The Influence of Action Requirements on

Action-Centered Selective Attention

By

JENNIFER A. IBBOTSON

B.Sc., Simon Fraser University, 1999

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Faculty of Education, School of Human Kinetics)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

September 2001

Department of Human Kinetics

The University of British Columbia
Vancouver, Canada

Date Sept. 20/2001

ABSTRACT

We have a number of internal mechanisms that are used to effectively handle incoming information in order for proper functioning to occur. Selective attention is defined as " those mechanisms that enable complex perceptual information to be constrained to control specific actions" (Tipper, Lortie and Baylis, 1992 p. 891). A means of studying this selectivity is to have a person select and act on a target object in the presence of distractor objects – a situation often encountered in our daily interaction with the immediate environment. Tipper et al. (1992) have employed such methods to develop an action-centered model of selective attention, attempting to explain the interaction between objects in the environment and goal-directed action. In previous research examining predictions from an action-centered model of selective attention, the primary focus has been on how reaching movements to selected target objects are affected by the presence and spatial location of distractor objects. The purpose of the present experiments was to investigate the manner in which object and response selection are influenced by the nature of the required action and interaction with objects within a person's perceptual-motor workspace. Experiment One revealed that selective response preparation and execution was unaffected by manipulation of the engagement properties of the target and distractor objects. Experiment Two investigated how the end goal of the actions afforded by target and distractor objects might emphasize the action requirements and therefore influence the action. Despite a robust distractor effect, the engagement properties of target and distractor objects did not interact to influence action. Taken together, the present results suggest that a distractor object's action requirement is not a crucial determinant of its potential influence on attention and action.

TABLE OF CONTENTS

List of Tables

List of Figures

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my supervisor, Dr. Romeo Chua. Thank you so much for the patience and guidance that you have given me throughout the last two years. I have really enjoyed the process and I thank you for the invaluable skills that you have passed on to me. I would like to thank Dr. Ian Franks and Dr. Daniel Weeks for their guidance and encouragement as members of my committee during the preparation of this manuscript.

Thank you so much to Shannon Bredin for answering my many research questions and for helping edit this manuscript. Your suggestions and support were very valuable. Special thanks to Paul Nagelkerke for helping me whenever I needed my urgent technical questions answered! I would also like to thank Dr. Romeo Chua, Sara Sturrock and Jeffrey Brown for their technical support in constructing my experimental setups. Leisha Lesko, Carla Olson and Sara Sturrock were essential in helping to carry out the first experiment. Thank you so much for your constant support and friendship over the last two years. Thank you to Andrea Mason and Erica Rae for your advice and friendship.

To my parents, I would like to express my sincere gratitude for providing me with a true foundation of love, guidance and encouragement. Thank you also to Joe, Mandi, Rob, Raye and Aden.

Finally, to the woman who started and fostered my interest in research, Dr. Christine Mackenzie, thank you so much for your encouragement, without which I would not have found my way into the world of motor control. Thank you so much for your enthusiasm and support.

DEDICATION

This thesis is dedicated to my best friend Jeffrey Brown. I couldn't have done this without you – Thank You so much for your love and support.

GENERAL INTRODUCTION

Functioning in a complex world requires an advanced information processing system that is able to fully process the important information and inhibit unnecessary information. For example, while driving a car it is necessary to be aware of a variety of visual and auditory information in the external environment as well as within the vehicle. However, some of the stimuli that are being received are not essential to the task of driving. Some of the signals must be ignored, such as music from a stereo or a friend in the passenger seat gesturing with her arms. These pieces of information are not vital to the task of driving and may in fact be distracting influences on the driver. How are we able to selectively choose what information is necessary and what information can be discarded for the accomplishment of actions in order to complete specific goals?

The general issue of how we function in an environment that requires us to select task-relevant information from an environment that includes other less relevant information has been an area of interest for investigators of attention. An early, and often cited, definition of attention provided by James (1890 as cited in Schmidt & Lee, 1999), states that:

> Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization and concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others. (James, 1890, pp. 403 – 404 as cited in Schmidt & Lee, 1999)

Over the past several decades, psychologists have sought to provide a theoretical and empirical base for James' description of attention. The study of attention has typically consisted of investigations of selective attention, concerned with the processes and mechanisms of information selection, and divided attention, concerned with limitations in the amount of information that can be selected. Investigators of selective attention have searched for the location of a bottleneck in the human information processing system and the basis for selection of information (e.g., Cherry, 1953; Deutsch & Deutsch, 1963; Norman, 1969; Treisman, 1969; Treisman & Gelade, 1980; Welford, 1952). Those researchers interested in divided attention have sought to determine the limitations in the number of activities that can be done at a time, or in the division of cognitive resources (e.g., Kahneman, 1973; Norman & Bobrow, 1975; Wickens, 1980).

In the present work, we have chosen to examine selective attention specifically for the purpose of action. Selection is an inherent feature of attention that is intimately linked with its function. Selective attention has been viewed as the ability of humans to act on the most relevant object with the most relevant action while inhibiting the actions to objects that are not advantageous for the achievement of the goal (Allport, 1987). Without selection all perceptual inputs would be processed and the decision mechanism lost, thus information processing would be inefficient.

How the human information processing system effectively deals with distracting information has been addressed by a number of researchers and will be of primary interest in the experiments carried out in the present thesis. A distractor is any stimulus that provides irrelevant information to the task. The irrelevant information provided by a distractor in most cases causes some type of disruption to the execution of the task. The irrelevant information interferes with the processing of the relevant information and may thus interfere with action preparation and execution. Tipper, Lortie, and Baylis (1992) have defined selective attention as "mechanisms that enable complex perceptual information to be constrained to control specific actions" (p. 891). Tipper and colleagues have developed a way of studying selective attention in a controlled but somewhat natural way by using target objects as well as distractor objects that appear in a random fashion – much like the environment that we deal with every day. From analysis of this type of task environment we may be able to determine what factors (e.g., the presence of distractors, the layout of the environment) have the greatest effect on information processing.

SELECTIVE ATTENTION AND ACTION

The present review of literature will focus specifically on studies of selective attention and action that involve the preparation and execution of movements towards target objects in the presence of distractor objects. The first section provides an outline of studies that have addressed the effect of the spatial relation between the target, distractor and participant on the accomplishment of a movement towards a target. The following section covers studies that have investigated the semantic relation between the target and distractor and how this affects the movement parameters throughout the task. The final sections will introduce the concept of the action requirements of the object, and discuss the potential effects of altering the action requirements of a distracting object on the accomplishments of the task goal. The review will conclude with the introduction of the present investigations of the influence of the action requirements of target and distractor objects on action selection and execution.

Action-Centered Selective Attention

We are able to accomplish goal-directed movements towards intended objects in the presence of a number of other objects. Understanding the internal mechanisms used to isolate the pertinent object or information from the irrelevant stimuli during a task is vital to the understanding of attention. A cognitive representation is formed for all objects within the visual field, meaning that both goal-specific and superfluous information are coded. Many hypotheses regarding what form of representation is accessed internally during selective attention have been proposed. Determining how this representation is formed and what it is related to are beneficial to understanding attention itself. Tipper et al. (1992) has proposed the internal representation that is the most probable in determining selective attention. The framework attempts to explain how distractor information competes with the target for the control of the action. This competition manifests itself as the distractor interfering with the successful completion of the goal (involving the target). The competition is based on the strength of the respective representations of the target and the distractor. The greater the competition between the representations, the more suppression of the non-relevant information is necessary in order for the target goal to be achieved. One of the main questions addressed by Tipper et al. (1992) was: what mechanisms result in certain distractors causing more interference?

Potential Reference Frames for the Distribution of Visuospatial Attention

Tipper et al. (1992) addressed four possible frames of reference that could potentially determine distractor effects during a visual-spatial task. The first framework was a 2-D retina-centered framework, based on an objects location as it is projected onto the retinal surface. This perspective postulated that in order for a distractor to interfere it must be within a certain range of the target, the closer the distractor to the target the more interference. Only within this range of the target will the distractor affect the retina-centered representation of the target. The second reference frame, referred to as the 3-D viewer-centered framework, proposed the notion of an attentional space that extended between the viewer and the current focus of attention. Accordingly, if a target stimulus appeared within this attentional space, detection and processing would be more efficient because attention was distributed within this space. By the same token, a distractor appearing within that space would also be attended to, resulting in greater interference. The environment-centered framework hypothesized that the representation used was one in which the objects in question (i.e., the target and distractor) were thought of in terms of their relation to the environment. The environment-centered representation would remain the same regardless of where the viewer was located with respect to the environment surrounding the target and distractor. Therefore, the amount of interference caused by a distractor would depend on the location of that distractor within the environment.

In contrast to the other three frameworks, Tipper et al., (1992) postulated that the framework on which selective attention is based is action-centered. This framework focuses on the relation between the location of the target and the distractor in relation to the participant's hand that was to perform the action. It is the action that is performed (i.e., which target is to be pointed to) that determines which distractor will cause the most interference.

Distractor Location

Response Path Hypothesis. In the now oft cited paper by Tipper et al. (1992), a number of experiments were conducted to determine whether or not visual selective attention was distributed according to an action-centered representation. In order to mimic a somewhat complex environment, a three by three matrix of possible target and distractor positions was used. The matrix was made up of nine push buttons (see Figure 1). Two light emitting diodes (LEDs) were located beneath each of the nine button positions. One LED was red, signifying the target position; while the other LED was yellow, representing a distractor to be ignored. Analysis was conducted on only the trials in which the target appeared in the middle row. This was done because the distractor could be in all three positions: front row, same row or back row. The response time to the target (time from stimulus onset to movement completion) was recorded in the presence of a distractor (both target and distractor changed locations randomly throughout the study). Participants began each trial by depressing the start button and waiting for the red light to appear underneath a button. This signaled the target button position that must be pushed in order to accomplish the goal. One of the constraints of the setup was that the distractor had to be the push button directly above, below or beside the target location. This helped to control the relation between the locations of the target and distractor objects.

Findings revealed that response time was longer for the trials in which a distractor was present as opposed to the trials without a distractor. They also found that when the distractor was in the path of the movement the response time was longer than when the distractor was not in the path. In a subsequent experiment, the start position was moved to a location beyond the three by three position matrix. Thus, participants were required to move towards their body when reaching to depress the target button (see Figure 2). In this case it was the distractor objects located in the back row that cause the most interference. The action-centered model of selective attention explains this change in distractor effects due to the manipulation of the start position. In the condition where the start position is beyond the buttons (Figure 2) the back-row distractors are now located between the start position and the target, thus, distractors at that location will cause more interference. This finding was the opposite of that found when the start position was in front of the three-by-three matrix (Figure 1). In this setup the trials with a front row distractor light showed the greatest interference effect on the movement. These two experiments revealed that the position of the hand at the onset of the trial had a huge impact on "the spatial nature of the interference" (Meegan & Tipper, 1998, p. 226).

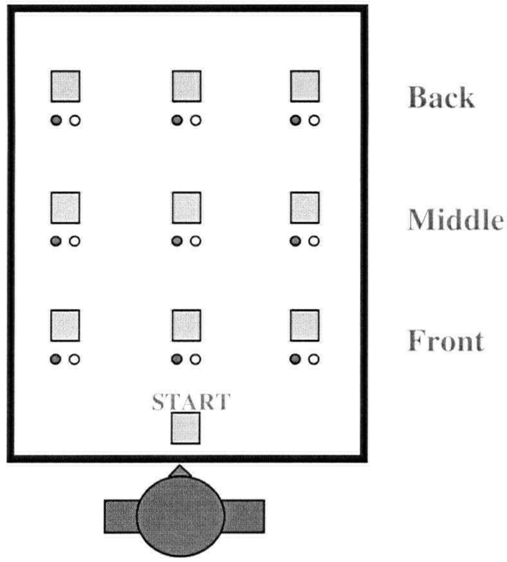

Figure 1. Stimulus board layout with the start position before the target/distractor array.

(Adapted from Tipper et al., 1992)

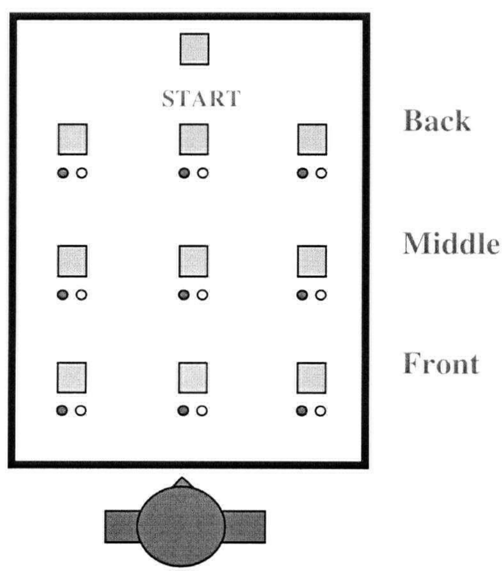

Figure 2. Stimulus board layout with the start position beyond the target/distractor array.

(Adapted from Tipper et al., 1992)

To summarize, Tipper et al. (1992) found that objects were represented relative to the path of the movement towards the target. Therefore, distractors located in the path of the movement had a greater interference effect than other distractor locations. This occurred regardless of the start position of the hand being either close or far from the body. These findings were consistent with the action-centered framework, as objects were represented with respect to where they were located in terms of the action. Tipper et al. (1992) proposed that there is an increased level of competition for action arising between distractor and target objects when a distractor is located in the path of the movement. Due to this increase in competition greater inhibition is required to suppress the action towards the irrelevant object. Because the distractor representation leads to an increased level of inhibition a greater amount of time is necessary for the initiation and execution of an appropriate response to the target.

Using a somewhat similar experimental paradigm to Tipper et al. (1992), Pratt and Abrams (1994) chose to use the dependent measures of reaction time and movement time for their experiment. They examined reaction time in an effort to more closely examine the programming/planning phase of the response. They postulated that if reaction time was affected by the presence of a distractor located in the movement path then this would signify that the "planning and preparation of the movement is conducted in action-centered coordinates" (Pratt & Abrams 1994, p. 246). Reaction time is often used as a window into the decision making process that occurs before movement execution begins (Marteniuk, 1976). Movement time was examined to determine whether or not distractor interference effects appeared during movement execution. Pratt and Abrams (1994) employed a task in which participants were required to move a handle in order to manipulate a small rectangular cursor towards a target located on a display positioned in front of the participant (example of the display shown in Figure 3.). The display had only three possible locations for the target, positioned horizontally across the monitor.

Pratt and Abrams (1994) found that the presence of a distractor increased both the reaction time and movement time of those trials. Furthermore, they found that a distractor in the path of the movement had a greater effect on the reaction time of a movement than a trial having the distractor located beyond the target. These results were consistent with an action-centered frame of reference. The important additional finding from this experiment was that of the increased time found for both the response planning phase, represented by reaction time, and the response execution phase, indicated by movement time. Moreover, the increased time found in movement time for those trials where distractors were located in the path of the movement occurred in the later portion of the movement, namely, the corrective phase. Pratt and Abrams (1994) posed that it is during this corrective phase of movement execution that it becomes necessary to inhibit the distractor in order for the accurate target location to be reached. Thus, they provided evidence supporting the notion that suppression of the distractor representation takes place in both the planning/programming (represented by reaction time) and movement execution phases of information processing.

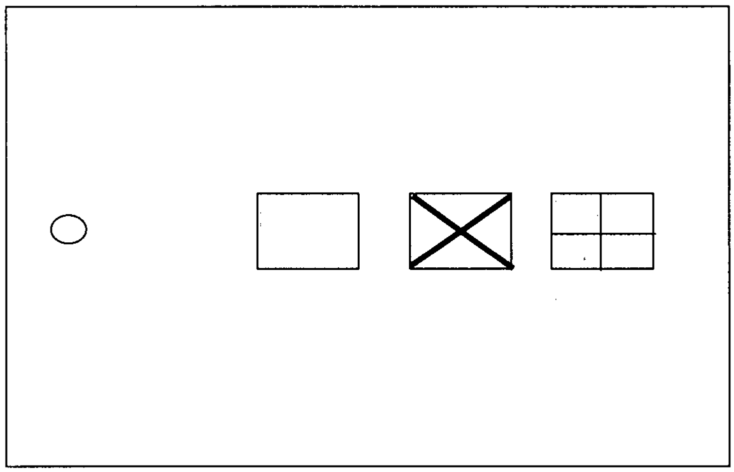

Figure 3. The stimulus layout with the diagonal cross designating the target and the plus sign designating the distractor to be ignored. The circle is the start position.

(Adapted from Pratt & Abrams, 1994)

Proximity of Hand Hypothesis. The action-centered model of selective attention was further refined by the work of Meegan and Tipper (1998). They wanted to investigate whether or not there was more to the action-centered model of selective attention than simply the distractor causing more interference when it was located in the movement path, between the hand and the target. In their work they postulated that it was in fact the distractor location relative to the hand that was the critical factor determining which distractor location caused more interference. Meegan and Tipper (1998) designed their experiment to distinguish between the response-path hypothesis and the proximity to hand hypothesis (Meegan & Tipper, 1998). The response-path hypothesis posed that it was the location of the distractor in relation to the movement path that dictated the strength of inhibition necessary to suppress an action to that distractor. The proximity to hand hypothesis suggested that the closer the irrelevant object was to the hand the more interference would result to the movement towards the target. They utilized the same experimental setup as that of Tipper et al. (1992) (see Figure 1).

One group of participants used their right hand and one group used their left hand for task execution. The dependent measures used for their study were the performance variables of reaction time, movement time, and total time. An interference score was used for each target/distractor arrangement by comparing the three temporal variables for the target alone trials with the corresponding target/distractor trials. They found that the different hand conditions (left/right) did not have a significant interaction with any of the dependent measures. When analyzing the data, Meegan and Tipper (1998) looked carefully at the interference caused by the specific distractor locations, particularly those in the first and middle row. They examined how the distractor locations differentially affected the movements towards the targets located in the back row. They performed a more comprehensive analysis than that carried out by Tipper et al. (1992) who only examined the targets located in the middle row. Meegan and Tipper (1998) found that distractors closest to the start position (i.e., those that were closest to the hand) caused the most interference. Distractors closer to the hand had a greater interference effect on irrespective of whether or not they were in the path of the movement. Meegan and Tipper (1998) found evidence in support of the proximity to hand hypothesis, which helped to provide a more constrained and robust action-centered model of selective attention.

The action-centered model of selective attention was refined when findings revealed that it was not only distractors in the path of the movement, but also distractors located closest to the hand that caused the greatest interference (Meegan & Tipper, 1998). In other words, selective attention, which is an observed phenomenon in which a person is able to distinguish between a target and a distractor, utilizes an action-centered cognitive representation (Pratt & Abrams, 1994). The strength of the internal representation is partially determined by the objects location with respect to the hand. To further generalize this model the internal representation can be thought of in terms of its relation to whatever end effector is being used to complete the task of interest. The effector used to carry out a task could be a body part (e.g., hand, foot) or a tool manipulated by the body. The notion of an action-centered framework has been investigated by a number of researchers employing a variety of different situations

(Castiello, 1996; Castiello, 1999; 1994; Lyons, Elliott, Ricker, Weeks & Chua, 1999; Meegan & Tipper, 1988; Pratt & Abrams, 1994, Tipper, Howard & Jackson, 1997).

Strength of Cognitive Representations. Tipper et al. (1997) conducted a study of selective attention that utilized a task that required the participants to grasp a target block (i.e., square cube). This task was more complex compared to previous studies using tasks, which required the pushing of a button or the movement of a handle. Blocks were used in an attempt to see if having actual 3-D obstacles in the reach path towards the target would affect the interference of the distractor on the task. In light of the experimental setup used (Figure 3), it is apparent that certain distractor locations became physical obstacles to the reach toward certain target locations. This added a new dimension to the distractor paradigm. The four boxes represented the possible locations for the 30mm square cubes that were used for the target and the distractor. There were two cubes used throughout the study, one was blue and the other green. The colour of the target block differed over trials and was revealed when the fixation point start position (shown as the circle in figure 4.) turned into a circle of either blue or green. This ensured that participants were attending to the fixation point prior to the onset of the trial. Once the colour was made known to the participant they were required to reach and grasp the block that corresponded with the colour of the circle.

Tipper et al. (1997) predicted that the interference from the distractors would follow the same pattern seen previously where the distractor in the path of the movement had the greatest effect on the task. For their purposes, the effect on the task was measured as a change in movement time and/or reaction time. Spatial plots along with maximum wrist height were used as dependent variables to monitor how the hand deviated from the optimal path to the target. The optimal path was determined from the trials in which no distractor block was used.

It was found that reaches made during trials with a distractor were different from those trials where no distractor was present. In terms of the spatial plots, the hand deviated away from the distractor if the distractor was located near to the hand. If the distractor was located far and the target was close to the hand then the spatial path of the hand was found to deviate more towards the distractor. They explained that the deviation towards the distractor object occurred because the inhibition of the distractor representation was not strong; due to the weak activation of the distractor object representation when in the far away position. Tipper et al. (1997) took this result as evidence for varying levels of inhibition of the representations formed by distracting objects. Greater levels of inhibition caused the hand to deviate away from the location of the distractor if the activation of that representation was strong. Distractors in the path of the movement (between the hand and the target) produced a stronger representation to compete with the target representation, thus requiring greater inhibition in order for it to be ignored. This evidence supported the action-centered model of selective attention in which objects in the path of the movement produce stronger interference than those distractors that do not fall within the action path. An increase in reaction time and movement time was found for distractor trials compared with target only trials. It did not matter whether the distractor was an actual physical obstacle in the path to the target. That is; a distractor in any of the four locations produced interference in both the temporal and spatial measures of the task.

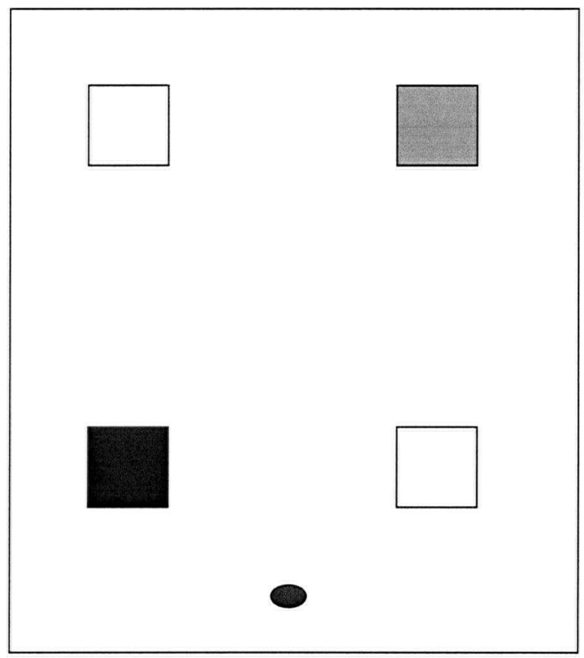

Figure 4. Table layout used for distractor experiments.

(Adapted from Tipper et al., 1997)

In light of these results Tipper et al. (1997) discussed a neural mechanism that could be used to explain the action-centered hypothesis of distractor effects. This mechanism utilizes the ideas surrounding the strength of activation of neuron cell population vectors (magnitude and direction) for certain reaches to a target alone or in the presence of a distractor. This model (example shown in figure 5) describes how the spatial plot of the reach depends on the strength of the internal representation (magnitude and direction in terms of the cell vectors) of both the target and the distractor objects. The reach direction can be predicted from this model because the target and distractor positions are mapped at the neuronal level relative to the current hand position (Tipper, Howard, & Houghton, 1998). The model, as seen in figure 5(d), incorporates the inhibition that is necessary to suppress the level of activation, depending on the hand position, produced by the distractor object. According to the results of their study, this model can predict path deviations from the optimal reach movement for each of the target/distractor arrangements (Tipper et al., 1997).

Visuomotor Competition. Meegan and Tipper (1999) carried out an extension of their previous study, using the same four-location setup (see Figure 3, Meegan and Tipper, 1998). To manipulate the action requirements of an object, Meegan and Tipper (1999) used a plexi-glass shield placed in front of a distractor cube. The addition of the barrier was done in an effort to examine whether or not visuomotor competition was an important factor when looking at distractor interference effects during a reach and grasp task. The authors' motivation was to move away from the visuospatial idea that had been pursued in previous studies. Meegan and Tipper (1999) wanted to change the basis of

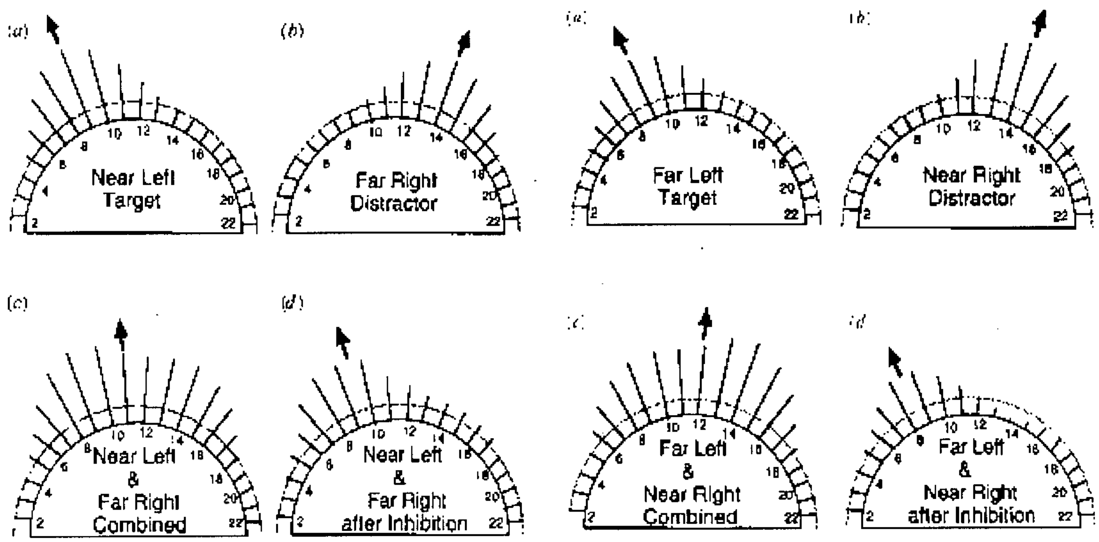

Figure 5. Simulation of neural activity representing a reach to a near-left target and far-right distractor (right four diagrams, a-d) and a reach to a far-left target and a near-right distractor (left four diagrams, a-d). All eight diagrams show the same population of cells. (From Tipper, Howard, & Houghton, 1998, p.1390)

action-centered selective attention to concentrate more on thinking of a task as a visuomotor race to action. Those actions that are easier to carry out become more competitive as they are coded with a stronger action representation.

The plexi-glass shield did not change the appearance and location of the non-relevant object but acted as a barrier, separating the participant from the distractor button. The barrier required the participants' trajectory of the hand to go over the shield in order to reach the distractor. The participant was able to notice the change in the setup but because the shield was clear the participant was also able to see that the object itself remained the same. The movement toward the same object location became increasingly difficult in the presence of the plexi-glass shield.

Meegan and Tipper (1999) wanted to see if the increased difficulty of the movement resulted in the distractor being less competitive in terms of action. If the movement toward the distractor was made more difficult than its action representation would be weaker compared to the action representation of the easily accessible target object. Thus, less interference due to the weaker action representation of the distractor would be seen in the movement toward the target. Meegan and Tipper (1999) compared trials where the distractor and target objects were situated at the same locations but differed in terms of the difficulty of the movement to the distractor object. The difference between the trials was that during one trial the distractor appeared as a normal object within the two by two matrix and in the other condition the distractor object had a plexi-glass shield in front of it.

The results of this study revealed that the plexi-glass covered distractor did in fact have a less distracting effect than the uncovered distractor. The interference effect resulted in an increase in response time when the obstacle decreased the motor processing efficiency of the movement. Meegan and Tipper (1999) used this result to conclude that the motor processing efficiency of the movement towards the distractor was decreased in the presence of the shield. Thus, the movement towards the target became the winner of the visuomotor competition. This study demonstrated that a non-relevant task object achieves a cognitive action representation along with a target object.

Distractor Location Effects and Spatial Alignment. To test the action-centered model of selective attention within a different environment, Lyons et al. (1999) employed the use of a virtual reality 3-D setup. Lyons et al. (1999) suggested that it was important to consider the spatial alignment of the task space and display space when discussing what frame of reference is used internally to code objects. It was postulated that Pratt and Abrams (1994) had neglected to consider how their task set up differed from that used by Tipper et al. (1992) (Lyons et al., 1999). In the earlier study (Tipper et al., 1992) there was no separation between the work and display space. A spatial misalignment existed between the two planes in the Pratt and Abrams (1994) apparatus, where a handle was used to manipulate a cursor located on a display displaced from the task space. Lyons et al. (1999) asserted that a better understanding was needed regarding how this remote manipulation setting interacted with the distractor effects.

Lyons et al. (1999) conducted a number of experiments, each looking at different aspects of a remote manipulation environment. For the first experiment, a similar set up was used to Pratt and Abrams (1994) where the participant's manipulation plane (tabletop) was different from the visual plane (upright monitor). The task space utilized a three-by-three matrix similar to that used by Tipper et al. (1992) (see Figure 1). The matrix, made up of nine blue circles, was displayed on a monitor placed vertically in front of the participant. At the trial onset the target circle would light up red. During distractor trials, a yellow circle would appear simultaneously in one of the other eight locations. The participants were required to move the mouse on the graphics tablet, which would in turn move a cursor on the monitor in the desired direction towards the target circle. The participants were unable to view their hand; whereby, the only visual feedback of their progress was from the monitor.

In contrast to previous studies that had found strong distractor effects, Lyons et al. (1999) found no significant distractor effects. Lyons et al. (1999) postulated a number of reasons for why their results did not conform to previous findings. One explanation was that the interference of the distractors had little effect because of the high accuracy component of their task. Although, similar to both Tipper et al. (1992) and Pratt and Abrams (1994), their task was more difficult than the tasks used in previous studies. Furthermore, there was a misalignment of the perceptual and motor workspace. Due to the increase in difficulty of their task, as well as the misalignment, the relation between target and hand became different and therefore, did not produce action-centered distractor effects.

In Lyons et al. (1999) second and third experiments a different apparatus was employed where the monitor was superimposed over the task space. The monitor was flipped and held upside down by a frame. The monitor screen was reflected up to the participant's eyes via a half-silvered mirror located parallel to the screen. The same three-by-three matrix was displayed on the monitor, and the participant manipulated the mouse to move the cursor to the target without vision of the hand. This setup was able to match the manipulation plane with the visual plane while maintaining the virtual environment scenario.

From these experiments, Lyons et al. (1999) found similar results to the previous distractor studies in which the distractors in the path of the movement had the greatest interference effects. Thus, these studies suggest that it was the misalignment between the task and visual space that was having an effect on the distraction of superfluous information on the target task. From these three experiments it appears that the action-centered model of selective attention relies on the alignment of the perceptual and motor workspaces in the presence of a difficult task. The accuracy demands of the task and the translation required between the proprioceptive and visual sensory information affects the internal representations that are made regarding the environment in which the target task is being performed (Lyons et al., 1999).

Summary. The studies reviewed above provide much support for the action-centered model of selective attention. Taken together, the work suggest that visual selective attention is distributed according to an action-centered framework, in which target and distractor objects are represented in terms of their location with respect to the action that is necessary to complete the task goal. During a target-directed movement, distractor objects that are situated along the path of the movement or that are proximal to the hand result in movement interference effects. These effects may also be mediated by such factors such as the alignment of perceptual and motor workspaces, and the difficulty of the movement.

Object Features

At the same time that the above experiments were being carried out on simple objects positioned in a multiple location setup, work on selective attention using a distractor paradigm was being done utilizing more complex objects (e.g., Castiello, 1996; 1999). The objects used in these studies were a variety of fruits such as apples, oranges, and cherries. How a distractor fruit that was similar or different to the target fruit affected the reach and grasp to the target was of interest. Castiello (1996,1999) used a somewhat different methodology when investigating the relation between targets and distractors. In these experiments, participants always knew the location of the target, and therefore, there was no uncertainty as to where the target movement would be made. The distractor fruit, if present, was located either to the left or right of that constant target location. Castiello (1996, 1999) hypothesized that the basis of selective attention was found in the strength of the distracting objects, which was determined by whether or not the distractors were viewed as potential objects for actions.

Using the setup described, Castiello (1996, 1999) found that no distractor effects were not evident regardless of where the distractor was located (i.e. along the hand path); task instructions (stressing reaction time or having the task be self paced); the task itself (pointing or grasping); or whether the distracting fruit was the same or different from the target fruit. Having a setup in which the target location is held constant results in a different environment from the experiments discussed previously. In the aforementioned experiments there was a high level of uncertainty with regard to where the target and distractor would be located. In the present study, the task environment was changed and the participants were now able to preplan the movement to the target. Therefore, less interference was seen from non-relevant objects being introduced to the scene.

Throughout his many experiments dealing with target and distractor objects and selective attention, Castiello (1996, 1999) did not find strong distractor effects. This was likely a result of the methodology used throughout his experiments. Only when participants were required to actively attend to the distractor, due to a secondary task such as naming the fruit at the end of the trial, was interference on the movement evident. Distractor effects appeared in experiments in which the distractor was emphasized, for example, when the use of a spotlight was used to draw attention to the distractor. Thus, Castiello (1996, 1999) concluded that distractor objects do not affect the selective attention for an action channel unless the objects require attention for mental or motor actions. If the location of the target is known prior to the task, it is intuitive to suggest that a distractor would have little, if no, effect on the task of reaching for the target. Competition for action would no longer exist because the action would be known ahead of time.

Object Size. To further understand how objects are coded during a movement task, another set of experiments, using a reach and grasp paradigm to a target in the presence of a distractor, was presented by Kritikos, Bennett, Dunai, and Castiello (2000). They used a similar setup as that used in Castiello's (1996, 1999) previous experiments. That is, the target was held at a constant location and the distractor object was presented at either side of the target.

Kritikos et al. (2000) examined both temporal and spatial variables using a 3-D motion analysis system to see whether differences could be detected over the different experimental conditions. They manipulated a number of independent variables: speed instructions (normal or fast); size of distractor (with respect to the target object); vision (limited or constant); and orientation of distractor (with respect to the target object). These manipulations were done in order to determine how these specific variables affected the temporal and kinematic measures of a reach and grasp task to a target at a constant location. The same basic task of reaching to the specified target location was performed under the many different conditions. Kritikos et al. (2000) anticipated finding inappropriate kinematic parameterization in terms of the target when the distractor had different features from the target (size/orientation). For example, in a trial where the target was a small cylinder and the distractor was a large cylinder it was hypothesized that adjustments to the kinematics of the reach and grasp movement would emerge. Another situation in which competition for action was expected to manifest itself as interference in the kinematic measures was when the orientation of the target and distractor were different from one another. This would result in different actions being required for the grasping of the two objects, causing a potential conflict in the response selection phase of the movement.

Kritikos et al. (2000) found that in the fast movement condition the amplitude of peak velocity and peak grasp aperture increased compared with the self-paced trials. The lack of constant vision resulted in a longer movement time and a decrease in peak velocity in comparison to the reach and grasp movements during the constant vision trials. They also found that when the distractor was a different size compared with the target there was interference. Peak velocity, and acceleration occurred earlier in the movement. This resulted in an increase in deceleration time. These findings all point to interference effects resulting from an increase in uncertainty with regards to the end goal of grasping the target object. However, the spatial path of the hand was unaltered by the presence of a distractor. That is, distractors that were the same size as the target did not appear to interfere with the movement. Furthermore, orientation of the distractor did not affect the grasp measures or the kinematic parameters of the movement. Kritikos et al. (2000) concluded that not all features of potential objects for action have the same salience in terms of how they are coded during movement planning. Therefore, some object features do not seem to affect the selective attention phenomenon. They also concluded that some irrelevant distractor features must be processed to a certain degree even though they are not required to perform the task.

The reaching and grasping studies are consistent with the findings found in the pointing studies, and in their support for the action-centered model of selective attention. When reaching and grasping a target object, those objects that are located closest to the hand cause the most interference to the movement. However, it is important to note that the interference effect was not demonstrated in all of the dependent measures examined in the experiments.

Many of the more recent studies have moved away from the use of geometric shapes as their task objects and onto more complex objects commonly dealt with in everyday life. The varied studies employ different approaches in order to address the issue of object features and action requirements. However, the motivations behind the studies are similar as the authors attempted to further the understanding of the phenomenon of selective attention for action.

Semantic Category

Humans have a great deal of experience with grouping certain objects into familiar categories. These categories are made up of objects that share the same semantic attributes (i.e., they share a similar meaning). Jervis, Bennett, Thomas, Lim and Castiello (1999) exploited these known semantic categories in their study in an effort to see whether or not these groupings had an effect on the relation between target and distractor during a reaching task. They wanted to determine if the semantic relation between the competing objects affected selection of the appropriate action to the target object. They used the broad categories of living versus non-living objects. Within the living semantic category the subcategory of fruit was used as targets in all three of the experiments.

A similar setup to that used by Castiello (1996, 1999) and Kritikos et al. (2000) was utilized, in which the target appeared at a constant location while the distractor was randomly changed from a left or right position. An example of their task under the same semantic category condition included a red apple target and a red apple distractor. The semantically incongruent condition had the participants reach to a target that was a red apple while a red rectangular box distractor flanked the target object. Jervis et al. (1999) found that the pre-movement planning phase was not affected. However, they did find that many of the kinematic measures, indicating the organization of the movement, were changed when the target and distractor were of different semantic categorizations. Most of these effects were due to changes in the grasping phase of the movement following the reach towards the target.

A second experiment in the study by Jervis et al. (1999) kept the semantic relation constant while manipulating the action the objects afforded. To achieve these differing action requirements across the target and distractor objects the size of the objects was manipulated. An apple was once again used as the target object. The different sized apples afforded different types of grasps to be used during the movement to acquire them. The distractor was either a small apple or a red box in relation to the larger target apple. It was found that movement time was longer for the trials with the small red box distractor compared to the no distractor trials. There was no difference between the small red apple distractor trials and the other trials with or without a distractor. The same differences appeared as in the first experiment concerning the organization of the movement. The small red box distractor caused a reorganization of the movement compared with the other trials. Specifically the grasp components of the movement towards the red apple were altered when the red box was present.

In their third experiment, Jervis et al. (1999) examined the effects of keeping the shape of the incompatible distractor constant in relation to the target object and the compatible distractor object. In this experiment, an orange was used as the target object. The compatible distractor was also an orange while the incompatible distractor was a similar looking orange spherical object. This arrangement helped control for the shape of the objects while keeping them semantically unrelated.

Jervis et al. (1999) found similar results to the previous experiments where a reorganization of the kinematic parameters occurred in the trials in which the distractor was not semantically related to the target. They concluded that that the semantic relation between the target and non-relevant object affected the coding of the objects. They posed the idea that the functional (action) requirements of the object and the semantic attributes of the object were contained in a single representation. Both the action requirements of the distractor (size) and the semantic relatedness of the distractor and the target resulted in interference effects on the movement towards the target. This provided evidence that during selective attention the non-relevant object size and semantic attributes are represented and thus compete with the same information about the relevant target object.

Learned Relations

Humphreys and Riddoch (2000) examined how learned relations between two objects affected the target movement towards one of those objects. A patient with bilateral lesions of the frontal and anterior temporal lobes was run through a battery of tests to see how he dealt with a reach and grasp movement to a target in the presence of a distractor object. The cortical lesions left the patient with an inability to ignore past experiences with certain objects. The patient had problems with automatically carrying out actions on familiar objects without volitionally wanting to, due to past interactions (history) with that object. This patient did not easily follow a task instruction containing only the end goal of the task. The authors believed that by looking at this patient, it might be beneficial to determining how cortically intact people isolate the appropriate object and action selection. Specifically, this research would help to determine how objects and actions are represented and thus inhibited during selective attention. The experimenters were also interested in how the associations between the actions afforded by the two objects interacted when they were either compatible or not compatible with each other. Throughout the experimental conditions Humphreys and Riddoch (2000) introduced certain restrictions on the action towards the target. The participant was given clear instructions regarding which object was the target and how that object should be grasped.

The tasks given to the participant were mainly reaching and grasping of a cup with or without an accompanying distractor object. The target varied in location from a right and left position. If a distractor was present it appeared at the opposite location to the target object. Throughout the experiments the manipulated variables were the orientation of the objects, the type of distractor (same or different object from target), and the specific task instructions given to the participant. The objects that were used all had something to do with teatime (i.e., coffee pot, cup, jug) so they were semantically and functionally related. Humphreys and Riddoch (2000) also examined the strength of interference caused by semantically related distractors compared with learned action related distractors.

The results of these experiments showed that for this patient the strength of the learned action associations was stronger than the semantic relatedness of the objects. They found that the orientation of the target cup and distractor cup had effects on the action as seen by errors occurring during the movement task. Humphreys and Riddoch (2000) concluded that object selection occurs before action selection. Object selection is affected by the feature similarities found between target and distractor objects and is based on the instructed features of the target. The strength of response activations of the two objects is what affects action selection, along with the learned and familiar responses to the object (Humphreys & Riddoch, 2000). It was postulated that the object representation and action representations for both target and distractor objects were joined in some way into an object-action assembly. Confusion resulted when the inhibition of the distractor action carried over to the target action representation. Due to the participant's inability to keep the end goal clearly defined, the inhibition that resulted was not directed specifically at the non-relevant object-action representation.

Action Requirements

Weir et al. (submitted) have recently conducted a set of experiments to examine further the idea of action representations and, more specifically, how and when the action requirements of objects are coded. They also examined how the action requirements of a distractor object influenced the movement and action towards a target object. The objects used in the experiments were either a turn or pull control knob. Distractors had action requirements that were either the same or different from that of the target object. The experimenters carried out two different task conditions. First, participants performed a block of trials where the specific action of the target was to be carried out, either a turn or a pull action. The target was presented either alone or together with a distractor. In the second condition, participants performed a simple pointing task to the target object. This condition was carried out in an effort to see whether or not the action requirements of the target and distractor switches had an effect on the movement even when the actions were not necessary for completing the task. Weir et al. (submitted) hypothesized that during the reach and action condition, when the distractor had different action requirements from the target, greater interference would be seen in the target movement. Their results confirmed this hypothesis. As expected the trials in which a distractor was present, compared with those where the target appeared alone, took a longer overall time to complete. There was an increase in total time when the action requirements were different for the distractor and the target. The kinematic data showed that the interference from the distractors caused changes early on in the movement. Weir et al.

(submitted) also found that during the pointing condition, when the action requirements were not necessary for the completion of the task, these effects were no longer present.

These investigators concluded that this lack of interference seen in total time and movement time during the pointing experiment shows that the action requirements came into play when the task necessitated the action to be carried out. During the pointing condition there were effects seen in reaction time. The trials in which a similar distractor object was present compared to the target object showed a shorter reaction time compared to the trials in which the distractor was different from the target. This showed that there were some residual effects of the first condition in which the participants became familiar with the differences between the action requirements of the two controls. During the pointing task the visual similarity of the target and distractor became a more prevalent feature during response selection.

Summary

The majority of the empirical work reviewed in the preceding sections has examined the spatial relation between the target and distractor and, in general, has supported an action-centered framework of selective attention. A consideration of intrinsic object features has also been undertaken to examine how they influence the relation between target and distractor objects. For example, the size of the object being grasped has been manipulated to see if the grasp aperture while reaching to the target object is affected by the different sized non-relevant distractor. Semantic categories of target and distractor objects have been considered to determine whether or not this relation has an effect on the information processing and execution of the movement to the target. Lastly, a preliminary study has examined the action requirements of the target and distractor objects and how they relate to selective attention and object and action representations.

Collectively, the empirical work to date provides considerable support for an action-centered model of selective attention. How this model holds up in a variety of different environments with diverse objects is yet to be determined. To gain a complete picture of what is occurring when objects and responses are being selected in order for a target object to be acquired it is important to gain more knowledge about the influence of the action requirements of the objects. With this knowledge, the action-centered model of selective attention can be strengthened to include many different workspace setups, thus increasing its generalizability. The following studies examine how the action requirements of objects are represented and therefore influence a response when a target or end goal is specified.

EXPERIMENT ONE:

The Influence of Object Action Requirements on Selective Attention

The ability to selectively choose relevant task information to effectively perform a motor response has been studied using a number of different tasks. Of primary interest to these studies are the factors that affect selection. Extrinsic and intrinsic object features have been explored. The action-centered model of selective attention was developed to describe the influence of the spatial relation between objects and the intended action (Tipper et al., 1992). It was established that irrelevant objects (i.e., distractors) located closer to the effector cause more interference than those objects farther away (Meegan and Tipper, 1998; Tipper et al., 1992). It was concluded that objects were represented according to where they were located in relation to the hand or effector for the action. To extend this model the relation between target and distractor intrinsic object features has also been studied (Castiello, 1996; 1999; Jervis et al., 1999; Kritikos et al., 2000). Semantic categories, learned object relations, object size and shape have all been manipulated. These studies have demonstrated that object features, in addition to spatial location, also have some influence on selective attention for action.

The present study extends the selective attention literature by examining the influence of the action requirements of objects on selective attention. How is selective attention affected by the manipulation of the action properties of the target and distractor objects involved in the task? This experiment follows work done by Weir et al. (submitted). These authors investigated how the action requirements of objects, both relevant and irrelevant, affected an action towards a target (the original motivation for their work was concerning control discriminability issues in regard to human factors).

Weir et al. (submitted) showed that the relation between the action requirements of the objects, being either the same or different, did have an effect on the movement towards a target. They found that more interference, seen as an increase in total time, occurred in the movement towards a target when the target and distractor objects had the same action requirements.

The purpose of the present experiment was to take a similar approach to Weir et al. (submitted) with modifications that would further make the action requirements of the objects involved in the task more prevalent than distractor location. The target was indicated by a location cue but the action requirement was the emphasis of the task. The action requirements of the target and distractor objects were manipulated in order to see if the relation between the object's actions had an effect on the preparation and execution of the movement towards the target. Any modification of the movement seen over the different target and distractor combinations would indicate some type of interference effect. This interference could be due to changes in selection of attention for the purpose of action. Changes in selective attention would indicate that the irrelevant object was either more or less salient and thus required varying degrees of inhibition depending on the objects action requirement in relation to the target action.

Hypothesis

It was expected that when the target and distractor had the same terminal action requirements the interference to the task, seen in both performance and kinematic measures, would be less than when the target and distractor shared the same action requirements. Based on past distractor experiments (Pratt & Abrams, 1994; Tipper et al., 1992), it was expected that when there were no distractor objects the reaction time and movement time would be faster than when distractors were present. It was also expected that distractors located in the front of the target would cause more interference than distractor switches located behind the target.

Method

Participants

Ten right-handed undergraduate and graduate students were recruited from the university population. All participants were naive to the purposes of the experiment. Participants took part in two one-hour sessions set up in the Perceptual Motor Dynamics Laboratory located in the School of Human Kinetics at the University of British Columbia. Both sessions were carried out on the same day with less than an hour separation between sessions for any given participant. This study was conducted in accordance with ethical guidelines established by the University of British Columbia (see Appendix A for sample of informed consent form). A fifteen-dollar remuneration was provided to the participants upon completion of the experiment.

Apparatus

The experimental setup used for this investigation was a three-location array arranged vertically on a tabletop. A three-location array was selected so that trials containing a near distractor, far distractor or no distractor could be examined with respect to the middle target location. A two-distractor array would not have allowed for a comparison of one target (middle target in the three target layout) across all three distractor conditions. The target objects were switches that required either a pull or turn action. The switches were visually similar but discriminable, which allowed the participant to recognize that the switches had different terminal action requirements. The switches had the same diameter of ~2 cm, therefore both objects required a similar grasp posture. Most simply, the grasp posture was expected to be the same for reaches to both switches due to the standardized size of the switches, but the terminal action requirement was different.

The apparatus consisted of a box-like task space in which the target and distractor objects were located. The box was divided into three equivalent sections (or locations) where the objects had the potential to be placed. Such a set-up allowed the object locations to be easily changed to accommodate the many target and distractor combinations over the trials of each condition. Underneath a plexiglass sheet covering each section was located two yellow light emitting diodes (LEDs). These LEDS illuminated the different sections in order to indicate which object was the target for that trial. The distractor switch was placed in one of the remaining sections that were not illuminated. The remaining section was covered with a plain piece of plexiglass. The box was placed on a table surface at which the participants were seated. A schematic diagram of the task space is presented in Figure E1.1.

The type of target switch was varied over the trials and was indicated by the location of the switch lighting up to signal the target location. The target in this experiment was defined by location. Defining the target switch by location ensured that the participant determined the action requirement of the target object only after the lighting of the section designated the target object. The light indicating the location of the target switch was done in an effort to remove the colour feature from the object itself. If the target switch were designated by a certain colour this would have added a distinguishing feature to the target switch to further differentiate it from the distractor. It was desirable that the distractor and target be most different from one another due to their respective action requirements and not any other outstanding feature characteristic.

Participants were fitted with a pair of liquid crystal eye goggles (Milgram, 1987) with the onset and offset of these spectacles controlled by custom written software. To ensure that they did not view the task space prior to the onset of the trial, the spectacles were set to opaque. The participants' cue to begin the task occurred when the goggles became transparent and vision of the task space was made available. The section designating the target object was illuminated at the same time the goggles opened.

To accurately monitor the kinematics of the participants' movements an OPTOTRAK ™ (Northern Digital Inc.) 3-D motion analysis system was used. The cameras monitored the movements of three infrared light emitting diodes (IREDs) that were placed on the right hand of the participant at the index finger (left, lower corner of the nail), thumb (right, lower corner of the nail) and wrist (styloid process of the radius of the right arm). Gathering movement data from these three points allowed for the calculation of kinematic values, which provided information on the aperture of the fingers throughout the task, as well as the trajectory of the hand as it moved from the start position to the target object. The OPTOTRAK ™ collected the IRED data at a frame rate of 400 Hz. The ODAU ™ 12-bit analog-to-digital converter was used to monitor the voltage changes at the pull and turn switch as well as the start switch at a sampling rate of 1000 Hz. This voltage data could then be linked to the OPTOTRAK ™ data during analysis.

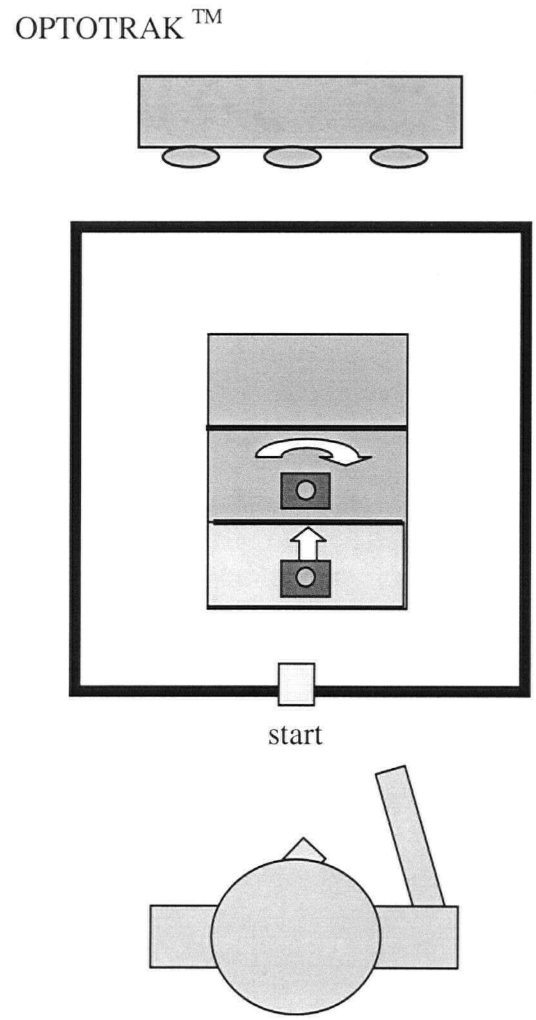

Figure E1.1. The task space for Experiment One in a different action distractor condition.

Task and Procedure

Participants were instructed to keep their right hand stationary at the start location, situated at the front of the box apparatus, until the warning tone had sounded and vision was made available. Once the hand was properly placed at the start position the experimenter pushed a button on the computer keyboard and a warning tone sounded. This tone was to let the participant know that, within 1-3 seconds, the target would appear. On some trials, only the target object would appear. On other trials, one or more objects could appear. Participants were instructed to prepare and execute their movement as quickly and as accurately as possible to the illuminated target object while ignoring any other switch, if present. In the reach and grasp movement condition the participants were instructed to reach and grasp the target as quickly and as accurately as possible. In the execute action condition the task included not only a reach but also the execution of the target switch, either pull or turn. After movement completion, participants were further instructed to remain at that target object until the computer generated a second tone. When this second tone was heard, the participant was required to move their hand back to the starting position and prepare for the next trial. Once again it was emphasized that the goal was to prepare and execute the movement as quickly and as accurately to the target object as possible while ignoring any other objects. Standardized movement instructions were given to the participants prior to the onset of the first condition and repeated in the middle and at the beginning of all trial blocks.

The action requirements of the target and distractor objects were randomized in an effort to see if a distractor of the same or different action affected the planning of the target action. If the target were always of the same known action then the action could be preplanned before the target location was made known. The interference occurring from the other switch (requiring the same or different action) would be less likely to arise.

Experimental Design

The experiment was composed of two conditions, one in which participants reached and grasped the target object and another that required participants to reach, grasp and execute the terminal action requirement of the target object. Each session consisted of 200 trials, with 10 trials for each distractor condition having a middle target location and 5 trials for each combination of front and back target location. Details of the trials for the grasp and execute action conditions are provided in Appendix B. The independent variables of this experiment were the presence and location of the target and distractor objects as well as the manipulation of the objects' terminal action requirements.

The two movement conditions were blocked into two sessions. One condition required the participant to reach and grasp the target object, indicated by the lighted section. The other condition required the participant to reach, grasp and execute the action requirement of the designated target object. The reach and grasp condition allowed the experimenter to remove the action requirements of the objects from the task. This provided a contrast to the action task trials where it was predicted that the action requirements of the target and distractor would influence both performance and kinematic measures of the movement. The order of conditions was counterbalanced across participants. Half of the participants performed the reach and grasp condition first while the other half performed the execute action condition first. It was expected that the order of the conditions might affect the salience of the action requirements of the objects, specifically in the reach and grasp condition. The participants that underwent the execute action condition first had experience with the objects' respective actions and this may be seen as having an effect on the second set of trials during the reach and grasp condition. Perhaps, even though the actions of the objects were not being carried out in the reach and grasp trials the participant would be affected by the distractors spatial location relative to the target object as well as the distractors action requirements due to residual effects of the execute action trials. The participants with little to no experience with the action requirements of the objects were expected to demonstrate spatial distractor effects when performing the reach and grasp trials first, but little interference due to the action requirements of the distractors.

Data Analysis

Kinematic data was filtered at 10 Hz using a 2^{nd} order dual-pass Butterworth filter. Using the central finite difference technique the position data in the x, y, and z coordinates were differentiated to produce velocity and acceleration profiles. These velocity profiles were used to determine peak velocity, and percent time to peak velocity. By calculating the difference between the index finger and the thumb IREDs the aperture data was obtained. This provided the measures of peak aperture, and percent time to peak aperture, measured in millimeters. Reaction time and movement time were calculated using the wrist IRED to define the start and end points following certain velocity and duration criterions. Velocity and acceleration profiles were used for the start and end of the movement following the algorithms provided by Chua and Elliott (1993). For this experiment the data were analyzed using an initial velocity criterion of 10 mm/s and a terminating velocity criteria of 30 mm/s. The criterions had to be maintained for a duration of 72 ms for a valid start and end of movement to be determined.

Only reaches toward the middle target were analyzed. Reaction time (RT) was analyzed in order to determine what was happening in the response selection and the initial movement planning phases of the movement. Reaction time was determined from the onset of goggles opening to when the wrist IRED moved. To explore what was happening during movement execution, including potential indications of online movement planning, movement time (MT) was analyzed. Movement time was calculated from the onset of wrist movement to the time when the wrist completed movement in the z-axis (i.e. switch was acquired). Reaction time and movement time were calculated using the velocity of the wrist IRED to define the start point and the end point of the movement.

Kinematic variables were analyzed to indicate if an interference effect occurred that effected the movement towards a target switch in the presence of a distractor switch. Specifically, peak velocity (PkVel) and percent time to peak velocity (%TPkVel) were used to provide indicators of movement speed and the portions of the movement in which the participant spent a greater proportion of time. If the participant was spending more time in deceleration than acceleration during the velocity profile, it could be assumed that more time was needed to home in on the target object. An increase in the percentage of time spent in deceleration could be indicative of the movement becoming more difficult because of a change in the environment or to the task, such as the addition of a distractor object.

Data were analyzed using planned comparisons on the performance and kinematic dependent measures. The planned comparisons were performed using an alpha level of $p < .05$.

Results

The medians for each of the performance (RT, MT, TT) and kinematic (PkVel, %TpkVel, PkAp, %TPkAp) measures were derived from the factorial combination of the experimental conditions.

Planned comparisons were performed in an effort to answer a number of questions regarding how action selection, preparation and execution, within the context of the action-centered model of attention, was affected by the manipulation of both the location and action properties of the target and distractor objects. The comparisons examined the influence of different target and distractor combinations on the dependent measures of interest, with respect to location and terminal action requirements. The main questions and the results of the planned comparisons will be outlined below separated into planned questions and then further by the performance and kinematic dependent measures themselves.

Reach and Grasp vs. Execute Action.

Were the performance and kinematic measures different for the reach and grasp versus the execute action movement conditions? It was expected that differences would be seen in terms of the dependent measures between the two action conditions. The execute action condition, thought to require a more complex movement, was expected to have greater values for all of the performance measures compared to the values for the reach and grasp trials.

Performance Measures. There was a significant difference between the total times of the two action conditions. It took the participants longer to prepare and execute the movement during the reach, grasp and execute movement condition (873.71 ms) compared with the reach and grasp condition (797.37 ms) regardless of what type of trial within that condition ($F (1, 32) = 21.5, p < .01$). Contrary to expectations, there were no RT differences between the reach and grasp (250.28 ms) and execute action conditions (265.52 ms) ($F (1, 32) = 1.8, p = .23$). Typically, reaction time studies have found that during a more complex/difficult movement condition there is an increase in movement planning time resulting in a longer reaction time. There was an effect of action condition on movement times ($F (1, 32) = 28.1, p < .01$).

Despite the lack of an effect in terms of reaction time, the type of action condition did influence both movement time and total time. The contribution of the increase in movement time (534.23 ms for reach and grasp condition and 589.39 ms for execute) accounts for the difference between the median total times of the movement conditions (see Table E1.1). Given that the difference between the two action conditions is in the terminal phase of the movement (i.e., engage the target switch vs. just grasp it), this finding suggests that participants may have taken time during the transport phase of their movement to program on-line the terminal action requirement of the target. This would account for the increase in time taken by the participants during the movement execution stage of the execute action condition.

Kinematic Measures. Kinematic measures were analyzed to reveal specific information on the trajectories and the movements of the hand from the start position to task completion. Of specific interest in the present comparison was whether differences in the kinematic measures would emerge as a function of the grasp versus the execute action movement condition. It was not known if differences would emerge between the conditions in terms of their kinematic profiles. If the increase in complexity

Table E1-1.

Total time, reaction time and movement time as a function of movement condition.

	Total Time (ms)	Reaction Time (ms)	Movement Time (ms)
Execute	*873.7 (81.5)	265.5 (45.5)	*589.4 (64.3)
Grasp	*797.4 (95.3)	250.3 (95.3)	*534.2 (64.7)

Note. Average within subject standard deviation is in the brackets

* $p > .01$

Table E1.2.

Peak velocity and percent time to peak velocity as a function of movement condition.

	Peak Velocity (mm/s)	% Time to Peak Velocity	Peak Aperture (mm)	% Time to Peak Aperture
Execute	1417.6 (136.6)	39.4 (7.2)	51.1 (4.9)	72.4 (9.1)
Grasp	1485.2 (100.5)	42.2 (5.5)	51.9 (5.8)	74.8 (9.9)

Note. Average within subject standard deviation is in the brackets

of the movement in the execute action condition resulted in the task becoming more difficult than it would be expected that peak velocity and percent time to peak velocity would be lower for the more difficult task condition (Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987). With an increase in task difficulty it has been shown that velocity measures typically decrease, accompanying the uncertainty arising from a difficult task. A similar logic would apply to the grasp measures of peak aperture and percent time to peak aperture (Wing, Turton & Fraser, 1986). With a more difficult task the level of uncertainty the participant experiences may increase. The participant's lack of confidence in the movement may result in the participant enlarging their grasp aperture in order to deal effectively with the uncertainty of the movement. An increase in aperture between the index finger and the thumb would allow the participant to produce an accommodating grasp for the object with little fear of missing the object. It is a form of overcompensating, a type of safety measure that has been observed when people are dealing with a difficult environment (Wing, Turton & Fraser, 1986).

Analysis of peak velocity did not reveal any differences between the grasp (1485.2 mm/s) and the execute action condition (1417.6 mm/s) ($\underline{F}$ (1, 8) = 1.1, $\underline{p}$ = .32). There was also no difference in the proportion of movement time taken to reach peak velocity between the two movement conditions ($\underline{F}$ (1, 8) = 2.9, $\underline{p}$ = .12). The participants appeared to have moved towards the target in a similar manner, in terms of velocity, regardless of the demands of the task (see Table E1.2). A similar pattern of results was seen for the grasping measures. There were no differences in peak aperture ($\underline{F}$ (1, 8) = .08, $\underline{p}$ > .50) or percent time to peak aperture ($\underline{F}$ (1, 8) = .73, $\underline{p}$ = .42) between the two movement conditions.

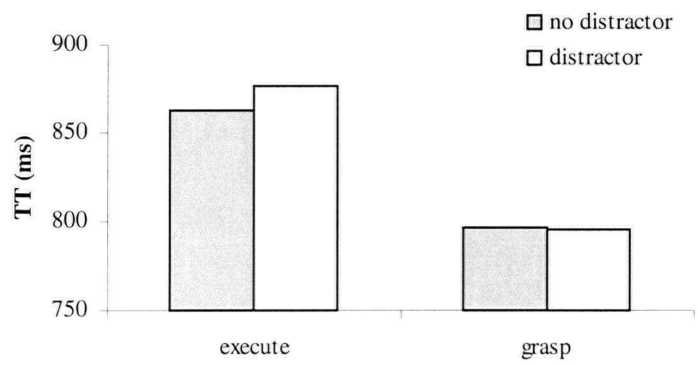

Figure E1.2. Total times for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

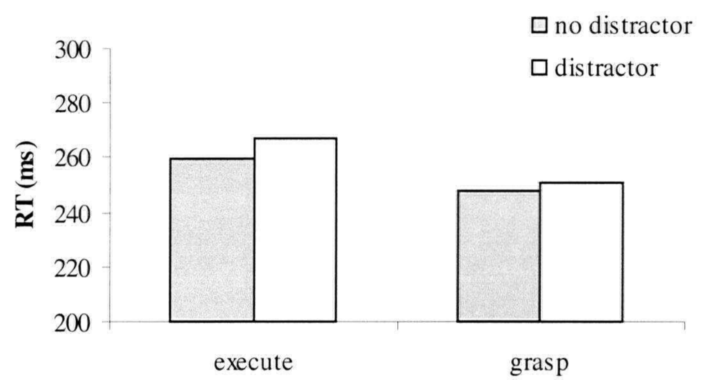

Figure E1.3. Reaction times for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

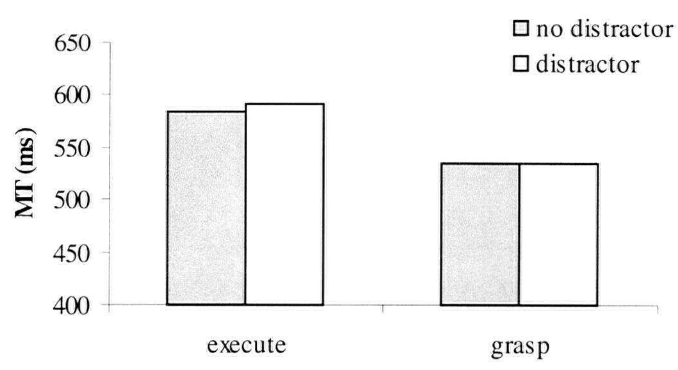

Figure E1.4. Movement times for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions

Distractor vs. No Distractor

The present comparisons examined the influence of the absence or presence of a distractor object. In the first comparison, trials in which a distractor was present were compared to those in which there was no distractor (a main effect for distractor). In the second comparison, distractor effects were examined within each action condition.

Performance Measures. There was no difference between the distractor and no distractor trials for any of the performance measures (see Table E1.3). For total time there was no significant difference between the no distractor (829.6 ms) and the distractor trials (836.0 ms) (F (1, 32) = .52, p = .48) (see Figure E1.2). For reaction time, the comparison failed to reach significance (F (1, 32) = 3.9, p = .058). The no distractor trials had an average reaction time of 253.4 ms and the distractor trials had an average reaction time of 259.0 ms (see Figure E1.3). It was expected that reaction time would be significantly different for the no distractor and the distractor conditions. There was no significant difference between the no distractor (558.4 ms) and the distractor trials (562.7 ms) in terms of movement time (F (1, 32) = .53, p = .47) (see Figure E1.4).

Was there an interference effect, in the form of an increase in time in the performance measures, which could be seen during the distractor trials, compared to the no distractor trials within the individual action conditions? There were no differences between the total times taken during the distractor and no distractor trials for the execute action condition (F (1, 32) = .20, p > .50) and the grasp condition (F (1, 32) = .18, p > .50). Similarly, there were no differences seen in terms of reaction times for distractor and no distractor during the execute action condition (F (1, 32) = .38, p > .50) and the grasp condition (F (1, 32) = .16, p > .50). Movement times for distractor and no

Table E1.3.

Total time, reaction time and movement time for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	Total Time (ms)		Reaction Time (ms)		Movement Time (ms)	
	no distractor	distractor	no distractor	distractor	no distractor	distractor
Execute	862.9	876.4	259.2	267.1	582.9	591.0
	(75.5)	(83.01)	(43.7)	(45.9.)	(62.7)	(64.7)
Grasp	796.4	795.6	247.5	251.0	533.9	534.31
	(124.1)	(88.1)	(75.2)	(56.1)	(75.7)	(65.7)

Note. Average within subject standard deviation is in the brackets

Table E1.4.

Peak velocity for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions..

	Peak Velocity (mm/s)		% Time to PkVEL	
	no distractor	distractor	no distractor	distractor
Execute	1424.7 (145.5)	1415.9 (134.4)	39.0 (6.2)	39.5 (7.5)
Grasp	1471.5 (104.2)	1488.6 (99.6)	42.0 (5.9)	42.3 (5.4)

Note. Average within subject standard deviation is in the brackets

Table E1.5.

Peak Aperture and % Time to Peak Aperture for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	Peak Aperture(mm)		% Time to Peak Aperture	
	no distractor	distractor	no distractor	distractor
Execute	*52.3 (4.7)	*50.8 (4.9)	72.2 (10.5)	72.4 (8.7)
Grasp	52.6 (6.3)	51.7 (5.7)	75.6 (9.5)	74.6 (9.9)

Note. Average within subject standard deviation is in the brackets

* $p > .05$

distractor trials were also not different from one another during the execute action ($\underline{F}$ (1, 32) = 1.4, $\underline{p}$ = .24) and the grasp condition ($\underline{F}$ (1, 32) = 3.9, $\underline{p}$ = .06). The average median values for these measures are found in Table E1.2. These findings are not consistent with previous research that has found an interference effect due to the presence of a distractor object (Pratt & Abrams, 1994; Tipper et al, 1992).

Kinematic Measures. Overall, the presence of a distractor did not lead to any differences in peak velocity ($\underline{F}$ (1, 32) = .17, $\underline{p}$ > .50). Further, movement condition did not interact with this effect [grasp condition ($\underline{F}$ (1, 32) = 1.0, $\underline{p}$ = .31); execute action condition ($\underline{F}$ (1, 32) = .28, $\underline{p}$ > .50)] (see Figure E1.5). The temporal symmetry of the velocity profiles was also not altered by the presence of a distractor. There was no difference in the percent time to peak velocity between the distractor and no distractor trials (($\underline{F}$ (1, 32) = .48, $\underline{p}$ = .50) (see Figure E1.6). This finding suggests that the distractor trials had no interference on the velocity profiles of the movements over the two conditions (see Table E1.4).

Examination of the grasping measures revealed an effect (see Table E1.5). Specifically, although there was only a weak main effect overall for the presence of a distractor ($\underline{F}$ (1, 32) = 4.1, $\underline{p}$ = .050), there was a distractor effect observed in the execute action movement condition (see Figure E1.7). Within the execute action movement condition, participants produced a larger peak aperture when the distractor was absent, compared to when it was present ($\underline{F}$ (1, 32) = 6.3, $\underline{p}$ = .017). No effect was seen in the grasp movement condition ($\underline{F}$ (1, 32) = 2.3, $\underline{p}$ = .14). Analysis of the percent time to peak aperture revealed no differences between the time taken by the participants to reach peak aperture for distractor and no distractor trials ($\underline{F}$ (1, 32) = .17, $\underline{p}$ > .50) (see Figure E1.8).

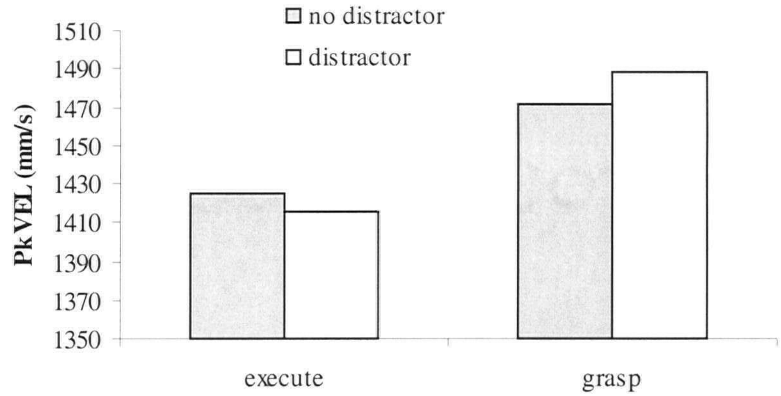

Figure E1.5. Peak velocity for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

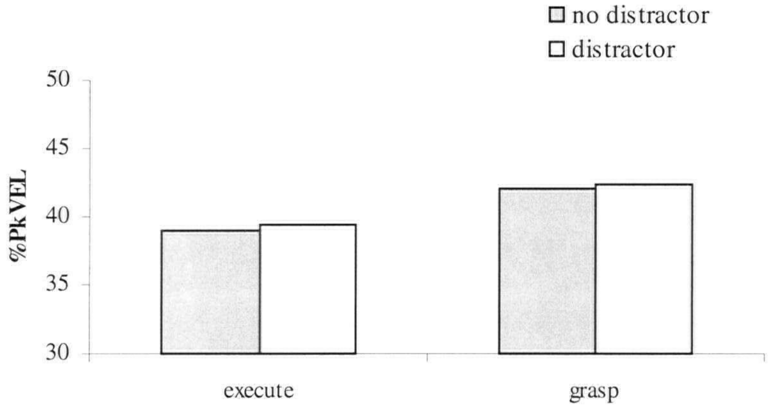

Figure E1.6. Percent time to peak velocity for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

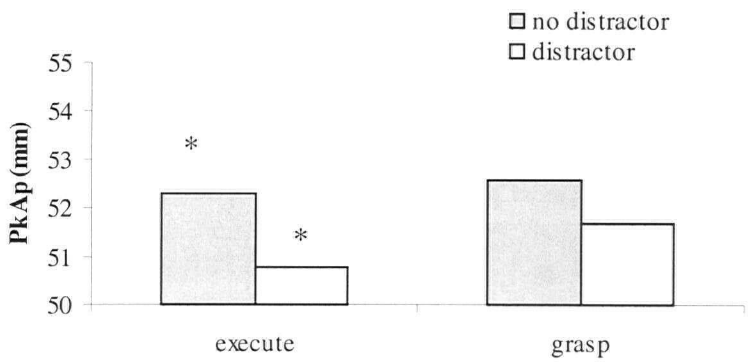

Figure E1.7. Peak aperture for movements executed in the presence or absence of a distractor under the execute and grasp movement conditions (* $p < .05$)

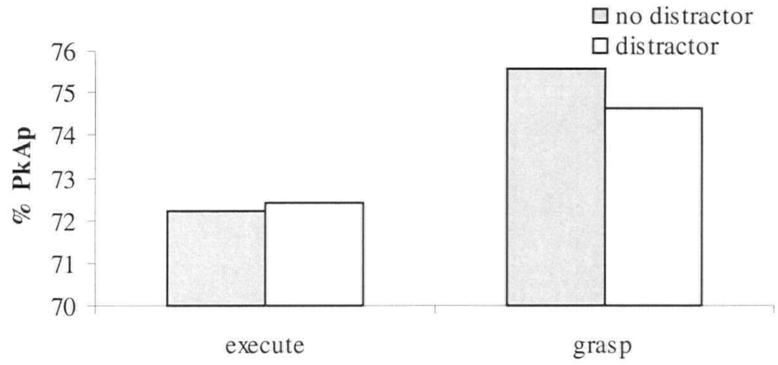

Figure E1.8. Percent time to peak aperture for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

Front Distractor vs. Back Distractor

The present comparison examined the influence of the spatial location of the distractor with reference to the target object. The distractor was located either in front or behind the target object. An action-centered attention model predicts that front positioned distractor objects, by virtue of being along the path of the movement to the target, would cause more interference than back or same row distractors (e.g., Pratt & Abrams, 1994; Tipper et al, 1992). It was expected that in the present experiment a similar pattern would emerge.

Performance Measures. The planned comparisons involving front and back distractors revealed no significant differences between trials with distractors in the two different locations (see TableE1.6). The differences in total time, reaction time and movement time were not significantly different ($p > .10$) between the distractor trials in terms of where the distractor was located with reference to the target (see Figure E1.9, E1.10, E1.11). An examination of the influence of distractor location within each action condition also failed to yield significant effects for any of the performance measures. There was a difference in movement time during the reach and grasp condition that was approaching significance with the front distractor trials having a movement time of 540.2 ms and the back distractor trials having an overall value of 528.4 ms, (F (1, 32) = 3.9, p = .056). The front distractors appeared to be causing a greater interference on movement time than the back distractors (see Figure E1.12). The lack of a robust distractor effect suggests that when performing a task within the present experimental paradigm there was little or no interference effect that was mediated by where the distractor object was located in terms of the target object.

Table E1.6.

Total time, reaction time, and movement time values for the distractor trials as a function of front row and back row positioned distractor objects.

	Total Time (ms)		Reaction Time (ms)		Movement Time (ms)	
	Front D	Back D	Front D	Back D	Front D	Back D
Execute	877.1	875.7	268.8	265.4	594.6	587.5
	(76.4)	(89.7)	(42.1)	(49.8)	(63.6)	(65.7)
Grasp	794.7	796.4	251.4	250.5	540.2	528.4
	(88.9)	(87.4)	(61.1)	(51.2)	(67.9)	(63.5)

Note. Average within subject standard deviation is in the brackets

Table E1.7.

Kinematic Measures for the distractor trials as a function of front row and back row positioned distractor objects.

	Peak Velocity (mm/s)		% Time to Peak Velocity		Peak Aperture (mm)		% Time to Peak Aperture	
	Front	Back	Front	Back	Front	Back	Front	Back
Execute	1416.3	1415.5	39.3	39.6	49.6	52.0	72.1	72.7
	(131.5)	(137.3)	(6.3)	(8.7)	(4.9)	(4.9)	(8.3)	(9.1)
Grasp	1477.4	1499.8	42.0	42.6	51.4	52.0	74.2	75.1
	(103.1)	(96.2)	(5.4)	(5.4)	(5.4)	(6.0)	(9.6)	(10.3)

Note. Average within subject standard deviation is in the brackets

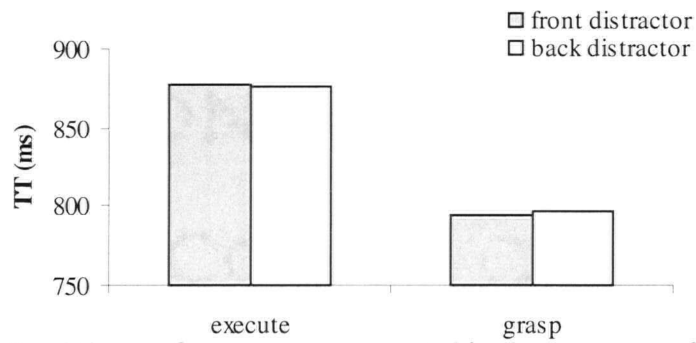

Figure E1.9. Total times of movements executed in the presence of a distractor located in front of and beyond the target, under the execute action and grasp movement conditions.

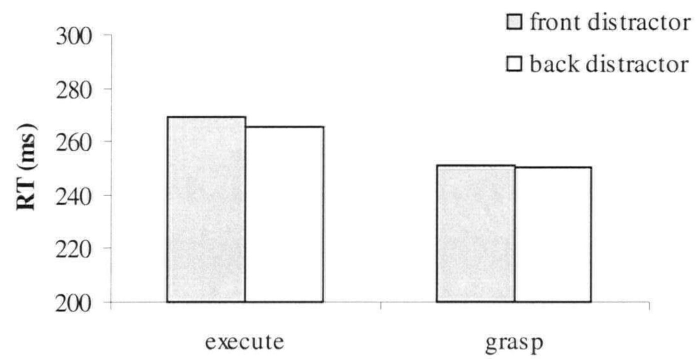

Figure E1.10. Reaction times of movements executed in the presence of a distractor located in front of and beyond the target, under the execute action and grasp movement conditions.

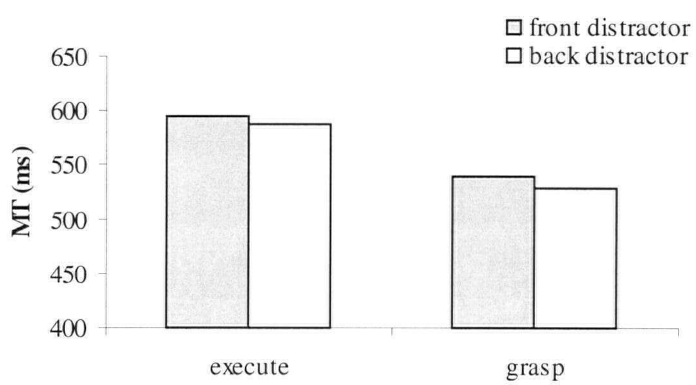

Figure E1.11. Movement times of movements executed in the presence of a distractor located in front of and beyond the target, under the execute action and grasp movement conditions.

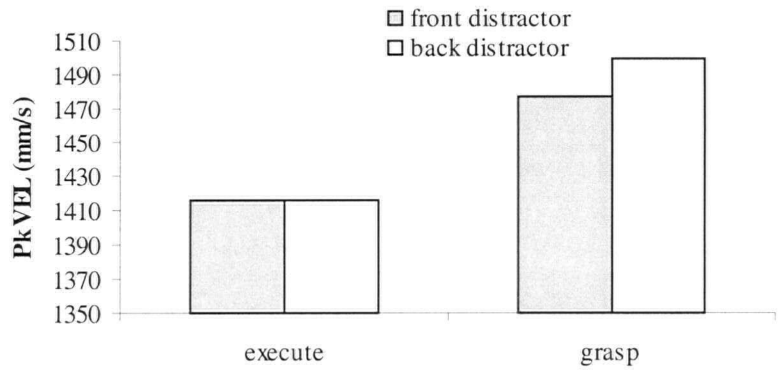

Figure E1.12. Peak velocity of movements executed in the presence of a distractor located in front of and beyond the target, under the two movement conditions.

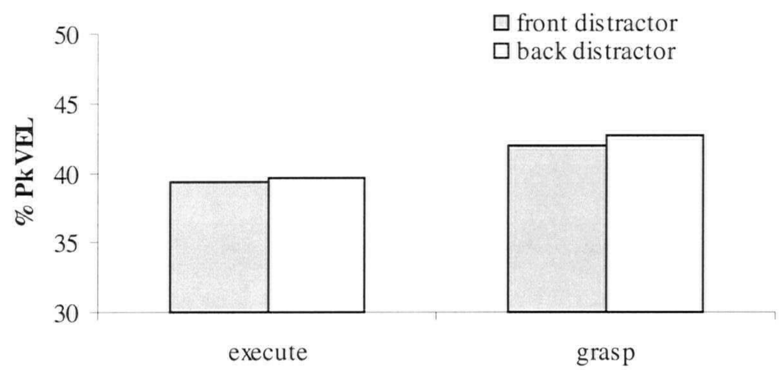

Figure E1.13. Percent time to peak velocity executed in the presence of a distractor located in front of and beyond the target, under the two movement conditions.

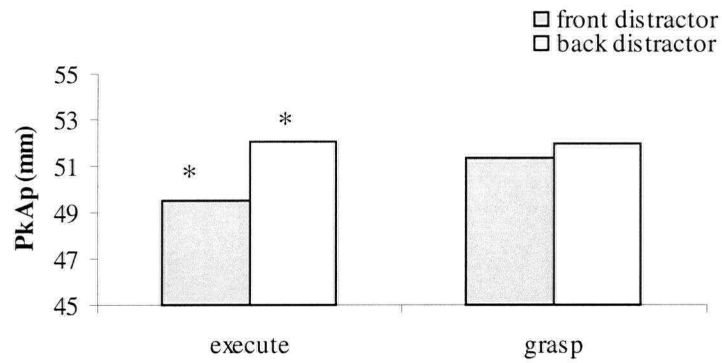

Figure E1.14. Peak aperture reached in the presence of a distractor located in front of and beyond the target, under the execute action and grasp movement conditions. (* $p < .01$)

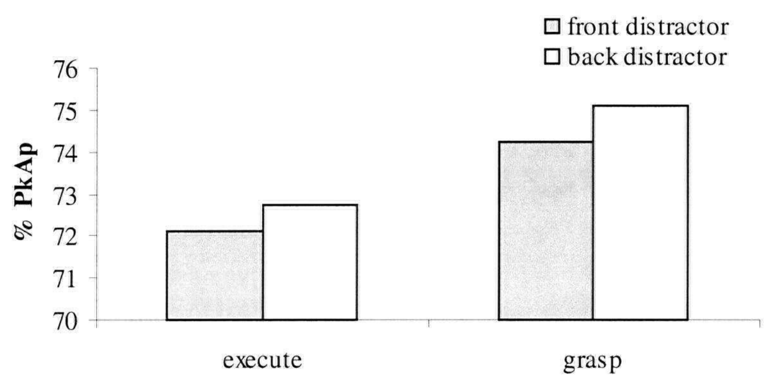

Figure E1.15. Percent time to peak aperture taken in the presence of a distractor located in front of and beyond the target, under the execute action and grasp movement conditions.

Kinematic Measures. Spatial location of the distractor did not influence the peak velocity of movements (F (1, 32) = 1.5, p = .24) (see Figure E1.13). Percent time to peak velocity was also unaffected (F (1, 32) = .78, p = .38) (see Figure E1.14 and Table E1.7).

There was a difference observed in the size of peak aperture produced by the participants during the front and back distractor trials (see Table E1.7). The presence of a distractor in the back row resulted in a larger peak aperture than a distractor in the front row (52.0 mm and 50.5 mm, respectively) (F (1, 32) = 7.4, p < .01) (see Figure E1.15). It appears that back row distractors may have had a greater influence on the size of aperture than front row distractors. The percentage of movement time taken to reach peak aperture was not affected by the location of the distractor (F (1, 32) = .80, p = .38) (see Figure E1.16).

Same vs. Different Action Requirements

Perhaps the most compelling question to be asked from this data concerns the examination of whether or not the action requirements of the objects has implications on the interference effect of the distractor objects. This question has not been addressed fully by previous research.

Performance Measures. Analyses failed to yield any significant results for the 3 performance measures (see Table E1.8). There was no difference in total time between trials in which the action requirements of the target and distractor objects were the same versus those in which the action requirements of the target and distractor were different (F (1, 32) = .41, p = .53) (see Figure E1.16). The same was true for reaction time (F (1, 32) = .02, p > .50) (see Figure E1.17), and for movement time (F (1, 32) = .002, p > .50)

Table E1.8.

Total time, reaction time, and movement time values for the distractor trials as a function of same and different action requirements for the target and distractor objects.

	Total Time (ms)		Reaction Time (ms)		Movement Time (ms)	
	Same D	Different D	Same D	Different D	Same D	Different D
Execute	878.0	874.9	266.0	268.2	590.7	591.3
	(90.3)	(75.7)	(53.4)	(38.4)	(63.1)	(66.2)
Grasp	798.1	793.0	252.0	249.9	534.5	534.2
	(85.9)	(90.4)	(60.9)	(51.4)	(65.8)	(65.6)

Note. Average within subject standard deviation is in the brackets

Table E1.9.

Peak Velocity and % Time to Peak Velocity for the distractor trials as a function of same and different action requirements for the target and distractor objects.

	Peak Velocity (mm/s)		% Time to Peak Velocity	
	Same	Different	Same	Different
Execute	1416.5 (132.0)	1415.2 (136.8)	39.5 (8.6)	39.4 (6.4)
Grasp	1488.8 (99.7)	1488.4 (99.6	42.7 (5.2)	41.9 (5.5)

Note. Average within subject standard deviation is in the brackets

Table E1.10.

Peak Aperture and % Time to Peak Aperture for the distractor trials as a function of same and different action requirements for the target and distractor objects.

	Peak Aperture (mm)		% Time to Peak Aperture	
	Same	Different	Same	Different
Execute	50.7 (4.8)	50.9 (5.0)	72.9 (7.9)	71.9 (9.5)
Grasp	51.6 (5.5)	51.8 (5.9)	74.3 (10.1)	75.0 (9.8)

Note. Average within subject standard deviation is in the brackets

(see Figure E1.18). Therefore, it appears that the action requirement of the objects did not affect the task of moving towards and acting on a target object. This in turn suggests that when representing a task space prior to and during a movement towards a target object, the action requirements of non-relevant objects within that space may not influence the distractor effect.

Kinematic Measures. Participants did not change their peak velocity or their percent time to peak velocity in order to deal with the distractor and target having the same or different action requirements (see Table E1.9). The action requirements of the objects within the visual array did not affect the participants' velocity profile towards the target (F (1, 32) = .01, $p > .50$) (see Figure E1.19). There was no difference between the percent time taken to reach peak velocity when the action requirements were the same or different (F (1, 32) = .0001, $p > .50$) (see Figure E1.20).

The grasping measures of the trials with the target and the distractor switches having similar versus different action requirements did not reveal any significant differences. There were no significant differences between the sizes of peak aperture during the two types of distractor trials (F (1, 32) = .20, $p = .66$) (see Figure E1.21). The switches having the same or different actions did not affect the percent of movement time it took for the participant to reach peak aperture (F (1, 32) = .51, $p = .48$). These findings indicate that the distractor and target action requirements did not affect the grasping kinematic variables differentially (see Table E1.10).

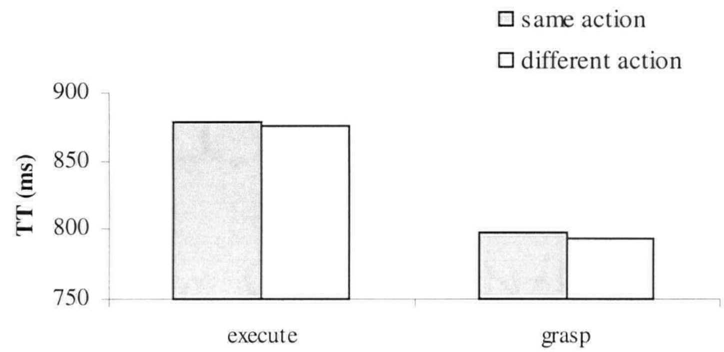

Figure E1.16. Total time of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

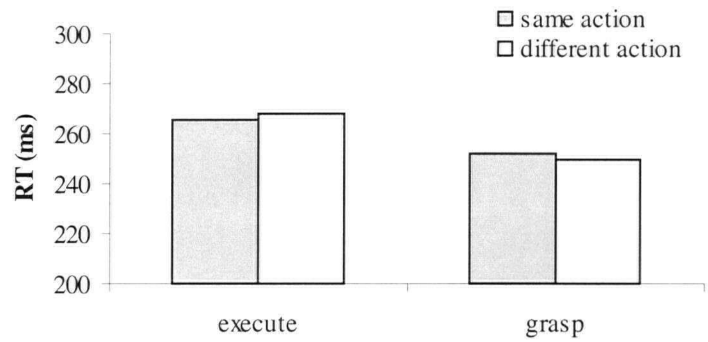

Figure E1.17. Reaction time of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

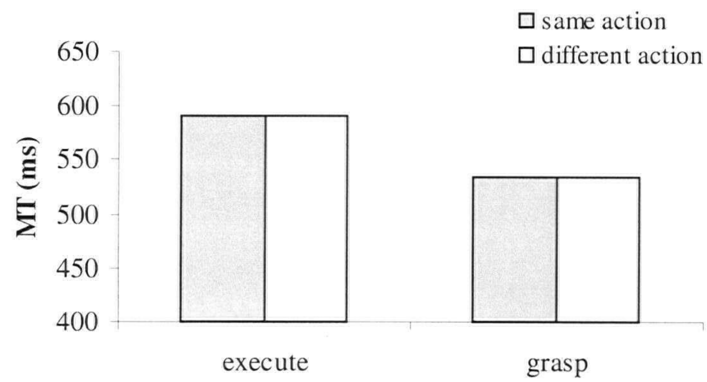

Figure E1.18. Movement time of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

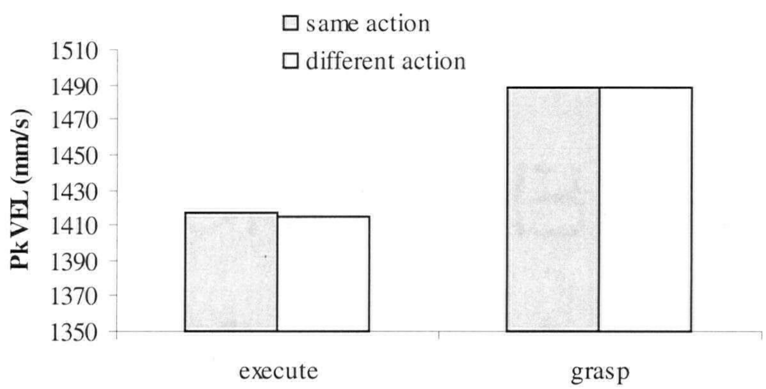

Figure E1.19. Peak velocity of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

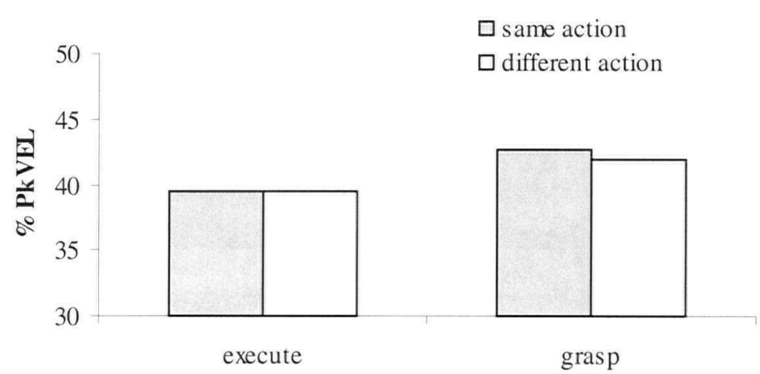

Figure E1.20. Percent time to peak velocity of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

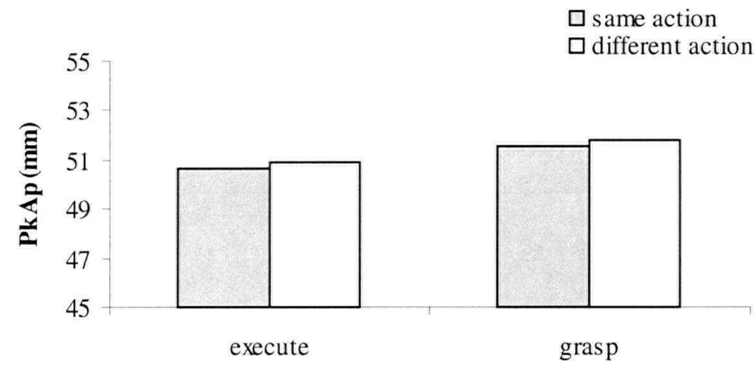

Figure E1.21. Peak aperture of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

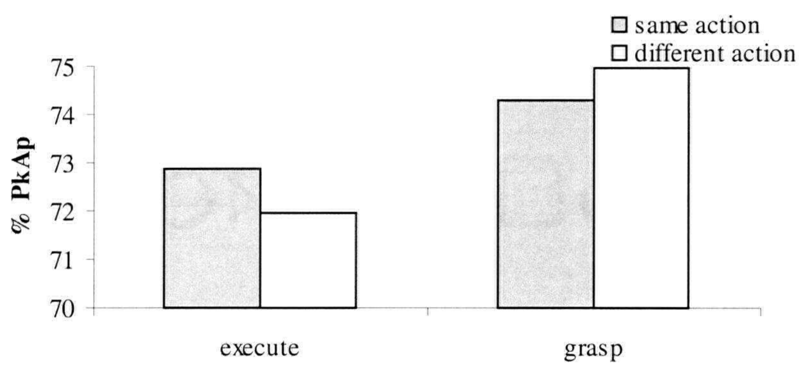

Figure E1.22. Percent time to peak aperture of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions.

Discussion

The purpose behind Experiment One was to examine whether the action requirements of target and distractor objects would have an impact on any interference effects on the movement that may arise due to the presence of a distractor. Based on the present results, it was difficult to determine if the action requirements had any influence because many of the distractor effects typically observed in experiments of this nature were not found. There are a number of reasons why this may have occurred due to the many methodological differences in the setup of this experiment from previous experiments. The absence of some of these effects may also be attributed to basic participant variability that could be attributed to the complexity of the task.

Contrary to expectations, whether participants were required to execute the terminal action of the object or simply to grasp the object had no influence on the time taken to select and prepare the movement. This is not consistent with findings of previous studies that have examined changes in reaction time, specifically increases in reaction time due to more complex/difficult movement conditions (Henry & Rogers, 1960). It has been demonstrated that when a movement is more complex, more movement planning time is required, resulting in an increase in reaction time. The present lack of a difference in the reaction time may be due to the variability that existed between and within the participants. Perhaps the repetitiveness of the task (140 trials per condition) resulted in the participants' automatic release of the start position prior to complete movement preparation. The participants did appear to have adopted different strategies, accounting for the variability, in order to accomplish the task as quickly and as accurately as possible. In Appendix C it appears that over the ten participants there was a great deal of variability, seen in the large between subject standard deviations for the performance measures. This variability is also seen within the participants as the within subject standard deviations (see Tables) are quite large. Some participants clearly demonstrated a difference between the conditions while others did not. It is apparent that some participants did not fully prepare their movements before leaving the start position.

Perhaps the effect of movement complexity on information processing was only apparent during the movement execution phase of the response. Some movement planning appears to have occurred during movement execution. The contribution of this increase in movement time accounts for the difference between the median total times of the movement conditions. This finding reveals that participants took time online during the transport phase of their movement to program the terminal action requirement of the target. This would account for the increase in time taken by the participants during the movement execution stage of the execute action condition.

Despite the differences in movement time there were no differences between the peak velocity and percent time to peak velocity when comparing trials from the grasp only condition and the execute action condition. This indicates that the velocity profile was not reorganized for the different movement conditions. It was expected that due to an increase in task requirements for the execute action condition peak velocity would have been slower and achieved earlier (Marteniuk et al., 1987). However, this was not seen in this experiment. Perhaps having to execute the action did not make the task more difficult but simply added a component. It appears that the online planning of the terminal action requirement of the target did not affect the velocity profile of the movement. Peak aperture and time to peak aperture were also not different for the two movement conditions. Whether or not the participant had to simply grasp the switch or execute the action had no affect on the size of the aperture of the hand. This does not follow previous research that has examined complexity of movements and how this affects the grasp (Wing et al., 1986). It appears that the size of the aperture was influenced only by the size of the object and since the switches were always the same diameter no differences in peak aperture occurred. The lack of a difference over all dependent measures when comparing the two movement conditions suggests that the difficulty of the execute action condition is questionable. Participants maintained a similar confidence in their movements during the execute action condition and the grasp condition.

Previous research has demonstrated that reaction time, movement time, and total time are typically longer for movements executed in the presence of distractors (Pratt & Abrams, 1994; Tipper et al, 1992). In contrast, the present results failed to reveal any distractor effects for these performance measures. The present findings are thus inconsistent with previous research that has found an interference effect due to the presence of a distractor object (Pratt & Abrams, 1994; Tipper et al, 1992). However, there have also been a number of studies that have had difficulty replicating a strong distractor effect (Castiello 1996, 1998; Gangitano, Daprati, & Gentilucci, 1998; Kritikos et al., 2000; Lyons et al., 1999).

The presence of a distractor had no impact on the velocity profiles of movements, regardless of whether or not participants were required to engage the target object. This finding is consistent with other studies (Kritikos et al., 2000; Lyons et al., 1999). Both peak velocity and percent time to peak velocity were also unaffected by the spatial location of the distractor in relation to the target. There have been studies that have shown that peak velocity is affected by the presence of a distractor; however, this effect has not always been mediated by the position of the distractor (Jackson, Jackson & Rosicky., 1995).

The absence of distractor interference effects is somewhat surprising. However, it is possible that this may have been due to a combination of the experimental design and potential performance strategies adopted by participants. In the present experiment, trials in which a distractor was present were intermixed with trials in which there were no distractors. Further, there were far less no distractor trials in relation to the distractor present trials (28 no distractor compared to 112 distractor trials per condition– only 25 % of the trials were no distractor trials). Because of the infrequent presentation of no distractor trials, it is possible that participants could have adopted a strategy in which they always prepared for the more difficult situation – a trial in which they would have to distinguish between a target and distractor. As such, on trials in which no distractor was present, participants could have taken additional time to confirm the absence of a distractor. This type of performance strategy has been proposed previously (Chua & Weeks, 2000).

In order to provide some support for the performance strategy proposed above, four of the original ten participants were brought back to the same experimental setup and tested with two blocks of no distractor trials only. The participants performed 40 trials in each movement condition (i.e., execute action, grasp). The position and action requirement of the target objects was varied over the 40 trials. The movement conditions were presented to the participants in the same order that they were originally presented.

The performance results were then compared to the no distractor trials from the original experiment.

Averaged over the performance measures for the four participants a difference was observed between the no distractor trials that were interspersed between many distractor trials compared with the no distractor only trials. Specifically, reaction time and movement time were shorter when participants performed a block of no distractor trials only. It is difficult to directly compare these no distractor trials to those performed by the participant's experimental sessions weeks prior; however, this may indicate that it was a limitation of our design that a stronger distractor effect was not seen. Perhaps it was necessary to increase the ratio of no distractor and distractor trials in order to achieve a robust distractor effect. It would have been beneficial to include a block of no distractor only trials to the block of randomized trials. This methodological change was implemented in Experiment Two. Previous studies have always combined no distractor trials with distractor trials. Including a block of no distractor trials only has not been implemented in previous studies.

Another factor that could have possibly resulted in the absence of robust distractor effects is the experimental task itself. Perhaps the complexity of the action requirement of the task changed the dynamic of the situation, and the interference effect was somehow lost or masked by the complexity of the task. The task had not only the involvement of the locations of the objects but also the action requirements of the objects. Because the task was quite different from previous tasks used in previous studies it could be that a comparison between them in terms of distractor effects is no longer valid. This explanation could make sense in the context of the results of this experiment, as there were differences between the movement times for the two movement conditions. However, because there were no effects seen in reaction time, the implications of complexity affecting selection are questionable. These findings suggest that the participants did not find it more difficult to select the target for action execution compared to selecting the target for grasping. If complexity did not enter as an influence on this experiment, then this explanation does not hold. In past experiments simple grasping tasks have been shown to demonstrate distractor effects (Gangitano 1998; Kritikos et al. 2000; Tipper et al., 1997).

In addition to the absence of distractor effects in general, the spatial position of distractors with respect to the target also had no impact. The distractor location effect is the basis of the action-centered attention model. The model suggests that irrelevant objects closer to the hand cause more interference to the task than those objects located farther from the hand (Tipper et al., 1992). The lack of interference due to distractor location could be due to the fact that the distractor object location was not illuminated while the target object location was. The salience of the illuminated target object was much greater than the distractor object, which simply appeared as a switch at the various locations. It may be inferred from the lack of a distractor effect that little attention was given to the distractor object. The normal interference effect was diminished and thus not observed, not only between the no distractor trials but also between the distractors at different locations.

In past experiments the distractor was similar to the target object in terms of salience. Usually, the distractor was identical to the target except for the modification of one feature such as colour or shape. Perhaps, in order to get a stronger distractor effect it would have been beneficial to illuminate the distractor with a different colour to increase the attention given to the distractor. It is possible that the modification that was made to our apparatus, of not emphasizing the distractor, changed too many factors from previous experiments to make them comparable. The distractor in this experiment was not illuminated because it was thought that it was not necessary to do so in order to represent to the participant that the switch required a certain terminal action. It was assumed that the location of the distractor did not have to be emphasized in order for it to be represented or processed by the participants. It is interesting to note that in work done by Castiello (1996; 1999) it was necessary to increase the attention given to distractors in order to produce a distractor effect. He utilized spotlights and secondary tasks to ensure that participants were attending not only to the target but also to the distractor objects. It has been shown that there is a greater level of neural activity with a more salient stimulus. An increase in neural activity is associated with the attention given to an object (Georgopoulos, 1990).

There was a distractor effect found within the execute action movement condition. Within the execute action movement condition the no distractor trials resulted in the participants producing a larger peak aperture than during the distractor trials. The implications of this result are unclear. It could be expected that the distractor trials, being the more complex, would result in a larger peak aperture. However, perhaps the added constraints of the execute action condition required an increased level of concentration. This level of concentration could result in the participants more closely monitoring the shape of their hand and therefore, results in a smaller, more precise grasp aperture than the less demanding task of reaching and grasping the switch. In the past, the presence of a distractor has been shown to have an impact on the peak aperture reached during a movement towards a target of a different size. Kritikos et al. (2000) found that peak aperture was larger in the presence of a distractor of a larger size than the target. However, Jackson et al., (1995) found that no distractor trials resulted in participants producing a larger peak aperture than distractor trials. It seems that differing results have appeared in the literature concerning how people grasp an object in the presence of a distractor object.

When distractors appeared in the back row, participants utilized a larger peak aperture than when distractors appeared in the front row. A larger peak aperture could be indicative of the participants overcompensating for the difficulty experienced during back distractor trials compared with front distractor trials. It is unclear why a back distractor would constitute a more difficult situation when reaching to the middle target. In this experiment it appears that back row distractors could be having a greater influence on the size of aperture than front row distractors. The comparison of the percent times to peak aperture revealed no differences between the time taken by the participants to reach peak aperture for distractor and no distractor trials. Previously it has been found that peak aperture was reached later on in the movement when a distractor was present (Jackson et al., 1995).

There were no differences in the performance measures in the trials in which the distractor objects had either the same or different action requirements to the target. It is difficult to conclude that the action requirements of the objects had no mediating influence on distractor effects due to the absence of a distractor effect itself. However, because there was no trend toward any significant difference it can be inferred that the action requirement had little affect on the distraction of the irrelevant switch. This in turn could suggest that when we are representing a task space prior to and during a movement towards a target object we do not code the terminal action of any non-relevant objects within that space. Therefore, from the present data, it appears that the action requirements of a distractor object may not be a factor in determining the degree of interference that the object could induce. More research is required in order to generalize this finding for different tasks and different task environments.

The action requirements of the objects within the visual array did not affect the participants' velocity profile towards the target. Grasp measures were also not seen to be different whether or not the action requirements of the distractor were the same or different. These patterns occurred within and over both movement conditions. It would be expected that if the differing action requirements of the objects had any influence on the task, than a change in speed and the grasp measures with which the participant approached the target would have been seen (Jervis et al., 1999; Kritikos et al., 2000; Tucker & Ellis, 1998). This provides further evidence that the action requirements of the target and distractor, being different or the same, did not affect the task and provided little effect on the interfering nature of the distractor on the movement itself.

Overall, it appears that the typical distractor effects were not observed in Experiment One (cf. Pratt & Abrams, 1994; Tipper et al., 1992). As discussed above, this could have been due to a number of factors, namely that this experiment is a variation of previous selective attention experiments, and the adjustments made to this experiment appear to have changed the task in such a way as to decrease the strength of the distractors influence on the task. The distractor object appeared to only influence the peak aperture. The way in which the peak aperture was affected by the distractors presence and location was atypical to that seen in previous experiments. Therefore, the present task itself must have resulted in the participants dealing with the distractor differently than that in previous experiments.

It is apparent that participants developed different strategies resulting in a great deal of variability within the data. Some participants demonstrated the typical distractor effects while others failed to show any effect from the distractor trials at all. The various strategies could have had a large impact on the significant findings of this experiment.

From past action-centered attention research, no distractor trials took less time for performance values compared with the distractor trials (Pratt & Abrams, 1994; Tipper et al., 1992). However, based on some of our past work utilizing the distractor paradigm, this "classic" distractor effect is in fact not as persistent as once thought. The tasks that have failed to produce this interference effect tend to be more complex than the early tasks utilized by Tipper et al. (1992). Some of the task complexities involved have required participants to perform visual/manipulation translations in order to accomplish the task (Lyons et al., 1999). The introduction of more demanding manipulation tasks has also resulted in findings that do not always comply with the interference effects seen in the simpler pointing studies (Castiello, 1996, 1999; Chua & Weeks, 2000; Ibbotson, Chua and Weeks, 2000; Ibbotson, Bredin, Chua, & Weeks, 2001; Kritikos et al., 2000). Perhaps the action-centered model of attention is only valid for very simple tasks. Our studies may be of use in extending this model of selective attention further beyond the simple laboratory experiments used previously.

Based on the possible factors influencing the results of Experiment One, modifications were made to Experiment Two. For example, the number of no distractor trials was increased in order to make them less frequent in relation to the distractor trials. These adjustments were done in an effort to determine what was occurring during the selective attention task of reaching, grasping and executing an action on a target. In Experiment Two the target was not designated by location. This was done to help alleviate any differences between the salience of the target and distractor objects (e.g., differences in illumination). Both the target and distractor objects were placed in front of the participant, with the target being distinguished by the stimulus provided at the onset of the trial. The stimulus was either auditory or visual in nature. Experiment Two was expected to help in distinguishing whether or not the action requirements of the distractor in relation to the action requirements of the target have an influence on performance and/or kinematic variables.

EXPERIMENT TWO:

Using The Goal of the Task to Designate the Target From the Distractor

In order to understand how objects with varying characteristics are related when appearing simultaneously within an environment it is important to understand how we are able to represent object features (i.e., action requirements). Hommel (1997) addressed the question of how actions are coded and dealt with cognitively. He introduced the idea of action concept codes that are made up of several effect codes. These effect codes arise from both sensory and motor events. Effect codes represent the sensory information coming in regarding the environment of interest. These effect codes provide much needed information about the features of the objects and the surroundings of the object; which is necessary for the planning of the movement. The effect codes also represent the motor responses that are necessary to carry out the task for accomplishment of the goal. Thus, the effect codes are both the incoming and outgoing information necessary for interacting in a complex environment. Hommel (1997) emphasized that sensory and motor information are essentially the same type of code working together to choose and execute the correct response. Another important portion of the effect code is dependent upon the specific intention of the person carrying out the task. The movement plus the end goal make up the action.

A mixture of these effect codes makes up an action concept code. These action concept codes are affected by the intention of the action and control both perception and action when carrying out a task. The intention of the action changes the goal of the action. It can then be said that the action concept codes includes the sensory and motor events as well as the end goal of the action. Action effects that are irrelevant can also be coded as a concept code and this has implications on response selection. During response selection it is imperative that the correct action concept code is chosen in order for the end goal to be accomplished. Not only the response but also the stimulus response compatibility are changed depending on the intention of the person carrying out the task (Hommel, 1997). Thus, the correct response for a task can only be accessed by the appropriate action concept that is made up of the effect codes of both the stimulus and response.

Experiment Two was intended to reveal how selective attention is affected by the manipulation of the action properties of the target and distractor objects involved in the task. Further, how does the end goal of the action requirements of the objects affect the relation between the target and distractor? Is the action concept code for the target affected by the effect code of an irrelevant distractor switch?

This experiment extends the work of other distractor studies that have examined how the object features of the target and the distractor influence selective attention. Many studies have found that intrinsic and extrinsic features of irrelevant objects do influence a movement to a target object. Object size as well as the semantic relation between the target and distractor object have been explored (Kritikos et al., 2000; Jervis et al., 1999). These object features have been shown to influence some but not all aspects of the movement towards a target. Weir et al. (submitted) found interference to the movement when the target and distractor object had different versus the same action requirements. In Experiment One there were no differences seen between the trials in which the action properties of the target and the distractor were either the same or different. It is still unknown exactly how or why object features influence the movement planning and execution. Specifically there have been differing results regarding the relation between the target and distractor object.

It was of interest to emphasize the end goal of the task in Experiment Two in order to further exploit the relation between the target and distractor objects. In Experiment Two the objects had either the same or different action requirements both resulting in DIFFERENT end goals. The end goal of the task was the factor that designated the target from the distractor object to the participant.

It was also of interest to determine whether or not different results arose between the reaching and grasping conditions of Experiment Two versus Experiment One. The primary difference between these experiments was how the target was specified. For the second experiment the end goal of the task defined the target while the location defined the target for the first experiment. Emphasizing the end goal of the task without requiring the action to be carried out, such as in the reaching and grasping condition of Experiment Two, may result in a similar level of interference to the execute action condition in which the distractor and target have the same action requirements. This was a different hypothesis then was predicted for Experiment One.

Hypothesis

It is unclear if there will be any differences between the reach and grasp and the execute action conditions in Experiment Two. Because the task necessitates that the end goal be determined in order to identify the target the differences between the two conditions may disappear. This is a different hypothesis from that of Experiment One. For Experiment Two it was hypothesized that when there are no distractors the reaction time and movement time would be faster than when distractors are present. It was hypothesized that when the target and distractor had the same action requirements but different end goals the interference to the task, seen in both temporal and kinematic measures, would be greater than when the target and distractor had different actions and different end goals. It was hypothesized that by making the end goal of the task prevalent the interference due to a distractor object having similar action requirements to the target would increase compared to a condition in which the end goal was not emphasized, as in Experiment One.

Methods

Participants

The participants were ten right-handed undergraduate and graduate students from a university population. This sample size was selected based on previous studies of this nature that have found ten participants to be a large enough sample to provide a significant finding. The participants took part in the approximately two and a half hour study that was set up in the Perceptual Motor Dynamics Laboratory located in the School of Human Kinetics at the University of British Columbia. There were two sessions that were carried out in the same day with no more than three hours separating them for any given participant. Each participant was made aware of the risks that may occur during the duration of the experiment and an informed consent agreement was signed. A fifteen-dollar remuneration was provided to the participants.

Apparatus

The apparatus consisted of a box-like task space in which the target and distractor switches were located, either left or right to the participant. The box containing the switches was placed on a table surface at which the participants were seated. The box contained two locations where the switches were placed and changed over the trials to accomplish the many target and distractor combinations for each condition. The four possible switches used were conventional light and volume switches. The light switches used were a rotary dimmer switch and a slider dimmer switch. The auditory switches were a rotary volume switch, similar to that used on a radio, and a slider volume switch, analogous to the older volume switches found on stereos or a present day equalizer control. A small light bulb and a buzzer were placed central to the presentation of the switches in front of the participant. The light bulb and buzzer were the stimuli that dictated to the participants which switch was the target. The target was the switch, that when activated, would cause the dimming of the stimulus. If the light bulb were illuminated at the beginning of the trial it would signal that the end goal was to dim the light. Thus the participant would have to select the light-dimming switch from the two choices that were presented when their glasses changed from opaque to clear. If a sound was heard at the onset of the trial it was a signal that the volume switch was to be selected to accomplish the end goal of decrease the loudness of the stimulus.

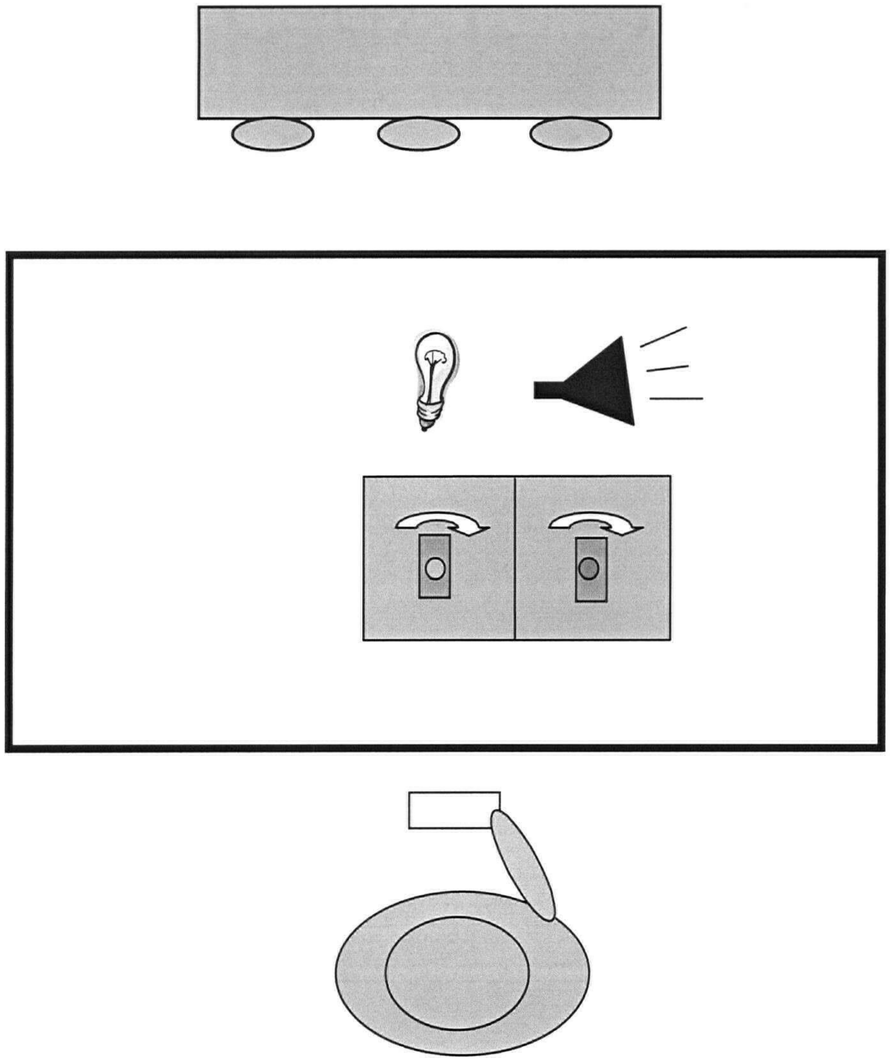

Figure E2.1. The task setup for Experiment Two in the same action configuration. The light bulb and music represent the two possible stimuli used to indicate the target.

The participants wore liquid crystal eye goggles (Milgram, 1987) to ensure that they did not view the task space prior to the beginning of the trial. The participants cue to begin the task occurred when the goggles become transparent and the stimulus was seen or heard simultaneously with the availability of vision of the task space.

To accurately monitor the kinematics of the participants' movements an OPTOTRAK ™ (Northern Digital Inc.) 3-D motion analysis system was used. The cameras monitored the movement of three infrared light emitting diodes (IREDs) placed on the right hand of the participant at the index finger (left, lower corner of the nail), thumb (right, lower corner of the nail) and wrist (styloid process of the radius of the right arm). Gathering movement data from these three points allowed the calculation of kinematic values that provide information on the spatial path of the fingers throughout the task as well as the magnitude of the speed of the hand as it moved from the start position to the target object. The OPTOTRAK ™ collected the IRED data at a frame rate of 400 Hz. The ODAU ™ was used to monitor the voltage changes at the rotary and slider switches as well as the start switch at a sampling rate of 1000 Hz. This voltage data was then linked to the OPTOTRAK ™ data for analysis.

Task and Procedure

There were two end goals that were used throughout the experiment. The goal was either to dim a light or turn down the volume of an auditory stimulus. These task goals were modeled after everyday tasks that humans perform. Manipulating a light source was thought to be similar to dimming or illuminating a light within a room. In our setup the light was dimmed by the activation of either a rotary dial or a slider switch. Both of these switches are commonly used in rooms found in both a home or work environment. The second task goal used in this experiment was modeled after the common task of adjusting the volume of the sound emanating from a radio. Similar switches, a rotary dial and a slider switch, were used to adjust the auditory stimulus when presented to the participant. Choosing these switches and these end goals was done in an effort to ensure that the participants would be somewhat familiar with the given tasks and the actions and end goals that accompany them.

The participants were presented with either a light or auditory stimulus and their task was to select the appropriate switch in order to turn down the stimulus and achieve the end goal. The distractor switch when activated would result in the wrong end goal being achieved by either the same or different action as the target. Using distractors of the same or different action requirement was done to see if the action requirements of the objects interfered more or less when the two objects presented visually had different end goals. It was thought that how the participants perceived the end goal would affect how they code the action requirements of the objects and the end goal.

There were two different conditions each containing two blocks of trials. The two conditions were randomized and counter balanced across the ten participants. In each condition there was a block of trials in which no distractors were present. During these shorter blocks of trials (40 trials each) the four possible target switches appeared by themselves providing a control condition to which the other conditions could be compared. The longer blocks of trials (120 trials each) had each of the four target switches appear at both the left and right positions in the presence of a distractor switch that had the same or different action requirement as the target but resulted in a different end goal. One of the conditions required the participants to simply reach and grasp the switch that would achieve the end goal while the other condition had the participants carry out the action requirement of the target in order to achieve the goal of turning down the stimulus.

The reaching and grasping block of trials allowed the experimenter to remove the action requirements of the switches from the task. It was thought that this condition would provide a contrast to the action task trials in which the action requirements of the target and distractor were most likely to be relevant to the task and thus impact on selective attention. By counterbalancing the participant's order of the conditions the salience of the action requirements of the objects was expected to be different. Those participants that carried out the action block of trials first were expected to have a firm knowledge of the switches respective actions and thus were expected to demonstrate the effect of the action requirements on the reaching and grasping task that followed. The greater effect was expected even though the actions of the objects were not being carried out in the reaching and grasping condition. It was expected that the distractor object would still affect the participant spatially as well as due to their action requirements similarity to the target object. Those participants with little to no experience with the switches during the reach and grasp condition were expected to have little interference due to the action requirements of the distractors but were still expected to show spatial distractor effects. The spatial distractor effects are seen in terms of deviations occurring in the spatial path of the movement either away or towards the distractor en route to the target object.

Participants were instructed to keep their hands at the start location until vision was made available by the goggles changing from opaque to transparent and until they had heard or seen the stimulus indicating the end goal of the task. Once the hand was properly located at the start position the warning tone was sounded. This tone was to let the participant know that, within 1-3 seconds, the target would appear. On some trials, only the target switch would appear. On other trials another switch would also appear. The participant had to prepare and execute their movement as quickly and as accurately as possible to the target switch corresponding with the action appropriate to change the light or auditory stimulus while ignoring the other switch, if present. After the movement was ended, the participants remained at the target until the computer produced a second tone. The participant moved their hand back to the starting position and prepared for the next trial following the second tone. It was emphasized that the goal of the task was to prepare and execute their movement as quickly and as accurately to the target switch as possible while ignoring any other inappropriate switches. The standardized task instructions were repeated at the beginning of all blocks of trials.

Experimental Design

The experiment was made up of two sessions, one with the task of reaching and grasping the target switch and one with the task of carrying out the action requirements of the target switch. Each condition was made up of two blocks of trials. The first block of trials contained 120 trials, in which distractor and no distractor trials were randomized throughout, with 5 trials for each distractor combination for each target location, (details are provided in Appendix D). The second, shorter, block of trials contained 40 no distractor trials. These blocks were used as baseline measures for a no distractor situation. Overall the experiment was made up of 320 trials for each participant. The independent measures of this experiment were the presence and location of the target and distractor objects, the stimulus indicating the end goal of the task, as well as the manipulation of the target and distractor objects terminal action requirements.

Data Analysis

The data were analyzed by looking at a number of dependent measures. Performance measures (reaction time (RT), movement time (MT), making up total time (TT) were determined. Reaction time and movement time were calculated using the velocity of the wrist IRED to define the start point and the end point of the movement.

Kinematic data were analyzed in a similar manner to that explained in Experiment One. The onset of the movement was taken as the point where the wrist moved at a velocity of 10 mm/sec. The end point of the movement was at the point where the wrist slowed to 50 mm/sec and stayed there for 25 msec. This strict end point criterion was necessary to determine the point at which the target was acquired by the participant, not the point at which the switch was completely activated. That would not have been a valid end of movement to the target. The median performance and velocity data were analyzed using a number of planned comparisons. The planned comparisons were performed using an alpha level of $\underline{p} < .05$.

Directly looking at the spatial paths of the movement has been found to be beneficial in revealing how the participant deals with changing conditions. The comparison of the spatial paths of reaches to different targets in the presence of distractors of the same or different action requirements was of interest. Distractor trials were compared with the spatial paths of the no distractor trials. These comparisons provided a way to quantify interference directly from the reach through space. If interference were occurring from an irrelevant object, differences would emerge between the spatial paths.

Spatial paths were analyzed using custom written software allowing the viewing of each displacement profile. An ideal straight-line equation was calculated for each trial using the specific movement initiation and movement end frame from the previous kinematic analysis. This straight-line equation was compared with the actual movement path at each frame and was used to calculate a maximum and minimum normal deviation. A negative distance represented a deviation of the wrist to the right of the straight path to the target. A positive distance was a leftward deviation from the straight line. These values were used to see if there were differences between the paths of the wrist during the different trial combinations on an individual participant basis. The deviation distances were averaged over the five trials that had a similar target and distractor combination for each condition. They were then normalized using the similar target and distractor combination values for the no distractor (block) trials. The no distractor (block) trials were treated as baseline measures for a normal reach to the target locations and thus were subtracted from the randomized trials in order to see if deviations occurred when the presence of a distractor object was a possibility. These mean normalized values were analyzed over the ten participants to see if differences emerged over the various target and distractor combinations.

The spatial deviations were analyzed similarly to the performance and velocity measures. They were compared using planned orthogonal comparisons to see if differences occurred in the specific comparisons of interest.

Results

The medians for each of the performance and kinematic measures were derived from the factorial combination of the experimental conditions.

Reach and Grasp vs. Execute Action

Performance Measures. Were there differences between the performance measures for the grasp only versus the execute action movement conditions? Overall, it was expected that there would be no differences in terms of the performance measures, specifically reaction time between the two movement conditions. Similar reaction time values were expected for the execute action and grasp conditions. Despite the fact that the grasp only task required a more simple motor response to that of the execute action task similar reaction times were expected. This is due to the need in both conditions to identify the end goal of the task and thus the action properties of the switch itself before selection could take place.

There were no differences for the two movement conditions in terms of total time. Overall, participants took the same amount of time to prepare and execute their movements to the target during both the grasp and the execute movement conditions (F (1, 9) = 2.1, p = .18). These results are displayed in Table E2.1.

There were no differences in terms of the reaction time taken by the participants during the two movement conditions (F (1, 9) = .01, p > .50) (see Table E2.1). This lack

Table E2.1.

Total time, reaction time, and movement time as a function of movement condition.

	Total Time (ms)	Reaction Time (ms)	Movement Time (ms)
Execute	942.9 (93.9)	358.4 (73.5)	*578.4 (57.5)
Grasp	909.2 (89.7)	359.8 (75.0)	*547.6 (46.6)

Note. Average within subject standard deviation is in the brackets.

Table E2.2.

Peak Velocity and % Time to Peak Velocity as a function of movement condition.

	Peak Velocity (mm/ms)	% Time to Peak Velocity
Execute	955.9 (68.8)	51.2 (4.8)
Grasp	983.3 (76.9)	51.5 (4.2)

Note. Average within subject standard deviation is in the brackets.

of a significant difference indicates that participants took the same amount of time from stimulus onset to movement initiation during all trials of the experiment regardless of the action component required for task completion. It took participants the same amount of time over all trials to select and prepare their movements. This finding follows the prediction that reaction time would not be different over the two conditions. The process of selecting a target based on the stimulus characteristics resulted in similar response selection over the grasp and execute condition.

Movement time was different for the two movement conditions ($F(1, 9) = 5.46$, $p = .044$). It took participants longer to move to the target during the execute movement condition (578.4 ms) compared to the grasp only condition (547.6 ms). This finding would suggest that participants planned the terminal action required by the target switch online. It appears that the selection and transport portions of the response were planned before movement initiation. For the execute action condition it appears that the target action was processed during transport. This online processing manifested itself as an increase in time taken to reach the target during the execute action movement condition compared to the grasp only condition.

Kinematic Measures. It was of interest to establish whether or not there were differences between the peak velocity (PkVel) and percent time to peak velocity (%TPkVel) for the grasp only condition compared to the execute action condition. It was found that there were no differences between PkVel ($F(1, 9) = .98$, $p = .35$) and the %TPkVel ($F(1, 9) = .12$, $p < .50$) between the two movement conditions. The values for these comparisons are found in Table E2.2

Distractor vs. No Distractor

Performance Measures. The differences between the performance measures during the various types of distractor trials were examined. It was important to establish whether or not there were any differences between the performance values for no distractor trials (random) compared to distractor trials. Significant differences were found for all performance measures between no distractor and distractor trials.

Participants took a greater overall time when preparing and executing their movements when a distractor was present (975.0 ms) compared to when there was no distractor (923.2 ms) (F (1, 27) = 21.7, $p < .010$) (see Table E2.3). This difference was significant for both reaction time (F (1, 27) = 7.9, $p < .010$) and movement time (F (1, 27) = 6.8, $p = .015$) (see Table E2.4, E2.5). The presence of a distractor switch resulted in the participants taking longer to prepare and execute their movements over both movement conditions (see Figure E2.2, E2.3. E2.4)

Kinematic Measures. Was there a difference between the velocity profiles of the no distractor (random) compared to distractor trials? There were no differences between the peak velocities reached during the no distractor (random) trials and the distractor trials (F (1, 27) = 1.8, $p = .20$) (see Table E2.6). The participants did not appear to decrease their peak velocity when another potential object for action was within the visual field (see Figure E2.5). However, there were some modifications to the velocity profile that occurred when a distractor object was present (see Figure E2.6).

When comparing the %TpkVel, a significant difference was found between the no distractor versus distractor trials. It took participants a greater proportion of movement

Table E2.3

Total time for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	Total Time (ms)		
	no distractor (block)	no distractor (random)	distractor
Execute	*846.4 (80.4)	*938.8 (89.1)	*993.3 (103.0)
Grasp	*815.9 (70.1)	*907.8 (90.6)	*956.7 (99.2)

Note. Average within subject standard deviation is in the brackets

*$p < .01$

Table E2.4

Reaction times for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	Reaction Time (ms)		
	no distractor (block)	no distractor (random)	distractor
Execute	*287.2 (62.5)	*362.6 (70.8)	*392.0 (80.4)
Grasp	*295.3 (62.9)	*357.3 (75.1)	*393.4 (81.0)

Note. Average within subject standard deviation is in the brackets

* $p < .01$

Table E2.5

Movement times for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	Movement Time (ms)		
	no distractor (block)	no distractor (random)	distractor
Execute	*560.3 (49.2)	*569.8 (50.1)	*591.6 (65.4)
Grasp	*521.1 (38.6)	*545.1 (44.3)	*532.1 (51.7)

Note. Average within subject standard deviation is in the brackets

* $p < .05$

Table E2.6

Peak Velocity for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	Peak Velocity (mm/ms)		
	no distractor (block)	no distractor (random)	distractor
Execute	*992.8 (53.3)	*956.7 (62.9)	937.2 (79.5)
Grasp	*1033.4 (66.2)	*979.6 (78.1)	960.1 (81.7)

Note. Average within subject standard deviation is in the brackets

* $p < .05$

Table E2.7

Percent time to Peak Velocity for movements executed in the presence or absence of a distractor under the execute action and grasp movement conditions.

	% Time to Peak Velocity		
	no distractor (block)	no distractor (random)	distractor
Execute	50.3 (4.5)	51.0 (4.2)	51.8 (5.3)
Grasp	51.3 (3.8)	51.1 (4.0)	51.9 (4.5)

Note. Average within subject standard deviation is in the brackets

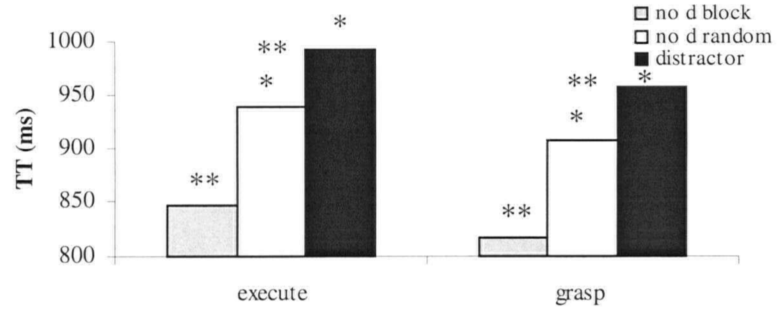

Figure E2.2. Total time for movements executed in the presence of a distractor or the absence of a distractor (blocked and random) under the execute action and grasp movement conditions. * $p < .01$

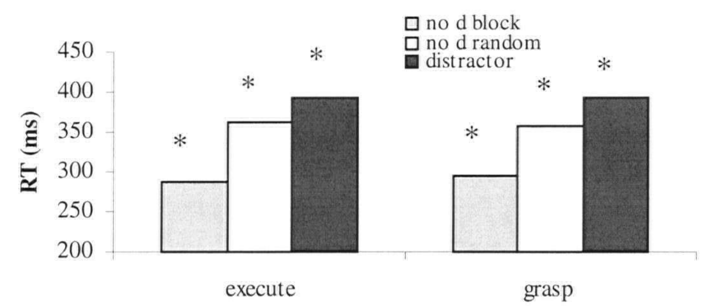

Figure E2.3. Reaction time for movements executed in the presence of a distractor or the absence of a distractor (blocked and random) under the execute action and grasp movement conditions.* $p < .01$

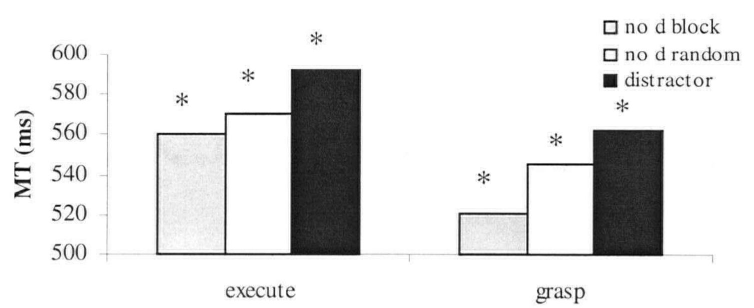

Figure E2.4. Movement time for movements executed in the presence of a distractor or the absence of a distractor (blocked and random) under the execute action and grasp movement conditions. * $p < .05$

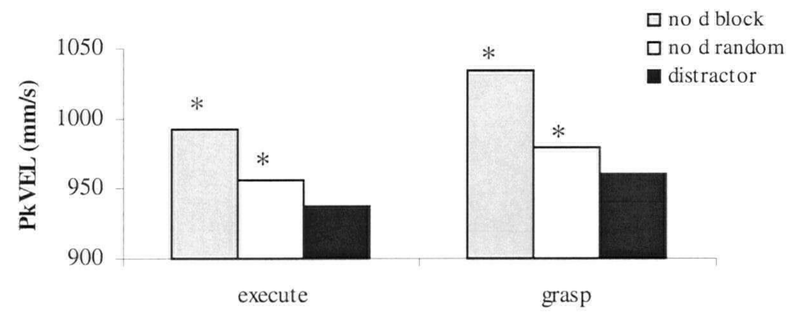

Figure E2.5. Peak velocity for movements executed in the presence of a distractor or the absence of a distractor (blocked and random) under the execute action and grasp movement conditions. * $p < .05$

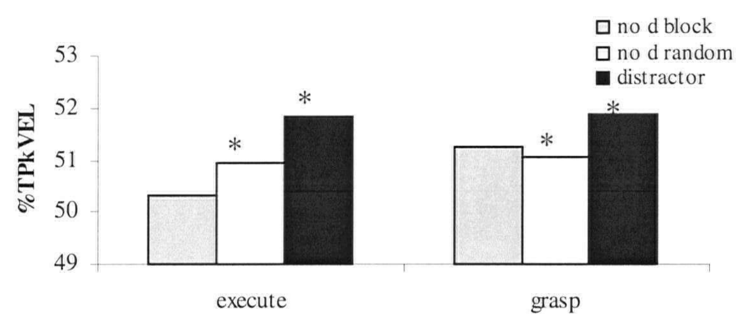

Figure E2.6. Percent time to peak velocity for movements executed in the presence of a distractor or the absence of a distractor (blocked and random) under the execute action and grasp movement conditions. * $p < .05$

time to reach peak velocity when a distractor switch was present (F (1, 27) = 6.8, p = .010) (see Table E2.7).

Left Target vs. Right Target

Performance Measures. Were there any performance differences between reaches to either the left or right targets? There was no significant difference between the total times taken to reach a left target compared to a right target (F (1, 9) = .41, p > .50) (see Figure E2.7). However, there was a difference between the reaction times of the left versus the right target movements (see Figure E2.8). It took participants longer to prepare the movement towards a right target compared to a left target (F (1, 9) = 5.3, p = .046) (see Table E2.8). There was no difference seen in the amount of time taken to execute a movement towards a left target compared to a right target (F (1, 9) = 4.5, p = .064) (see Figure E2.9).

Kinematic Measures. There was a significant difference in the magnitude of peak velocity between reaches to the left and the right targets (F (1, 9) = 26.2, p < .01) (see Table E2.9). Participants reached a greater velocity during the reaches to the right target compared to reaches to the left target (see Figure E2.10).

The percent time to peak velocity was also different between the reaches to the left and right target (see Figure E2.11). Participants took a smaller percentage of movement time to reach peak velocity when reaching to the right target compared to the left target (F (1, 9) = 6.0, p = .036) (see Table E2.9). Thus, participants took a longer time in the deceleration phase of the movement when they were reaching for the right target.

Table E2.8

Total time, reaction time and movement time for movements executed in the presence of a distractor to either a left or right target during the two movement conditions.

	Total Time (ms)		Reaction Time (ms)		Movement Time (ms)	
	Left	Right	Left	Right	Left	Right
Execute	968.7	987.5	*376.4	*388.0	586.8	581.9
	(94.3)	(102.4)	(72.1)	(82.3)	(58.7)	(61.9)
Grasp	945.0	935.9	*378.3	*384.3	563.1	549.7
	(97.0)	(95.6)	(78.2)	(79.9)	(50.1)	(48.4)

Note. Average within subject standard deviation is in the brackets

* $p < .05$

Table E2.9

Peak Velocity and % Time to Peak Velocity for movements executed in the presence of a distractor to either a left or right target during the two movement conditions

	Peak Velocity (mm/ms)		% Time to Peak Velocity	
	Left	Right	Left	Right
Execute	**928.2 (70.4)	**959.2 (77.5)	*52.1 (4.6)	*51.0 (5.2)
Grasp	**947.3 (77.7)	**985.9 (83.3)	*51.6 (4.5)	*51.6 (4.1)

Note. Average within subject standard deviation is in the brackets

*$p < .05$; ** $p < .01$

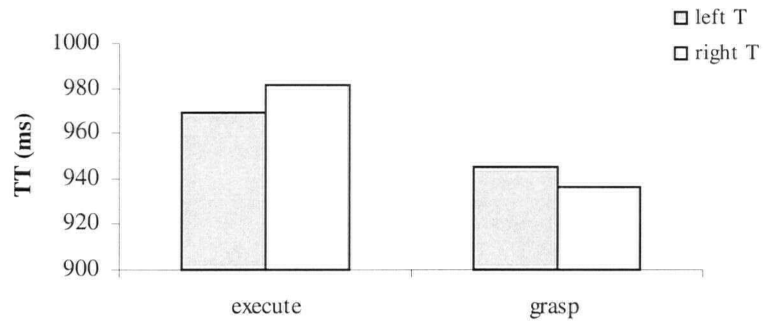

Figure E2.7. Total time of movements executed to left or right targets, under the execute action and grasp movement conditions.

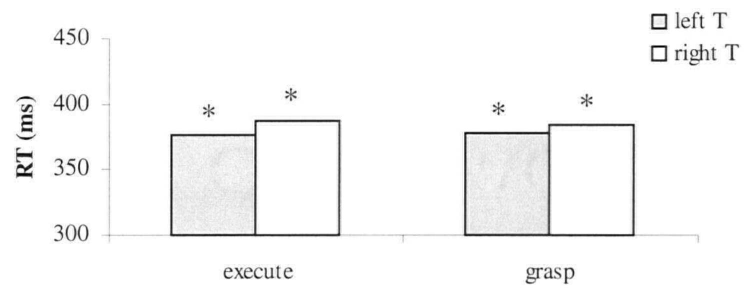

Figure E2.8. Reaction time of movements executed to left or right targets, under the execute action and grasp movement conditions. * $p < .05$

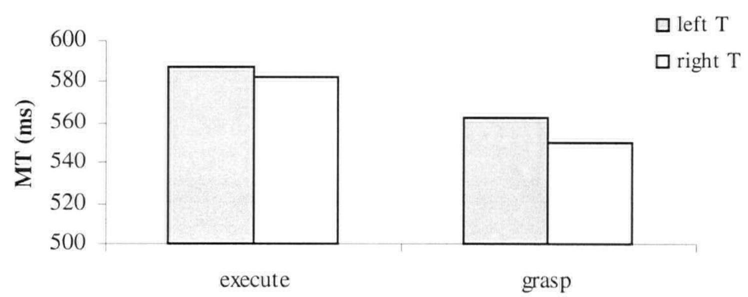

Figure E2.9. Movement time of movements executed to left or right targets, under the execute action and grasp movement conditions.

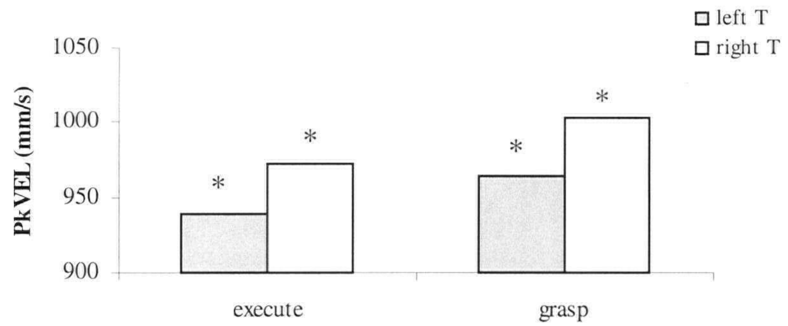

Figure E2.10. Peak velocity of movements executed to left or right targets, under the execute action and grasp movement conditions. * $p < .05$

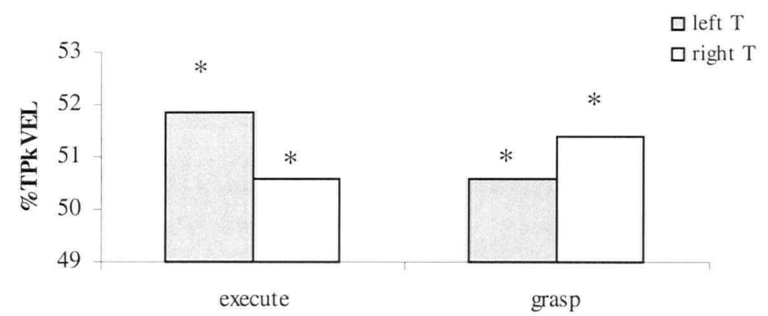

Figure E2.11. Percent time to peak velocity of movements executed to left or right targets, under the execute action and grasp movement conditions. * $p < .05$

Same vs. Different Action Requirements

Performance Measures. Was there a difference in terms of performance measures between the distractor trials in which the terminal action requirement was either the same or different from that of the target? No differences were found in any of the three performance measures, between trials with the distractor object having a similar or different action requirement to the target object [TT- (F (1, 27) = .91, p = .35); RT (F (1, 27) = .11, p > .50); MT (F (1, 27) = .08, p > .50)]. This result indicates that the terminal action requirement of the distractor had no influence on the distractor effect seen in both movement preparation and movement execution (see Figure E2.12, E2.13, E2.14). It appears from this analysis that the distractor object was equally as distracting throughout the movement regardless of its action characteristics (see Table E2.10).

Kinematic Measures. No differences emerged between the velocity profiles of the trials having a distractor object of the same or different action requirement as the target object (see Figure E2.15 & E2.16). These values can be found in Table E2.11. Participants did not change their movement strategy in terms of the timing or magnitude of peak velocity depending on the action requirement of the distractor object [PkVel (F (1, 27) = .18, p > .50); %TpkVel (F (1, 27) = .34, p > .50)].

No Distractor (Blocked) vs. No Distractor (Random).

Performance Measures. Were the no distractor (random) trials different from the no distractor (block) trials? It was found that participants responded to the target faster during the block of no distractor trials compared to the no distractor trials that were presented to them during the randomized condition (interspersed between distractor trials) (see Figure E2.2). The participants took less total time during the no distractor

Table E2.10.

Total time, reaction time and movement time for movements executed in the presence of a distractor with either the same or different action requirements as the target during the two movement conditions.

	Total Time (ms)		Reaction Time (ms)		Movement Time (ms)	
	Same	Different	Same	Different	Same	Different
Execute	984.1	1002.4	388.8	395.1	587.7	595.5
	(99.2)	(106.7)	(78.0)	(82.9)	(63.2)	(67.6)
Grasp	958.1	955.3	392.6	394.1	561.2	563.0
	(103.8)	(94.5)	(83.9)	(78.2)	(54.6)	(48.8)

Note. Average within subject standard deviation is in the brackets

Table E2.11.

Peak Velocity and % Time to Peak Velocity for movements executed in the presence of a distractor with either the same or different action requirements as the target during the two movement conditions.

	Peak Velocity (mm/ms)		% Time to Peak Velocity	
	Same	Different	Same	Different
Execute	931.6 (80.0)	942.7 (79.0)	51.8 (5.5)	51.8 (5.1)
Grasp	960.2 (84.6)	960.0 (78.8)	51.8 (4.8)	51.9 (4.3)

Note. Average within subject standard deviation is in the brackets

* $p < .05$

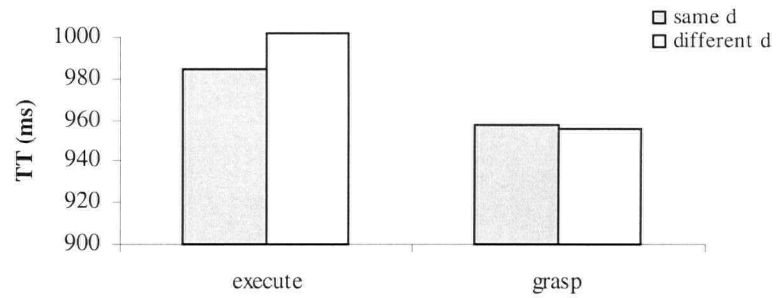

Figure E2.12. Total time of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions

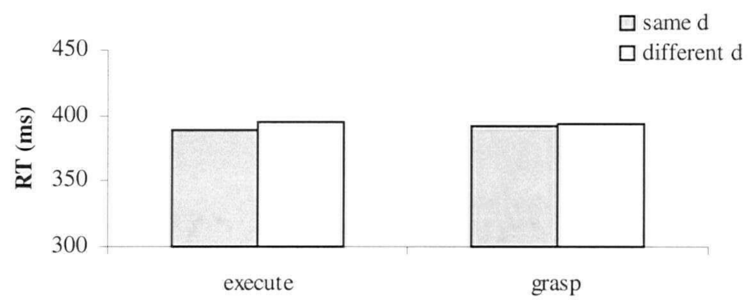

Figure E2.13. Reaction time of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions

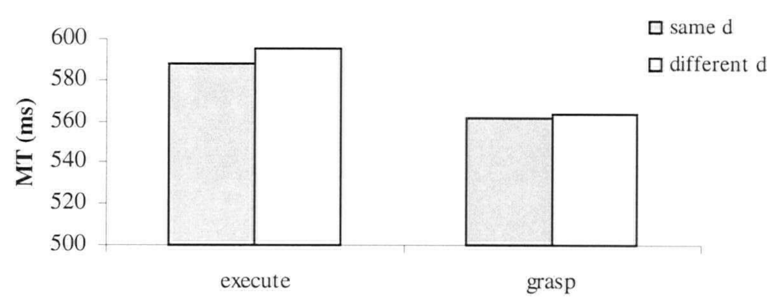

Figure E2.14. Movement time values of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions

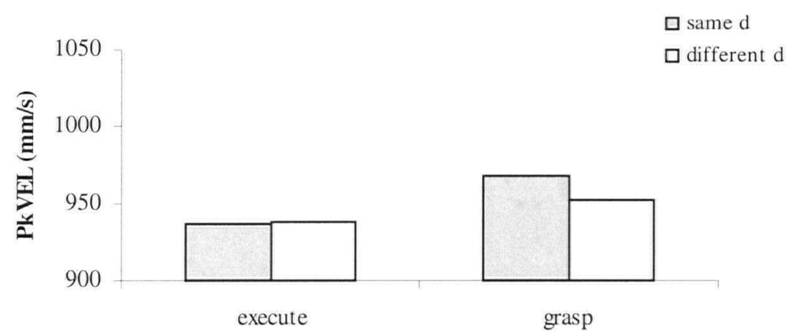

Figure E2.15. Peak velocity of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions

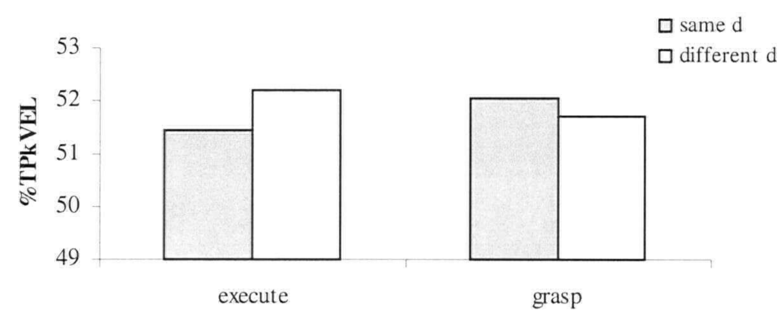

Figure E2.16. Percent time to peak velocity of movements executed in the presence of a distractor having the same or different action requirement compared with the target, under the execute action and grasp movement conditions (block) trials compared to the no distractor (random) trials ($\underline{F}$ (1, 27) = 51.7, $\underline{p}$ < .01) (see Table E2.3). In the no distractor (block) trials participants did not anticipate the presence of a distractor and therefore there was no potential choice as for which switch to reach. Therefore, a shorter time was needed to prepare and execute the response. Reaction times were faster during the no distractor (block) trials; participants selected and prepared their responses more rapidly ($\underline{F}$ (1, 27) = 26.0, $\underline{p}$ < .01) (see Table E2.4 & Figure E2.3).

No significant differences were found for movement time ($\underline{F}$ (1, 27) =3.8, $\underline{p}$ = .062). It took a similar amount of time to execute the movement to the target in the no distractor trials, regardless of randomized or blocked (see Table E2.5).

<u>Kinematic Measures.</u> The comparison between the no distractor (block) and the no distractor (random) trials revealed that participants reached a significantly higher peak velocity during transport when no distractor trials were blocked compared to when the no distractor trials were interspersed between distractor trials ($\underline{F}$ (1, 27) = 7.0, $\underline{p}$ = .014) (see Table E2.6). There were no differences in the percentage of movement time taken to reach peak velocity ($\underline{F}$ (1, 27) = .38, $\underline{p}$ > .50) (see Table E2.7). The organization of the velocity profile was not changed during the different no distractor trials.

Spatial Plots and Deviation Analysis

Different comparisons were of interest when considering the deviations of the path of the wrist as participants moved from the start position towards the target. The minimum deviations from the straight line were normalized using the no distractor (block) trials. It is important to note that the normalized deviations must be thought of with reference to the no distractor (block) trials. The values represent deviations that are greater or less than the deviations made by the participants during the no distractor (block) trials. The data was manipulated such that for each direction of reach the positive values represent deviations towards the distractor or the possible distractor location, while negative deviations represent movements away from the distractor location. Examples of a normal left and right target reach in the presence of a distractor are seen in Figures E2.17 and E2.18.

It was found that on average the deviations occurred at 48.3% and 49.6% of movement time for the left and right target reaches respectively. This indicates that the deviations occurred in roughly the middle of the movement and did not occur as a result of any initiation or termination of movement but rather as an alteration in the transport phase of the movement.

Aside from the minimum deviations (the deviations to the right of the straight line) that were analyzed in the planned comparisons, it is of interest to note that there were the occasional errors made by the participants. These errors appeared as large positive deviations (for right targets) or large negative deviation (for left target) that represented the participant moving in the wrong direction prior to recovering and acquiring the proper target. Most of the participants demonstrated these errors. The distribution of the errors across participants is seen in Table E2.12. An example of the difference between a normal deviation and what would constitute a major error deviation is seen in Figure E2.19 and E2.20. The participant deviated towards the distractor on both trials; however, in the second trial the distractor had a much greater interference effect on the spatial path of the movement. This deviation would constitute an error.

Errors were determined by looking at the maximum and minimum deviations from the straight line. Those trials with abnormally large deviations were visually inspected to see if the participant did in fact move substantially towards the distractor location. There were different levels of errors. There were errors that were extremely large, in which the participant had been close to contacting the distractor switch. The frequency of errors for each type of trial and condition for the ten participants is found in Table E2.12 and Table E2.13. More errors occurred during the execute action condition compared to the grasp movement condition. It is also of interest to note that the errors occurred more frequently in the left target conditions where a right distractor object was present. This result goes along with the other findings of this experiment that have shown that right distractors cause more interference than left distractors. This effect is consistent with previous research that has demonstrated a similar ipsilateral effect with right hand reaches (Howard & Tipper, 1997, Meegan & Tipper, 1998, Tipper et al., 1992, Welsh, Elliott & Weeks, 1999). The extreme errors, resulting in very large positive or negative deviations, were not normalized and included in the deviation analysis. Large errors would have biased the analysis. It was the subtle differences in the spatial paths over the different trials that were of interest. The remainder of the errors, of a more moderate size, were included as they represented the natural inclination of the

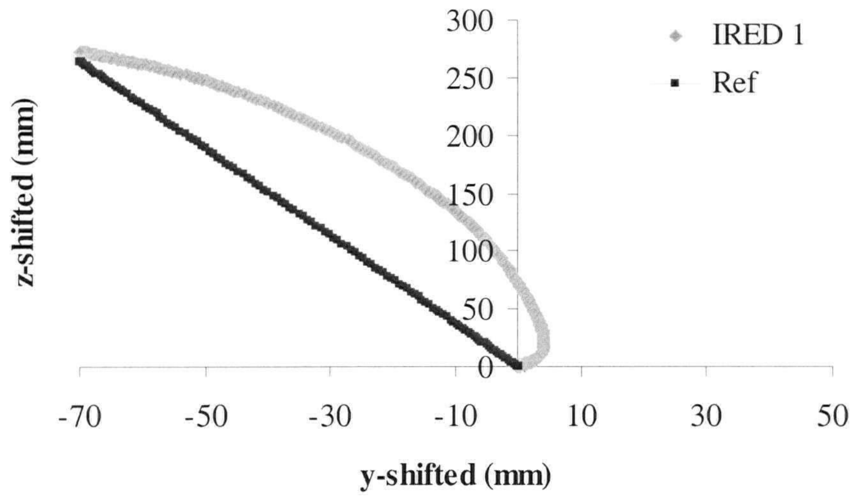

Figure E2.17. An example (s8-9) of a normal trial for s8 during a reach and grasp trial. In this trial the left target was a slider light switch and the right distractor was a rotary audio switch.

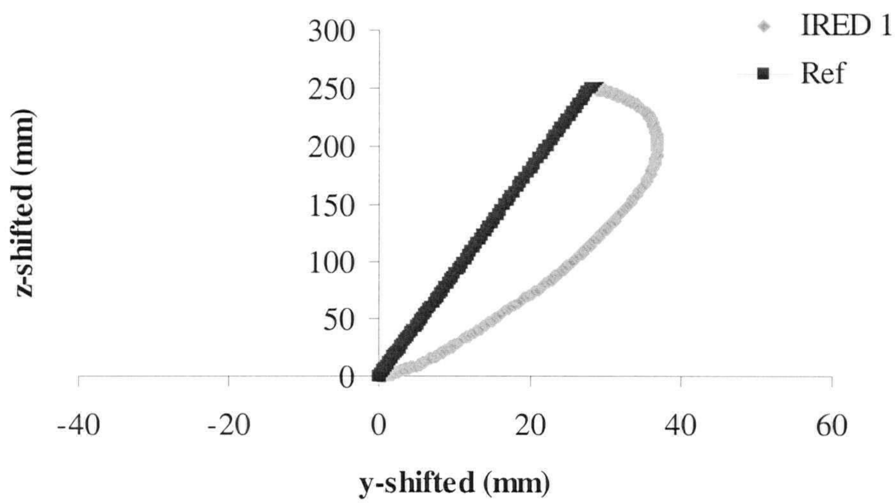

Figure E2.18. An example (s8-22) of a normal trial for s8 during a reach and grasp trial. In this trial the right target was a rotary audio switch and the left distractor was a slider light switch.

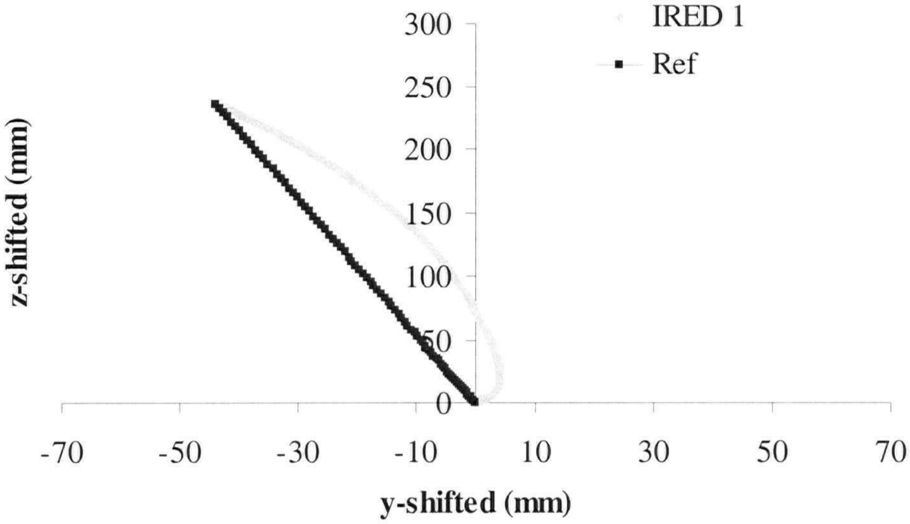

Figure E2.19. An example (s1-101) of a normal trial for s1`during a reach and execute action trial. In this trial the left target was a rotary audio switch and the right distractor was a rotary light switch.

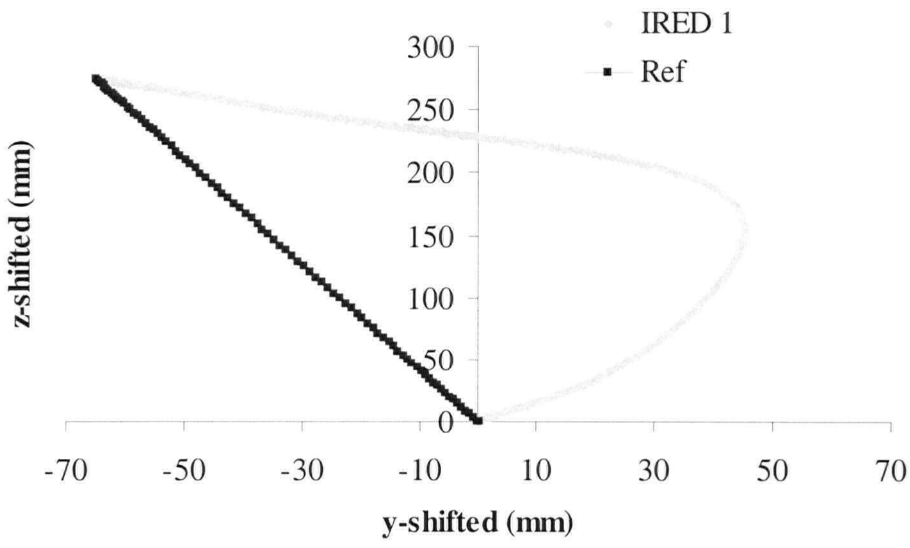

Figure E2.20. An example (s1-117) of an error trial for s1`during a reach and execute action trial. In this trial the left target was a rotary audio switch and the right distractor was a rotary light switch.

participants to deviate towards the irrelevant switch. Subtle differences did appear, as millimeter differences were found to be significant. These small significant deviations were consistent in magnitude with other research that has examined path deviations in a similar setting (Welsh et al., 1999).

It is also of interest to note that on occasion participants had the desire to reach and grasp the light bulb. These trials were also be considered as errors. These error trials could lead one to assume that the light visual stimulus could have acted as a second distracting influence in the visual field.

Left vs. Right Targets. Were the deviations from the reference path different for left versus right target reaches? There was no effect of target location on path deviations (see Figure E2.21). There were no significant differences in the way that participants reached for the target regardless of the target being located to the left or to the right (F (1, 9) = .71, p = .42). This same pattern was seen over the two movement conditions (see Table E2.14).

Distractor vs. No Distractor Trials. It was of interest to determine whether or not the presence of a distractor switch caused the participants to deviate more towards or away from the distractor compared to the deviation of the reference path. This comparison was made within the right target location and left target location trials separately. For the left target trials there was a significant difference between the magnitudes of path deviation when no distractor compared to a right distractor was present. When there was a right distractor the participants deviated more towards the right than when there was no distractor switch (F (1, 18) = 26.3, p < .001) (see Table

Table E2.12.

The error distribution across participants during the two movement conditions.

Participant	**Execute Errors**	**Grasp Errors**
1	2	1
2	3	1
3	10	4
4	4	3
5	8	7
6	12	13
7	10	5
8	0	1
9	1	0
10	5	4
AVERAGE	**5.5**	**3.9**

Table E2.13.

The frequency of the errors of all ten participants as they occurred in the different trial types over the two movement conditions.

	Execute		**Grasp**	
	Left	**Right**	**Left**	**Right**
No distractor	1	0	2	0
Same action distractor	14	11	11	8
Different action distractor	18	11	10	8
Total	**33**	**22**	**23**	**16**
Over Condition	**55**		**39**	

Table E2.14.

The average deviation of the hand over each condition for left and right target movements.

	Left Target (mm)	Right Target (mm)
Execute	4.3 (7.0)	1.5 (4.8)
Grasp	2.5 (6.8)	1.6 (4.1)

Note. Average within subject standard deviation is in the brackets.

Table E2.15.

The average deviation of the hand for left and right target movements in terms of distractor condition.

	Left Target (mm)	Right Target (mm)
No distractor	* -1.0 (5.1)	0.7 (4.5)
Same action distractor	* 6.0 (8.1)	1.8 (4.4)
Different action distractor	* 5.2 (7.4)	2.3 (4.6)

Note. Average within subject standard deviation is in the brackets.

* $p < .01$

E2.15). The influence of the right distractor, causing the wrist to deviate to the right as it moves towards the left target, is shown in Figure E2.22.

A similar but nonsignificant trend was seen for the right target trials (F (1, 18) = 1.11, p = .31). During right target reaches, participants did not deviate differently during no distractor compared to left distractor trials (see Figure E2.22). Therefore, for the right target trials there was not a significant change in the path of the movement when a distractor switch was present.

Same vs. Different Action Requirements. There were no differences between the amount of wrist deviation occurring during trials where the target and distractor objects had either the same or different action requirements (see Table E2.15). The action requirement of the distractor did not have an effect on the path of the wrist [left target (F (1, 18) = .26, p > .50); right target (F (1, 18) = .12, p > .50)]. Whether or not the action requirements of the switches were the same or different did not influence the strength of the distractor effect on the path of the movement.

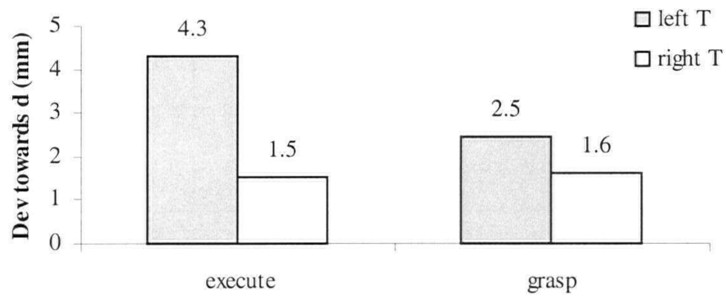

Figure E2.21. The average deviation towards the distractor for both left and right target trials for the two movement conditions.

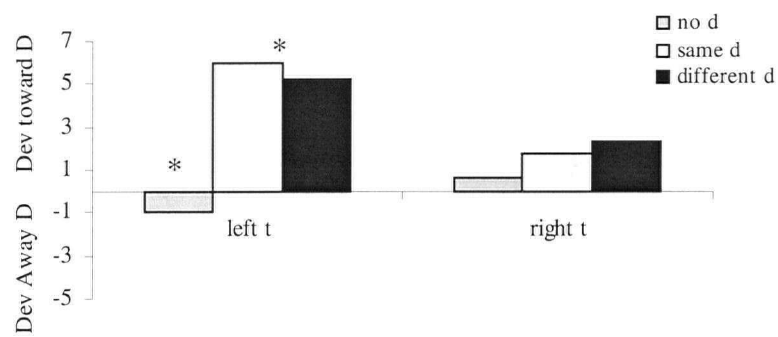

Figure E2.22. The average deviation towards the distractor for both left and right target trials for the two movement conditions. * $p < .01$

Discussion

The motivation behind Experiment Two was to determine how designating the target by the end goal of the task affected the relation between the target and distractor objects. It was expected that the association between the target and distractor would be observed as an interference effect on the movement. Interference was expected in performance and velocity measures as well as in changes of the movements' spatial paths. Participants dealt with a distractor object that had either the same or different action requirement as the target object. It was of interest whether or not the relation between the action requirements of the distractor and target objects influenced the interference effect. In an effort to determine accurate baseline measures participants carried out two types no distractor trials. The no distractor trials were presented either randomized with distractor trials or blocked, no distractor only trials.

It was assumed that the way in which the objects action requirements were represented would be affected by requiring participants to perceive the end goal of the task. The end goal was revealed at the onset of the trial as one of two possible stimuli whose intensity was to be decreased by the participant. It was hypothesized that when the target and distractor objects had the same action requirements but different end goals, the interference to the task, seen in both temporal and kinematic measures, would be greater than when the target and distractor had different actions and different end goals. It was expected that the spatial plots of movements towards a target object in the presence of a distractor object would be different from movements to a target presented alone. The direction of this change in spatial path was unknown due to inconsistencies in the literature regarding this phenomenon.

It took participants the same amount of time to prepare their movement to the target switch when either grasping or executing the target. The process of selecting a target based on the stimulus characteristics resulted in response selection to be similar over the grasp and execute movement conditions. This is due to the fact that in both conditions the participants were required to identify the end goal of the task and thus the action properties of the switch itself before selection could take place.

There were no differences between the velocity profiles of trials during the grasp only compared to the execute action movement condition. Participants reached a similar peak velocity at a similar percent of movement time for the grasp and execute action movement conditions. It appears that there was no need for participants to elongate the deceleration phase of the movement during the seemingly more difficult execute action condition.

It took participants longer to execute their movements during the execute action condition. This finding would suggest that participants were planning the terminal action required by the target switch online. It appears following movement initiation participants were planning the terminal action requirement of the target online during transport for the execute action trials. This online processing manifested itself as an increase in time taken to reach the target during the execute action condition compared to the grasp only condition. It would seem that participants should have been processing the terminal action in order to properly select the target based on the end goal dictated by the stimulus. This however was not the case. Participants appeared to have been selecting the target based on the correct switch's association with the stimulus aside from the actual action that would accomplish the modulation of the stimulus. Thus, it was not necessary or efficient for the participants to code the terminal action requirement of the target before initiating the movement towards it.

Interference due to the presence of a distractor was seen in a number of the dependent measures for Experiment Two. Participants had longer reaction times, movement times, and total times when a distractor was present compared to when it was absent. These findings were consistent with previous distractor experiments in which performance temporal measures were increased on trials in which an irrelevant object was present in the visual field (Pratt & Abrams, 1994; Tipper et al., 1992; Tipper et al., 1997).

Effects of distractors on movement velocity profiles have been shown to sometimes modify the peak velocity as well as the organization of the profile in terms of the percentage of time taken to reach peak velocity (Jackson et al., 1995). Like many interference effects due to distractors this finding has not been seen consistently over distractor studies and there have been studies that have found no effect of distractors on velocity measures (Kritikos et al., 2000; Lyons et al., 1999). It has been found that distractors can cause participants to move at a slower speed when presented with a target as well as a distractor object compared to target alone trials (Jackson et al., 1995). In the present experiment peak velocity was not influenced by the presence of a distractor. However, there was an interference effect on the relative timing of peak velocity. Participants took less time in the deceleration phase of their movement when a distractor was within their visual field. Jackson et al. (1995) showed a similar organizational change occurring in the velocity profiles of distractor trials compared to no distractor trials. Because these effects are not seen globally over similar studies it is uncertain how important these measures are in understanding the interference effect of irrelevant objects on a selective reaching task. It would be valuable to determine what experimental conditions are necessary in order to see modifications to velocity measures. There is not enough information at the present time to determine this.

Similar to Experiment One, there were no differences between the performance or velocity measures for trials in which the target and the distractor had the same action requirements compared to trials in which the action requirements were different. The distractor was equally as distracting regardless of its action requirement (cf. Experiment One). This was seen over both movement conditions. Participants did not change their movement strategy in terms of the timing or magnitude of peak velocity depending on the action requirement of the distractor object. Even though the presence of a distractor had an effect on the organization of the velocity profile of the movement the specific terminal action characteristics of the distractor objects did not.

In Experiment Two there were only two possible target locations, one to the right and one to the left of the start position. It took participants more time to process and prepare a movement to a target located to the right of the start position. There was no effect of target and distractor location on the time it took to execute the movement. The increase in time taken to reach ipsilaterally is different from the majority of distractor studies that have examined left versus right reaches in terms of reaction time (Meegan & Tipper, 1998; Tipper et al., 1992; Welsh et al., 1999). It appears that our location effect is opposite to the common finding referred to the ipsilateral effect. Past studies have found that contralateral reaches in the presence of an ipsilateral distractor take longer to prepare than ipsilateral reaches. This effect has been attributed to the increased accessibility of information arising from the right visual field when using the right hand to perform an action. Thus a right side distractor will be more competitive with a left reach because it will be coded more rapidly than its left side counterpart (McGarry & Franks, 1997; Welsh et al., 1999). A left distractor is expected to be less competitive therefore less distracting due to the fact that left visual field information must be passed from the right to the left hemisphere before it affects right hand responses. It is unclear why this usually consistent finding was not found in this experiment.

The result of left reaches taking less time to prepare compared to right reaches could be explained by literature that has examined viewing perceptual asymmetries (Nicholls, Bradshaw & Mattingley, 1999). It has been shown that during a selection task participants were more likely to select objects with a left side emphasis compared with a right side emphasis. This finding is attributed to the presence of a left to right scanning bias that people exhibit, specifically people that have learned to read and write from left to right. This explanation may help to explain the left side advantage in terms of reaction time that was seen in Experiment Two.

In terms of target location, participants reached a greater peak velocity during the right target trials compared to the left target trials. This is consistent with previous findings in which there was a decrease in peak velocity seen for contralateral reaches (Jackson et al., 1995). It is also interesting to note that participants took a longer time in the deceleration phase of the movement when they were reaching for the right target. This difference was only seen during the execute action condition.

For the right target reaches participants reacted slower but reached a greater velocity at a later point in the movement when reaching for a right compared to a left target. It appears that it took participants longer to process movements to the right. This could be due to uncertainty that remained throughout the movement as participants moved towards the target, thus they took longer when slowing down to approach the target. It is unclear why the greater peak velocity occurred. Perhaps it is easier to reach a faster speed when moving the right arm to the right compared to the left. Response selection and programming may not be the factors that influenced the peak velocity in this experiment.

It was interesting to examine the deviations of the spatial paths with reference to left and right movements. There have been a number of studies that have examined path deviations, both lateral and vertical deviations, in the presence of distractors during a selection task. These studies have resulted in a number of different perspectives on how and why the hand deviates when moving towards a target in the presence of a distractor object. In the past it has been found that participants deviate away from distractors (Howard & Tipper, 1997; Tipper et al., 1997). This was thought to be due to the idea that neuronal populations are activated representing reaches towards both the target and distractor locations. These neurons are coding for the direction of the reach (Georgopoulos, 1990). When two objects are present within the visual field movements towards these potential objects for action are coded within these neuronal populations. The resulting movement lies somewhere in between the two objects unless inhibition occurs on the neurons coding for the irrelevant object. There tends to be overlap between neuronal populations coding for two objects. When the irrelevant objects neurons are inhibited the portion of neurons that overlap onto the target objects representation cause a shift in the direction coded by the target object. Thus, this theory poses that inhibition of some of the crucial neuronal information results in a deviation of the spatial path away from the distractor. If the inhibition on the movement towards the distractor is stronger, the deviation away from the distractor will be greater.

This supposition regarding neuronal populations and deviations away from interfering objects does not hold for some of the more recent distractors studies including the present experimental results (Castiello, Badcock & Bennett, 1999; Welsh et al. 1999). There have been a number of different results that have emerged from analysis of deviations. The opposite distractor effect has been seen in some studies. For example, Welsh et al. (1999) found that the spatial path of a movement toward a target in the presence of a distractor veered toward the distractor. The present deviation analysis was consistent with this finding. No effect on spatial paths has been seen in a number of studies (Castiello et al., 1999; Kritikos et al., 2000).

The randomized trials were normalized with reference to their no distractor (block) counterpart. A number of significant findings arose from this analysis. It was found that there were no differences between the reaches for the left target versus reaches for the right target. The amount of deviation was similar for reaches to the two locations. The rest of the analysis on the deviation data was done within each of the reach locations.

For left target reaches there was a distractor effect observed in terms of spatial deviation. There was an increase in the amount of deviation from the normalized spatial path when a distractor was located at the right location. The participants deviated more towards the right distractor compared to the no distractor trials when the right location was occupied by a black box.

It was found when participants reached to the right there were no differences in the amount of deviation between the spatial paths for the no distractor trials compared to the distractor trials. However, there was a trend towards the deviation being greater during trials where a distractor was present.

One possibility that could explain the deviations towards the distractor could be that participants were experiencing response competition with the distractor object when attempting to move towards the target location. The competition between actions to both locations would manifest itself as a movement path falling somewhat in the middle of both possible targets. This effect appeared more strongly during reaches to the left location. Reaches to the right location where only approaching significance. The amplification of the effect in the left target reaches could be due to the fact that the natural reach with the right hand to the left must cross the path of the right distractor. Thus, because a left target reach must cross the irrelevant objects position the interference effect is increased. The reach to the right does not require the participant to approach the area in which a movement to the left location would occur.

An intent to minimize error could also be responsible for participants choosing a path in the middle of two possible target locations. By initially moving out in between the two locations, and then over to the target, the possibility of making a blatant error to the wrong target is minimized (Welsh et al., 1999). This type of movement, taking the trajectory out in front of the midline before crossing to the target, was seen in some of the spatial profiles. This demonstrated that the participant was not committing to a target until well into movement execution. This did not follow with the instructions that were provided to the participants at the beginning of each condition. Even though extreme cases were recorded as errors, it appeared that a similar strategy was employed by participants on a more subtle level throughout the trials. Participants had their path slightly oriented towards the other possible target location in case they were in error as they moved towards what they had selected as the target.

The relation of the action requirements of the target and distractor switches did not mediate the distractor effect seen in the deviation analysis. There was no difference in the deviation of the spatial path when the actions were the same or different. Thus, it appears that the action requirement of the objects did not come into play when the participants were planning and executing their movements towards the target.

There were significant differences between the errors that occurred in the execute action versus the grasp condition. Participants were more likely to deviate extremely (therefore, they initially chose the wrong switch), during the execute action condition. Intuitively one would have expected the opposite result because in the execute condition it was more important to select the correct switch in order to actually decrease the intensity of the stimulus. It could be that the added complexity of activating the switch led to more uncertainty as to which was the correct target switch.

Due to the lack of a significant distractor effect in Experiment One it was deemed necessary to carry out a block of no distractor only trials following the randomized block of trials for each condition in Experiment Two. No distractor (block) trials were performed significantly faster than the no distractor (random) trials. Total times of the movements were faster when the no distractor trials were blocked. Reaction time was also significantly faster for the no distractor (block) trials. During the blocked no distractor trials, participants were not expecting a distractor; therefore, they were able to more efficiently select the switch based on location as well as end goal. During the no distractor (random) trials the participants were expecting a distractor switch based on the ratios of no distractor versus distractor trials. There were always more distractor trials than no distractor trials in the randomized blocks. Movement time was not different between the blocked and randomized no distractor trials. This further suggests that people were selecting the target prior to movement initiation because it was only this stage (RT) that was affected by the no distractor trials being blocked and the possibility of a distractor switch being alleviated.

There were differences in the velocity profiles of the no distractor (block) trials compared to the no distractor (random) trials. A greater peak velocity was reached when the no distractor trials were blocked compared to the no distractor trials interspersed between the distractor trials. The percent time to peak velocity was not different over the two no distractor conditions. It appears that participants were more confident in their movements toward the target when they did not expect a distractor switch to be present.

The implications of these results are that no distractor trials are handled differently depending on the context in which they are presented. Even though a strong distractor effect was seen for the randomized no distractor trials, an even stronger interference effect was seen during the block of no distractor trials. This suggests that during the randomized trials participants treated the no distractor trials differently due, perhaps, to a strategy that involved preparing for the worse case scenario (i.e., the presence of a distractor). Participants had to determine that no distractor was present before preparing a response to the target. In the blocked trials, participants knew that no distractor switch would appear; therefore, they simply found the target and prepared and executed the response. There was no debate as to which switch to move to and there was no need to be wary of a possible irrelevant object introducing a choice to response selection.

Distractor effects were found in the performance and velocity measures as well as in the deviation analysis of the spatial plots of Experiment Two. These results showed that with this apparatus and methodology participants were influenced by the presence of an irrelevant object within their task space. Distractor objects interfered with movements made to targets selected based on the end goal of the task.

It has been speculated that an object, even when there is no intention to act, can encourage an action to be cognitively coded (Ellis & Tucker, 2000; Tucker & Ellis, 1998). Michaels & Carello (1981) explicated how "affordances are the acts or behaviors permitted by objects, places and events" (p. 42). In their view, objects contain information that can be processed by the user to accurately perceive the *meaning* of the object. Tucker and Ellis (1998, 2000) found that actions associated with different visual object features are potentiated even when irrelevant to the task at hand. The increased potency of these actions appeared in terms of compatibility effects affecting reaction time. Ellis and Tucker (2000) found that irrelevant object features (size, orientation) affected the task depending on the action afforded by the object features. One of the tasks required participants to respond to either a high auditory tone stimulus with a precision grip on a dowel or to a low tone with a power grip on a dowel. Simultaneously presented with the auditory stimulus was a visual object (affording a certain type of grip) such as a pen or a hammer. They found that when the visual object afforded the same grip as the tone the task was facilitated and a decrease in reaction time occurred. This led

Ellis and Tucker (2000) to the conclusion that the irrelevant object features representing the action properties of the object were being promoted cognitively. These studies examining the direct coding of action-related properties of irrelevant objects have a direct relation to the discussion on the relation between targets and non-relevant distractor objects. Tucker and Ellis (1998) provided evidence that action properties are represented, due to the visual object features, even before there is any intention by the person to act upon the object. They dealt with action properties that affected how the object could be grasped and manipulated.

Having the participants select the target based on the necessary end goal did not enhance the effect of the relation between the terminal action requirements of the target and distractor. Consistent with Experiment One, there was no influence of the relation between the action requirements of the target and distractor objects on any of the dependent measures. This would lead to the conclusion that during selection for action, certain intrinsic object characteristics such as action requirements are not coded and thus do not influence the cognitive process. Thus, contrary to Tucker and Ellis (1998, 2000), it appears in Experiment Two that the terminal action properties of the distractor object were not coded cognitively in such a way as to potentiate an action that would interfere with the desired response.

GENERAL DISCUSSION

Many recent studies have been carried out in an effort to extend the knowledge base regarding selective attention during reaching and grasping/manipulation tasks. There has been a need to expand on the idea of action-centered attention (Tipper et al., 1992) regarding how both relevant and irrelevant objects are represented and dealt with in an environment. The action-centered selective attention model predicts that irrelevant objects that are closer to the hand cause more interference to a movement towards a target object. Many experiments have been performed to explore the issue of spatial location and the interference effects of irrelevant objects within the visual array. Recently, it has become of interest to see what other object features, besides location, come into play when moving and manipulating in an environment containing superfluous potential objects for action.

In the past, studies of selective attention for action have found modest effects of distractor features influencing the interference effects on the movement. It is obvious that in our normal lives we are constantly dealing with a heterogeneous environment containing many different objects of varying sizes and shapes. Different object features have been manipulated in past studies including size, shape, orientation, dimensionality, semantic category and terminal action requirement.

The influence of the relation between specific object features on an interference effect has been dependent on what feature was manipulated. It appears that certain object features have greater influence on the selection process. This could be taken to mean that certain object features are more relevant to the preparation and execution of movements towards a target and therefore cause more interference. Object size has been a common manipulation in these studies. The comparison of performance and kinematic measures for movements directed toward similarly sized objects versus different sized objects has led to conclusions regarding how people deal with objects of varying characteristics in their environment. A greater distractor effect has been found when target and distractor objects are of a different size compared to when they are of a similar size (Gangitano et al., 1998; Jervis et al., 1999; Kritikos et al., 2000; Kritikos, Dunai, & Castiello, 2001).

The present experiments were carried out in an effort to determine the influence of the terminal action requirements of the objects on the selection process during a reaching and grasp/execute task. The action requirements of an object are due to an amalgamation of its intrinsic features and are intimately bound to the function of that object (Tucker & Ellis, 1998). An understanding of the relation between these features results in the knowledge of the action requirements of the object. The object features that must be understood are not only the object's mechanical properties but also its size and texture. It is believed that when viewing objects, their actions are represented even when an action towards that object is not cognitively desired (Tucker & Ellis, 1998).

In the present experiments it was presumed that by manipulating the action requirements of objects present within a visual field, the influence of the intrinsic features, namely the terminal action requirements, could be determined. To accomplish this, objects were presented to the participants having either similar or different action requirements. In the first experiment the target object was designated by location (the illumination of the section) and in the second experiment the target was designated by the desired end goal of the task. In Experiment Two it was important to try and remove location as being the prime method of target identification. Presumably, by emphasizing the function of the object, the influence of the action requirements of the objects would be magnified. This however, was not the case. Over both experiments there were no changes in the distractor effect mediated by the same or different action requirements of the target and distractor objects.

Previously, the influence of certain object features has been attributed to the increase in information that must be processed when the distractor object is different from the target. With more information to organize, arising from different sized objects in the visual field, the interference to the movement is greater (Allport, 1987; Kritikos et al., 2000). One would think that this finding would extend to differences seen in other object features shared between target and distractors. This has not been the case. Many studies have found that a difference or similarity between certain features other than size has not influenced the interference effect (Castiello 1996; Kritikos et al., 2000; 2001). The main explanation for the lack of an effect from these object features is that they are not necessary for the accomplishment of the goal. It is postulated that perhaps features like the semantic category or the dimensionality of objects do not come into play when planning a movement towards the object (Kritikos et al., 2000). If the object feature of interest is not necessary for control of the action to the target than it will not influence attention. Posner (1980) states "attention represents a system for routing information and for control of priorities"(p.9). Perhaps, representing the object's terminal action requirements during these experiments was not a priority in terms of selecting the target.

It is difficult to reconcile this explanation with the present findings. One would think that the terminal action requirement of an object would come into play when planning an action to that target. However, it is important to note that in both Experiment

One and Two, there were no differences between reaction times of the reach and grasp versus the execute action movement conditions. The differences between these two conditions arose during the movement execution phase of the response. This shows that in the case of both experiments the terminal action appeared to be planned online rather than prior to movement initiation. If the terminal action requirement does not influence selection and is planned during the movement, then the action required by the distractor will not likely influence its impact on the movement. Strictly based on Experiment One, this finding would not be convincing, as the action requirement was not a necessary factor in selecting the target object. However, even when the actions of the objects were emphasized, as in Experiment Two, there was no influence seen on the distractor effect in terms of a same or different relation between the objects actions. This would emphasize the fact that the terminal action was not affecting or mediating selection of the appropriate target.

Based on the present experiments it is apparent that the terminal action requirements of objects do not influence the selection for action process during a simple reach and grasp or simple reach and execute task. This leads to the possibility that not all object factors are represented when an irrelevant object is present within a visual field. Perhaps not all visual objects potentiate actions that are intrinsic to their function when those actions have little to do with the task at hand.

The present experiments have added further to the body of literature addressing selective attention for action. The role of object action requirements has been further explored. In Experiment One, no distractor effects were found. In particular, there was no influence of action requirement on the dependent measures examined. It appears that the lack of a finding in relation to the action requirements of the objects was repeated in Experiment Two. There was a distractor effect seen in Experiment Two. However, this effect was not mediated by the terminal action requirement of the distractor and the target. Therefore, based on the present experiments, there is no influence of object action properties on the selection and preparation of a movement toward a target object. This adds to the previous literature that has examined the influence of object features on the movement to a target in the presence of a distractor.

The nonsignificant distractor effects in Experiment One and the difference between the no distractor (random) and the no distractor (blocked) in Experiment Two have implications on selective attention literature. From these results, the importance of the context in which movements are carried out is emphasized. It is very important to understand that a no distractor trial may not always be an appropriate control with which to compare demands on selective attention. When randomized in the midst of distractor trials, no distractor trials may require an equal amount of processing time as distractor trials because of anticipation that results from the context of the task. In order to accomplish the task of preparing and executing a movement as quickly and as accurately as possible it is necessary for the participants to be wary of any possible irrelevant objects within the visual array. Therefore, at the onset of a trial the participant must survey the scene and select the target from the other potential objects for action. Thus, a no distractor trial in the midst of distractor trials may still demonstrate interference effects because of the high possibility of a distractor object being present.

It is also possible that the present experiments were inadequate at emphasizing the importance of object actions to the task. Future experiments could be carried out that utilize a methodology that would more strongly require the participants to decipher the target from other objects based on their action requirements and functions. Perhaps these experiments would provide further information on how and when the action requirements of objects enter into the selection for action process. The effect of object location in relation to the effector has been well established for simple reaching tasks; however, the effect of intrinsic object properties and more complex tasks remain uncertain.

CLOSING REMARKS

The primary motivation behind the present studies was to determine whether the terminal action requirements of objects, in addition to their spatial relations, would influence the process of selectively distinguishing a target from a distractor object, and preparing and executing an action toward that target object. If the action-centered model, as proposed by Tipper and colleagues (e.g., Tipper et al., 1992), is indeed "action" centered, it seemed reasonable to assume that the characteristics of the actions required by the objects would play a role in selection for action. Evidence to support a role for terminal action requirements on selective attention was not found. In contrast to previous research that has shown that selective attention for action is subject to the presence and location of distractor objects in relation to the effector, the present studies demonstrated that the relation between the action requirements of target and distractor objects did not influence the process of object and action selection.

REFERENCES

Allport, A. (1987). Selection for action: Some behavioural and neurophysiological considerations of attention and action. In H. Heuer & A.F. Sanders (Eds.), Perspectives on perception and action (pp. 395 – 419). Hillsdale, NJ: Erlbaum.

Castiello, U. (1996). Grasping a fruit: Selection for action. Journal of Experimental Psychology: Human Perception and Performance, 22, 582 – 603.

Castiello, U. (1999). Mechanisms of selection for the control of hand action. Trends in Cognitive Sciences, 3(7), 264 – 271.

Castiello, U., Badcock, D.R., & Bennett, K.M.B. (1999). Sudden and gradual presentation of distractor objects: Differential interference effects. Experimental Brain Research, 128 (4), 550 – 556.

Cherry, E.C. (1953). Some experiments on the recognition of speech, with one and two ears. Journal of the Acoustical Society of America, 25, 975 – 979.

Chua, R., & Elliott, D. (1993). Visual regulation of manual aiming. Human Movement Science, 12, 365 – 401.

Chua, R., & Weeks, D.J., (2000). Relative Organizational Mapping in Teleoperations. Journal of Sport and Exercise Psychology, 22 (Suppl.), 27.

Deutsch, J.A., & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 70, 80 – 90.

Ellis, R. & Tucker, M. (2000). Micro-affordances: The potentiation of components of action by seen objects. British Journal of Psychology, 91, 451 – 471.

Gangitano, M., Daprati, E., and Gentilucci, M. (1998). Visual distractors differentially interfere with the reaching and grasping components of prehension movements. Experimental Brain Research, 122, 441 – 452.

Georgopoulos AP. (1990). Neurophysiology of reaching. In: M. Jeannerod (Ed.), Attention and performance XIII. (pp. 227 – 263). Hillsdale, NJ: Erlbaum.

Henry, F.M., & Rogers, D.E. (1960). Increased response latency for complicated movements and a "memory drum" theory of neuromotor reaction. Research Quarterly, 31, 448 – 458.

Hommel, B. (1997). Toward an action-concept model of stimulus-response compatibility. In B. Hommel & W. Prinz (Eds.), Theoretical issues in stimulus-response compatibility (pp. 281 – 319). Amsterdam: Elsevier.

Howard, L.A., & Tipper, S.P. (1997). Hand deviations away from visual cues: Indirect evidence for inhibition. Experimental Brain Research, 113 (1), 144 – 152.

Humphreys, G.W. & Riddoch, M.J. (2000). One more cup of coffee for the road: Object-action assemblies, response blocking and response capture after frontal lobe damage. Experimental Brain Research, 133, 81 – 93.

Ibbotson, J.A., Bredin, S.S.D., Chua, R., & Weeks, D.J. (2001). Targets, distractors, and objects in action-centered attention. Journal of Sport and Exercise Psychology, 23(Suppl.), 90 – 91.

Ibbotson, J.A., Chua, R. & Weeks, D.J. (2000). Interaction of target and distractor features in action-centered attention. Journal of Sport and Exercise Psychology. 22(Suppl.), 54 – 55.

Jackson, S.R., Jackson, G.M., & Rosicky, J. (1995). Are non-relevant objects represented in working memory – The effect of non target objects on reach and grasp kinematics. Experimental Brain Research, 102 (3), 519 – 530.

Jervis, C., Bennett, K., Thomas, J., Lim, S., & Castiello, U. (1999). Semantic category interference effects upon the reach-to-grasp movement. Neuropsychologia, 37, 857 – 868.

Kahneman, D. (1973). Attention and Effort. Englewood Cliffs, NJ: Prentice-Hall.

Kritikos, A., Bennett, K.M.B., Dunai, J. & Castiello, U. (2000). Interference from distractors in reach-to-grasp movements. The Quarterly Journal of Experimental Psychology, 53(1), 131 – 151.

Kritikos, A., Dunai, J., & Castiello, U. (2001). Modulation of reach-to-grasp parameters: Semantic category, volumetric properties and distractor interference? Experimental Brain Research, 138, 54 – 61.

Lyons, J., Elliot, D., Ricker, K.L., Weeks, D.J., & Chua, R. (1999). Action-centered attention in virtual environments. Canadian Journal of Experimental Psychology, 53, 176 – 187.

Marteniuk, R.G. (1976). Information Processing in Motor Skills. New York: Holt, Rinehart and Winston.

Marteniuk, R.G., MacKenzie, C.L., Jeannerod, M., Athenes, S., & Dugas, C. (1987). Constraints on human arm movement trajectories. Canadian Journal of Psychology, 41(3), 365 – 378.

McGarry, T. & Franks, I.M. (1997). A horse race between independent processes: Evidence for a phantom point of no return in the preparation of a speeded motor response. Journal of Experimental Psychology: Human Perception and Performance, 23(5), 1533 – 1542.

Meegan, D.V., & Tipper, S.P. (1998). Reaching into cluttered visual environments: Spatial and temporal influences of distracting objects. The Quarterly Journal of Experimental Psychology, 51A (2), 225 – 249.

Meegan, D.V., & Tipper, S.P. (1999). Visual search and target-directed action. Journal of Experimental Psychology: Human Perception and Performance. 22(5), 1347 – 1362.

Michaels, C.F. & Carello, C. (1981). Direct Perception. NJ: Prentice-Hall, Inc.

Milgram, P. (1987). A spectacle-mounted liquid-crystal tachistoscope. Behavior Research Methods, Instruments and Computer, 19, 449 – 456.

Nicholls, M.E.R., Bradshaw, J.L., & Mattingley, J.B. (1999). Free-viewing perceptual asymmetries for the judgment of brightness, numerosity and size. Neuropsychologia, 37, 307 – 314.

Norman, D.A. (1969). Memory and Attention. New York: John Wiley & Sons, Inc.

Norman, D.A., & Bobrow, D.G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44 – 64.

Posner, M.I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32, 3-25.

Pratt, J., & Abrams, R.A. (1994). Action-centered inhibition: Effects of distractors in movement planning and execution. Human Movement Science, 13, 245 – 254.

Schmidt, R.A. & Lee, T.D. (1999). Motor control and learning: A behavioral emphasis (3rd ed.). Champaign, Illinois: Human Kinetics.

Tipper, S.P., Howard, L.A., & Houghton, G. (1998). Action-based mechanisms of attention. Philosophical Transactions of the Royal Society of London B., 353, 1385 – 1393.

Tipper, S.P., Howard, L.A., & Jackson, S.R. (1997). Selective reaching to grasp: Evidence for distractor interference effects. Visual Cognition, 4(1), 1 – 38.

Tipper, S.P., Lortie, C., & Baylis, G.C. (1992). Selective reaching: Evidence for action-centered attention. Journal of Experimental Psychology: Human Perception and Performance, 18, 891 – 905.

Treisman, A.M. (1969). Strategies and models of selective attention. Psychological Review, 76, 282 – 299.

Treisman, A.M., & Gelade, G. (1980). A feature-integration theory of attention. Cognitive Psychology, 12 (1), 97 – 136.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. Journal of Experimental Psychology: Human Perception and Performance, 24, 830 – 846.

Weir, P.L., Weeks, D.J., Welsh, T., Elliott, D., Chua, R., Roy, E.A., & Lyons, J. (submitted 2000). Influence of terminal action requirements on action-centered distractor effects. Unpublished paper.

Welford, A.T. (1952). The 'psychological refractory period' and the timing of high-speed performance: A review and a theory. British Journal of Psychology, 43, 2–19.

Welsh, T.N., Elliott, D., & Weeks, D.J. (1999). Hand deviations toward distractors, evidence for response competition. Experimental Brain Research, 127, 207 – 212.

Wickens, C.D. (1980). The structure of attentional resources. In R.S. Nickerson (Ed.), Attention and Performance VIII (pp. 239 – 257). Hillsdale, NJ: Erlbaum.

Wing, A.M., Turton, A., & Fraser, C. (1986). Grasp size and accuracy of approach in reaching. Journal of Motor Behavior, 18 (3), 245 – 260.

All information and data collected are coded to maintain confidentiality. Data are stored in a locked lab/office to which only the investigator will have access. Normally data is retained for a period of five years post-publication, after which time it may be destroyed.

INFORMED CONSENT

I have read and understand the procedures used in this study.

I understand that I can ask the experimenter any questions I might have regarding the procedures and instructions for this study. I understand that I will receive further debriefing following my participation.

I understand that the research material will be encoded and held confident by the principal investigator.

I understand the possible benefits of joining the research study, as well as possible risks and discomforts.

I understand that I have the RIGHT TO REFUSE to participate or that I may WITHDRAW my participation from this experiment at any time without any penalty and prejudice.

I hereby CONSENT to participate in this study and acknowledge RECEIPT of a copy of the information, and consent form.

Name (please print):____

Signature:____

Date: ____

If you have any concerns regarding your treatment, please contact Dr. Richard Spratley, Director of UBC Research Services and Administration, 822-8598.

Appendix B

Experimental design (trial distribution) for Experiment One.

Grasp	Front Target		Middle Target		Back Target	
	TURN	PULL	TURN	PULL	TURN	PULL
No Distractor	5	5	10	10	5	5
Back Distractor -same action	5	5	10	10	0	0
Front Distractor -same action	0	0	10	10	5	5
Middle Distractor -same action	5	5	0	0	5	5
Front Distractor -different action	0	0	10	10	5	5
Middle Distractor -different action	5	5	0	0	5	5
Back Distractor -different action	5	5	10	10	0	0

Execute Action	Front Target		Middle Target		Back Target	
	TURN	PULL	TURN	PULL	TURN	PULL
No Distractor	5	5	10	10	5	5
Back Distractor -same action	5	5	10	10	0	0
Front Distractor -same action	0	0	10	10	5	5
Middle Distractor -same action	5	5	0	0	5	5
Front Distractor -different action	0	0	10	10	5	5
Middle Distractor -different action	5	5	0	0	5	5
Back Distractor -different action	5	5	10	10	0	0

Appendix C

Execute Action Condition

Between subject standard deviations for the Performance Measures of Experiment One.

Execute	TT	RT	MT
No Distractor	175.0	59.9	121.0
Distractor	168.7	68.0	112.7
Front Distractor	160.7	68.0	110.4
Back Distractor	176.8	68.0	114.9
Same Distractor	168.3	67.1	110.8
Different Distractor	169.2	69.0	114.5

Grasp Condition.

Between subject standard deviations for the Performance Measures of Experiment One.

Grasp	TT	RT	MT
No Distractor	161.6	66.5	88.1
Distractor	152.7	64.4	95.9
Front Distractor	150.2	65.3	88.0
Back Distractor	155.3	63.6	103.7
Same Distractor	153.7	65.4	98.6
Different Distractor	151.8	63.4	93.1

Appendix D

Experiment Two - experimental design of the grasp and execute action conditions.

	Light Stimulus				Sound Stimulus			
GRASP	Left Target		Right Target		Left Target		Right Target	
	turn	slide	turn	slide	turn	slide	turn	slide
No Distractor	5	5	5	5	5	5	5	5
Right Distractor - same action	5	5			5	5		
Right Distractor - different action	5	5			5	5		
Left Distractor - same action			5	5			5	5
Left Distractor - different action			5	5			5	5
No Distractor - blocked	5	5	5	5	5	5	5	5

	Light Stimulus				Sound Stimulus			
EXECUTE	Left Target		Right Target		Left Target		Right Target	
	turn	slide	turn	slide	turn	slide	turn	slide
No Distractor	5	5	5	5	5	5	5	5
Right Distractor - same action	5	5			5	5		
Right Distractor - different action	5	5			5	5		
Left Distractor - same action			5	5			5	5
Left Distractor - different action			5	5			5	5
No Distractor - blocked	5	5	5	5	5	5	5	5