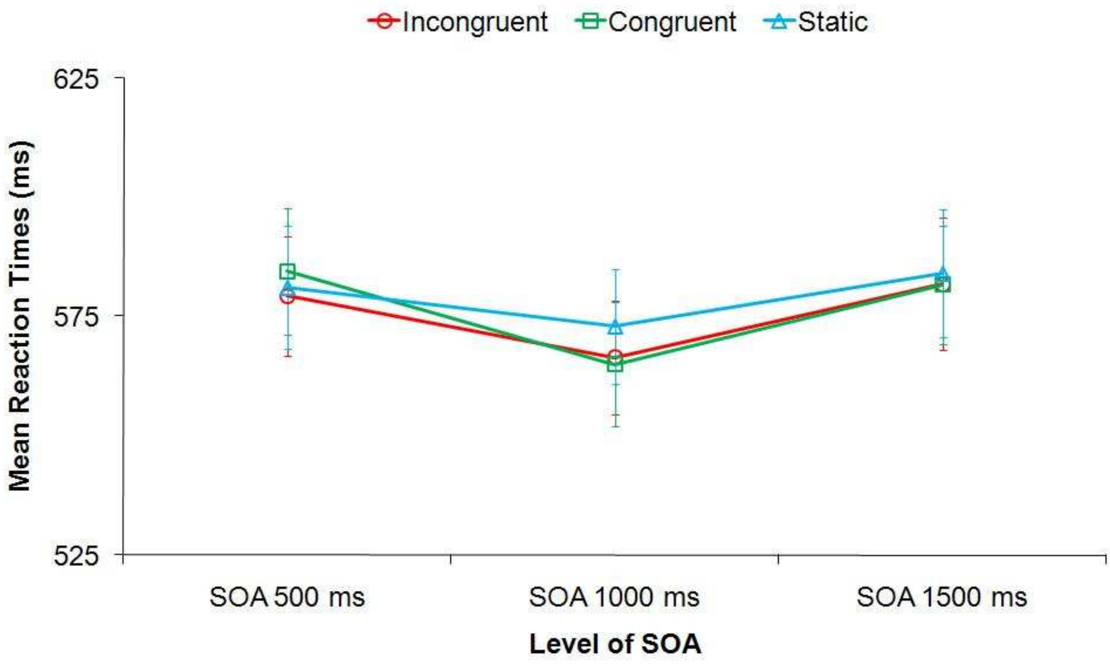

Figure 29. Mean Reaction Times for Incongruent, Congruent and Static Trials at SOA 500, 1000 and 1500 ms when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

For congruency by direction, the results indicated that again RTs were faster when the visual target was preceded by an auditory stimulus than when the visual target was presented by itself. Also participants were at their fastest to respond at SOA 1000 ms, i.e., when the onset of the visual target coincided with the termination of the auditory stimulus.

4.2.2.3 Facilitation by looming of the auditory stimulus

The final analysis defined trials as Receding, Looming or Static dependent on the auditory stimulus in relation to the body. Receding Trials were those in which the auditory stimulus was laterally moving away from the body on either side of the participant's head; Looming Trials were those in which the auditory stimulus was laterally moving towards the body on either side of the head and Static Trials were those in which the auditory stimulus was presented directly in front of the participant.

A Repeated Measures ANOVA with Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that there was a significant effect of Trial Type, $F(3, 87) = 55.032$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Receding, Looming and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster in Looming Trials than Receding Trials, $p < 0.01$. Figure 30 shows the mean RTs for each Trial Type with error bars.

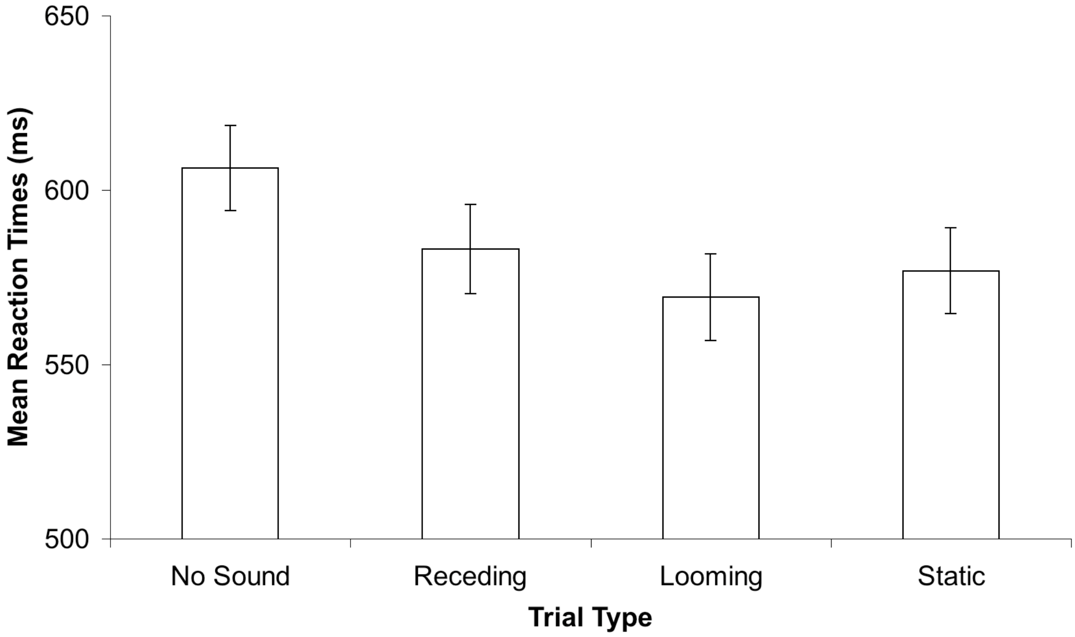

Figure 30. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

Looming RTs were further analysed by a 3 x 3 Repeated Measures ANOVA using SOA (500, 1000 and 1500 ms) and Trial Type (Receding, Looming and Static) as the within-subjects factors indicated there was a significant effect of SOA, $F(2, 58) = 16.283$, $p < 0.01$, Trial Type, $F(2, 58) = 13.318$, $p < 0.01$ and a significant interaction between SOA and Trial Type, $F(4, 116) = 2.590$, $p < 0.05$. Pairwise comparison for SOA showed that participants were significantly faster at SOA 1000 ms than SOA 500 ms or 1500 ms, $p < 0.01$. Pairwise comparisons for Trial Type indicated that participants were faster in Looming Trials than Receding or Static Trials, $p < 0.01$. Pairwise comparison for the interaction between SOA and Trial Type indicated that at

SOA 500 ms participants were faster in Looming Trials than Receding Trials, $p < 0.01$. At SOA 1000 ms participants were significantly faster in Looming Trials than Receding or Static Trials, $p < 0.01$. At SOA 1500 ms there were no significant differences between Trial Types. Figure 31 shows the mean RTs for each Trial Type at each level of SOA with error bars.

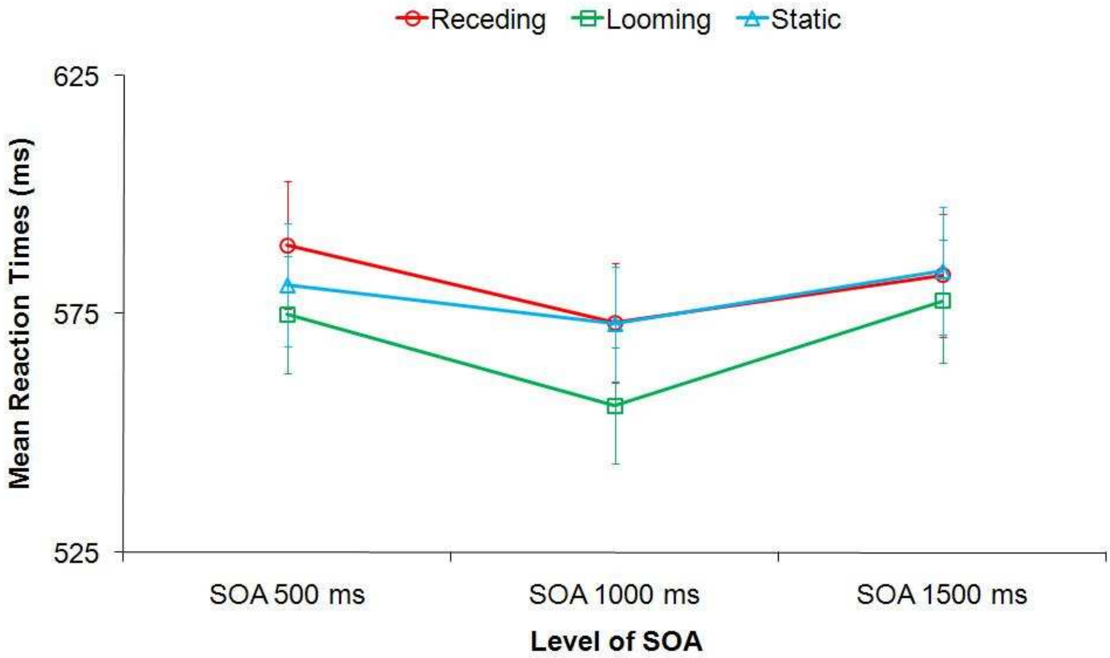

Figure 31. Mean Reaction Times for No Sound, Receding, Looming and Static Trials at SOA 500, 1000 and 1500 ms. Error Bars represent Standard Error

In summary, for trials defined by whether the auditory stimulus was looming or not the results indicated that, as with the other two sets of analysis, when the visual target was preceded by an auditory stimulus participants were faster to respond than when the visual target had been presented on its own. Also participants were faster to respond when the auditory stimulus was looming than if it was receding or static. This was true for SOA 500 ms and 1000 ms but not 1500 ms. Also participants were at their fastest to respond at SOA 1000 ms. This indicated that the looming auditory stimuli facilitated participants' motor responses. The results of the other two analyses revealed that participants were also faster to respond to the visual target when the auditory stimulus was presented to the hemifield the motor response was towards. However the direction of motion of the auditory stimulus to the required response direction did not affect performance.

4.2.3 Discussion

Experiment 8 was designed to test whether manipulating the levels of SOA between the auditory stimulus and visual target led to an effect on participants' RTs. Secondly if the manipulation of SOA did have an effect, was there an optimal level of SOA for looming auditory stimuli to facilitate participants' motor responses.

The main finding of this experiment was that there was a significant effect of SOA manipulation on participants' RTs. The period of time the participant was presented with the looming stimulus before the onset of the target did affect the amount of time it took them to respond to the target. Participants were at their fastest to respond at 1000 ms, meaning that the onset of the visual target was at the point of termination of the auditory stimulus. As it is possible to tell if a looming stimulus is on a collision trajectory or not (King et al., 1992; Lin et al., 2009), for 500 ms it could have been that the mechanism for determining if a looming stimulus was on a collision trajectory may not have had sufficient time to make this judgement. So the behavioural bias for looming stimuli on a collision trajectory may not have been present. Alternatively for 1500 ms it may have been the case that this bias had arisen but in the time from the termination of the auditory stimulus to the onset of the visual target the level of facilitation had decayed. This could have been due to the period of time between the auditory stimulus and the visual target being greater than 300 ms meaning it was no longer in the short term auditory store (Cowan, 1984).

So far all the experiments reported in this thesis that utilised looming auditory stimuli, indeed the majority of experiments reported in this thesis, the participants' responses had been on the same axis as the auditory stimulus, i.e., the moving auditory stimuli travelled in line with the participant's shoulders and the responses the participant had to make were also in line with the participant's shoulders. However people do not operate in a single axis environment, the majority of people's interactions take place in a 3D environment. This means a stimulus that may facilitate a response does not always present itself on the same axis as the response; for example, the best response to a looming object may not be to move back but to move to the side.

Thus Experiment 9 tested whether the observed looming facilitation of the previous experiments was still present when the required response the participant made was orthogonal to the auditory stimulus. If the looming facilitation was still present even when the response was not on the same axis as the auditory stimulus this would speak to the robustness of the facilitation. It would also mean that responses would not need to be limited to the same axis as the auditory stimulus. This could be beneficial in a real-world context as looming auditory stimuli could be used to facilitate any directional motor response rather than just responses on the same axis.

4.3 EXPERIMENT NINE

Experiment 9 was designed to replicate the findings of Experiment 8 with several changes to the methodology. The most fundamental change was to the required response to the visual target. Unlike in the previous experiments where the participant moved the joystick to the left or right depending on the visual target, they instead moved the joystick forward or backward, making their response orthogonal to the axis of the auditory stimuli. There was also a change in the position of the joystick from a ‘Centre Stick' to a ‘Side Stick' position. This was done to make the participant more comfortable, as the arm's natural position is to be in line with the shoulder, not in line with the centre of the chest. Finally there was only a single level of SOA, 1000 ms, as this was where looming auditory stimuli facilitation appeared to be at its strongest.

4.3.1 Method

4.3.1.1 Participants

Eighteen students participated in the experiment, of whom 10 were female. The mean age of the participants was 23.3 years (SD 4.6 years). All participants were right-handed. All other details were as for Experiment 8.

4.3.1.2 Materials and Design

The experiment was conducted in the same sound-attenuated booth that was used for Experiments 7 and 8. The visual targets and auditory stimuli were the same as used in Experiments 7 and 8. Presentation of the visual and auditory stimuli followed the same pattern as before and the responses were collected using the same joystick as utilised in Experiments 7 and 8. However there was a change to the positioning of the joystick from the Centre Stick position, at the mid-line, to the Side Stick position, to the right hand side of the participant. Figure 32 shows the joystick and required motor response in non-orthogonal and orthogonal settings.

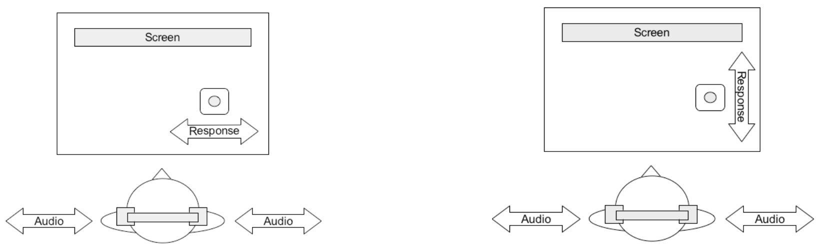

Figure 32. Joystick and required motor response in Non-orthogonal (left) and Orthogonal (right) settings.

4.3.1.3 Procedure

The participant performed the same task as was described in Experiment 7. However there was a change in how the participant was required to respond to the visual target. The response to the visual target was counterbalanced across the participants: for half of the participants, a blue target required the joystick to be pushed forward, and a yellow target required the joystick to be pulled back. For the other half of the participants, this requirement was reversed. Participants were randomly assigned to each group.

There were a total of 450 trials for each participant. In 100 of the trials only the visual target was presented; there was a 50/50 split between blue visual targets and yellow visual targets. There were 50 trials in which only an auditory stimulus was presented, 10 of each sound type. These were used as Catch Trials to test whether the participant was waiting for the visual target to appear before making a response, as instructed, rather than responding to the auditory stimulus. There was only a single level of SOA of 1000 ms.

The remaining 300 trials were distributed between the four moving and one static auditory stimuli. There were 50 of each of the moving auditory stimuli and 100 of the static auditory stimulus. For each auditory stimulus type, there was an equal number of blue and yellow presentations of the visual target. Hence the auditory stimulus was not predictive as to the colour of the visual target and thus the required motor response.

4.3.2 Results

RTs were prepared for analysis using the same method as utilised in Experiment 7 and 8. On average, participants responded correctly 96% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The same statistical analysis was applied to all the results reported here; this was a Repeated Measures Analysis of Variance (ANOVA) utilising Bonferroni-corrected Pairwise Comparisons. Only a single analysis was conducted for Experiment 9: facilitation by looming of the auditory stimulus. This was due to the design of the experiment (with movement of responses being in an orthogonal direction to the movement of the auditory stimuli) being unsuitable to conduct hemifield and directional analyses.

4.3.2.1 Facilitation by looming of the auditory stimulus

The analysis defined trials as Receding, Looming or Static dependent on the auditory stimulus in relation to the body. Receding Trials were those in which the auditory stimulus was laterally moving away from the body on either side of the participant's head; Looming Trials were those in which the auditory stimulus was laterally moving towards the body on either side of the head and Static Trials were those in which the auditory stimulus was presented directly in front of the participant.

As in Experiments 7 and 8 the effect of bi-modal presentations was compared to that of uni-modal trials. A Repeated Measures ANOVA with Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 21.839$, $p < 0.01$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.910, 32.472) = 53.013$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Receding, Looming and Static Trials than No Sound Trials, $p < 0.01$.

Participants were also significantly faster in Looming Trials than Receding and Static Trials, $p < 0.01$. Figure 33 shows the mean RTs for each Trial Type with error bars.

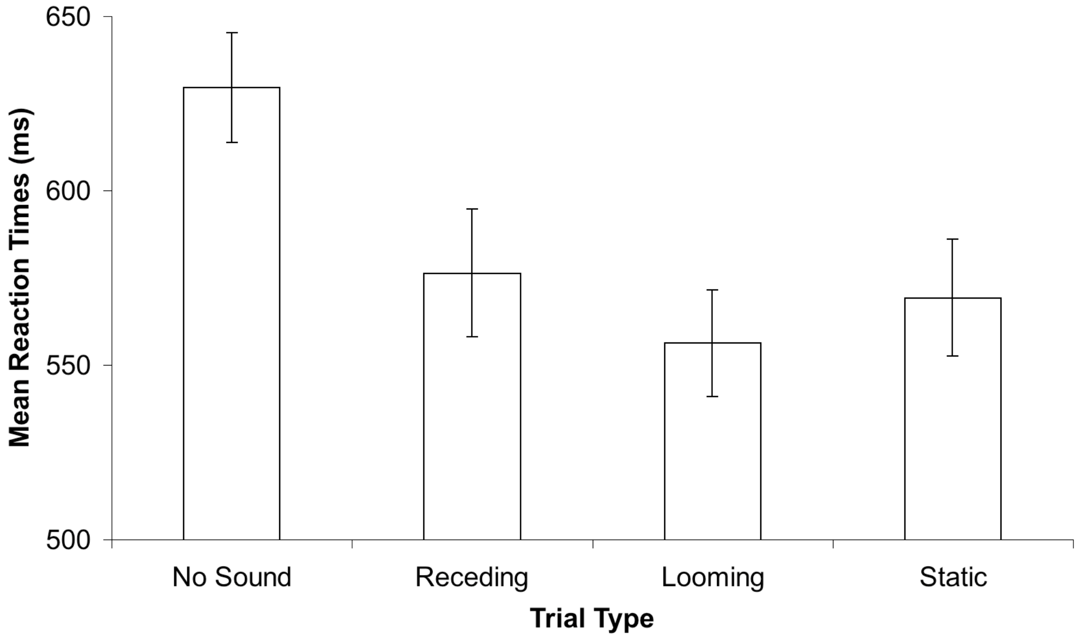

Figure 33. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

In summary, participants were faster to respond to the visual target when it was preceded by an auditory stimulus, and participants were faster when the auditory stimulus was looming rather than when it was receding or static. This indicates that RTs were facilitated by bi-modal stimulus presentations and that looming auditory stimuli facilitated motor movements to a greater degree than receding or static auditory stimuli.

4.3.3 Discussion

The results of Experiment 7 and 8 had already found evidence for looming auditory stimuli facilitating participants' motor responses to a visual target when compared to receding or static auditory stimuli. This was the case even though the auditory stimuli were task-irrelevant and participants were specifically asked to ignore them during the experiment. Previous research had already shown that looming stimuli led to motor responses on the same axis as the looming stimulus, i.e., a monkey or human presented with a stimulus looming in front of them would move backwards

(Schiff et al., 1962; Ball and Tronick, 1971; Freiburg et al., 2001). The results of Experiment 9 revealed that task-irrelevant, looming auditory stimuli appeared to facilitate motor responses even when the response was orthogonal to the direction of the auditory stimulus. This suggests that looming auditory stimuli facilitate motor responses in any direction, not just responses on the same axis as the auditory stimulus.

The implication of this in a real-world setting is that any looming auditory stimulus, irrespective of where it approaches from, could facilitate a person's motor responses rather than having to create a separate looming stimulus for every possible direction of motor response. It may even be possible to present looming auditory stimuli to a single ear to facilitate responses, though this would mean losing the hemifield facilitation noted in some of the previous experiments reported in this thesis.

While the experiments reported here so far have shown that the looming facilitation effect appears to be a largely consistent effect they have not done much to illuminate the possible locus of this effect. In the current paradigm participants performed a defined motor movement based on the properties of the visual target, be it the location or the colour. The use of this 'Choice Task' meant that the possible locus of the effect could have been in one or more of three possible places: the looming auditory stimulus may have reduced the time participants took to perceive the onset of the visual target; it may have reduced the time it took participants to process the properties of the visual target such as its location or colour; or it may have in some way facilitated the preparation or execution of the participants' motor responses.

If the looming auditory stimuli were acting as a form of warning that a motor response would soon be required there is evidence in the literature indicating that it is a decrease in the time taken to reach the threshold for performing the motor movement that is being facilitated. Fecteau and Munoz (2007) conducted an experiment in which Rhesus monkeys performed a visual localisation task. The task required the monkeys to stare at a central fixation point and wait for a visual target to appear and then move their eyes to the target's location. On some trials the visual target was preceded by a visual warning stimulus. During the experiment visuomotor and motor neurons in the monkeys' superior colliculus were recorded. The results indicated that when the visual target was preceded by a warning stimulus the monkeys' RTs were faster than when no warning was presented. Secondly, and more importantly, the results indicated that it was the variable rise to threshold, i.e., the rate at which information accumulates to trigger an action, that best predicted the monkeys' RTs. This study shows that it is possible to disentangle at least facilitation of either detection of the visual stimulus or facilitation of the response.

Experiment 10 was designed to attempt to disentangle these possible hypotheses from each other via the implementation of both a Detection and a separate Choice Task. The Detection Task involved participants making a single defined response to a visual target irrespective of its properties, while the Choice Task was the same task as completed by participants in Experiment 9. However even with this change to the methodology it would only be possible to separate facilitation of visual detection/motor response from facilitation of visual discrimination.

4.4 EXPERIMENT TEN

In Experiments 1 to 9, participants were asked to perform a Choice Task: they were presented with a visual target and they chose a response dependent on the properties of that target, either the location or the colour. This meant that it was difficult to define the locus of the facilitation of motor responses being observed in the results of these experiments. It may have been that the facilitation arose from improving participants' detection of the onset of the visual target, improved discrimination of the visual target's properties or possibly some form of facilitation of the participants' motor system. To try and disentangle these possibilities from each other Experiment 10 was comprised of two different tasks, a Detection Task and a Choice Task. The Detection Task involved participants making the same response to the visual target irrespective of the target's properties and the Choice Task involved participants performing the same task as in Experiment 9. There were three levels of SOA as opposed to the single level in Experiment 9, as the effect of manipulating SOA had not been investigated when the motor response was orthogonal to the auditory stimulus. The three levels of SOA were 1000, 1250 and 1500 ms. 1000 ms was chosen for the robustness of results of facilitation when the visual target's onset was at exactly the point of the termination of the auditory stimulus. 1500 ms was chosen to confirm that a 500 ms gap between the termination of the auditory stimulus and the onset of the visual target negated the facilitatory effect of looming auditory stimuli. 1250 ms was chosen to see if a shorter period of time between termination and onset of the stimuli than that for 1500 ms would lead to greater facilitation than 1000 ms. The hypothesis of Experiment 10 was that if looming auditory stimuli were facilitating processing of the visual target's properties there would only be facilitation from the looming auditory stimuli in the Choice Task and not in the Detection Task. If however there was facilitation from the looming auditory stimuli in both the Detection and the Choice Tasks this would indicate that the looming auditory stimuli were facilitating the detection of onset of the visual target or facilitating the preparation or execution of the motor response.

4.4.1 Method

4.4.1.1 Participants

Sixty-eight students participated in the experiment, of whom 65 were female. The mean age of the participants was 18.8 years (SD 0.8 years). All other details were as for Experiment 9.

4.4.1.2 Materials and Design

The experiment was conducted in the same sound-attenuated booth that was used for Experiments 7 to 9. The visual targets and auditory stimuli were the same as used in Experiments 7 to 9. Presentation of the visual and auditory stimuli were the same as before and the responses were collected using the same joystick, in the Side Stick position as utilised in Experiment 9.

4.4.1.3 Procedure

The participant started each trial by focusing on the fixation cross. After a random period between one and two seconds, the participant was presented with either the visual target; the visual target and an auditory stimulus; or just an auditory stimulus.

In the Detection Task, for a trial where a visual target was presented, either alone or paired with an auditory stimulus, the participant responded only to the detection of the target irrespective of its colour. The response to the visual target was counterbalanced between participants: half were instructed to push the joystick forwards on detection of the visual target while the other half were instructed to pull the joystick backwards on detection of the visual target. After making their response to the visual target, the participant returned the joystick to its original position, which started the next trial. Participants were randomly assigned to each group.

In the Choice Task, for a trial where a visual target was presented, either alone or paired with an auditory stimulus, the participant made a response dependent on the colour of the visual target. Responses to the visual target were counterbalanced across participants: for half the participants, a blue target required the joystick to be pushed forward, and a yellow target required the joystick to be pulled back. For the other half of the participants, this requirement was reversed. Participants were randomly assigned to each group. Participants were randomly assigned to either the Detection or Choice Task group.

For the auditory stimulus/visual target trials, both Detection and Choice Tasks, there were three levels of SOA. These were SOA 1000, 1250 and 1500 ms for which the auditory stimulus always preceded the visual target. At SOA 1000 ms, the participant had heard the auditory stimulus fully before being presented with the visual target. At SOA 1250 ms and 1500 ms, the participant had heard the auditory stimulus fully followed by either 250 ms or 500 ms of silence before the visual target was presented.

There were a total of 747 trials for each participant. In 168 of the trials only the visual target was presented; there was a 50/50 split between blue visual targets and yellow visual targets. There were 75 trials in which only an auditory stimulus was presented, 15 of each sound type. These were used as Catch Trials to test whether the participant was waiting for the visual target to appear before making the response, as instructed, rather than responding to the auditory stimulus.

The remaining 504 trials were evenly split between the three levels of SOA, with each level having 168 trials. Of these 168 trials, 56 contained a static auditory stimulus. The other 112 trials were evenly distributed between the four moving auditory stimuli, meaning that there were 28 of each moving auditory stimulus. For each level of SOA there was an equal number of blue and yellow presentations of the visual target. Hence the auditory stimulus was not predictive as to the colour of the visual target and thus the response required.

After the participant had completed all 747 trials, each participant was administered the same 5-AFC test as given in Experiment 7.

4.4.2 Results

RTs were prepared for analysis using the same method as utilised in Experiments 7 to 9. On average, participants responded correctly 96% of the time, thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The results of the 5-AFC test revealed that participants were able to correctly identify which auditory stimulus they heard 88% of the time. The same statistical analysis was applied to all the results reported here; this was a Repeated Measures Analysis of Variance (ANOVA) utilising Bonferroni-corrected Pairwise Comparisons. Only a single analysis was conducted for each task type (Detection and Choice): namely facilitation by looming of the auditory stimulus. This was due to the design of the experiment being unsuitable to conduct hemifield and directional analyses. All analyses defined trials as Receding, Looming or Static depending on the auditory stimulus in relation to the body. Therefore Receding Trials were those in which the auditory stimulus was laterally moving away from the body on either side of the participant's head; Looming Trials were those in which the auditory stimulus was laterally moving towards the body on either side of the head and Static Trials were those in which the auditory stimulus was presented directly in front of the participant.

4.4.2.1 Detection Task: Facilitation by looming of the auditory stimulus

The first series of analyses was centred on the Detection Task that was completed by half of the participants. As in Experiments 7 to 9 the effect of bi-modal presentations was compared to that of uni-modal trials. A Repeated Measures ANOVA with Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 54.439$, $p < 0.01$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, F(1.414, 41.018) = 159.660, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Receding, Looming and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster in Looming Trials than Receding Trials, $p < 0.01$. Figure 34 shows the mean RTs for each Trial Type with error bars.

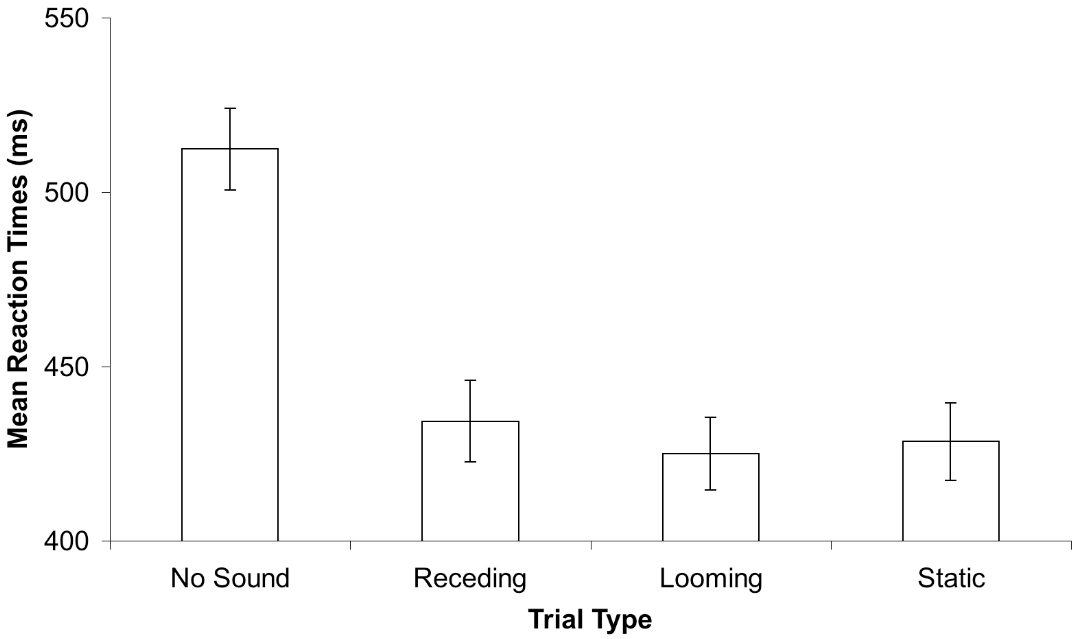

Figure 34. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

A 3 x 3 Repeated Measures ANOVA using SOA (1000, 1250 and 1500 ms) and Trial Type (Receding, Looming and Static) as the within-subjects factors indicated there was a significant effect of SOA, F(2, 58) = 25.971, $p < 0.01$ and Trial Type, F(2, 58) = 8.406, $p < 0.01$. There was no significant interaction between SOA and Trial Type, $p > 0.05$. Pairwise comparison for SOA showed that participants were significantly faster at SOA 1250 ms than SOA 1000 ms or 1500 ms, $p < 0.01$. Pairwise comparisons for Trial Type indicated that participants were faster in Looming Trials than Receding Trials, $p < 0.01$. Figure 35 shows the mean RTs for each Trial Type at each level of SOA with error bars.

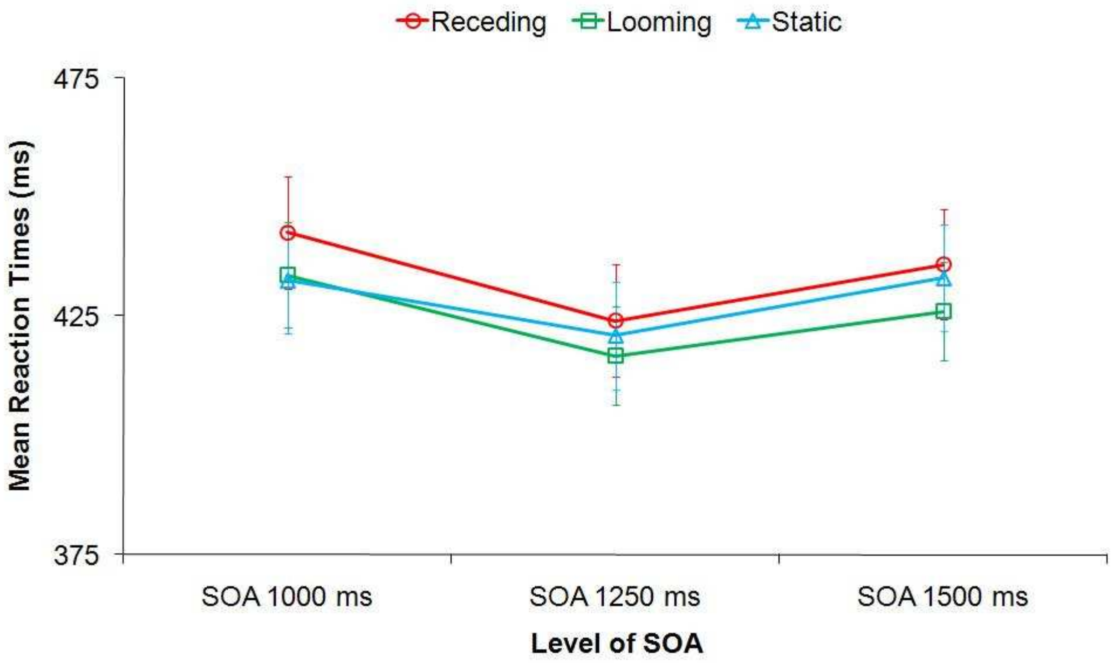

Figure 35. Mean Reaction Times for No Sound, Receding, Looming and Static Trials at SOA 1000, 1250 and 1500 ms. Error Bars represent Standard Error

In summary for the Detection Task the results indicated that participants were faster to respond when the visual target was preceded by an auditory stimulus. Participants were faster when the auditory stimulus was looming rather than when it was receding. Participants were also significantly faster at SOA 1250 ms than 1000 ms or 1500 ms.

4.4.2.2 Choice Task: Facilitation by looming of the auditory stimulus

The second series of analyses was centred on the Choice Task completed by the other half of the participants. A Repeated Measures ANOVA with Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 40.041$, $p < 0.01$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.746, 66.349) = 112.208$, $p < 0.01$. Pairwise comparisons indicated that participants were faster to respond to the visual target in Receding, Looming and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster in Looming and Static Trials than Receding

Trials, $p < 0.01$. Figure 36 shows the mean RTs for each Trial Type with error bars.

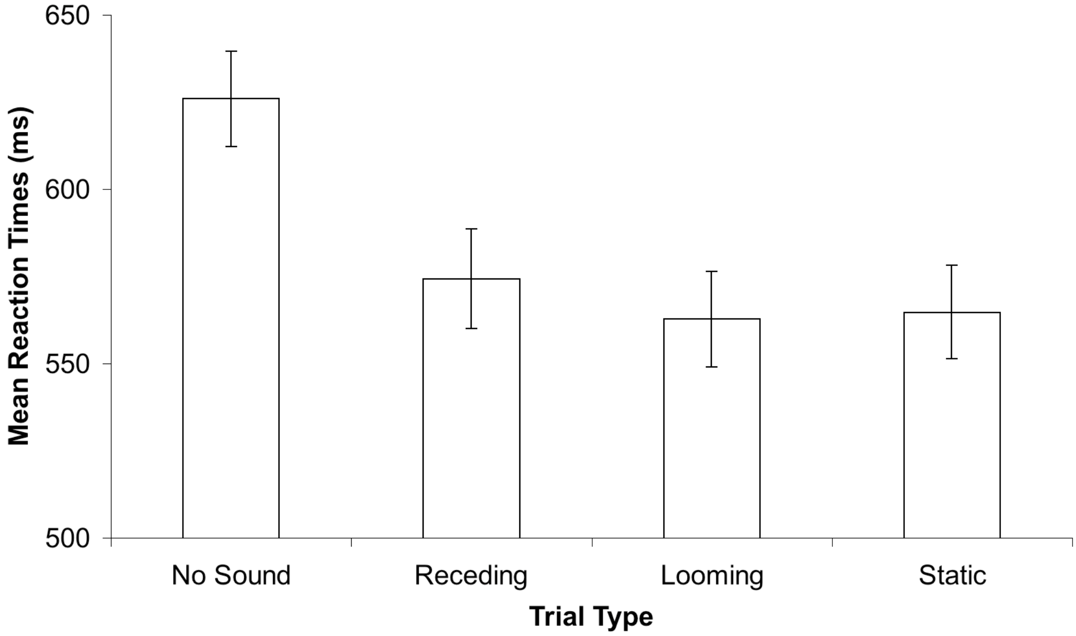

Figure 36. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

A 3 x 3 Repeated Measures ANOVA using SOA (1000, 1250 and 1500 ms) and Trial Type (Receding, Looming and Static) as the within-subjects factors indicated there was a significant effect of SOA, $F(2, 76) = 34.471$, $p < 0.01$, and Trial Type, $F(2, 76) = 14.940$, $p < 0.01$, and a significant interaction between SOA and Trial Type, $F(4, 152) = 2.686$, $p < 0.05$. Pairwise comparison for SOA showed that participants were significantly faster at SOA 1250 ms and 1500 ms than SOA 1000 ms, $p < 0.01$. Pairwise comparisons for Trial Type indicated that participants were faster in Looming and Static Trials than Receding Trials, $p < 0.01$. Pairwise comparisons for the interaction between SOA and Trial Type indicated at SOA 1000 ms participants were significantly faster in Looming and Static Trials than Receding Trials. There were no significant differences between Trial Types at SOA 1250 ms and 1500 ms. Figure 37 shows the mean RTs for each Trial Type at each level of SOA with error bars.

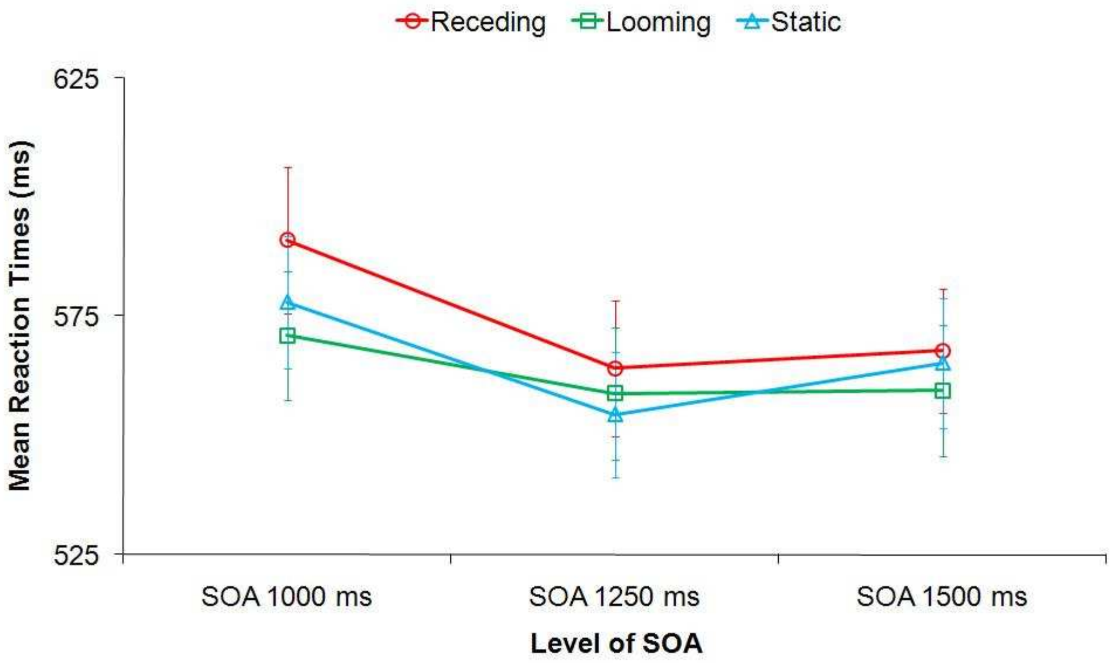

Figure 37. Mean Reaction Times for No Sound, Receding, Looming and Static Trials at SOA 1000, 1250 and 1500 ms. Error Bars represent Standard Error

To summarise the results of the Choice Task, participants were faster to respond to the visual target when it was preceded by an auditory stimulus. Participants were also faster to respond in Looming and Static Trials than Receding Trials. When SOA was factored into the analysis the results revealed that participants were faster at SOA 1250 ms and 1500 ms than 1000 ms though there were no differences between Trial Types except at SOA 1000 ms where participants were faster in Looming and Static Trials than Receding Trials. For the Detection Task the results were similar in the fact that participants were faster when the visual target was preceded by an auditory stimulus, faster in Looming rather than Receding Trials, and faster at SOA 1250 ms than 1000 ms and 1500 ms.

4.4.3 Discussion

The aim of Experiment 10 was to attempt to disentangle the possible locus of the observed facilitation of participants' motor responses to a visual target when preceded by a looming auditory stimulus. As stated before, facilitation could arise from three or more possible points: the detection of onset of the visual target; the participants' processing of the attributes of the visual target such as its location or its colour, thus determining the required response; and finally the preparation or execution of the physical motor response the participants had to make to the visual target.

If there was looming facilitation in only the Choice Task this would indicate that looming auditory stimuli were most likely facilitating the processing of the visual target's properties, as participants did not have to discern any details of the visual target in the Detection Task. If however there was facilitation in both the Choice and the Detection Task this would indicate that it was the detection of the onset of the visual target or the response to the visual target that was being facilitated. The results of Experiment 10 supported the latter of these two hypotheses, as there appeared to be facilitation from looming auditory stimuli over receding stimuli in both the Detection and the Choice Task as opposed to just the Choice Task. However, as looming stimuli did not appear to facilitate responses to any greater extent than static stimuli it could also be the case that there was more a negative impact of receding stimuli than a positive impact of looming stimuli.

The results of this experiment did not allow any conclusions to be drawn about whether the locus of facilitation arose from improvements in detection of the onset of the visual target or if it arose from improving the preparation or execution of motor responses. The research of Fecteau and Munoz (2007) suggests that it is more likely the response to the visual target rather than its detection that was being facilitated by the looming auditory stimuli, although there is alternative evidence that it may be detection of the stimulus that requires a response that is facilitated. Romei, Murray and Thut (2008) found that looming auditory stimuli led to increases in visual cortex excitability. This could be seen as evidence that looming auditory stimuli facilitate visual perception rather than facilitating the lowering of motor response thresholds.

These diverging sources of evidence suggest that the precise manner in which bi-modal stimuli facilitate motor responses may be a complex process to disentangle. Trying to answer this question in any more depth is not within the remit of this thesis, thus the final experiment reported here instead focused on replicating the looming facilitation in both the Choice and the Detection Task when the motor response was no longer orthogonal to the axis of the auditory stimulus.

4.5 EXPERIMENT ELEVEN

Experiment 11 utilised the same two tasks as in Experiment 10, however there was a change to the response method and levels of SOA. Unlike the previous experiment where the participant moved the joystick forward or backward in response to the visual target, they now moved the joystick to the left or right. This was done to replicate the findings of the previous experiment but with the responses no longer orthogonal to the axis of the auditory stimulus. The multiple levels of SOA were reduced to a single SOA of 1000 ms as this was where the facilitation from the looming auditory stimuli was most prominent in the previous experiments.

4.5.1 Method

4.5.1.1 Participants

Forty students participated in the experiment, of whom 28 were female. The mean age of the participants was 21.6 years (SD 3.5 years). All other details were as for Experiment 7 to 10.

4.5.1.2 Materials and Design

The experiment was conducted in the same sound-attenuated booth that was used for Experiments 7 to 10. The visual targets and auditory stimuli were the same as used in Experiments 7 to 10. Presentation of the visual and auditory stimuli were the same as before and the responses were collected using the same joystick, in the Side Stick position, as utilised in Experiments 8 to 10.

4.5.1.3 Procedure

The participants performed the same tasks as were described in Experiment 10. However there was a change in how the participants were required to respond to the visual target. In the Detection Task, half of the participants were instructed to make a leftward joystick movement on detecting any visual target while the other half were instructed to make a rightward joystick movement on detection of any visual target. This was counterbalanced across participants, and participants were randomly assigned to each group.

In the Choice Task, responses to the visual target were also counterbalanced: for half the participants, a blue target required a leftward joystick movement, and a yellow target required participants to make a rightward joystick movement. For the other half of the participants, this requirement was reversed. Participants were randomly assigned to each group. Participants were randomly assigned to either the Detection or Choice Task group.

For the auditory stimulus/visual target trials, both Detection and Choice Tasks, there were a total of 450 trials for each participant, with only a single level of SOA of 1000 ms. In 100 of the trials only the visual target was presented; there was a 50/50 split between blue visual targets and yellow visual targets. There were 50 trials in which only an auditory stimulus was presented, 10 of each sound type. These were used as Catch Trials to test whether the participant was waiting for the visual target to appear before making a response, as instructed, rather than responding to the auditory stimulus.

The remaining 300 trials were distributed between the four moving and one static auditory stimulus. There were 50 of each of the moving auditory stimuli and 100 of the static auditory stimulus. There was an equal number of blue and yellow presentations of the visual target. Hence the auditory stimulus was not predictive as to the colour of the visual target and thus the required motor response.

After the participant had completed all 450 trials, each participant was administered the same 5-AFC test as given in Experiment 7.

4.5.2 Results

RTs were prepared for analysis using the same method as utilised in Experiment 7 to 10. On average, participants responded correctly 98% of the time. Thus there was no analysis of participants' errors. None of the participants had to be removed for responding over 50% of the time to catch trials. The same statistical analysis was applied to all the results reported here; this was a Repeated Measures Analysis of Variance (ANOVA) utilising Bonferroni-corrected Pairwise Comparisons. Three different sets of analyses were conducted for each task type (Detection and Choice): facilitation by hemifield location of the auditory stimulus; facilitation by direction of movement of the auditory stimulus; and facilitation by looming of the auditory stimulus. The first two sets of analyses were conducted to integrate the findings across the experiments of Chapter 3 while the third analysis was to investigate the effects of looming auditory stimuli.

4.5.2.1 Detection Task: Facilitation by hemifield location of the auditory stimulus

The first series of analyses was centred on the Detection Task that half of the participants had to complete. As described in the procedural section for this experiment the Detection Task involved participants making a defined joystick movement when they detected the appearance of a visual target. This response was irrespective of the colour of the visual target.

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented in relation to the response, irrespective of its direction of movement. Congruent Trials were those in which the auditory stimulus was presented to the hemifield consistent with the side of the body the joystick was moved towards, i.e., left hemifield auditory presentation - leftward joystick movement; Incongruent were those in which the hemifield and responding side were inconsistent, i.e., left hemifield auditory presentation - rightward joystick movement; and Static were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

As in Experiments 7 to 10 the effect of bi-modal presentations was compared to that of uni-modal trials. A Repeated Measures ANOVA with Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 52.377$, $p < 0.01$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.369, 26.012) = 175.834$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Figure 38 shows the mean hemifield RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

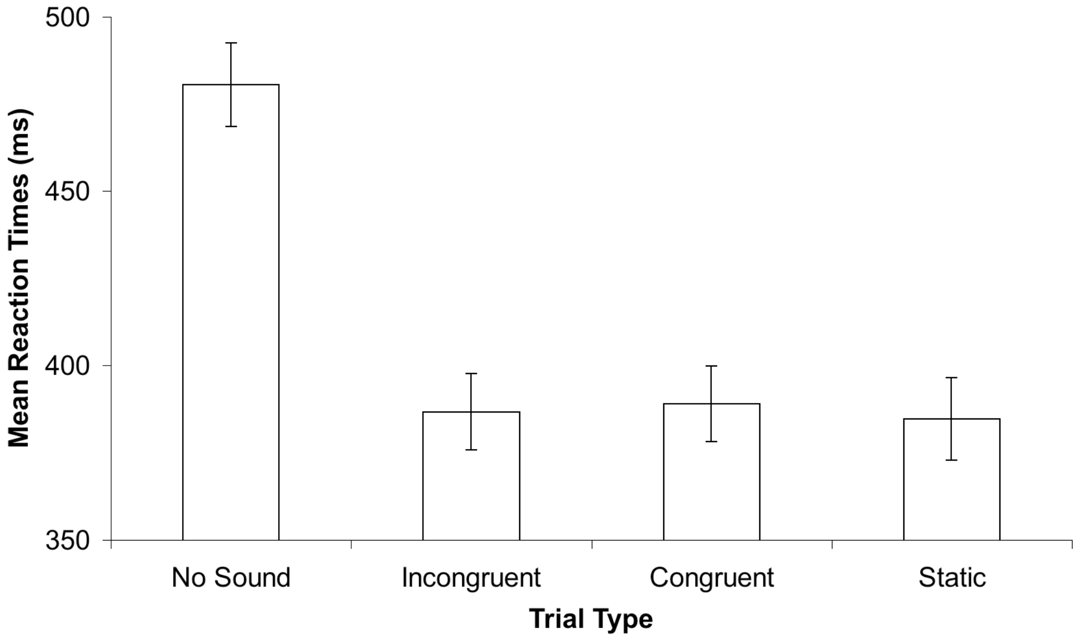

Figure 38. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

4.5.2.2 Detection Task: Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target as a function of the direction of movement of the auditory stimulus irrespective of it looming or receding. This was irrespective of the hemifield to which the auditory stimulus was presented. In this analysis, Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant made, i.e., a leftward moving auditory stimulus with a leftward joystick movement. Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant made, i.e., a leftward moving auditory stimulus with a rightward joystick movement. Static Trials were those in which the auditory stimulus was perceived as being directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

A Repeated Measures ANOVA with Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 28.398$, $p < 0.01$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.522, 28.926) = 163.516$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Figure 39 shows the mean RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

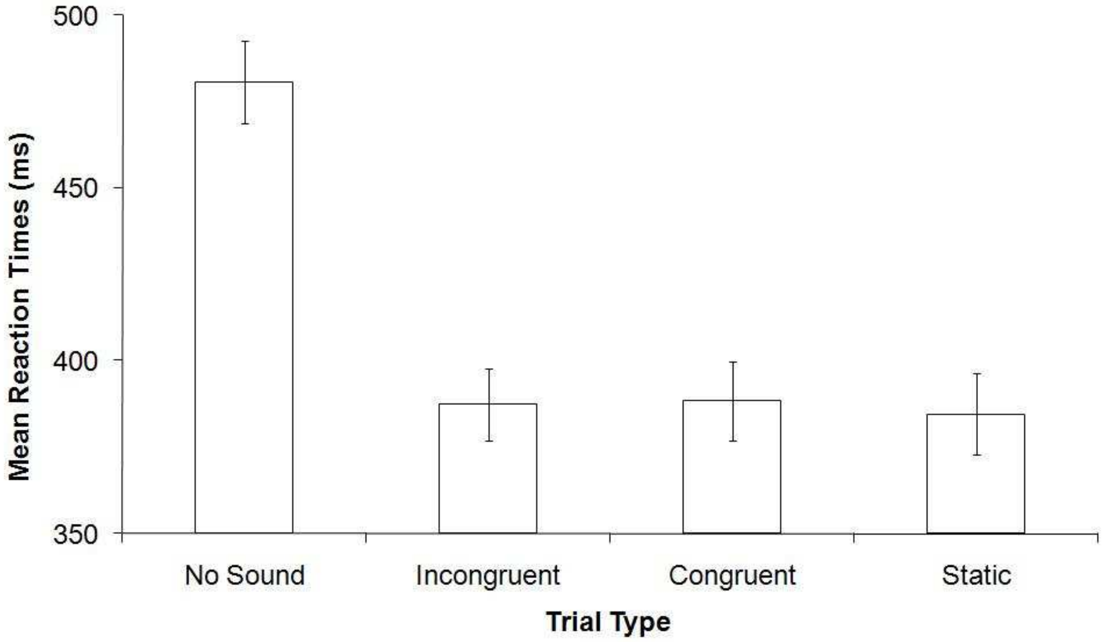

Figure 39. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

4.5.2.3 Detection Task: Facilitation by looming of the auditory stimulus

The final analysis defined trials as Receding, Looming or Static depending on the auditory stimulus in relation to the body. Therefore Receding Trials were those in which the auditory stimulus was laterally moving away from the body on either side of the participant's head; Looming Trials were those in which the auditory stimulus was laterally moving towards the body on either side of the head and Static Trials were those in which the auditory stimulus was presented directly in front of the participant.

A Repeated Measures ANOVA with Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 21.992$, $p < 0.01$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.704, 32.385) = 144.775$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Receding, Looming and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster to respond to the visual target in Looming Trials than Receding Trials, $p < 0.05$. Figure 40 shows the mean RTs for each Trial Type with error bars.

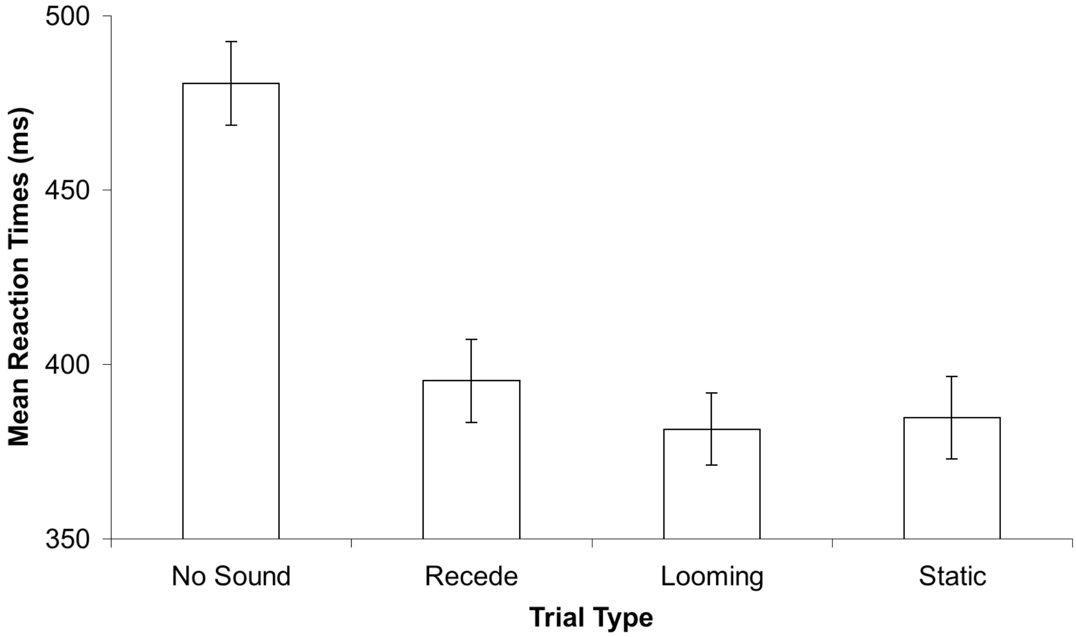

Figure 40. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

Thus for the Detection Task when congruency was defined by Hemifield or Direction participants were significantly faster when the visual target was preceded by an auditory stimulus than when it was not, but there was no difference between the bi-modal trial types. When trials were defined as Receding, Looming or Static the results indicated, as with Hemifield and Direction, that participants were faster to respond to the visual target when preceded by an auditory stimulus. Participants were also faster in Looming Trials than they were in Receding Trials.

The second series of analyses was centred on the Choice Task that the other half of the participants completed. As described in the procedural section for this experiment the Choice Task involved participants making a defined joystick movement when they detected the appearance of a visual target. Unlike in the Detection Task, in which the participants made the same response irrespective of the colour of the target, in the

Choice Task the colour of the target dictated the response required.

4.5.2.4 Choice Task: Facilitation by hemifield location of the auditory stimulus

The first series of analyses defined congruency dependent on the hemifield to which the auditory stimulus was presented in relation to the response, irrespective of its direction of movement. Congruent Trials were when the auditory stimulus was presented to the hemifield consistent with the direction of the response (leftward or rightward); Incongruent Trials were those in which the hemifield and direction of response were inconsistent; and Static Trials were those in which the auditory stimulus was presented directly in front of the participant. Finally, No Sound Trials were those in which only the visual target was presented.

A Repeated Measures ANOVA with Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 11.876$, $p < 0.05$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.123, 40.329) = 100.337$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster to respond to the visual target in Congruent Trials than Incongruent or Static Trials, $p < 0.05$. Figure 41 shows the mean hemifield RTs for each Trial Type with error bars when congruency was defined by the hemifield to which the auditory stimulus was presented.

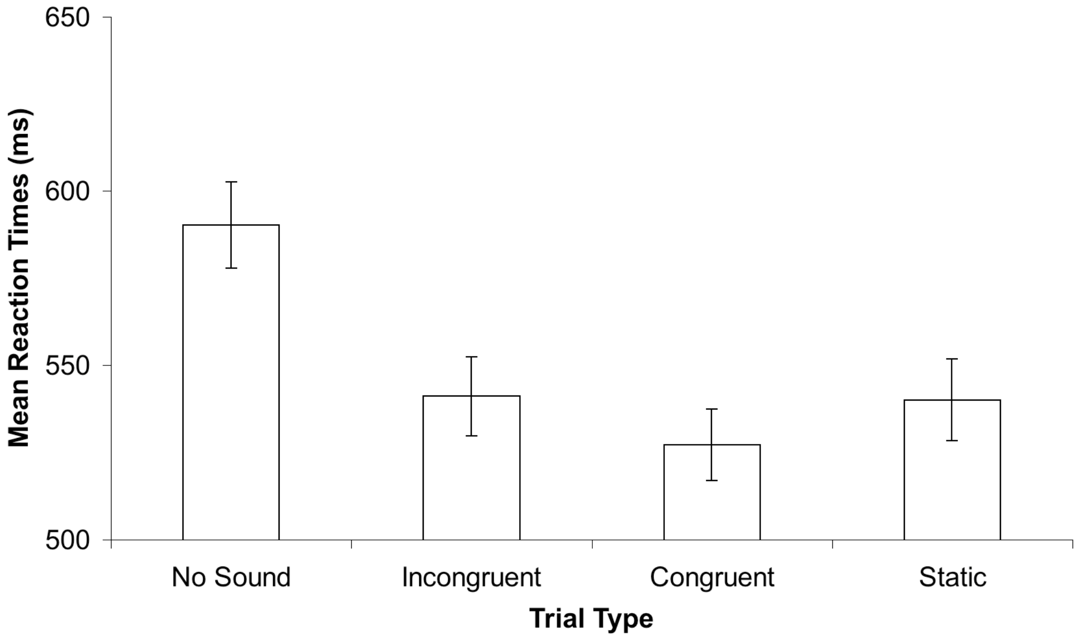

Figure 41. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the hemifield to which the auditory stimulus was presented. Error Bars represent Standard Error

4.5.2.5 Choice Task: Facilitation by direction of movement of the auditory stimulus

The second set of analyses focused on participants' RTs to the visual target as a function of the direction of movement of the auditory stimulus irrespective of it looming or receding, and irrespective of the hemifield to which the auditory stimulus was presented. In this analysis, Congruent Trials were those in which the auditory stimulus was moving in the same direction as the motor movement the participant had to make in relation to the colour of the visual target, i.e., a leftward moving auditory stimulus with a leftward joystick movement; Incongruent Trials were those in which the auditory stimulus was moving in the opposite direction to the motor movement the participant had to make, i.e., a leftward moving auditory stimulus with a rightward joystick movement; and Static Trials were those in which the auditory stimulus was perceived as being directly in front of the participant. Finally, No Sound Trials were where only the visual target was presented.

A Repeated Measures ANOVA with Trial Type (No Sound, Incongruent, Congruent and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 14.010$, $p < 0.05$. This was corrected for using

Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(1.933, 36.735) = 103.421$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Incongruent, Congruent and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster to respond in Incongruent Trials than Static Trials, $p < 0.05$. Figure 42 shows the mean RTs for each Trial Type with error bars when congruency was defined by the direction of the auditory stimulus.

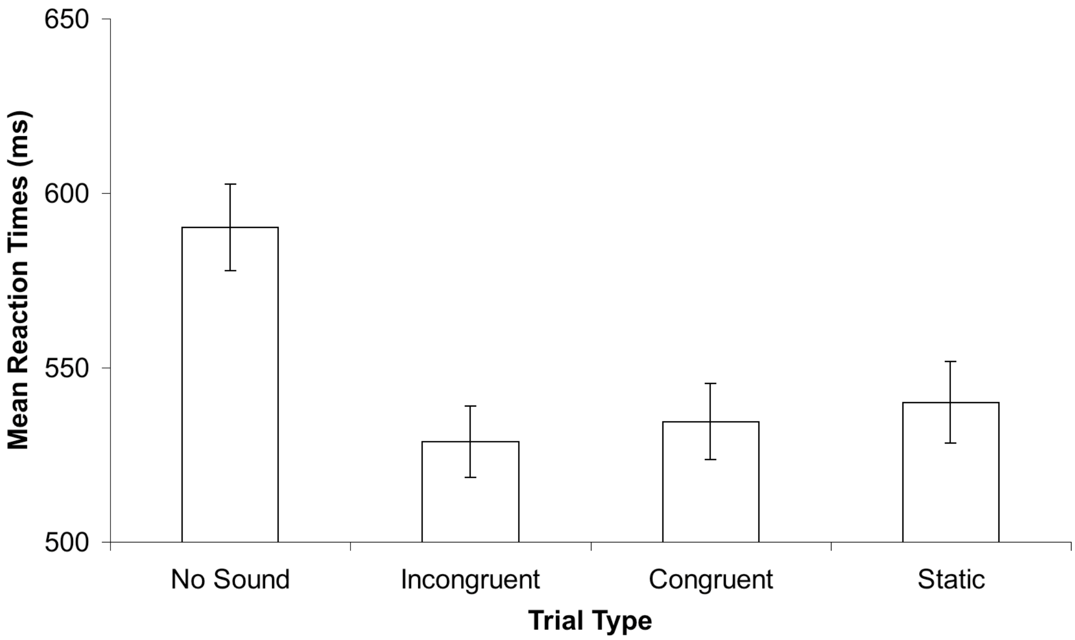

Figure 42. Mean Reaction Times for No Sound, Incongruent, Congruent and Static Trials when congruency was defined by the direction of the auditory stimulus. Error Bars represent Standard Error

4.5.2.6 Choice Task: Facilitation by looming of the auditory stimulus

The final analysis defined trials as Receding, Looming or Static dependent on the auditory stimulus in relation to the body. Therefore Receding Trials were those in which the auditory stimulus was laterally moving away from the body on either side of the participant's head; Looming Trials were those in which the auditory stimulus was laterally moving towards the body on either side of the head and Static Trials were those in which the auditory stimulus was presented to directly in front of the participant.

A Repeated Measures ANOVA with Trial Type (No Sound, Receding, Looming and Static) as the within-subjects factor indicated that the assumptions of sphericity had been violated, $\chi^2(5) = 12.512$, $p < 0.05$. This was corrected for using Greenhouse-Geisser estimates of sphericity. The corrected results indicated that there was a significant effect of Trial Type, $F(2.133, 40.536) = 84.057$, $p < 0.01$. Pairwise comparison indicated that participants were faster to respond to the visual target in Receding, Looming and Static Trials than No Sound Trials, $p < 0.01$. Participants were also significantly faster to respond to the visual target in Looming Trials than Receding and Static Trials, $p < 0.05$. Figure 43 shows the mean RTs for each Trial Type with error bars.

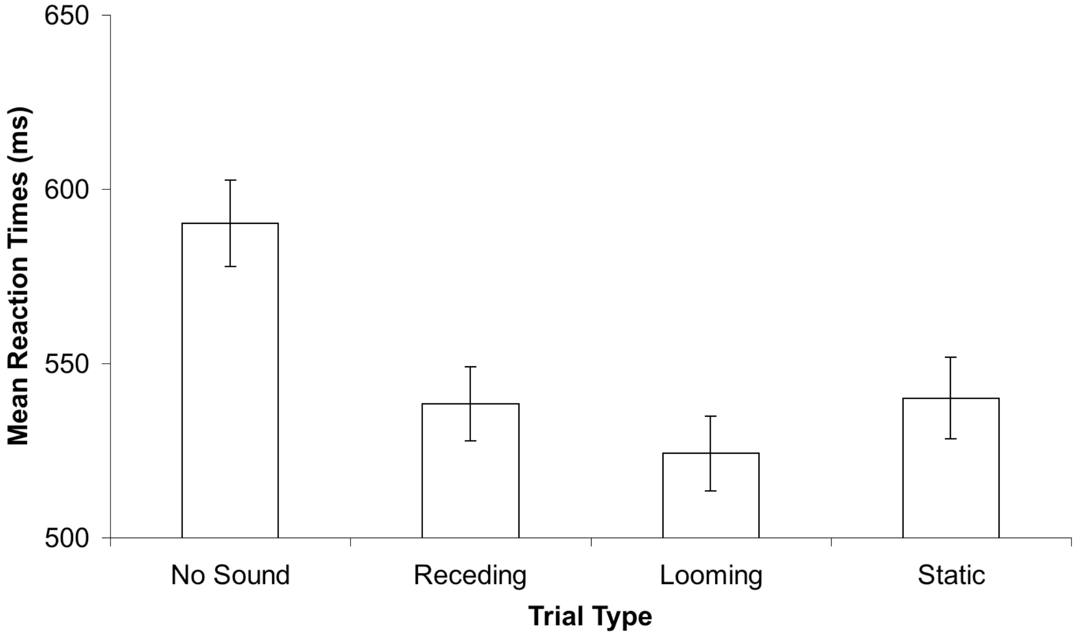

Figure 43. Mean Reaction Times for No Sound, Receding, Looming and Static Trials. Error Bars represent Standard Error

To summarise the results of the Choice Task when congruency was defined by both hemifield, direction and looming, participants were faster to respond to the visual target when it was preceded by an auditory stimulus in all cases. For Hemifield, the results also showed that participants were faster in Congruent Trials than Incongruent or Static Trials. For Direction participants were faster to respond in Incongruent Trials than Static Trials. Finally for Looming participants were faster in Looming Trials than Receding or Static Trials. This pattern of results was similar to those of the Detection Task: participants were faster to respond to the visual target when it was preceded by an auditory stimulus and participants were faster in Looming Trials than Receding Trials.

The overall pattern of these results suggested that looming auditory stimuli facilitated participants' motor movements in response to the visual target. This was case even though the auditory stimulus was task-irrelevant. Also participants were facilitated by the presentation of a bi-modal stimulus in comparison to uni-modal.

4.5.3 Discussion

The aim of this final experiment was to confirm that looming auditory stimuli facilitated a motor response to visual targets in both the Detection Task and the Choice Task when the required motor response was on the same axis as the auditory stimuli.

The central findings of this experiment supported this hypothesis: participants were faster in trials where the visual target was preceded by a looming auditory stimulus than trials where it was not. This was true for both the task involving detecting a visual target and the task involving choosing the appropriate response to the visual target depending on its visual properties. The results indicated that there was facilitation from looming auditory stimuli in both the Detection and the Choice Task as opposed to just the Choice Task. Also for the Choice Task there appeared to be facilitation from the looming stimuli compared to both the receding and static auditory stimuli, which was not the case in Experiment 10.

These results, while not indicating which is more likely, suggest that looming stimuli appear to either be facilitating the detection of the onset of the visual target or facilitating the motor system. In either case it is clear that the looming stimuli improved RTs in a visual task even when the looming stimulus was task-irrelevant. This indicates that looming auditory stimuli may be suitable for facilitating a number of motor responses in varying visual tasks.

4.6 GENERAL DISCUSSION

The aim of the series of experiments reported in this chapter was to determine if task-irrelevant, looming auditory stimuli could be used to facilitate participants' motor responses while performing a visual task. As with the previous experiments reported in this thesis participants were tasked with only responding to the visual target while ignoring all auditory stimuli.

The results of Experiment 7 indicated that firstly, participants' motor responses were facilitated by bi-modal stimulus presentations in comparison to uni-modal presentations. As well as participants being facilitated by bi-modal stimuli, there also appeared to be facilitation of motor responses by which hemifield the auditory stimulus was delivered to, i.e., if the auditory stimulus was delivered to the hemifield the motor response was towards participants were faster than if it was presented to the opposite hemifield. Both of these findings replicate those of the experiments in Chapter 3. What was different from Chapter 3 was the change to a looming auditory stimulus, and the result of this change was that participants' responses were facilitated to a greater degree by looming stimuli than receding or static auditory stimuli.

A similar pattern of results was observed in Experiment 8, with bi-modal presentations; presentation to the congruent hemifield and looming auditory stimuli led to a greater degree of facilitation than uni-modal presentation, incongruent hemifield presentation and receding or static stimuli. Experiment 8 also included multiple levels of SOA to test the effect of presenting the visual target at varying times after the onset of the auditory stimulus. This manipulation revealed that participants were facilitated to the greatest degree when the onset of the visual target was at the point of termination of the auditory stimulus. This indicated that the auditory stimulus had to be heard fully for it to have the greatest effect. A possible reason for the other two levels of SOA not facilitating responses to the same degree may have been due to the visual target being presented either too early or too late in relation to the onset of the auditory stimulus.

While the first three experiments of Chapter 4 had shown that task-irrelevant, looming auditory stimuli facilitated motor responses, the stimulus and the motor responses were always on the same axis, i.e., the auditory stimuli moved in line with the shoulders and the motor response was also in line with the shoulders. If looming stimuli only facilitated responses made on the same axis, they would be limited in their application to real-world situations. Thus Experiment 9 tested whether task-irrelevant, looming auditory stimuli could facilitate responses in general, rather than only in specific directions in relation to the auditory stimulus. The results indicated that participants' motor responses were still facilitated to a greater degree by task-irrelevant, looming auditory stimuli even when the required motor response was orthogonal to the auditory stimulus. This showed that looming auditory stimuli are not limited to facilitating responses in a single direction and this has useful potential benefits in applying the results to real-world applications.

Experiment 10 was conducted in an attempt to disentangle the locus of the observed facilitation by looming auditory stimuli. It set out to accomplish this by having participants perform both the task that had been used in Experiments 1 to 9 - choosing a motor response dependent on the visual target's properties - and a new Detection Task where participants had to respond only to the onset of the visual target, irrespective of its properties. It was hypothesised that if the locus of the facilitation was in improving the time taken to process the properties of the visual target there would be facilitation in the Choice Task but not the Detection Task. If however the locus was improving either the detection of the visual target or reducing the time to prepare or execute a motor response, then there would be facilitation in both tasks. The results indicated facilitation in both the tasks suggesting that it was the participants' detection of the visual target or the preparation or execution of their motor responses that was being facilitated. Evidence from Fecteau and Munoz (2001) suggests that it was most likely the latter case.

The final experiment of Chapter 4, Experiment 11, was to confirm that task-irrelevant, looming auditory stimuli facilitated motor response in both the Detection and Choice Task when the response was once again on the same axis as the auditory stimulus. As with Experiments 7 and 8 bi-modal presentations facilitated responses in comparison to uni-modal presentations. Also, congruent hemifield stimulus response presentations and looming auditory stimuli led to greater facilitation than incongruent hemifield stimulus response presentations and receding and static auditory stimuli. However, in the Detection Task there were no hemifield effects, and there was only facilitation for looming stimuli when compared to receding .

The overall results of these experiments showed that while the looming auditory stimuli were task-irrelevant, participants were still faster to respond in bi-modal than uni-modal trials, and participants were generally faster in the Looming Trials than Receding or Static Trials. Participants' responses still appeared to be facilitated when the response was orthogonal to the axis of movement of the auditory stimulus. Facilitation was present in both the Detection and Choice Tasks, meaning that the locus of facilitation was most likely at the visual stimulus detection stage or the preparation or execution of motor response stage. The relevance of these two findings, orthogonal responses and facilitation in the Choice and Detection Task, is that looming facilitation may be implemented in varying visual tasks requiring many different forms of motor responses. The consistent effect of facilitation of motor responses by looming auditory stimuli supports the previous research, outlined in this chapter's introduction, showing that looming stimuli have special properties compared to their receding and static counterparts.

Chapter 5 of this thesis will discuss the overall implications of the experiments from Chapters 2 to 4 as well as possible real life applications in military and civil environments of these implications.

CHAPTER FIVE

5.1 INTRODUCTION

The purpose of this final chapter is to present an overview of all the experiments carried out over the course of this thesis, their findings and what the results mean in relation to the question posed at the beginning of this thesis. As well as a summary of the experiments and their results, this chapter will lay out a set of possible future experiments as well as possible applications of the findings in both a military and a civilian context. Finally this chapter will end with a summary and conclusion of all the findings of this thesis.

5.2 AIMS AND SUMMARY OF CHAPTER TWO

The experiments reported in Chapter 2 tested whether task-irrelevant, moving auditory stimuli facilitated participants' motor responses to a visual target. Experiment 1 had participants responding to a visual target, a grey box, that randomly appeared to either the left or the right of a central fixation cross on a computer screen. Participants responded to the visual target by either pressing the 'z' key on the main body of the keyboard for a left target or the '2' on the numeric keypad for a right target, i.e., 'z' for a left target and '2' for a right target. The presentation of the visual target was always presented in tandem with a 365 millisecond (ms) auditory stimulus, delivered over headphones, that was either moving from the participant's left-hand side to right-hand side, vice versa or was static at the participant's mid-line. The results of Experiment 1 failed to support the hypothesis that moving auditory stimuli would facilitate motor responses. The results indicated that participants were not significantly faster in trials containing a moving auditory stimulus than they were in trials containing a static auditory stimulus.

Experiment 2 followed the same general method as Experiment 1 except for a change in the manner in which the participants responded to the visual target, a change in the length of the auditory stimulus and the introduction of multiple levels of Stimulus Onset Asynchrony (SOA). The motor responses the participants made were collected using a custom keyboard with only four keys, two central and two peripheral. The central keys were used to start each trial while the two peripheral keys were used to respond to the visual target, i.e., a left hand visual target required the left peripheral key to be pressed and vice versa for a right hand visual target. The auditory stimuli were reduced in length from 365 ms to 265 ms and three levels of audio stimulus/visual target SOA were used, 0, 60 and 100 ms. The custom keyboard recorded the time taken from the onset of the visual target to when the participants lifted their fingers from the centre keys, and the time taken to lift from the centre keys to press either of the peripheral keys. These times were labelled Lift Reaction Time (RT) and Move RT respectively and were analysed separately. The results of Experiment 2 showed that there were no differences between Trial Types or SOA for Move RT. There were significant differences for Lift RT which showed that the participants' responses were at their fastest at SOA 100 ms. The results also suggested that moving auditory stimuli might indeed have facilitated motor responses. However out of the two types of moving auditory stimuli – one moving towards the responding hand and the other away – only the trials that contained an auditory stimulus moving away from the hand appeared to lead to faster responses compared to trials containing a static auditory stimulus.

This partial facilitation is interesting when viewed in the context of the Simon effects (Simon and Rudell, 1967; Craft and Simon, 1970). The Simon effect is where congruency between a task-irrelevant feature of a stimulus and the required response to the stimulus leads to faster reaction times. Thus if a participant had to make a left or right motor response depending on the colour of a light they would be faster to respond if the light was on the same side of the body as the respond hand even though the position of the light is task-irrelevant.

How this relates to the results of Experiment 2 is that there appeared to be an extension of the Simon effects as not only did the auditory stimulus move on the same axis as the required response, it was also completely task-irrelevant. This differs from the standard Simon effect where the task-irrelevant feature is part of the stimulus being responded to. However it seems more likely considering only one of the two types of moving stimuli generated faster responses that the observed facilitation relates to the locational component of the Simon effect. It could have been that it was the onset location, rather than motion, of the auditory stimulus that was the facilitating factor in

Experiment 2. In trials where the stimulus was moving away from the participants' responding hand, its starting position was compatible with the location of the participants' required response. This would explain why there was facilitation in these trials and none in the trials where the auditory stimulus moved towards the location of the required response, as the starting point in these trials was to the opposite side of the response area. This is supported by the fact that at SOA 0 ms participants were faster in both Incongruent and Static Trials than Congruent Trials, as the onset auditory stimulus in both these Trial Types was closer to the responding hand than the Congruent Trials.

While there appeared to be some form of facilitation in Experiment 2, in reality it amounted to, at best, an improvement of approximately 10 ms. It is hard to envision a situation where a 10 ms difference in reaction time would change the outcome of a real-world situation. Overall the implications of the findings of the first two experiments in this thesis did not appear to indicate that task-irrelevant, moving auditory stimuli could usefully facilitate motor responses to visual targets.

5.3 AIMS AND SUMMARY OF CHAPTER THREE

The experiments of Chapter 3 were designed to test for possible facilitation from task-irrelevant, moving auditory stimuli while accounting for the facilitation arising from the Simon effect. In Experiments 1 and 2, from Chapter 2, when a trial contained a moving auditory stimulus it moved from one hemifield to the other, e.g., the auditory stimulus moved from the participant's left-hand side to their right-hand side crossing their mid-line. In Experiments 3 to 6 the auditory stimuli were configured in a manner that while still producing this perception of motion, it no longer crossed the participant's mid-line, e.g., the auditory stimulus moved from the participant's left-hand side but stopped at the participant's mid line. The length of the auditory stimuli were also changed from 265 ms to 250 ms. Also a new No Sound condition was created to compare the effect of bi-modal stimuli compared to a set of uni-modal counterparts. The aim of the experiments of Chapter 3 was the same as that of Chapter 2: using the newly constructed auditory stimuli, to test the hypothesis that moving auditory stimuli that were task-irrelevant would facilitate participants' motor responses to a visual target.

The first experiment of this chapter, Experiment 3, had participants performing the same task as Experiments 1 and 2, though the visual target was changed from a light grey box to a black box. Participants still responded to the visual target in the same manner as before. Experiment 3 also implemented three levels of SOA: 0, 125 and 250 ms; these levels of SOA were used for all the experiments reported in Chapter 3. Finally the auditory stimuli were presented to the participants via a pair of loudspeakers rather than over headphones. The results of Experiment 3 indicated that participants were faster to respond to the visual target if it was accompanied by an auditory stimulus than if it was unaccompanied. Although the reverse was true for the Move RTs, this effect was less than the improvement in Lift RT, so that the overall reaction time from target onset to response (Lift RT plus Move RT) was reduced. Participants were also significantly faster to respond when the auditory stimulus was presented to the same side of the body as the required motor response than if it was delivered to the opposite side of the body. There was also an effect of SOA where participants' responses were faster the greater the time between the onset of the auditory stimulus in relation to onset of the visual target. Regarding the effect of auditory movement on motor responses the results indicated that participants were faster in trials containing static auditory stimuli than moving. However, at a SOA of 250 ms participants faster to Congruent Trials than Incongruent ones.

Experiment 4 followed the same methodology as Experiment 3, other than a change to the response method utilised by the participants. In the previous experiments using the custom keyboard when participants responded to the visual target they had to lift both hands off the central keys before pressing either of the peripheral keys. Experiment 4 changed the response method so participants only had to lift the responding hand off the central keys to make their response. The results of Experiment 4 were similar to those of Experiment 3, showing bi-modal, hemifield and SOA facilitation. Facilitation arising from the movement of the auditory stimuli only appeared at an SOA of 250 ms with Congruent Trials leading to faster responses than Incongruent and Static Trials.

For the last two experiments of Chapter 3, Experiments 5 and 6, there was a change in the task the participants had to perform. Previously the participants responded to the location of the visual target, i.e., whether it appeared to the left or the right of a central fixation cross. For Experiments 5 and 6 the task was changed to responding to the colour of the visual target, the target now always being presented in the centre of the display screen. The response the participants had to make to the visual target depended on its colour, e.g., if the target was red the left peripheral key was pressed and vice versa for a green target. For Experiment 5 this was the only change from the method of Experiment 4. The results indicated that for Lift RTs there appeared to be bi-modal, hemifield and SOA facilitation, and overall Congruent Trials led to faster responses than Incongruent ones. There were no significant differences in any condition for Move RTs.

In Experiment 6, the final experiment of Chapter 3, there were two major changes to the methodology: the first was a return to presenting the auditory stimuli over headphones and the second was the collection of participants' motor responses via a joystick rather than a keyboard. The colours of the visual targets were also changed from red/green to blue/yellow to control for possible red/green colour-blind participants. The task was the same as in Experiment 5 but now participants moved a joystick either left or right depending on the colour of the visual target, e.g., if the target was blue the joystick was moved leftward or it was moved rightward if the target was yellow. The results of Experiment 6 were as for the other experiments of Chapter 3: there were indications of bi-modal, hemifield and SOA facilitation. Facilitation arising from the movement of the auditory stimuli only appeared at an SOA of 125 ms with Congruent Trials leading to faster responses than Incongruent ones.

The overall results of Experiments 3 to 6 indicated that for all four of the experiments participants were faster to respond to the visual target in bi-modal trials than they were in uni-modal. This is not a surprising result as previous literature has shown that bi-modal stimuli leads to faster responses than their uni-modal components (Hershenson, 1962; Bernstein et al., 1969, Hecht et al., 2008).

Another effect that was present in all four experiments was that participants were faster to respond when the auditory stimulus was presented to the same side of the body as the required motor response. This hemifield effect also appeared to be present when the participants' method of response was with a joystick in Experiment 6 rather than the keyboard used for Experiments 3 to 5. This meant that the participants were no longer responding to left hemifield auditory presentations with their left hand but now with their right. One possible explanation of why there were hemifield effects at this point was that the joystick was positioned centrally to the participant's body. There is evidence (Simon, Hinrichs and Craft, 1970) that the locational component of the Simon effect still takes place even when a participant's hands are crossed so that the right hand is placed on the left hand side of the body and responds to left hand side stimuli. It could be that the same process that gives rise to this effect gave rise to the results of Experiment 6. It should also be noted that this hemifield effect was present when the delivery method for the auditory stimulus was moved from speakers to headphones.

One other pattern of results that was repeated throughout all the experiments of Chapter 3 was that participants' responses were faster the greater the period of time between the onset of the auditory stimulus and the onset of the visual target. It may have been that the participants were using the auditory stimuli as a cue that a target was going to appear. If participants were in fact using the auditory stimuli in such a manner it would make sense that the greater the amount of time between the onset of the auditory stimulus to that of the visual target the faster the motor response. This is because the greater amount of time between the onset of the auditory stimulus in relation to the visual target meant the more time the participant had to prepare to respond, i.e., there was greater time to prepare when SOA was 250 ms than when it was 125 ms. Whilst this could be possible, steps were taken to reduce the likelihood of this happening. The catch and visual target only trials implemented for the experiments of Chapter 3 were designed so that participants should have not been using the onset of the auditory stimulus as an indicator that a visual target was going to appear. This was accomplished by having some trials with just the visual target as well as some trials of just the auditory stimulus.

Regarding facilitation by moving auditory stimuli, Experiment 3 to 6 indicated that at the higher levels of SOA participants were faster to respond in Congruent Trials, where the stimulus and response were in the same direction, than Incongruent Trials. Only in Experiment 4, at an SOA of 250 ms, did Congruent Trials lead to faster responses than Static Trials. This mixed series of results would make it difficult to claim that moving auditory stimuli usefully facilitated motor responses over comparable static stimuli. A possible explanation for why moving auditory stimuli failed to consistently facilitate motor responses is that of binaural sluggishness. It has been reported that the minimum amount of time that a moving auditory stimulus has to be presented for its movement to be detected ranges from 100 ms (Perrott and Pacheco, 1989) to 300 ms (Grantham, 1986). It may have been that the SOAs used in Experiments 3 to 6 were too short in duration for the movement of the auditory stimulus to be detected before the participant responded to the visual target.

On one final point relating to the results of Experiments 3 and 4, it was noted that when analysing the Move RTs, participants were faster to respond in the uni-modal trials than they were in the bi-modal. This result appears to go against previous research, e.g., Hershenson (1962), that show participants should be faster in bi-modal trials; indeed this result goes against the results of the Lift RTs analysis as well. It could be that the lift section of the experiment involved some component of decision making that the move section did not, though when looking at the combined reaction times of both the Lift and Move components over both experiments, the uni-modal trials average response time is 55 ms slower than the bi-modal trials. This would indicate that bi-modal trials led to faster overall responses even if a component within the response was faster for uni-modal trials.

In summary the experiments of Chapter 3 indicated that whilst moving auditory stimuli facilitated motor responses this facilitation was neither robust nor consistent; it did not arise in every experiment and when it did arise it was not at the same level of SOA throughout. However the experiments did show facilitation for other factors such as bi-modal facilitation and hemifield facilitation. Both of these facilitation effects were persistent across all the experiments of Chapter 3 and arose even though the auditory stimuli were task-irrelevant.

5.4 AIMS AND SUMMARY OF CHAPTER FOUR

With the inconsistent results from Chapter 3 regarding facilitation of moving auditory stimuli there was a fundamental change in the auditory stimuli for the experiments reported in Chapter 4. In all the previous experiments, 1 to 6, the moving auditory stimuli were designed to give rise to the perception of a sound that moved either left-to-right or right-to-left. While there were changes to the onset and termination locations of these stimuli as well as their length and method of presentation they followed this basic form of moving leftward or rightward for all experiments. For

Experiments 7 to 11 the auditory stimuli were changed to give the participants the perception of a sound that was either laterally looming or receding. Looming auditory stimuli were chosen, as there is evidence that looming stimuli have special properties when compared to other moving stimuli. One of the main properties of looming stimuli is the behavioural response they elicit which is predominantly one of avoidance (e.g. Schiff et al., 1962). Using these special properties Experiments 7 to 11 aimed to test whether participants' motor responses to a visual target could be facilitated by task-irrelevant, looming auditory stimuli.

The task and response method in Experiment 7 was the same as that of Experiment 6, i.e., participants were required to move the joystick either left- or rightward depending on the colour of the visual target. The main change in Experiment 7 was to the auditory stimuli, which went from the 250 ms moving and static stimuli of Experiments 3 to 6, to 1000 ms looming, receding and static auditory stimuli. As with Experiments 3 to 6 the looming and receding auditory stimuli did not cross the participant's mid-line. The auditory stimuli were delivered over headphones; this method of presentation was used in every experiment of Chapter 4. Unlike the previous four experiments of Chapter 3, Experiment 7 had only one level of SOA, 1000 ms. The results indicated once again that there appeared to be facilitation for bi-modal presentations in comparison to uni-modal and for presenting the auditory stimuli to the same hemifield as side of the body the motor response had to be made towards. Regarding facilitation by direction, it appeared that only in trials where the auditory stimulus moved in the opposite direction to the motor response was there a difference to trials where the auditory stimulus was static. The main result of Experiment 7 was that participants were faster to respond to the visual target if the auditory stimulus was looming than if it was receding or static.

Experiment 8 was the same as Experiment 7 except for the introduction of three levels of audio/visual SOA: 500, 1000 and 1500 ms. The results indicated a similar pattern of results as Experiment 7 except with no directional facilitation. Regarding the effect of SOA participants were at their fastest to respond at 1000 ms, i.e., when the visual target's onset was directly after the termination of the auditory stimulus.

To test whether this facilitation of motor responses in the presence of looming auditory stimuli was dependent on the motor response and auditory stimulus being on the same axis, Experiment 9 changed the response method. This was accomplished by having participants either move the joystick forward or move it backward depending on the colour of the visual target, instead of moving it left- or rightward. The joystick was also moved from the centre stick position (directly in front of the participant) to a side stick position (to the right-hand side of the participant). The results indicated that even when the response was orthogonal to the auditory stimulus there was still bi-modal presentation facilitation and more importantly participants were still faster to respond to the visual target when the auditory stimulus was looming than when it was receding or static.

The final two experiments of Chapter 4 and of the thesis, Experiments 10 and 11, were designed to test the possible locus of the observed facilitation arising from looming auditory stimuli. This was done by having participants perform both the Choice Task used in Experiments 7 to 9, i.e., making a motor response to the visual target dependent on its colour, and a Detection Task where the participants made a motor response when they detected any visual target irrespective of its colour.

In Experiment 10 participants performed the Choice Task in the same manner as in Experiment 9. The participants performing the Detection task either moved the joystick forward or moved it backward, depending on which counterbalanced group they were in, on the detection of any visual target irrespective of its colour. Facilitation may have arisen from reducing the time taken to detect the visual target to the time it took to process the target's properties such as its colour/location. Similarly facilitation may have arisen when preparing or executing the motor response. Once again three levels of SOA, 1000, 1250 and 1500 ms were used to test for the effect of varying SOA on RTs which had been observed in the previous experiments. The results for both the Detection and Choice Task showed that there was facilitation for both bi-modal presentations and looming auditory stimuli in regard to the motor responses. There was also an effect of SOA with participants being faster at the higher levels of SOA than the lower. Since there was looming facilitation in both the Detection and Choice Tasks this indicated that it was either the participants' detection of the visual target or the preparation or execution of their motor responses that was being facilitated.

It was not possible to distinguish between these two possibilities for facilitation in Experiment 10, although there is evidence from other studies that suggests that the facilitation arises from facilitating the preparation or execution of the participant's motor response (Fecteau and Munoz, 2007).

The final Experiment of Chapter 4, Experiment 11, tested participants again on both the Detection and Choice Tasks, with the responses made to the visual target being the same as those made in Experiment 8, i.e., in the Choice Task the joystick was moved left- or rightward depending on the colour of the visual target and in the Detection Task the joystick was either moved left- or rightward on detecting the visual target irrespective of its colour. As with Experiments 7 and 9 there was only a single level of SOA, 1000 ms. The results followed the same general pattern of those of Experiment 10: there appeared to be facilitation for bi-modal presentations and looming auditory stimuli in both the Detection and the Choice Tasks as well as a hemifield facilitation effect. As with the other experiments there appeared to be little to no facilitation due to the direction of the auditory stimulus in regard to the motor responses. As with Experiment 10 the presence of facilitation by looming auditory stimuli in both the Detection and Choice Tasks indicated that it was the detection of the visual target or the preparation or execution of the motor response that was being facilitated.

Overall the results of Experiments 7 to 11 indicated once again that participants were significantly faster in bi-modal trials than uni-modal. This pattern of results tallies with previous research of bi-modal facilitation (e.g. Hershenson, 1962), though it should be noted that this appears to be the first time this effect has been shown with task-irrelevant, looming auditory stimuli. As with the bi-modal facilitation there were also significant hemifield effects for Experiments 7, 8 and 11, though for Experiment 11 the effect appeared to only be present in the Choice Task and not the Detection Task. There were no hemifield effects for Experiments 9 and 10 due to the direction of the motor response being orthogonal to the moving auditory stimuli. The presence of the hemifield effect in Experiment 11 is of added interest as unlike Experiments 7 and 8 where the joystick was in a centre stick position, for Experiment 11 it was in a side stick position. This meant that all the motor responses the participants made in this experiment were on the right-hand side of the body yet there was still an advantage to make responses towards the left-hand side of the body when the auditory stimulus was presented to the left hemifield. While the hemifield facilitation could be attributed to the locational component of the Simon effect (Craft and Simon, 1970) it is noteworthy that this effect arises even when the responding section of body is on the opposite side to the location of the stimulus. Secondly, it is interesting that the hemifield facilitation only arises in the Choice Task and not the Detection Task. This could be due to the different natures of the two tasks: in the Detection Task the participants only had to decide if a visual target was present or not, while in the Choice Task they had to decide if a visual target was present and if so which response did its properties dictate. This extra component of processing could have led to the results observed in Experiment 11.

Another recurring effect was motor facilitation arising from manipulations to the SOA between the auditory stimulus and the visual target. In Experiment 8 the fastest reaction times occurred when the visual target appeared immediately at the termination of the auditory stimulus, while in Experiment 10 the fastest responses were generally 250 ms after the termination of the auditory stimulus. Experiments 7, 9 and 11 only had a single level of SOA it was not possible to use these to investigate SOA differences. The results of Experiment 8 were in line with the previous experiments that showed participants' motor responses were generally at their fastest right after the auditory stimulus had been presented. The results of Experiment 10 however seemed to go against the previous findings; if this had only been the case for the Detection Task and not the Choice Task this outlier result might have been attributable to the difference in task type. However as it was present in both the Choice and the Detection Task it is harder to explain this result. One possibility is that somehow the change in response method between the two experiments might have had an effect. In Experiment 8 participants made their motor response on the same axis or plane as the auditory stimulus but for Experiment 10 the motor responses were orthogonal to the auditory stimuli. This difference between the response types is borne out by comparing the results of the 1500 ms SOA responses for Experiment 8 compared to the Choice Task of Experiment 10. In the former participants responded around 582 ms after the visual target appeared while in the latter it was 559 ms. The responses at 1000 ms SOA though were similar at 568 ms and 575 ms respectively.

In regard to directional effects, as with the previous experiments in this thesis, the results were mixed. Of the three experiments where directional analysis was possible (Experiments 7, 8 and 11) only 7 and 11 showed any effects. Both indicated that incongruent moving stimuli generated faster motor responses than static stimuli, and in the case of Experiment 11 this was only for the Choice Task but not the Detection Task. Lack of consistent results regarding directional facilitation in these two experiments, along with the results of the previous experiments, would appear to indicate that facilitation of motor responses will not arise from the directionality of the auditory stimulus alone.

Finally, regarding the main change between Chapters 3 and 4, the use of looming auditory stimuli, the results showed greater levels of robustness and consistency (see Appendix 1 for a table of effect sizes). Across all five experiments of Chapter 4 there was a consistent facilitatory effect of looming auditory stimuli. In all the experiments the bi-modal trials that contained a looming auditory stimulus led to faster motor responses than trials that contained a receding auditory stimulus. Also, for the majority of the experiments the looming trials led to faster motor responses than the static trials, though it should be noted that looming trials were not faster than static trials in the Detection tasks of Experiments 10 and 11. Facilitation of motor responses from looming auditory stimuli also appeared to be present when the motor response was orthogonal to the auditory stimulus. This indicates that the looming stimulus facilitatory effect was not limited to motor responses on the same axis as the auditory stimulus. This has implications for any practical applications as it means that looming stimuli do not need to be paired with specific motor responses. Moreover, this indicates that the looming stimuli facilitated general motor movements. This is interesting in regard to looming stimuli as previous studies such as Schiff et al. (1962) and Freiberg et al. (2001) have only studied responses on the same plane as the looming stimulus. The results of these experiments complement the findings of Bach et al. (2009) who performed a similar experiment with participants responding to a target after the presentation of a looming or receding auditory stimulus. However there were some important differences between their experiment and the experiments reported in Chapter 4. Firstly, while the experiments of Chapter 4 tested looming, receding and static auditory stimuli, Bach et al. (2009) tested only looming and receding stimuli. Also unlike in this thesis where the only target was visual, Bach et al. (2009) had participants responding to both visual and auditory targets meaning that participants would have been actively monitoring the auditory stream in anticipation of an auditory target. While it cannot be said that participants in the experiments reported in this thesis were not monitoring the auditory stream it is fair to say that it might not have been as closely monitored as the auditory stream in Bach et al. (2009) due to the auditory stream being task-irrelevant. The other major difference between Bach et al. (2009) and this thesis was that participants in the former only responded with a single button press on a stimulus response box, while the experiments of Chapter 4 required a much larger motor movement as well as a choice as to which response was required.

In summary, the experiments of Chapter 4 indicated that, as with Chapter 3, participants were faster to make a motor response to a visual target if it was part of a bi-modal presentation compared to a uni-modal presentation. There were also hemifield effects in which participants made motor responses faster to the side of the body that the auditory stimulus was delivered to. The main finding of Experiments 7 to 11 was that task-irrelevant, looming auditory stimuli appeared to offer a consistent facilitation of motor responses and that this facilitation did not appear to be dependent on the direction of the motor response.

5.5 FUTURE DIRECTIONS

Future experiments could continue with looming auditory stimuli to see if the facilitation noted in Chapter 4 could be improved further still. One possible manner in which this could be investigated would be to change the perception of which part of the body the auditory stimuli were looming towards. Lin et al. (2009) indicate that participants were faster to respond to looming stimuli that were perceived to be on a collision course with the participant's body than those on a collision course with the participant's head.

It might also be beneficial to investigate manipulating the angle at which the auditory stimuli loomed at the participant, as in all the experiments reported in this thesis the stimuli always loomed either laterally towards the left side or right side of the participant's head. Stimuli looming from different directions may have different effects to the ones observed in the experiments of this thesis.

Another series of experiments could decrease the level of acuity of the visual target to attempt to use the ventriloquist effect to bolster facilitation. This effect is where one stimulus ‘captures’ another, in the example of a ventriloquists dummy its mouth movements captures the perceived location of the auditory stimulus giving rise to the perception that the sound is coming from the dummy’s mouth. Alais and Burr (2004) have shown that it is also possible for sound to be the dominate stimulus if the visual stimulus is poorly perceived. Thus if the level of acuity of the visual target is reduced the looming auditory stimuli may have a greater effect on motor responses than has being observed in the experiments of Chapter 3.

Leading on from this it would also be interesting to see if looming auditory stimuli could be used to facilitate other motor movements than hand/arm. Humans are not limited to making motor responses with just their arms so being able to facilitate other motor movements would be beneficial. Such an experiment could be to test participants responding to sudden visual stimuli using foot pedals, for example. If looming auditory stimuli facilitated such responses this may be useful in car collision warning systems.

In all the experiments in this thesis the auditory stimulus was always task-irrelevant and the participant was given instructions to ignore the auditory stimuli and focus on the visual targets. The looming auditory stimuli may have a greater effect if the participant was also told to pay attention to both modalities rather than just the visual domain.

Finally it may be of interest to look at looming auditory stimuli used in conjunction with auditory icons, earcons or with speech to see what effect their combination may have on motor responses. Auditory icons are auditory stimuli that have natural connotations, such as a dog barking or the sound of a glass breaking. Auditory icons have already been shown to be easier to learn than abstract auditory warnings (Perry, Stevens, Wiggins and Howell, 2007); it may be that incorporating looming with auditory icons could improve the effectiveness with which listeners respond to these icons. The same possible improvements may be applicable to earcons - abstract musical sounds - as well. A final direction in which looming auditory stimuli could be used is to incorporate looming into speech. Vocal directional cues could be improved by having the vocalisations looming towards the listener and as shown by Experiments 9 and 10 it would not be necessary for the direction of looming to be congruent with the direction indicated by the voice.

5.6 MILITARY APPLICATIONS

In a paper investigating perceived urgency and response times to auditory warning signals, Haas and Casali (1995) commented that a change in response time of just 60 ms could make the difference between a pilot who is performing low level manoeuvres flying into terrain or not. Although the results of the experiments reported in this thesis do not generate this level of facilitation, future experimentation may improve responses towards this time. However, this is not the only way or possible application that looming auditory stimuli may be of benefit in a military environment.

5.6.1 Auditory Icons and Earcons

As stated in the future directions section of this chapter looming auditory stimuli could possibly be used to improve the effectiveness of auditory icons and earcons usage. Auditory icons have already been shown to be of use in a military aviation context by Smith, Stephen and Parker (2004), who showed that participants were faster to respond to auditory icons than they were to respond to abstract auditory stimuli. One of the auditory icons that they used was the sound of an arrow to signify a surface to air missile; another sound was a call of a bird of prey to indicate the presence of an enemy fighter. If these sounds were constructed to also be looming it is likely that response times should be faster still. The same possible improvements should also be applicable to earcons.

5.6.2 Audio displays

Audio displays, used for navigation, targeting and radar tasks in a military environment have already been shown to be improved by the incorporation of 3-D audio (Shilling, Letowski and Storms, 2000; Bronkhorst, Veltman and van Breda, 1996; Oving, Vetlman and Bronkhorst, 2004; Tannen, Nelson, Bolia, Warm and Dember, 2004; Parker, Smith, Stephen, Martin and McAnally, 2004). It is possible to envision these 3-D audio displays to be enhanced further still by looming auditory stimuli. For radar operators, looming auditory stimuli could be used to effectively draw their attention to new information, such as an enemy craft entering controlled airspace, or to warn of impending collisions. For targeting and engagement of enemy craft, a very time-critical situation, looming auditory stimuli could be used to capture an operator's attention, or used as a cue as to when an enemy is within the optimal range of engagement.

5.6.3 Controlled Flight Into Terrain and Spatial Disorientation

On the 2nd of June 1994 a Royal Air Force Chinook, call sign F4J40, crashed into a hill in the Mull of Kintyre in Scotland killing all 27 crew and passengers on board. This was reported as a case of Controlled Flight Into Terrain (CFIT) in which an airworthy craft under pilot control is unintentionally crashed. While the exact cause of F4J40's crash has yet to be determined one known cause of CFIT is spatial disorientation.

Spatial Disorientation (SD) is where a pilot's sense of the orientation of their aircraft is temporarily out of sync with the craft’s actual orientation; this can lead to pilots making corrections to the craft's orientation that are, in reality, not needed. Holmes, Bunting, Brown, Hiatt, Braithwaite and Harrigan (2003) conducted a survey of UK military aircrew personnel on their experiences of SD. Of the 711 respondents, 21% reported that they had experienced an episode of SD that they would classify as significant and that under different conditions could have put flight safety under risk. The results of this survey suggested that even with training SD is still a cause of significant concern in a military aviation environment.

There have been attempts to use auditory warning systems to counter the effects of SD; this has the added advantage of reducing the aircrew's reliance on instruments, which generally require pilots to stop looking out of the canopy and focus their attention on the instrument panel. This of course can be an undesirable action to perform in certain situations. Wickens, Small, Andre, Bagnall and Brenaman (2008) tested pilots' abilities to correct their aircraft from an inverted pitch down orientation. To help the pilots perform the correct righting manoeuvre, on some trials they were presented with a voice command informing them to roll the craft left or right to correct the inversion; this was followed by a second voice command to pull up to increase the craft's altitude. The results indicated that the vocal commands significantly reduced the amount of time it took the pilot to perform the necessary corrective manoeuvres compared to a control condition of using only the standard displays. While these are promising results, the use of vocal commands can in some situations not be as effective as a tonal warning. The pilot first has to understand what information the speech is conveying, they may have to do this in an already noisy environment and also may have to contend with other voice communications coming in over their headset. Using looming auditory stimuli could reduce some of these concerns. For instance, a pilot could be trained to know that the pitch of a looming auditory stimulus indicates the current pitch of their craft, i.e. a high tone means they are pitching up, a low tone means they are pitching down, whilst the side of their body that the stimulus is presented to indicates whether the craft is inverted or not, i.e., the left side of their body means the craft is inverted, the right side of their body means that the craft is non-inverted. Thus, if they hear a low-pitched auditory stimulus that looms to the left side of their body they know that they need to roll their craft and pull the nose up.

As stated before, looming auditory stimuli have the benefit of capturing attention which would be useful in a situation where the pilot has to perform correction manoeuvres as quickly as possible. It should also be noted that it has been shown that auditory localisation, a prerequisite to know where an auditory stimulus is looming from, can be maintained under sustained +G acceleration (Nelson, Bolia and Tripp, 2001). This is beneficial from the point of view that looming auditory stimuli would still be perceived even if pilots are suffering from grayout, a condition where one's vision becomes dimmer, which can lead to SD (Braithwaite, Dunford, Crowley, Rosado and Albano, 1998).

5.6.4 Force XXI Battle Command Bridge & Below (Blue Force Tracking)

Looming auditory stimuli could be used to improve Blue Force Tracker/Tracking (BFT) systems such as the Force XXI Battle Command Bridge and Below (FBCB2) system from Northrop Grumman. This system uses GPS to track friendly and hostile units that are displayed on a screen. It has the ability to inform the user of the location of both friendly and hostile units as well as other geographical features such as minefields and installations. It can generate warnings to inform users when they are approaching locations that require the user's attention such as a way-point on a map. Looming auditory stimuli could be used to capture the attention of the user to improve the response times to critical events.

5.6.5 Boomerang

Boomerang, a mobile shooter detection system designed by DARPA, uses acoustical information from the environment to detect the location of a weapons discharge and thus hopefully the location of the person firing the weapon (if they are not using a remote firing system). This system can then inform the user where they may need to direct returning/suppressing fire. One of the manners in which the system informs the user where the shot has come from is in the form of voice announcements such as 'shooter at 6 o'clock'. If the system presents voice announcements and the user is in control of a Stabilised Weapon And Reconnaissance Mount (SWARM) Remote Weapon Station (RWS), looming sound could be used to improve the user's response time. A combination of the voice announcement that looms may capture the user's attention and reduce the time it taking to bring weapons on target.

5.6.6 Future Integrated Solider Technology

If mobile shooter detection systems are reduced in size sufficiently to be wearable by individual soldiers, it could be implemented into the Ministry of Defence Future Integrated Solider Technology (FIST) Program. Future soldiers' helmets incorporating multi-directional audio systems could be envisioned that could be fed information by a Boomerang type system. Thus when a unit comes under fire the Boomerang would detect where the shot originated from and inform the solider of the location of the shooter. This information could be presented to the solider using looming auditory stimuli or a voice stating direction of shooter.

5.7 CIVILIAN APPLICATIONS

It is not hard to see how the military applications of looming auditory stimuli could also be transferred to the civilian sector. Air traffic control systems could be improved by using looming auditory stimuli to alert a controller about possible collisions between craft. Civil aircraft could benefit from the same improvements in navigation and warning systems that military craft would have. Looming auditory stimuli could be incorporated into warning systems in cars to warn drivers when the car ahead of them has braked sharply. In fact most applications that apply in a military environment, short of targeting and engagement, should be able to cross into the civilian domain.

5.8 SUMMARY AND CONCLUSIONS

The results of the experiments of Chapter 2 indicated that moving auditory stimuli that were task-irrelevant did not facilitate participants' motor responses to a visual target. The results of Chapter 3 also showed that moving auditory stimuli did not consistently facilitate motor responses though there were facilitation effects from bi-modal stimuli as well as from hemifield effects. In Chapter 4 there was also facilitation from bi-modal presentations as well as hemifield effects but the main result was that motor responses did appear to be facilitated by looming auditory stimuli that were completely task-irrelevant. These findings indicate that moving, particularly looming, auditory stimuli may be a good candidate for improving time-critical motor responses in military or civilian environments.

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Appendix 1

Experiment	Audio Visual Type	Trial Type	Cohen's D	Task
Three	SOA 250	Congruent vs Incongruent	0.19	LRT
Four	SOA 250	Congruent vs Static Congruent vs Incongruent	0.37 0.56	LRT LRT
Five	No Sound vs Sound	Congruent vs Incongruent	0.16	
Six	SOA 250	Congruent vs Incongruent	0.24	
		Median	0.24	
Seven	No Sound vs Sound	Loom vs Static Loom vs Receding	0.28 0.25	
Eight	SOA 500 SOA 1000 SOA 1000 No Sound vs Sound	Loom vs Receding Loom vs Receding Loom vs Static Loom vs Receding	0.21 0.25 0.26 0.12	
Nine	No Sound vs Sound	Loom vs Receding Loom vs Static	0.28 0.19	
Ten	No Sound vs Sound No Sound vs Sound SOA 1000	Loom vs Receding Loom vs Receding Loom vs Receding	0.15 0.13 0.22	Detection Choice Choice
Eleven	No Sound vs Sound No Sound vs Sound No Sound vs Sound	Loom vs Receding Loom vs Receding Loom vs Static	0.28 0.29 0.32	Detection Choice Choice
		Median	0.25	