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Response selection processes under 'free choice' task conditions

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Response Selection Processes Under 'Free Choice' Task Conditions

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Contents

Abstract

The majority of previous literature on response selection processes indicates that studies that have utilized the precue paradigm have done so under forced choice conditions. Under these condition the decision making process undertaken by the participant is influenced by the stimulus presented, and ultimately removed. The Experiments contained in this thesis utilized a free choice paradigm to investigate response selection when participants have a choice of available responses from which to select. The studies described in Chapter 2 highlight the influence of precue location on response selection and grouping. Response frequencies were significantly higher for precue matched locations and effectors under free choice conditions than unmatched locations and effectors. The Experiments in Chapter 3 involved flexion and extension movements of fingers, with precues now indicating specific movement directions, as well as effector/location parameters. Results indicated that grouping of responses occurs due to spatial features shared by the precue and stimulus, as opposed to effector features. Finally, the results of the Experiments in Chapter 4 indicate the influence that grouping of target objects by identity, colour and shape have on response selection. Response targets that shared features with a precued target were selected over unmatched targets. These Experiments indicate that under free choice situations, response selection process are highly influenced by precued locations and objects, with precue/target spatial relationships appearing to be stronger than precue/target effector relationships.

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Chapter 1

General Introduction

1.1 Background

When interacting with a complex environment, an individual is presented with a myriad of stimuli. Many of these will be superfluous to the actions being undertaken. Individuals must therefore learn to allocate attention towards those stimuli that they feel are relevant to the action being performed. As individuals become more skilled, they are able to ignore irrelevant stimuli, and thus reacting to relevant stimuli is easier and quicker. Higher skilled individuals may also be able to anticipate other peoples' future actions based upon these stimuli, and start programming a response earlier than lesser skilled individuals.

The process of selectively attending involves excitatory processes associated with relevant information, as well as inhibitory operations that suppress distracting stimuli. Inhibitory operations are used to suppress unwanted responses and play a significant role in stimulus recognition and response selection, but are commonly overlooked in processes associated with movement preparation. Examples of this process abound in 'Real World' situations. When driving a car, attention must be focused on relevant stimuli such as other road users, traffic signals etc, while irrelevant stimuli such as shop fronts and advertisements on the side of the road must be ignored. In sport selectively attending to the relevant stimuli is vital to ensure success, focusing on the correct body cues of an opponent for example. Previous winner of the World Footballer of the year award Ronadinho perfected the 'No look pass' bemusing opponents by presenting them with contrasting movement stimuli. This highly specific example shows the importance placed on making attending to relevant stimuli difficult, and how success in this area can help lead to successful performance during sporting activities. This successful attentional focus is also present in everyday life and in our interaction with the environment we interact with.

Anticipation is an integral process in the rapid and successful response to a stimulus. It is well known that response times to expected stimuli are quicker than to unexpected stimuli. Consider a batsman in cricket expecting a standard full delivery from a fast bowler. If this ball is bowled, the batsman will have a good chance of playing a successful defensive block or attacking shot. However if the bowler decides on a short pitched 'Bouncer' style delivery, the batsman may not be able to change his planned response in time resulting in either an increase in reaction time or an incorrect response (in this case incorrect shot) being selected. The influence of advance information on reaction time has numerous practical applications for strategy and tactics in sport and combat situations. From a theoretical standpoint, it also provides a basis for understanding the processes underlying selective attention and movement preparation. Interestingly, while most research on selective attention has been directed towards understanding how excitatory and inhibitory processes influence latency measures, relatively little attention has been given to how these processes influence which response is actually chosen. In the present research, we consider how advance information and the mechanisms underlying selective attention influence selection processes when participants have the freedom to choose any option from several alternatives (i.e., free choice).

A common technique used to investigate mechanisms of selective attention and movement preparation is the precue paradigm (E.g. Rosenbaum 1980). Precues give participants advance information about features of an upcoming stimulus and/or required response. This advance information may be valid or invalid depending on whether stimulus/response features match that of the precue. The typical finding is that reaction times for valid trials are quicker compared to when no advance information is provided whereas there is a reaction time cost on invalid trials (Adam, Hommel &

Umiltà, 2003). These reaction time benefits and costs have served as a basis for testing theories of selective attention as well as processes underlying movement selection and preparation.

In most research on selective attention, either a many:1 or a 1:1 stimulus/response mapping has been employed (see Adam, Hommel and Umiltà, 2003 for a review). In the case of many:1 mapping, the response is specified from the outset and hence response selection processes are not involved. For 1:1 stimulus/response mappings, the specific response to be produced is fully specified by the characteristics of the stimulus. Therefore, regardless of whether one must react to a situation that is expected or unexpected, there is only one appropriate response on any particular trial. It is interesting that these forced choice situations in which the selection of responses is externally determined have so commonly been used in the investigation of cognitive processes associated with selection and speeded decision making. In real world situations (e.g., sport, combat and driving), people are often placed in conditions of free choice where they can use an internal mode of selection to choose from a range of possible responses. Indeed, it has been suggested that mechanisms of selection that underlie decision making in internal versus external choice situations are fundamentally different (e.g., Baylis, Tipper and Houghton, 1997; Buckolz, Goldfarb and Khan, 2004).

1.2 Precue paradigms

Research that has been directed towards understanding the mechanisms involved in selective attention and the preparation of movements has commonly been undertaken using precue paradigms. In these experiments, participants are given advance information concerning certain features of upcoming stimuli (e.g. location, colour or identity) or responses (effector, movement direction and extent). The information provided can be valid, in the sense that the information given corresponds to the required response. Alternatively, the precue may be invalid, in that the information provided does not correspond to the required response. Typical findings in these studies are that reaction times following valid precues are quicker than when no advanced information is given. However, reaction times following invalid precues are longer than when there is no advance information. For example, in one of the early studies using the precue paradigm, Posner (1980) required participants to make simple or choice reactions to one of two stimuli. Under the simple reaction time condition, participants had a single key to press when they identified a change in luminance at one of two points. In the choice reaction time condition, participants were required to identify whether the detection stimuli was higher or lower than the precue. In both simple and choice conditions, participants were presented with a precue consisting of either a '+' sign or a left- right pointing arrow. If the '+' sign was presented, there was equal likelihood of the response stimulus being presented on either the left or the right of fixation. If an arrow precue was presented, there was probability of 0.8 that the stimulus would occur on the cued side. Under both simple and choice conditions, quickest reaction times occurred in trials with a valid precue and slowest reaction times in trials with an in-valid precue. This clearly showed indicated the reaction time benefits of a valid spatial precue in focusing attention for forthcoming stimuli, and highlighted the fact that it may be possible to orient attention after a spatial cue without changes in visual fixation. Since the work of Posner (1980), many studies have utilised the precue technique for providing information regarding upcoming movements, with these precues taking a number of different forms, such as providing information on the specific limb to be used (Rosenbaum 1980) or the position of targets to be responded to (Reeve and Proctor, 1986; Cauraugh & Horrell 1988)

1.3 The influence of advance information on response preparation

Rosenbaum (1980) used precues to provide advance information regarding arm, direction and extent of movements in a target based pointing task. Precues provided could contain information on one, two, three or none of the variables involved in the movement. The condition in which full precue information was provided produced the fastest reaction times, whilst the precue containing no response specific information produced slowest reaction times. When information was given on two of the three variables in the precue, there were significant differences in mean reaction times depending on the uncued variable. Reaction times were shortest when the uncued variable was the extent of the movement, and longest when the uncued variable was which arm would be used. Responses in which arm and extent but not direction were cued produced reaction times shorter than the arm uncued condition, but longer than the extent uncued condition. Similarly, when only a single feature of the response was precued, reaction times differed depending on which feature was presented. Again all three were significantly different, with responses requiring extent and direction programming having the shortest reaction times. Next shortest was extent and arm followed by direction and arm. These data suggest that under precue conditions, it is possible to undertake a certain amount of response programming prior to the stimulus. Under this particular protocol, it appears that specification of which arm will be required in the response has the largest effect on reaction time, and therefore appears to be most important feature required for pre-programming. In both the single and dual feature precue conditions, those which required arm programming after the stimulus showed longest reaction times.

Larish and Frekany (1985) performed similar experiments but found contrary results to those of Rosenbaum (1980). Rosenbaum found differences in reaction times depending on the response features presented to the individual within the precue. He proposed that the components were specified serially and that they were done so in no particular order. However, Larish and Frekany found that knowledge of movement direction was required before arm or extent could be programmed. Programming of movement direction however, can occur regardless of what information is provided about the arm and extent of the movement. They also reported that responses in which more than one motoric decision had to be made were done in parallel, again in direct contrast to Rosenbaum. They quoted the reaction times found for the four movements carried out when direction information was not present in the precue as support for this statement. An increase in the number of movement parameters that had to be programmed in the reaction time interval (from 1-3) should have displayed an associated rise in reaction times. However this was not the case.

It should be noted that there were slight methodological differences in the Larish and Frekany experimental design that may account for the contrary results found, namely the standardisation of stimulus-response (S-R) pairs across all trials. This was not done in the experiments by Rosenbaum, and may go someway to explaining the difference in findings. In a second experiment undertaken by Larish and Frekany the effect of manipulating a pre-programmed movement at initiation was investigated. Invalid precues were utilized in order to produce a paradigm that required reprogramming of certain parameters of a response. They found that alterations in parameters of 'arm' or 'extent' could be made independently of any other response features, and could be done so simultaneously. However, when the alteration required a change in direction of movement, there was no difference in reprogramming time depending on the number of additional factors that also needed reprogramming. This indicated that the entire response has to be reprogrammed as soon as direction changes.

The manner in which a precue is presented will have varying effects on the programming of the response. Spatially related cues, such as the highlighting of possible target locations or an arrow pointing at a certain location, have been shown to have beneficial effects on the orientation of an individuals attention. The focusing of perceptual processing resources on a possible stimulus area facilitates faster response time and accuracy. The point at which response cueing benefits occur within the information processing system is of some debate. Adam, Hommel and Umiltà, (2003) indicated that previous examinations had suggested 3 possible locations within the information processing system; to the motor system, to stimulus-response translation and to perceptual encoding. Miller (1982), who had manipulated the movement precuing technique used by Rosenbaum (1980) to produce the *response-cueing task*, interpreted the various cueing benefits they had found as being due to differential response preparation processes and located within the motor system. Participants were required to make button press responses with index and middle fingers of both hands to various stimuli following precues. Following a warning signal either a non informative precue was presented (plus signs precuing all 4 possible responses positions) or pairs of precues were presented at various positions. These cues indicated positions assigned to two fingers on the same hand (*Prepared: hand* condition), homologous fingers on different hands (*Prepared: fingers* condition), two different fingers on different hands

(*Prepared: neither* condition). Miller suggested that the benefits found in the hand cued condition were due to factors that allowed more efficient preparation of two effectors on the same hand than of two effectors on different hands. However Reeve and Proctor (1984, 1985) argued that the benefits lie in the stimulus-response translation process. They alternated the placement of the participants' fingers on the response keys so that they overlapped and became ordered (from left to right) "right index, left middle, right middle, left index". This resulted in an important change in the results. The usual advantage for the hand-cued condition turned into an advantage from the neither-cued condition. This indicated that the left/right hand cue condition benefit found in several precue studies, may be due to a left/right stimulus location benefit. Reeve and Proctor stated that this implied that the location for the precuing benefit was in the response translation stage. Adam (1994) highlighted the possibility that the arrangement of the targets may have enabled an early perceptual encoding advantage in the left-right precue condition. To investigate this, the target array was manipulated by moving the centre two targets closer together, thus forming a stronger perceptual subgroup. This manipulation significantly reduced the strength of the left-right advantage. It was suggested that these results indicated the benefits of the precue were due to perceptual grouping of targets, be they inner-outer or left-right.

1.3 The Influence of Perceptual Factors

In real world situations, it is often the case that when individuals have to respond to an unexpected situation, the stimuli presented to them does not indicate a particular response that must be produced. It is more often the case that the individual has a choice of responses, and selection is not predefined. An individual may prepare a particular response based on certain contextual information, but have to produce an entirely different response when the final stimulus information is provided. What effect do the various features of the initial stimulus information have on response selection? This study will examine the effects of a pre-programmed response on a subsequent response in which the subject is free to select a number of responses. It has been suggested that when a particular response is pre programmed, and subsequently not needed, features and characteristics of this response will bias actual response selection. This may take the form of activation or inhibition of certain response elements. A number of studies have investigated inhibition using procedures that required selection processes governed by the stimulus array (external) as well as self-determined selection (internal).

Tipper, Brehaut and Driver (1990) asked participants to respond (by depressing keys) to a target stimuli presented on a computer screen, and ignore distractor stimuli that were presented at various locations. They found that reaction times were slower in trials in which the target stimuli were presented at a site previously occupied by a distractor stimuli, compared to trials were target stimuli location was unrelated to the distractor location in the previous trial. It was suggested that this increased RT was due to the presence of a residue of the inhibition from the previous trial at that location. It is clear that these distractors cannot simply be ignored during visual searching, even in trials in which the selection process is not undertaken by the individual.

There appears to be conflicting evidence concerning the ease with which individuals can respond to targets that have previously been ignored. Park and Kanswisher (1994) presented individuals with two identical targets in two locations, and the participant had to select one to respond to. In subsequent trials, when participants had to respond to the unselected target position, RT's were faster than when there was no relation to previously unselected targets. Other studies (Posner, Rafal, Choate and

Vaughn, 1985; Lupiánez, Milliken, Solano, Weaver and Tipper, 2001) have found evidence that responses in which the participant is required to return attention or gaze to previously attended targets were slower than those in which attention was shifted to new targets. These studies therefore provide evidence that not only is there a reduced response time to previously used targets, but also a preference to respond to novel targets rather than return gaze to a target that previously required a cognitive action, be it recognition or inhibition

Baylis *et al* (1997) investigated both internal and external selection processes in basic target-response paradigms. They stated that objects that are defined as distractors by an individual, rather than by the nature of the experiment itself e.g. O's represent targets, X's represent nontargets, are more fully analyzed and their characteristics more readily recognised in later tests. This self selection process clearly involves greater analysis of the objects placed within an individual's vision than when targets and distractors are pre defined.

There have also been studies that have shown that similarities between nontargets, as well as between targets and nontargets, can have a negative effect on visual search speed and efficiency (Duncan & Humphreys 1989). Heterogenous nontargets are thought to form a less easily defined group than nontargets sharing the same features, making them harder to group together and reject simultaneously.

These studies are designed to investigate this precuing effect in tasks in which it may be possible for participants to place response targets into visual and/or stimulus groups. In addition to this we will be using stimuli that specify a set of possible alternatives rather than the 1:1 mapping mentioned earlier.

1.4 Selection and Grouping

The debate over the grouping of visual targets, with presentation of space-based and object-based theories of selective attention has been ongoing for a number of years (See Duncan, 1984 for a review). An extensive list of studies can be found in support of both arguments. Egly, Driver and Rafal (1994) show evidence of both object-based effects *and* spaced-based effects in normal participants within the same situation. Response latencies to stimuli at one location were delayed if 'covert orienting had been directed by peripheral brightening to a different location within the same object', indicating a spaced based component of selection, as attention was always focused on the same object. An object focused component of selection was evident in trials in which participants had to respond to non-precued stimuli. In this case reaction times were faster to stimuli placed within the same object as a pre-cue, compared to equidistant stimuli contained in separate objects than a pre-cue. It is clear that stimuli were 'grouped' (all be it with the aid of external images, as opposed to an internally produced).

It is our assumption that response selection biases have a number of underlying factors that may be manipulated in order to fully explore the effects of distractor placement on motor programming tasks. Studies examining response selection have investigated the effect of grouping response features using both precue and distractor paradigms. Egly *et al* (1994) examined the precue costs of presenting a precue at one end of a rectangular shape, and then presenting the response stimulus at either the uncued end of the same object, or within an uncued object. They found that response times were quicker when the stimulus occurred within the same object as the precue. Bekkering and Pratt (2004) investigated the effect of both object and spaced based selection processes. They replicated previous findings of object-based advantages in precue tasks with non-target based responses (i.e. key press response). They then investigated the effect of using goal directed hand movements under the assumption that the underlying processes would be space based. They found that responses were quicker to uncued targets that shared directional characteristics with a precue than targets which were uncued and shared no directional characteristics with a precue. Additionally, in two further experiments, they found that the object-based response effect was found even in tasks which contained both object-based and space based characteristics and required goal-directed responses. They concluded that when both object and space based cues are combined in a goal-directed action, the selection process of a response is primarily object based.

Investigations have also looked at the effect of presenting distractors within objects containing the target to be responded to. Egly et al (1994) used two separate tasks to indicate this, the first utilizing single objects in which stimuli were placed, the second, lines of circles. In the first experiment, participants were found to respond most rapidly when a visual precue was presented at one end of an object, and a target then presented at the same location, as would be expected in terms of the focusing of attention. They also found that responses were quicker to targets placed at the other end of a cued object, than within an uncued object equidistant from the precue location. The second experiment utilized 2 rows of 4 circles as their cued and uncued objects, the findings of experiment one were replicated. This second experiment replicated these initial findings, indicating that any object based grouping includes 'grouping by proximity as well as by connectedness' indicting the link between both spatial and object grouping.

Adam and colleagues put forward a Grouping Model in which they tried to combine previous thoughts on stimulus and response set coding processes;

'If the cue indicates a strong, good subgroup of stimuli that corresponds closely with a strong and similar grouping of responses, then a fast, automatic selection (activation) of the cued responses occurs. If, on the other hand, the cue indicates stimuli belonging to different subgroups, or there is a mismatch between the grouping of the stimuli and the grouping of the responses, then a slower, effortful process is needed to create a good, finely tuned subgroups (Adam *et al,* 2003 pp 308)

1.5 1:1 mapping in selective attention programmes

It is important to again state that most of the recent literature investigating selective attention has involved the presentation of stimuli with direct 1:1 mapping between the stimulus and response. In other words, there is no uncertainty as to which response the individual should produce. The action is therefore externally determined, where choice is actually removed from the individual. These experiments have been designed to investigate the cognitive processes of decision making, yet they are being carried out under conditions in which the individuals' decision making process is predefined by the stimuli presented to them. This therefore removes all decision making from the task.

As discussed earlier, studies that have been undertaken involving a free choice element are not prevalent in the decision making literature. However there are a number that have found noteworthy results. Studies have been undertaken that have found subliminal cues can have an effect on subsequent free choice (where the individual is free to choose from a number of responses) paradigms (Schlaghecken & Eimer, 1997). In these studies, participants were first presented with a masked arrow cue that pointed either left or right. After this they were either faced with a forced choice response, where an arrow pointed left or right and they had to respond in that direction. Alternatively there was a free choice condition, where a double ended arrow was presented and they could respond in either direction. It was found that in free choice trials, when the interval between the precue and the stimulus was short, participants were more likely to respond in the same direction as the masked prime. However, in free choice trials with a longer precue-stimulus delay, responses were biased away from the prime.

It is the aim of this investigation to examine the features associated with selective attention and the grouping of response parameters under both free and forced choice conditions. The free choice paradigm employed was designed to replace the decision making element of response selection that has been removed from many previous studies due to the mapping of precues and responses. The basis for each version of the paradigm used in the experimental chapters involved the presentation of a specific individual location/response as a precue. A subset of responses not containing this precued response was then presented as a stimulus. Participants were asked to react as fast as possible and select a response from this stimulus set.

The investigations contained in Chapter 2 provided participants with precues that either grouped response effectors on the same hand, or matching effectors on opposite hands. Following these precues, stimuli were presented that placed the individual into either a free or forced choice paradigm. Of interest to us were the selection processes undertaken under free choice conditions, and whether the precuing of a particular effector influenced the selection process of the participant. Both 'Go-to' and 'No go-to' precues were used, and their varying effects examined.

Investigations in Chapter 3 examined the effect of precuing both individual effectors, as well as effector direction (flexion/extension movements). With 2 parameters now under investigation, the strength of preparatory and inhibitory factors of these parameters under free choice conditions was the main focus of the first experiment. Within the second experiment a condition was utilized in which the direct spatial mapping of stimuli to effectors was altered. Under this paradigm it was hoped that separation of the coding of spatial response features and effector response features would be possible. Identification of these response features enabled further investigation of the mechanisms involved in the pre-programming of response features based on an informative precue.

Chapter 4 contains a set of experiments that were designed to investigate the effect of the specific features of target objects on response selection under free choice conditions. The effect of precue object identity, colour and shape, in relation to other selectable targets, was of interest. Specifically we were interested in whether precue image features may override the bilateral precue effector preparatory effect seen in previous experiments.

Chapter 2

Response Selection and Grouping Processes under Free Choice and Forced Choice Conditions in a Basic Precue Paradigm

2.1 Introduction

Finger keypress responses have commonly been employed in studies of speeded perceptual-motor behaviour because they provide a simple method by which reaction times can be recorded. They also have the advantage that they enable relatively straightforward manipulation of factors pertaining to stimulus-response mappings and the relation between response features. With regard to the latter, researchers have compared preparatory processes associated with fingers on the same or different hands and between homologous and non-homologous fingers.

In one of the early studies to show grouping effects between finger responses using 1:1 mapping, Miller (1982) required participants to produce index and middle finger key press responses to one of four possible stimuli. Precues were presented prior to stimulus onset that either provided no specific advance (i.e., *uninformative* precue) or enabled preparation of two of the four possible responses (i.e., *informative* precue). The *informative* precue specified either two fingers on the same hand (*prepared:hand* condition), the same finger on either hand (*prepared:finger* condition) or alternate fingers on either hand (*prepared:neither* condition). The results indicated that reaction times in the *prepared:hand* condition were faster than reaction times in the *prepared:finger* and *prepared:neither* conditions and may therefore be hierarchical in nature.

In order to investigate the locus of the precuing benefits, Reeve and Proctor (1984) extended the work of Miller (1982) by manipulating the orientation of response effectors and visual targets. One group of subjects were required to overlap their hands, resulting in the order of fingers from left to right now being right index; left middle; right middle; left index. This cross matching of response effectors will be discussed in greater detail in chapter 3, however it is useful to note here that a visual spatial relationship was found to effect response preparation rather than effector grouping. The RT benefit of precuing effectors on the same hand was no longer present, with responses to targets grouped spatially to the left or right of visual fixation producing quickest reaction times. Of interest in this investigation was whether this spatial benefit of precue grouping occurred in the free choice trials employed.

In a recent study, Adam and Pratt (2004) compared precuing benefits of finger responses with that of pointing responses. The stimulus display consisted of a row of four boxes similar to that described above. In one condition, the responses consisted of finger keypresses of the index and middle fingers of both hands arranged in a spatially compatible manner with that of the four stimulus boxes. In another condition, participants were required to perform pointing responses to one of the boxes. On each trial, the precue consisted of two of the boxes being coloured red. This was then followed by one of these boxes turning green. Adam and Pratt showed that for the finger keypresses, reaction times were fastest following a precue in which either the left or right side was specified (i.e., both precued locations were either the two left boxes or the two right boxes). The next quickest reaction times occurred when either the two inner or two outer stimulus locations were precued while the slowest reaction times were observed when an inner and outer location were precued. Interestingly, these precue effects were not observed for the pointing responses. Adam and Pratt proposed that response related processes are involved for tasks involving more than one effector and hence response characteristics have an important influence on precuing benefits.

To date, most decision making studies in the motor control area have utilised only forced choice response conditions in which there is a 1:1 mapping between stimuli and responses. In the current study we intended to utilize the 'Free choice' paradigm that has been used in a number of previous studies (Berlyne 1950, 1957). Our aim was to further investigate the process of response grouping found in previous studies. Where grouping in forced choice investigations has led to reductions in reaction times, under free choice conditions we were interested in the influence grouping may have on response selection processes. We examined this grouping of response features through utilization of a multiple effector response paradigm. It was hoped that grouping of targets and/or effectors would take place based on cue position, resulting in a preference for selecting a particular response when placed in a free choice situation. Whilst the choice of response was not completely free in the sense that a sub group of two targets was indicated by the stimulus, selection of either of these targets equated to correct response selection. The use of multiple effectors increases the influence that grouping mechanisms have on responses. In the present experiments, we extend the precuing effects observed by Adam and Pratt (2004) to response selection under free choice conditions. The experiments involved a novel paradigm in which participants were required to choose from a range of possible responses following the presentation of advance information. On each trial, a precue was presented that indicated to the participant which response to produce (go-to precue) or prevent (no-go-to precue). This was followed by the stimulus that specified a subset of possible responses rather than a specific response (1: many stimulus-response mapping). The choice of response available to the participants depended on whether the precued response was within or outside the range of alternatives specified by the stimulus. In Experiment 1, the choice was between two fingers on the same hand while in Experiment 2, participants were given a choice between fingers on different hands. The inclusion of two ISI's in both these experiments allowed investigation of the timing of any precue presentation may have on free choice selection. It was possible to investigate possible conscious strategic processes that may have been undertaken under longer response preparation times. In terms of response selection hypothesis, it was expected that response selection would be biased towards homologous fingers to that of the precue under free choice conditions.

2.2 Experiment 1

Method

Participants

Twenty four self declared, right hand dominant, university students served as participants in the study (12 males, 12 females, ages 18-35 yrs). All participants in this experiment were naive to the hypothesis being tested and inexperienced at the experimental task. They gave their informed consent prior to participation in the study. The experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, Bangor University for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

Participants sat in a chair in front of a 17" computer monitor that was placed on a table top. The monitor was positioned 45 cm in front of the participants. The display on the monitor consisted of four squares (4 x 4 cm) arranged horizontally with a separation of 4 cm (side to side) on a black background. The squares had a white outline and were not filled. The middle and index fingers of the left hand were placed on the 'F' and 'G' keys of a standard keyboard, respectively, while the index and middle fingers of the right hand were placed on the 'J' and 'K' keys, respectively. The four squares on the monitor were mapped in a spatially compatible manner with the four finger presses such that the leftmost square corresponded to the left middle finger keypress, and so on.

Procedure

At the beginning of each trial, the four target squares appeared on the screen. A precue was then presented which consisted of one of the squares turning green for 1000 msec before returning to its normal state. The stimulus was presented between the second and third squares following an interval of either 100 or 750 msec. It consisted of an arrow pointing to the right or left. The stimulus arrow defined a subset of responses. An arrow pointing to the right specified the two right hand finger responses while an arrow pointing to the left corresponded to the two left hand responses (see figure 2.1). The stimulus remained on screen until the participant made a response.

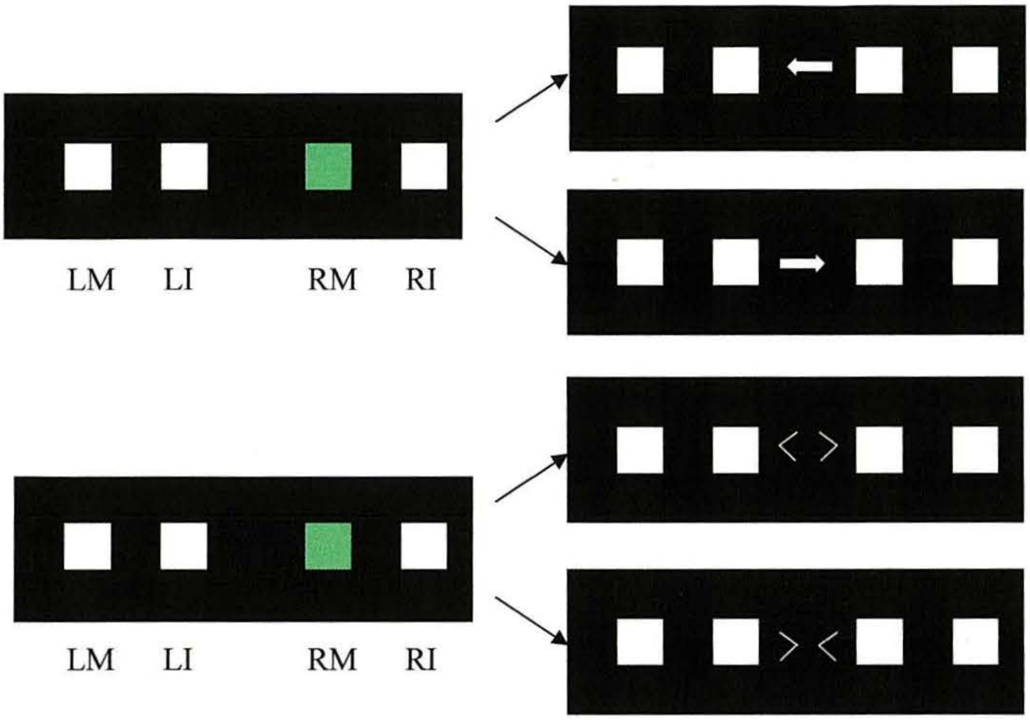

Figure 2.1 Diagram of stimulus display consisting of four target boxes on a computer monitor. Each trial involved the presentation of a precue (left panel) followed by a stimulus arrow pointing to the left or right in Experiment 1 (Top, right panels), or a pair of stimulus arrows pointing inwards or outwards in Experiment 2 (Bottom right panels). Free choice trials are shown in each of the upper stimulus diagrams and forced choice in the lower.

In one block of trials (i.e., go-to precue), participants were instructed to press the response corresponding to the precue if the stimulus arrow pointed to the same side as the precue. This was a forced choice situation in that only one alternative was appropriate. For example, if the right index finger was precued and the stimulus arrow pointed to the right, participants had to press the right index finger key. However, if the arrow pointed to the opposite side to that of the precue, the participant now had a free choice situation in that they could choose either of the two responses. In another block of trials (no-go-to precue), participants were told to prevent producing the response that corresponded to the precue. Therefore, if the stimulus arrow pointed to the same side as the precue, participants were required to produce the response that did not correspond to the precue. For example, if the inner right box was precued and the arrow pointed to the right, participants were required to respond with their right middle finger. If the arrow pointed to the left, participants again had a free choice situation and could choose between the index and middle fingers of the left hand.

Each participant performed two blocks of trials, one in which the precues were designated as go-to precues and one in which precues were designated as no-go-to precues. For each block of trials, the eight combinations of the four precue positions and two stimulus directions were randomized in a pseudo random fashion such that each combination was administered before any was repeated. Each combination was administered twenty times giving a total of 160 trials per block. Since each combination of precue position and stimulus direction occurred equally often, there was a probability of 50% that the stimulus would point to the same or opposite side to that of the precue. The order of the Go-To and No-Go-To precue trial blocks was counterbalanced between participants.

Of primary interest in the present experiment were those trials in which the stimulus arrow pointed to the opposite direction to that of the precue (i.e., free choice trials). Specifically, we were interested in whether participants would choose the finger response homologous or non-homologous to the precue. Hence, our primary dependent measure consisted of the frequency of responses. This was analyzed by submitting participant means to separate 2 Precue Condition (go-to, no-go-to) x 2 ISI (100, 750 msec) x 2 Response Type (same finger, different finger) fully repeated measures ANOVA. In addition, a separate analysis of both free choice and forced choice RT's was undertaken. This was carried out using a 2 Precue Condition (go-to, no-go-to) x 2 ISI (100, 750 msec) x 3 Response (forced choice, same finger, different finger) fully repeated measures ANOVA. Interactions were broken down using Tukey (HSD) post-hoc tests. Degrees of freedom were corrected by greenhouse geisser where appropriate throughout this thesis.

Results

Response Frequencies

The analysis of response frequencies revealed a significant interaction between Precue Condition and Choice, $F(1, 23) = 9.1$, $p < .01$. Breakdown of this interaction revealed that for the go-to precue condition, the proportion of trials in which participants produced a finger response that was homologous to the precue was greater than non-homologous finger responses. For the no-go-to precue condition, there was no difference in the frequency of responses between homologous and non-homologous finger responses. This was the case at both ISIs (see Figure 2.2).

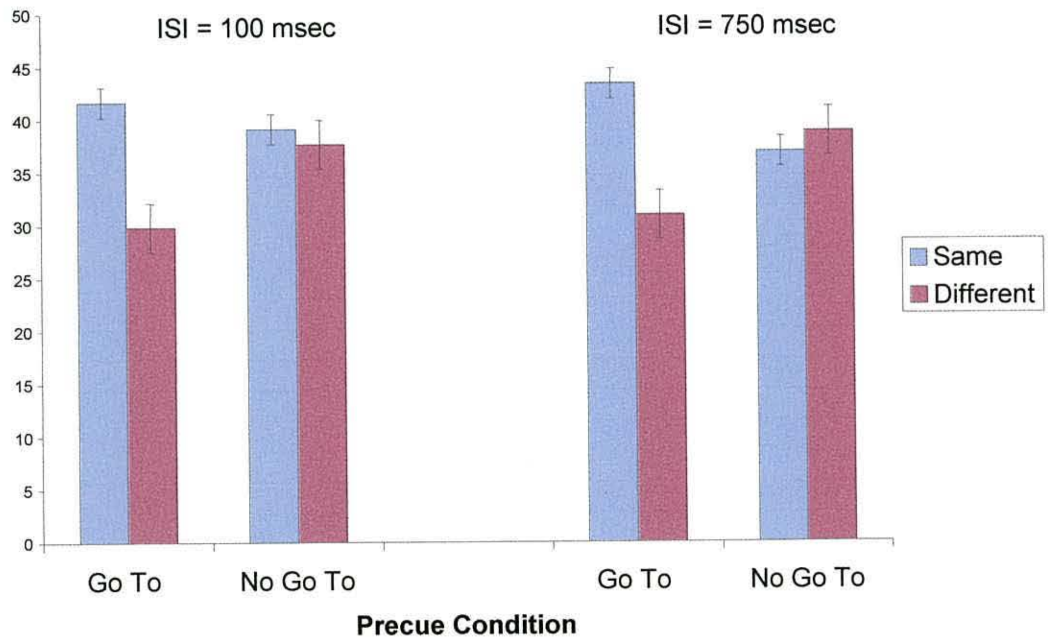

Fig.2.2 Response frequencies under free choice conditions following both Go to and No Go to conditions and for both 100 msec and 750 msec ISI intervals.

Reaction Times

The analysis of free and forced choice reaction times revealed a significant 3 way Precue Condition x ISI x Choice interaction, $F(2, 46) = 11.2$, $p < .01$. Breakdown of this interaction revealed that in the go-to condition, reaction times were shorter for the forced choice compared to free choice trials. Also, on free choice trials, reaction times were shorter for same finger than different finger responses at longer ISI (see Table 2.1). In the no-go-to condition, reaction times for the forced choice trials were longer than the free choice trials but only at ISIs of 100 msec. Also, at longer ISIs, reaction times were shorter when participants produced a finger response that was different to the precue than when a same finger response was chosen.

	No go-to precue		**Go-to precue**	
Response	ISI = 100	ISI = 750	ISI = 100	ISI =750
Forced Choice	557	406	490	358
	(11)	(10)	(16)	(10)
Homologous finger	516	433	539	415
	(13)	(10)	(17)	(12)
Non-homologous finger	516	418	550	431
	(13)	(11)	(19)	(11)

Table 2.1; Mean Free choice reaction times for ISI = 100msec and ISI = 750msec trials under Go-to and No go-to precue conditions n=24. Standard error shown in parenthesis.

Errors: In the go-to block of trials, participants produced the non-precued response on the same hand as the precue on 5% of the trials. The precued response was inappropriately produced when the arrow pointed in the opposite direction on 3% of trials. In the no-go-to condition, the precued response that was to be prevented was produced on 4% of the trials. All other error rates were ≤1%.

2.3 Experiment 2

Method

Participants

Twenty four self declared, right hand dominant, university students served as participants in the study (12 males, 12 females, ages 18-35 yrs). All participants in this experiment were naive to the hypothesis being tested, inexperienced at the experimental task and had not partaken in Experiment 1. They gave their informed consent prior to participation in the study. The experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, Bangor University for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

The same apparatus was used as in Experiment 1.

Procedure

At the beginning of each trial, the four target squares appeared on the screen. Similar to Experiment 1, a precue was then presented that consisted of one of the squares turning green for 1000 msec before returning to it's unfilled state. The stimulus was then presented between the second and third squares following an interval of either 100 or 750 msec. The stimulus again remained on screen until a response was made. In contrast to Experiment 1 where the stimulus consisted of an arrow pointing to the right or left, the stimulus in this experiment consisted of arrows pointing inwards or outwards. Arrows pointing inwards specified the index fingers of each hand while arrows pointing outwards specified the middle fingers.

For go-to precue trials, participants were instructed to press the response corresponding to the precue if the stimulus arrow corresponded to that of the precue (e.g., an index finger response was precued and the arrow pointed inwards). If the stimulus arrow did not correspond to the precue (e.g., index finger precue but arrow pointed outwards), participants could choose a response from either hand that corresponded to the precue. Thus, in contrast to Experiment 1 where the choice was between fingers on the same hand, the choice was now between homologous fingers on separate hands.

For no-go-to precue trials, if the stimulus arrow corresponded to the precue, participants were required to produce the corresponding finger response on the non-precued hand. For example, if the right index finger was precued and the stimulus arrow pointed inwards, participants would be required to produce the left index finger response. However, if the stimulus arrow did not correspond to the precue, participants were placed in a free choice situation. For example, if the right index finger was precued and the stimulus arrow pointed outwards, participants could choose either a middle finger response from either hand.

Participants performed one block of trials under the go-to precue condition and another block under the no-go-to precue condition. For each block of trials, the eight combinations of the four precue positions and two stimulus arrows were randomized in a pseudo random fashion such that each combination was administered before any was repeated. Each combination was administered twenty times giving a total of 160 trials per block. The order of the Go-To and No-Go-To precue trial blocks was counterbalanced between participants.

Of primary interest in the present experiment were those trials in which the stimulus arrow did not correspond to the precue. Specifically, we were interested in whether participants would choose the finger response on the same or other hand to that of the precue. Hence, our dependent measures consisted of the frequency of responses on the same and different hand to that of the precue and the latency of these responses. These measures were analyzed by submitting participant means to separate 2 Precue Condition (go-to, no-go-to) x 2 ISI (100, 750 msec) x 2 Response Type (same hand, different hand) fully repeated measures ANOVA. Interactions were broken down using Tukey (HSD) post-hoc tests.

Results

Response Frequencies

The analysis of response frequencies revealed significant interactions between precue condition and response type, $F(1, 23) = 6.9$, $p < .01$, and ISI and response type, $F(1, 23) = 24.1$, $p < .001$. The three way interaction between precue condition, response type and ISI was also significant, $F(1, 23) = 5.2$, $p < .05$. As shown in Figure 2.3, participants chose a finger response on the same hand as the precue more often than a response from the other hand. This was the case for both go-to and no-go-to precue trials. However, the proportion of trials in which the same hand was chosen was greater in the go-to compared to no-go-to precue condition.

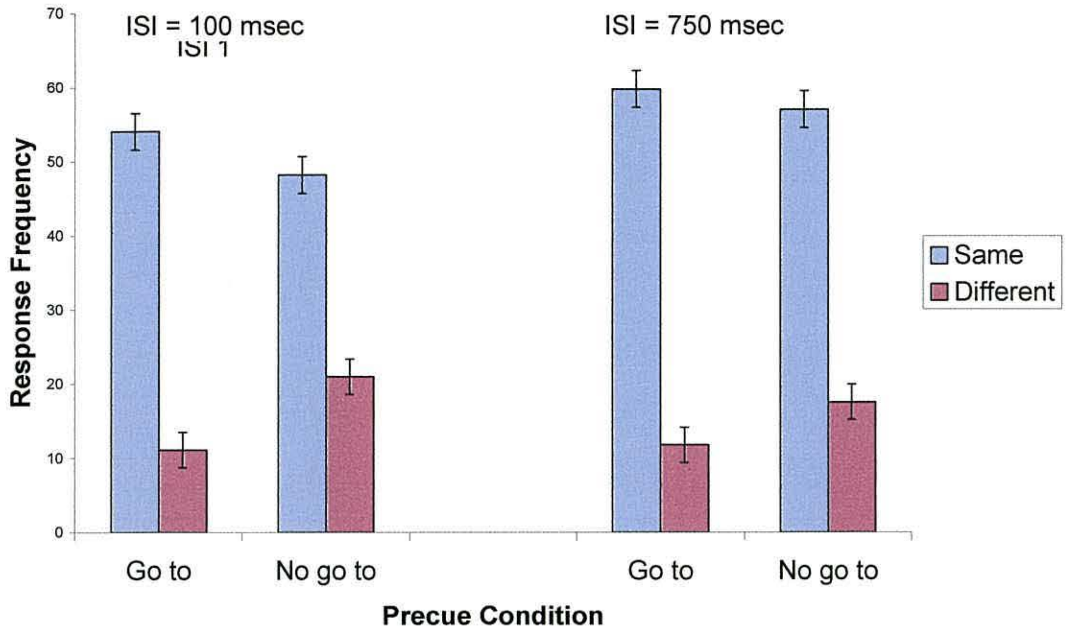

Fig. 2.3 Response frequencies under free choice conditions following both Go to and No Go to conditions and for both 100 msec and 750 msec ISI intervals.

Reaction Times

The analyses of reaction times revealed only a significant effect of ISI, with reaction times decreasing as ISI increased (632 msec and 498 msec respectively) However, it is important to note that the number of trials in which participants chose a response from the different hand to the precue was very low. This could account for the lack of reliable findings from reaction time measures.

	No go-to precue		**Go-to precue**	
Response	ISI = 100	ISI = 750	ISI = 100	ISI =750
Forced Choice	608 (13)	474 (9)	544 (17)	410 (9)
Homologous finger	606 (14)	491 (10)	631 (16)	501 (12)
Non-homologous finger	607 (11)	479 (9)	622 (15)	479 (10)

Table 2.2; Mean Free choice reaction times for ISI = 100msec and ISI = 750msec trials under Go-to and No go-to precue conditions n=24. Standard error shown in parenthesis.

Errors

Under go-to conditions, responses equating to the precue being selected were produced on 5% of free choice trials. Similarly, under no-go-to conditions, responses equating to the homologous non precued finger were produced on 3% of trials. All other error rates were ≤1%.

2.4 Discussion

The purpose of the current study was to investigate the influence of excitatory and inhibitory processes on speeded perceptual-motor decision making. Whilst previous examinations have focused on this area, the decision making element utilizing free choice situations has not yet been examined. Participants were presented with a four target array that mapped spatially to four keys depressed by the index and middle fingers of each hand. A precue was provided that informed participants to prepare one of the four responses, followed by a stimulus indicating a subgroup of two targets (those mapped either to the right or left hand) from which a response should be selected. In the go-to condition, if the precue target was contained within the stimulus set participants were to produce the response corresponding to the precue. If the precue was not contained within the stimulus set then subjects were free to select either target. In the no-go-to condition the precued target was to be inhibited and *not* selected if contained within the stimuli set, with either target being available if the precue was not within the stimulus set. The nature of these free choice trials means that it was possible to investigate the effect of precuing certain stimulus and/or response features on the decision making processes.

Before discussing the effect of response preparation on free choice responses, it is important to first confirm that preparation of a response had indeed taken place. Evidence of response preparation was demonstrated in the reaction time findings with forced choice response latencies being significantly quicker than of those produced under free choice response conditions. On this evidence we can assume that subjects were indeed using the precue to prepare a particular response prior to stimulus presentation.

The data from Experiment 1 showed that under go-to conditions precue presentation had a marked effect on response selection. More specifically under free choice conditions response frequencies were higher for homologous precue responses than non-homologous under both ISI's. Adam (2003) and Miller (1982) found that in tasks requiring finger press responses by effectors on both the left and right hands, precue presentation had a significant effect on response latencies. It appeared easier to prepare two responses on the same hand than it did to prepare two responses on homologous fingers on different hands. However, precuing two effectors that were not homologous to either the finger or hand that was precued produced the slowest response latencies. This appears to indicate that although response grouping processes make it easier to prepare multiple similar responses on the same hand, preparation of similar responses across hands is still possible and indeed does occur.

The results from the go-to condition in Experiment 1 are consistent with the preparation of response features across hands. It appears that grouping of response effectors occurred, with activation of an effector by the presentation of a precue at a spatially mapped target leading to activation of the same finger on the uncued hand.

This response preparation was also evident in the reaction time results, with faster reaction times evident when subjects produced homologous stimuli responses compared to non-homologous. There is clear indication here of response features being prepared on multiple effectors despite individuals only being instructed to prepare a single response.

In Experiment 2 participants were now required to make response selections between fingers on separate hands. Under go-to conditions, responses were far more likely to be produced by the finger on the same hand as the precued finger than any other response. This is consistent with the results found by Miller (1982) and Adam *et al* (2003). Preparation of responses produced by effectors on the same hand is more efficient than preparing responses produced by finger-matched effectors on different hands.

The data from the no go to condition is similar to that seen in the go to condition in that responses were more frequently made by effectors on the same hand as the precue following a free choice stimulus. This may be due to the processes undertaken during inhibition of a response. Extensive attentional resources may be required in the process of inhibiting a response. It has been documented that the process of inhibiting a response involves activation of many of the systems used in recognition of a response (Houghton and Tipper 1996). Before inhibition can take place, attention must be diverted towards the target; this would lead to focus being indirectly placed on the adjacent target. A tendency to select this adjacent target under free choice conditions was observed in the current experiment, which indicates that this attentional allocation may occur.

In the first experiment, it was found that under no-go to conditions, reaction times were slower to the single target available following a forced choice stimulus than to the homologous target in free choice conditions. This may be explained by the extra selection processes undertaken during target selection. Under free choice conditions, upon presentation of the stimulus, no recall of the inhibited target is required and subjects simply select one of the available targets. However under forced choice conditions, subjects have to first recognise the inhibited target and suppress any responses to this target, before then selecting the responses linked to the available target. This extra processing may result in the longer reaction times present under the shorter ISI conditions.

As presented previously in this discussion, effects found in both this and previous experiments have been strongest when grouping of effectors occurs within hands as opposed to between hands. It may be suggested that in Experiment 1, where the stimulus presented naturally grouped the responses by hand, that stronger effects were found than in Experiment 2, where responses were grouped across hands. The grouping of effectors in Experiment 1 should adhere to the 'Top-down' processes described in many previous examinations. However Experiment 2 may well involve effortful 'Bottom-up' processes, the undertaking of which may dilute the cross-over effects of both activation and inhibition present in Experiment 1.

Both these two no-go to findings clearly require additional investigation; however the focus of this thesis will remain on the processes involved under excitatory precues. No-go to precues and their influence will be discussed at a later date, with suggestions of future modes of exploration proposed.

Chapter 3

The Influence of Precue Presentation on Free Choice Response Selection in a Flexion and Extension Movements of the Fingers

3.1 Introduction

The preceding investigation highlighted the influence that preparatory factors can have on response selection processes. Initial investigations (Miller 1982) discussed the arguments put forward for continuous and discreet information processing models. Continuous models suggested that information was constantly being received and processed. Discreet models however suggest that chunks of information must be collect before they can be processed and responses selected. Miller suggests that the process of response preparation was a complex one and that certain stimulus characteristics can be processed early than others. It appeared that it was possible for response preparation to be undertaken as soon as specific stimuli attributes or codes are clearly defined and processed, he labelled this an asynchronous discrete coding model. An assumption of this paradigm was that preparation of two fingers on the same hand results in faster response times than preparation of two fingers on different hands.

This assumption was challenged however by Reeve and Proctor (1984) who utilised a response set that altered the relationship between effectors and stimuli. This manipulation is of high significance in the current chapter and was also used as evidence in challenging the asynchronous discrete coding model. Reeve and Proctor (1984) utilized a crossed hands paradigm in order to test the findings obtained by Miller (1982). Specifically, they tested the results obtained that indicated preparatory effects were more efficient when effectors on the same hand were precued. The assignment of fingers to response keys was altered so that the hands were overlapped. From left to right, the response keys were now depressed by the right index, left middle, right middle and left index fingers. Precues were presented that placed possible responses into the *prepared: hand*, *prepared: finger* or *prepared: neither* groups as used by Miller (1982). This meant that targets corresponding to either both fingers on the same hand, the same finger on either hand, or different fingers on either hand were precued. One of these precued targets was then presented as the stimulus and participants had to select and produce the appropriate response as quickly as possible. Participants performed a number of trials under either the overlapped hands condition as described above, or the standard adjacent hand placement condition as used in the investigation by Miller. It was noted that whilst the advantage of precuing either hand when they were placed in standard adjacent arrangement was still present, when in the new overlapped condition, the effect of precuing either hand disappeared and was replaced by an advantage under the *prepared: neither* condition. Due to the arrangement of response effectors in the overlapped hand condition, an advantage of precuing either two targets on the left or right of visual fixation was now beneficial in terms of response preparation. It was suggested that the advantage seen in the initial investigation under the *prepared: hand* condition might therefore not be due to differing response preparation processes, and merely due to faster cue processing. A precue on one side of visual fixation would focus attention towards this spatial area. Presentation of a stimulus at this location would therefore require little or no attention relocation, resulting in rapid stimulus identification and consequently, fast reaction times. If, however, a stimulus was located on the opposite side of visual fixation than a precue, attention would have to be relocated before response programming could commence, resulting in slower reaction times.

Miller (1985) responded to this suggestion and presented data to support the initial model proposed. Several issues were raised concerning the data presented by Reeve and Proctor which may have led to the erroneous dismissal of theories put forward by Miller (1982). The reaction times for the overlapped and adjacent hand conditions were markedly different, with responses in the overlapped condition being around 220 msec slower than in the adjacent condition. Miller (1985) identified this as a significant issue, indicating increased task difficulty compared to the adjacent hand condition. Miller suggested that the unnatural arrangement of the effectors may have led participants to code responses in terms of spatial location rather than hand. It was suggested that the observed hand-preparation advantage in the adjacent hands condition may have occurred due to cueing of spatial response codes as much as the cueing of particular response effectors.

This statement is highly significant in relation to the current study. It is intended that the beneficial effects of preparing responses based on both spatial response codes and of response effectors will be investigated using a manipulation of the free choice paradigm. Further examination of the hand advantage was carried out by Proctor and Reeve (1986) using a hand/target set up similar to that used in the current study. To remove the possible mitigating factor of increased task complexity, hand placement was altered so that the alternating of response effectors did not inhibit movement of the fingers. As previously stated, concerns were raised regarding the method in which response effectors were manipulated in previous efforts to alter the relationship between stimuli and fingers. Proctor and Reeve intended the new set up to eliminate these concerns. Participants rotated their wrists so that the fingers of each hand were pointing towards each other. A vertical stimulus set was used, enabling the index and middle fingers of one hand to effect responses from the top two targets, while the index and middle finger of the other hand were mapped to the bottom two targets. This arrangement was congruent to the adjacent hand placement condition utilized in previous studies using a horizontal target arrangement (Reeve & Proctor 1985). The overlapped condition required interlinking of the fingers so that from top to bottom targets were assigned to the left middle, right middle, left index and right index respectively. This resulted in the precuing of the two top and bottom targets now grouping fingers on opposite hands, mirroring the layout used in the overlapped hand condition in their previous examination. By interlinking rather than overlapping the fingers, it was hoped the problems associated with increased task complexity in the initial experiments would be avoided. Results indicated that in the overlapped hand condition, reaction times were quickest when the two top or two bottom stimuli were precued i.e. the *prepared: finger condition.* The hands adjacent condition again showed quickest reaction times following the *prepared: hand* condition. It appears then that spatial representation of the targets is the predominant factor in response programming, rather than the ability to prepare effectors on either hand more efficiently.

This study aimed to investigate this spatial versus effector precuing benefit utilizing a combination of elements from the hand placement strategy employed by Proctor and Reeve (1986) and using a free choice paradigm similar to that used in the previous investigation (see Chapter 2). By utilizing a more complex set-up that involved both flexion and extension movements of these same four effectors it was intended that this new protocol would enable investigation into the effects of movement specific precues on response selection and effector preparation. Specifically, we wanted to investigate the strength of the response preparation effects found under free choice conditions in the experiments detailed in chapter one, as well as the spatial precuing effect found by Proctor and Reeve (1986). Our initial experimental question was 'Does the specification of a particular movement by a precue predispose an individual to produce a movement matched response, or will the spatial element of the precue override this?' The use of this 'directional' parameter of movement selection enables parallels to be drawn between the current study and those undertaken by Rosenbaum

(1980). In those early precue paradigm investigations it was suggested that the 'Direction' element of a movement was of significant importance, and had a large influence on response times. Rosenbaum discussed the possibility that those response features presented in the precue were prepared prior to stimulus presentation, and showed that features of a response *could* be pre-programmed and presentation of certain characteristics enabled faster response times than others. It was therefore interesting to see whether preparation of 'Direction' as a response feature in the current study lead to biases when a free choice response selection paradigm was employed.

Experiment 1 was designed to replicate the findings of the previous examinations involving finger movement responses to a stimulus. Of interest was the effect of the added 'Direction' factor in response selection. We hoped to further investigate the influence of precues on response selection, and examine whether the 'Same hand' advantage seen in previous examinations was affected by the added direction features of a precue. In a similar way that the hand, direction and extent factors were examined in the work of Rosenbaum (1980) the influence of hand, finger and direction were investigated in this study. Flexion and extension movements of the index and middle fingers were used, resulting in 8 possible responses being available. A single response was precued followed by a stimulus. This stimulus either indicated that the precued response should be produced, or that any response on the non precued hand could be produced. Participants were told to react as fast as possible to the stimulus and were informed to use the precue information to prepare that particular response to enable rapid response times.

Experiment 2 was designed in a such a way that it would provide follow up data to our initial experiments in much the same way as Reeve and Proctors overlapped hand experiments provided for research of the hand advantage. The relocation of response effectors aided our understanding of whether the effects found previously were due to spatial or perceptual factors. This relocation was achieved by requiring each participant to rotate a specified hand by 180 degrees. This meant that a response that was matched spatially between left and right hands on the display, did not match in terms of effector or direction. Production of a matched effector and movement response under free choice conditions would indicate that the precue benefits were due to effector-based advantages. However, production of a location-matched response would suggest that the precue benefits are influenced predominantly by spatial characteristics of the precue and stimulus. Regardless of the data produced, it was hoped that additional knowledge on the processes involved in response selection under these fairly novel paradigms would be obtained. The results obtained in the experiments contained in chapter 2 of this thesis showed some ambiguity concerning no-go-to precue trials. The complex nature of the process involved in programming and grouping under these inhibitory precue conditions require significant investigation. The investigations contained in this chapter however are carried out under go-to conditions only, allowing focus to be centred on the influence of an excitatory precue.

3.2 Experiment 1

Method

Participants

Sixteen university students served as participants in this study. All participants in this experiment were naïve to the hypothesis being tested and inexperienced at the task. Informed consent was obtained from each participant before the study and the experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, University of Wales-Bangor for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

Participants were seated in front of a 17" computer monitor placed on a table top and raised to ensure the centre of the monitor was at eye level. The monitor was positioned approximately 45 cm from the participant's eyes. The display consisted of four red circles (1 cm in diameter) arranged in a rectangle on a dark grey background (see Figure 3.1) The horizontal distance between the circles was 7.5 cm and the vertical distance was 5.5 cm. A fifth red circle was positioned at the central point of the four other circles. The index and middle fingers of the right and left hand were inserted between 8 microswitches that were mounted vertically in front of the participant (see Figure 3.2). In this configuration, the hands were oriented vertically in the frontal plane with the participants' palms facing the body and the fingers of each hand pointing towards each other. This meant that the microswitches could be depressed by flexion and extension movements of the index and middle fingers. The upper circles were responded to by movements of the index fingers while the lower circles were responded to using the middle fingers.

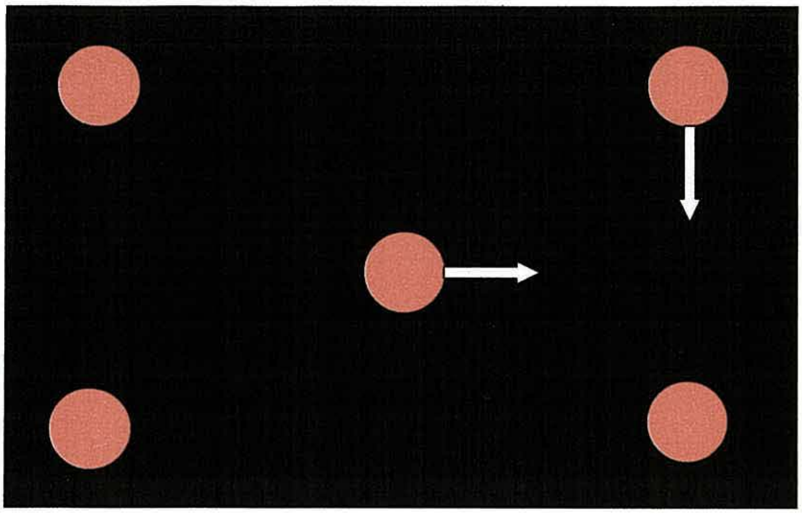

Figure 3.1 Experiment 1 display showing both precue and stimulus arrows

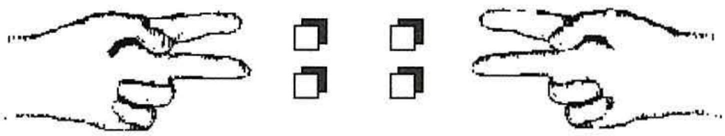

Figure 3.2 Hand placement for Experiment 1

Procedure

At the beginning of each trial, the five circles appeared on the screen. A precue was then presented at one of the four outer circles. This consisted of an arrow pointing from the circle in either an upward or downward direction for 1500-2500 msec. Upward pointing arrows represented finger extension whilst downward arrows represented flexion. Participants were told to prepare the response corresponding to the precue. The stimulus was then presented at the centre circle and consisted of an arrow pointing to either the left or the right. The stimulus arrow defined a subset of responses. A left pointing arrow specified the left hand fingers while a right hand arrow specified the right hand fingers.

Participants were instructed to produce the response corresponding to the precue if the stimulus arrow pointed to the same side as the precue. This was therefore a forced choice situation where only one response was appropriate. For example, if the precue consisted of an upward arrow from the upper left circle that was followed by a left pointing stimuli, the required response was an extension movement of the left index finger. If however, the stimulus arrow pointed to the opposite side to that of the precue, participants were placed in a free choice situation in which they could choose any of the responses on that hand. For example, if the precue consisted of an upward arrow from the upper left circle that was followed by a right pointing stimulus, the participant was free to choose any movement using the index and middle fingers on the right hand.

There were 8 possible precue positions (extension and flexion for each finger) and 2 possible stimuli directions (left, right). The sixteen combinations of precue and stimulus were randomized so that each combination was administered before any was repeated. Each of the 16 combinations was presented fifteen times giving a total of 240 trials.

Data Analysis

RTs quicker than 100msec or slower than 800msec were removed from the participant's data set ($\leq$ 5% of total trials for all participants). Our data analysis was primarily focused on trials in which the stimulus arrow pointed in the opposite direction to the precue (i.e. free choice situation). Of particular interest was the relationship between the finger and action specified in the precue and the response produced by the participant. We were interested to see whether subjects produced responses that shared features with the precue. (e.g. finger and action) The four possible free choice responses were therefore coded in relation to the features of the precue (Same finger:Same action[SF:SA]; Same finger:Different action [SF:DA]; Different finger:Same action [DF:SA]; Different finger:Different action [DF:DA]).

Our dependent measures were the frequency and latency of the responses produced. The frequency of each free choice response was described as a proportion of the total number of free choice trials. Participant proportion means for these responses were therefore submitted to a 4 response type (SF:SA; SF:DA; DF:SA; DF:DA) repeated measures ANOVA.

RT data for the same four free choice responses as well as the single forced choice (FC) response was analysed using a 5 response type repeated measures ANOVA. (FC; SF:SA; SF:DA; DF:SA; DF:DA)

Results

Response Frequencies

Analysis of the free choice trials revealed a significant main effect for response type $F(3,45) = 102.506$, $p < .01$. Breakdown of this main effect revealed that SF:SA responses were produced more often than any of the other responses. There was no bias between the production of any of the remaining three responses. (See Figure 3.3)

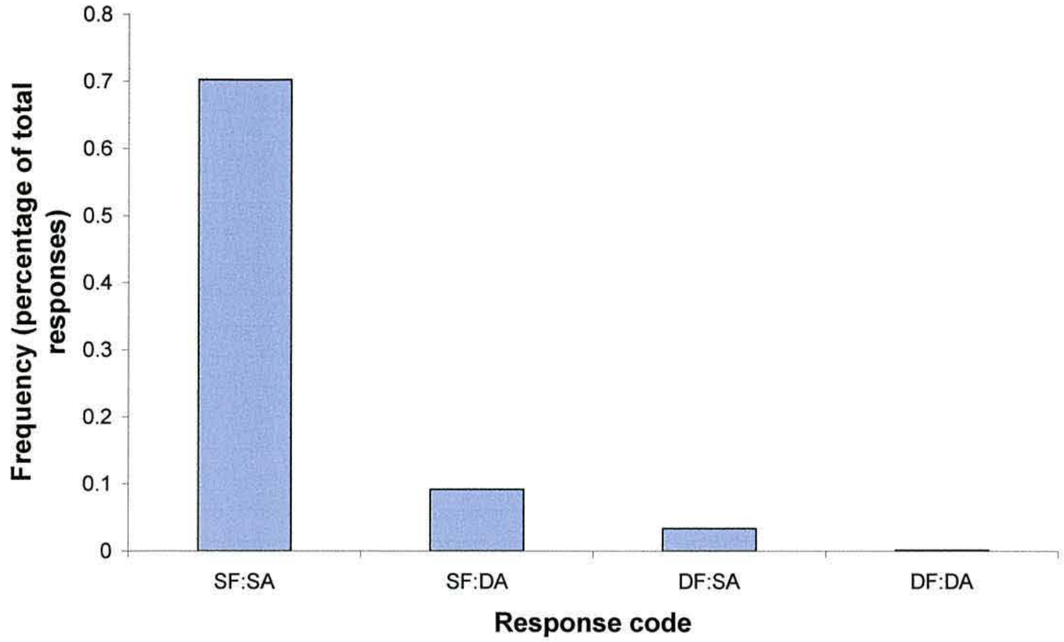

Figure 3.3; Response frequencies for each of the four free choice response options. (SF:SA = same finger:same action; SF:DA = same finger:different action; DF:SA = different finger:same action; DF:DA = different finger:different action)

Reaction Times

The analysis of reaction time for the four free choice responses and single forced choice response revealed a significant main effect for response type, $F(4,32) = 17.995$, $p<.05$. Breakdown of this main effect revealed that FC responses were initiated faster than all other responses. SF:SA responses were initiated faster than both DF:SA and DF:DA responses. Finally, SF:DA and DF:SA responses were both initiated faster than DF:DA responses. (See table 3.1)

	FC	**SF:SA**	**SF:DA**	**DF:SA**	**DF:DA**
RT	334 (7)	376 (16)	429 (12)	468 (16)	536 (20)

Table 3.1; Mean reaction times for each of the four possible free choice responses and single correct free choice response n=17. Standard error shown in parenthesis.

Errors

In the free choice condition, the precued response was produced on 3% of trials. Under forced choice conditions, participants produced a different finger: same action response on the same hand as the precue on 2% of trials. All other error rates were $\leq 1\%$.

Discussion

Miller (1982) performed a number of experiments examining the response programming effect of providing informative precues prior to stimulus presentation. Evidence was put forward in support of the hypothesis that preparation of response effectors located on the same hand was more efficient than preparation of effectors on different hands. This theory was challenged however in a number of future studies (Reeve & Proctor 1984). With alteration of the relationship between response targets and effectors, the beneficial effect of precuing fingers on the same hand disappeared. It was suggested that the original precuing effect found by Miller was not in fact due to more efficient preparation of response effectors, but due to facilitated cue processing. Placement of the precues in a pair to the left or right of a central fixation point was suggested as a primary factor in efficient response programming. The aim of this study was to further investigate the roles that stimulus location and response effectors have in movement programming and response selection.

The results from Experiment 1 are consistent with the data produced in Chapter 2 of this thesis. The studies contained in Chapter 2 investigated the response selection effects when a finger response is precued on one hand, followed by an alternate hand free choice stimulus. It was found that selection of the homologous finger to the precue occurs more frequently than the non-homologous finger. In this experiment we further tested this cross-hand activation by utilising a paradigm where both a finger and associated response action (flexion or extension) was precued. The results indicated that when a specific finger *and* action is precued, activation and preparation of both of these response features occurs on the non-precued limb. Response frequency data showed responses that were homologous to the finger *and* action of the precue were significantly more likely to be produced than any other available response under free choice conditions. It is possible that activation of specific response parameters is occurring in the non-precued hand. Further evidence of this is provided by the RT data, where the precue matched responses on the non precued hand were faster than all other free choice responses.

The results of the current study seem to indicate that the activation of precue features in non precued limbs takes place. This cross-over activation spreads as far down the response selection pathway as the action of a finger. What is not clear from this study however is whether this activation is based on the spatial features of the precue, or the effector preparation that occurs following the precue. The next experiment is designed to investigate this by utilising a similar paradigm to the crossed hands design used by Reeve and Proctor (1984, 1986). The spatial mapping of the stimulus and the effectors will be altered. Now an effector matched response will not correspond to a stimulus matched response. As detailed previously, the direct mapping of a responses spatial location and the effector and direction used to elicit that response was altered. This meant production of a matched spatial response between hands would require the selection of a non-matched effector and direction. Similarly, an effector and direction mapped response would require selection of a non-matched spatially located response. It was hoped this would assist in locating the mechanisms behind the preparatory effect found in the previous experiment, whether it is effector or spatial factors that cause cross activation.

3.3 Experiment 2

Method

Participants

Sixteen university students served as participants in the study (7 males, 9 females, ages 18-28 years). All participants in this experiment were naïve to the hypothesis being tested and inexperienced at the task. Informed consent was obtained from each participant before the study and the experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, University of Wales-Bangor for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

The apparatus was the same as in Experiment 1. However, participants were instructed to rotate one of their hands so that their palm faced away from them (see Figure 3.4). Half the participants were required to rotate their left hand and the other half required to rotate their right hand.

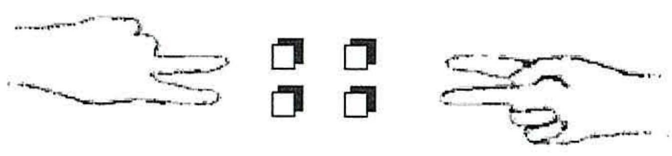

Figure 3.4; Hand placement for Experiment 2

Procedure

At the start of each trial, the five circle display appeared on the monitor. Similar to Experiment 1, a precue that consisted of an arrow pointing either upward or downward was presented at one of the four circles for 1500-2500 msec. Upward pointing arrows represented an action away from the body, downward arrows represented an action toward the body. This meant that for the non rotated hand, the mapping of precues to movements was the same as that used in Experiment one (i.e. upward arrows indicated extension movements, downward arrows indicated flexion movements). However, for the hand that was now rotated, these direction/action relationships were altered. Therefore, for the rotated hand (palm facing away from the body) an upward arrow would still signify a movement away from the body, but this would now be a flexion movement, whilst downward arrows now indicated flexion movements.

The precue was followed by a stimulus arrow presented at the central circle pointing to either the left or the right. Participants were given the same instructions as in Experiment 1. If the stimulus arrow pointed to the same side as the precue, participants had to respond by pressing the switch corresponding to the precue. If the stimuli pointed in the opposite direction to the precue, participants were free to press any switch on the non-precued hand. This resulted in the same free and forced choice conditions as in Experiment 1. In the free choice condition, the same four responses were possible, i.e. any action with either finger on the non-precued hand. However, it is important to note that due to the rotating of one of the response hands, the relationship between the finger and action response produced and the precue had been altered. A free choice response that matched the precued movements would now correspond to a different spatial location than the precue. For example, when the right hand had been rotated, an upward pointing arrow at the top left target would require preparation of an index finger extension movement of the left hand. Upon presentation of a rightward pointing arrow, the participant is placed in a free choice situation. A precue matched finger and action response (index finger extension of the *right* hand) would now occur at a spatial location corresponding to a downward pointing arrow at the bottom right target. This would clearly indicate that the spatial location of a precue does not affect the activation of the non precued hand. Similarly, if a spatially matched response is produce, this would correspond to a different finger and action being used, indicating effector preparation does not affect response selection.

Data Analysis

Responses quicker than 100msec and slower than 800msec were removed from the data set. Of primary interest in this experiment were again those trials in which participants were placed in a free choice situation. Specifically, we were interested in whether participants would produce responses that shared the spatial features of the precue (location, direction), or whether features of the precue effector would bias response selection (finger, action). Dependent measures were the frequency and reaction time of responses. Response frequencies were expressed as a proportion of free choice trials. The dependent measures were analyzed by submitting participant means to 2 separate ANOVAs. Response frequencies in the free choice condition were analysed using a 4 Response types repeated measures ANOVA. (SF:SA; SF:DA; DF:SA; DF:DA). RT data for the four free choice responses as well as the single forced choice response was also analysed using a 5 response type (FC; SF:SA; SF:DA; DF:SA; DF:DA) repeated measures ANOVA. Post hoc tests were performed using Tukey (HSD).

Results

Response frequencies

One subject's data were removed before analyses due to high error response rates. All analysis was therefore carried out on the remaining 15 subject's data. Analysis of the free choice condition revealed a significant main effect for response type, F (1.28, 17.97) = 9.902 p>.01. Breakdown of this effect revealed that DF:DA responses were produced significantly more often than any of the other three possible responses. Recall that although this response did not share response features with the precue (finger, action), it corresponded to the same location and direction of movement as the precue. There was no significant bias between the remaining 3 responses.

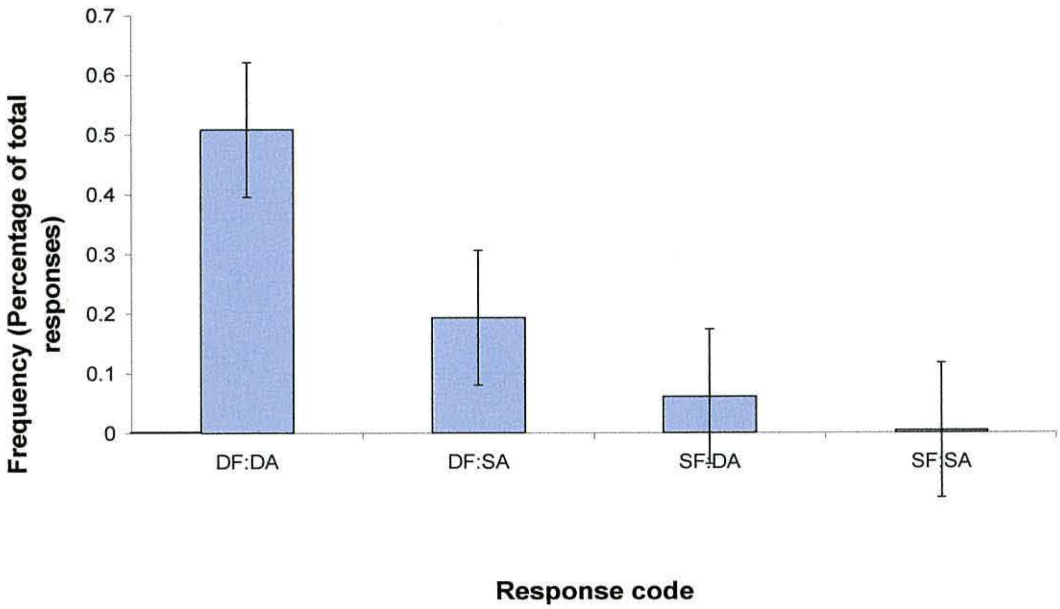

Figure 3.5; Response frequencies for each of the four free choice response options. (SF:SA = same finger:same action; SF:DA = same finger:different action; DF:SA = different finger:same action; DF:DA = different finger:different action)

Reaction Times

Reaction time analysis was carried out on the four possible free choice responses and single forced choice response. This revealed a significant main effect for response F(1.74, 24.48) = 4.32 p>.05. FC responses were significantly faster than SF:DA and DF:SA responses. There was no difference in reaction times between the 4 possible free choice responses.

	FC	SF:SA	SF:DA	DF:SA	DF:DA
RT	322 (28)	390 (31)	403 (29)	397 (28)	350 (36)

Table 3.2; Mean reaction times for each of the four possible free choice responses and single correct free choice response n=15. Standard error shown in parenthesis.

Errors

Under free choice conditions, the precue was produced on 7% of all trials. All other free choice error response rates were ≤ 1%. Under forced choice conditions, responses made with a different action but using the precue finger were produced on 2% of trials. Responses with the same action but produced with the non-precued finger on the precue hand also equated to 2% of trials. All other errors were ≤1% on forced choice trials.

Discussion

Experiment 2 was intended to provide evidence to support either the effector or spatial location for the precue effect seen in Experiment 1. Through the manipulation of limb placement, it was possible to alter the spatial relationship between the targets and effectors for one set of effectors used to illicit a response. The results indicated that when participants were provided with a precue and then told to produce any response on the non-precued hand, dominance for spatially mapped response selection occurred. Selection of a response that did not match either the effector or the direction of the precue occurred more often than a precue matched response. This appears to support the data found by Reeve and Proctor (1984) in their cross hands condition. Reeve and Proctor found an advantage for responses produced on the same side of visual fixation as a precue, despite the fact that these responses were produced by non-homologous effectors to the precue (different hands). Here, our results also show a spatial dominance, again despite the fact that these responses are produced using non-homologous effectors (different fingers and actions).

3.4 General discussion

Considerable debate has taken place regarding the 'hand advantage' in finger response precuing tasks and on the motoric and nonmotoric components of this effect (Miller 1982, 1985; Proctor & Reeve, 1985, 1986; Reeve & Proctor 1984). The free choice paradigm utilized in Chapter 2 of this thesis was modified and employed here in order to investigate the influence of preparatory effects on response selection following unexpected stimuli, where individuals are able to select freely from a number of response alternatives. Finally, the impact of a non compatible relationship between response effectors and stimulus features was investigated. This would hopefully shed some light on the influence of motoric and nonmotoric components of response preparation and selection under free choice conditions.

The methodological set up was such that participants' hands were oriented vertically in the frontal plane with the palms facing the body. Participants were required to make flexion or extension movements of their index and middle fingers resulting in the pressing of one of eight microswitches. Precues were presented, resulting in activation and preparation of the associated movement by the participant. This precue was followed by a stimulus indicating that either the precued response should be produced (forced choice) or that participants were free to select one of the four responses on the non-precued hand (free choice). In Experiment 2 the same set up and precue/stimulus array was utilised, however participants were required to rotate one of their hands resulting in miss-matching of response effectors between the left and right hands. This protocol was designed to investigate whether any effects on response preparation occurring in Experiment 1 could be attributed to a spatial precuing effect, or whether the motoric components of finger preparation have the foremost influence on advance preparation effects.

As discussed in Chapter 2 of this thesis, an assumption of the Experiments performed here is that the participants used the advance information provided by the precues in order to selectively prepare the associated response. The reaction time data indicates that participants did indeed prepare the precued response. Reaction times were significantly faster when the precued movement was produced due to a forced choice stimulus compared to any of the responses produced following a free choice stimulus.

In Experiment 1, the analysis of response frequencies indicated that under free choice conditions participants selected responses on the non precued hand that were homologous to the precue. For example, if a right index finger flexion movement was precued and the stimulus presented placed the participant in a free choice situation, the participant was more likely to produce a left index finger flexion movement. There is strong indication that the preparatory effects seen in previous experiments utilising key depression tasks (Miller, 1982, 1985; Reeve & Proctor 1984, 1985; Chapter 1 of this thesis) are present when the number of parameters within a response is increased.

Experiment 2 required the same responses to be made to identical precue and stimuli. However, participants were required to rotate one of their hands so that their palm faced away from them. This removed the matching of response effectors, analogous to the 'hands adjacent' condition in previous studies (Miller, 1982; Reeve and Proctor 1984). Experiment 2 reproduced a stimulus/target/effector arrangement similar to that found in the 'hands overlapped' condition in previous studies (Reeve and Proctor 1984). The results of this condition would provide important evidence for either the motoric or non-motoric location for the response advantages seen in movement preparation.

Response selections under free choice conditions indicated that responses on the non-precued hand matching the direction and action of the *precue* were more likely to be produced than a homologous response matching the direction and action of the *response* prepared. This result appears to indicate that under free choice conditions, where individuals are free to select from a number of responses containing options corresponding to homologous precue and response actions, pre-programming of responses results in responses matching the visual stimuli precued are produced. This corresponds to the non-motoric translation processes proposed by Reeve and Proctor (1984. See also Cauraugh and Horrell, 1988; Proctor and Reeve 1985, 1986).

Whilst further examination of this effect in multiple action responses is clearly required, especially considering the depth of analysis undertaken to investigate single action response selection and the 'hand advantage', it seems possible to suggest that precue effects appear to operate predominately at a stimulus-response translation level under free choice conditions.

Chapter 4

The Influence of Stimulus Features on Response Selection under Free-Choice Conditions

4.1 Introduction

The present study was intended to investigate the effect that specific features of a precue (e.g. colour, shape) have on response selection under free choice conditions. Previous studies in this area have tended to focus on visual orienting, and the effect of precue presentation on object selection times. Although these investigations were centred on vision and attentional focus, and utilized paradigms seemingly removed from our own, it seems pertinent to still review this literature. The costs and benefits of a visual precue on selection capabilities is likely to be closely linked to free choice selection of a target from a stimulus group. Focusing of an individual's attention on a particular object within a target set, followed by presentation of this object as an available response within a second response set, will undoubtedly affect selection preferences.

Folk, Remington and Johnston (1992) investigated the hypothesis that attention shifts are influenced by the relationship between the features of an event that is presented prior to stimulus presentation, and the properties involved in the task. The investigation focused on abrupt onset cues and colour precues presented prior to a visual search task. In the abrupt-onset experiment, valid precues resulted in reaction time benefits, regardless of the stimulus onset condition. However invalid precues resulted in reaction time costs only when the precue onset condition matched the stimulus presentation condition. Invalid abrupt-onset cues did not influence reaction time when the task required differentiation between coloured targets.

A second experiment was carried out by Folk et al, further examining the prediction that involuntary shifts of attention occur only when the cue properties presented match the features of a stimulus to be searched for. This time colour discontinuities were used in the cues, and both the onset- and colour-target conditions were used. As their hypothesis predicted, invalid cues resulted in slower reaction times only when the search targets contained colour discontinuities. The pattern of results in the onset-target condition seemed to indicate that there was no effect of an invalid colour cue on reaction times (See also Folk, Remington and Wright, 1994).

The data from these two experiments clearly show that when properties of a cue match the properties of an expected stimulus, involuntary attention shifts occur. Regardless of whether the precue was valid or invalid, participants' attention was pulled toward its location. It is interesting to note that this was the case even when participants knew with 100% certainty whether the precue was valid or not. The common utilization of valid and invalid cues occurs under randomized conditions. Here participants are told to expect precues to be valid, although on occasion they will be invalid. Other studies have employed visual search and discrimination paradigms to investigate the effects of feature variables on search patterns. For example, Beck (1966) ran a series of experiments concerning perceptual grouping of objects. It was found that when secondary objects presented in the visual field were similar to primary objects, discrimination between the two sets was difficult. These discriminatory problems were present even when certain features of the two objects were altered (e.g. rotation of letters to appear as different shapes). This seems to indicate that even large feature changes may not greatly affect grouping of visual stimuli.

Further studies by Quinlan and Humphreys (1987) and Duncan and Humphreys (1989) investigated the effect of stimulus similarity on visual search. The stimuli used were letters of similar construction (E.g. L, T, P, R, B etc). These stimuli were then manipulated by rotating them at angles of 45° and 180°. These symbols now maintained the same properties as the original targets, but were presented in a different manner.

Results indicated that target search times were impacted heavily by the relationship between targets and non-targets. When non-targets and targets have high similarity levels, search times were significantly slower. The implication is that ignoring the distracting non-targets is more difficult when they share features with the targets. These results have been seen in several visual search investigations. Carter (1982) required differentiation of 3 digit numbers by colour. The main purpose of this experiment was to investigate the effect of the number of objects presented in a display on search time. It should be noted however that search time was related to similarity in colour between targets and non-targets. With longer search times seen when the colours of targets and non-targets were of a similar density and hue.

The investigations detailed above indicate the strength of influence that response features have on response selection processes. This influence was investigated under the free choice selection conditions used in the previous studies in this thesis. Where attention shifts in previous examinations (Folk et al 1992, 1994) resulted in reaction time costs and benefits during visual search tasks, we hypothesised that similar effects would be seen under response selection conditions. Presentation of an excitatory precue composed of individual visual features was expected to influence response selection. More specifically, response selection would be biased towards objects that shared similar visual features with the precue.

Experiment 1 in the current Chapter focused on the colour and shape of a precued target and the influence of these features on response selection under free choice conditions. A precue matched object, as well as two non-matched objects, was presented within the subgroup indicated by the stimulus, and response frequencies of each target analysed. Experiment 2 involved a similar design and process, with an important change in the layout of the subgroup indicated by the stimulus. Where in Experiment 1 all 3 targets were highlighted as a stimulus, now only 2 out of the 3 were highlighted. Finally, 2 further experiments were conducted to investigate the individual effects of both precue shape and precue colour on response selection.

4.1 Experiment 1

Method

Participants

10 university students with normal or corrected to normal vision served as participants in the study. All participants were naïve to the hypothesis being tested and inexperienced in the experimental task. Informed consent was obtained prior to participation in the study. The experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, University of Wales-Bangor for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

Participants were seated in front of a computer monitor (17") placed approximately 45cm from the participant's eyes. The display consisted of a white background with 6 coloured objects arranged horizontally in the centre of the monitor. The objects consisted of two sets of three different coloured shapes; a red circle, yellow triangle and turquoise square (see Figure 4.1). All objects were 1.4cm in width and height, with 0.5 cm space between each. A standard keyboard was placed in front of the participant. The index, middle and ring fingers of the left hand were placed on the 'G', 'F' and 'D' keys respectively, while the index, middle and ring fingers of the right hand were placed on the 'J', 'K' and 'L' keys respectively. The 6 objects on the monitor were mapped in a spatially compatible manner to the 6 keys.

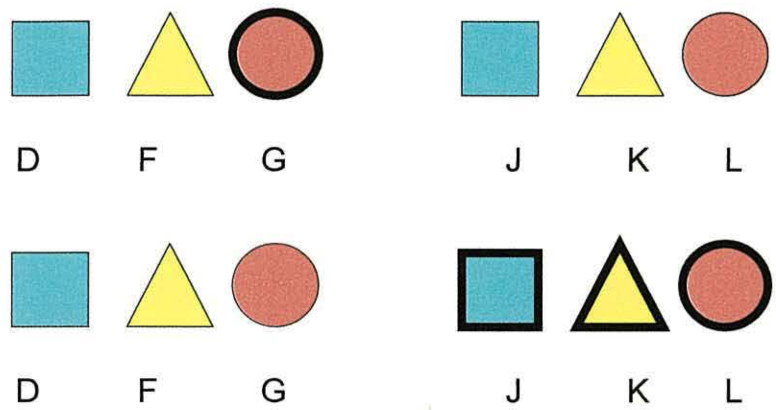

Figure 4.1; Layout of display and mapping of key placement in current Experiment; Precue (top pane) followed by free choice stimulus (bottom pane)

Procedure

At the start of each trial, the 6 target objects appeared on the screen. A precue was then presented which consisted of one of the objects being emboldened with a black outline for 1000msec. Participants were informed to prepare the associated button press response to this object following a randomised ISI of between 1000 and 2000msec. The stimulus was then presented which consisted of all three objects in either the left or right groups being emboldened in the same way as the precue. If the stimulus set contained the precued object, the participants were required to respond by making the prepared response (i.e. a forced choice trial). If the stimulus set did not contain the precued object, participants were free to press any of the corresponding response keys (i.e. a free choice trial). The order of the objects within each set was randomised and counterbalanced across all trials.

Each object on a particular side was precued in each of the 3 locations. For each precue position the precued object occurred at each position on the opposite side. For each object this gave 9 trials, therefore a total of 27 trials for all 3 objects. Each object was precued on both the left and right side, giving 54 trials. Similarly, stimulus location could occur on the left or right side, giving a total of 108 trials. The total trial number was doubled to give a final total of 216 trials per participant.

Data Analysis

Of primary interest in this experiment were the trials in which participants were placed in a free choice situation. We were specifically interested in whether participants would select responses that corresponded to the precued object. For each object precue (circle, triangle, square), the proportion of trials in which each object was produced in the free choice situation was submitted to a one-way ANOVA. Also, for each finger precue (index, middle, ring), the proportion of trials in which each finger response was produced was submitted to a one way ANOVA.

Reaction time data were analysed for each object precue by submitting mean reaction times for the three possible free choice responses and the single forced choice response to a one way ANOVA.

Results

Response Frequencies

Analysis of the object precues revealed no significant effects. Circle: $F(2,27) = 1.10$, $p>.05$, Triangle; $F(2,27) = 1.52$, $p>.05$, Square; $F(2,27) = 2.25$, $p> .05$). Hence there was no influence of the precue on object selection in the free choice condition.

Analysis of the finger precue data revealed significant main effects for index finger, F (2,27) = 65.94 p <.001 and middle finger F (2,27) = 24.52 p <.001. Following an index finger precue, participants were more likely to select an index finger response than either a middle or ring finger response. Similarly, following a middle finger precue, participants were more likely to select a middle finger response than any other (Figure 4.1)

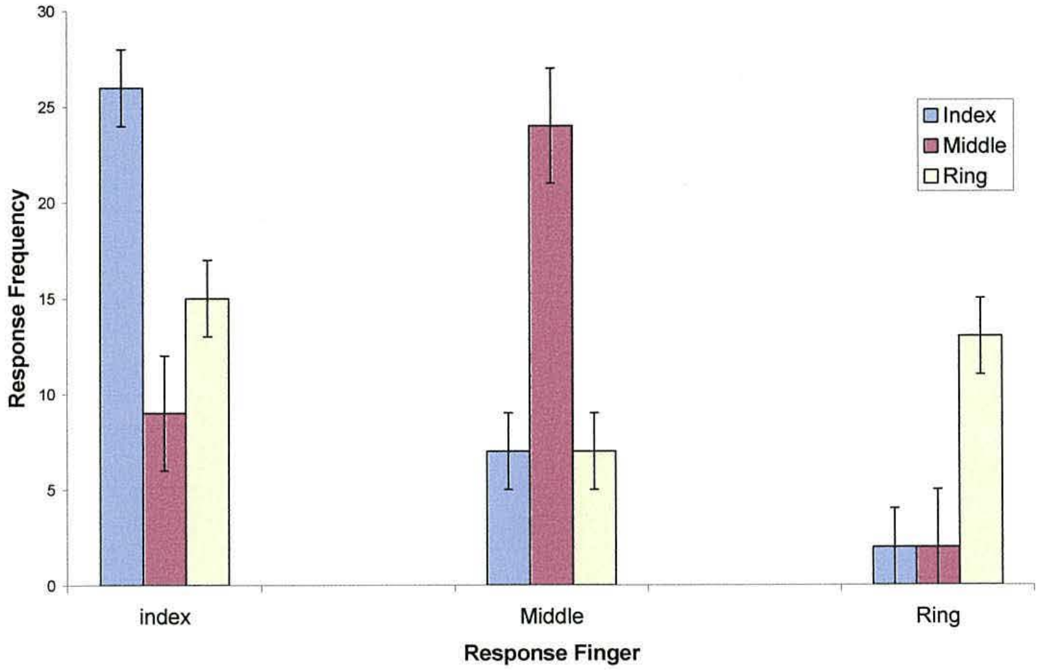

Figure 4.2; Mean response frequencies for each finger precue condition n=10.

Reaction Time

Under the Free Choice condition, 3 participants did not have data for all possible precue-response combinations. These participants were omitted from the reaction time analysis. Analysis of the reaction times for the object precues revealed no significant effects (Forced choice; F(2,27) = .947, p>.05 Circle; F(2,27) = .948, p>.05, Triangle;

F(2,27) = .903, p>.05, Square; F(2,27) = .863, p>.05). Similarly for finger precues, no significant effects were found (Forced choice; F (2,27) = .945, p> .05, Index ; F (2,20) = .510, p> .05, Middle ; F (2,24) = .314, p> .05, Ring ; F (2,25) = .727, p> .05). Tables 4.2 and 4.3 display mean reaction times under both finger and object precue conditions.

	Finger Precue		
Response finger	Index	Middle	Ring
Index	309 (5)	310 (7)	310 (5)
Middle	344 (7)	321 (6)	331 (9)
Ring	317 (7)	375 (13)	336 (8)

Table 4.1; Mean reaction times for each finger precue condition n=10. Standard error in parenthesis

	Object Precue		
Response Object	Circle	Square	Triangle
Circle	314 (6)	312 (6)	318 (5)
Square	318 (6)	321 (7)	313 (6)
Triangle	323 (6)	326 (6)	324 (6)

Table 4.2; Mean reaction times for each object precue condition n=10. Standard error in parenthesis

Errors

In all Experiments in this Chapter, trials with reaction times longer than 800msec were removed prior to data analysis. This equated to less than 5% of trials for all participants. No significant effect was seen for error responses.

Discussion

Experiment 1 was designed to investigate the effect of different objects on response selection. Where previous studies have noted significant effects on RT in visual search tasks where grouping of objects by colour and shape occurs (E.g. Beck 1966; Quinlan and Humphreys 1987), we were interested on whether these effects would carry over into free choice response selection tasks. Employment of a free choice paradigm would enable us to compare our results to those in which only directional precues were presented and where effects were seen largely due to spatial similarities between precues and response targets (Chapter 3). It was expected that under free choice conditions, response frequencies would be higher for objects that had the same features (colour and shape) as the precue than either of the two other available response targets. No significant effect was found concerning the object selected as the response and that which was presented as the precue. Regardless of whether a circle, triangle or square was precued, under free choice conditions there was no influence on object selection. There was however, a significant effect concerning the finger on which the precue was presented. Participants were more likely to respond with an index finger response following an index finger precue. Similarly, a middle finger response was much more likely following a middle finger precue. It is clear that the effector relationship that has been examined in the previous chapters of this thesis is present in the current experiment.

Re-examining the methodology of the current experiment raises some issues that may help resolve this. Following the presentation of a single object as the precue (and expected activation of this object by the participant) a variable ISI occurred followed by the stimulus. The stimulus consisted of all three objects on one side of the display being embolden in a similar manner to the precue object. If the stimulus occurred on the opposite side of the display as the precue, participants were placed in a free choice situation and were free to select any of the objects as their response. It is important to note that a shift of attention was not required in order to detect the specific stimuli. It is likely that once the precue was presented to the participant, they would focus their attention on this specific object, enabling the fastest possible reaction time if it were contained within the stimulus set as instructed. Attention may have been focused on the expected object and *lack* of stimulus presentation at the precued location may have initiated responses under free choice conditions, rather than the presentation of the free choice stimulus itself.

As soon as the participant was aware that the stimulus had not occurred at the precued object, they could begin initiating a response on the other hand, without the need to shift attention at all. Without the need for specific attentional focus being placed on the free choice stimulus set, participants could simply rely on the dual activation of response effectors on separate hands to enable fast response initiation. In conclusion it appears that perceptual features of the precue had no effect on the response selection processes. The response factors noted in the previous chapters of this thesis were replicated however.

4.3 Experiment 2

Introduction

The results obtained in Experiment 1 differed from those that were expected based on previous examinations using visual search paradigms. We suggest that this was due to the methodological design of the study. Without the need to reallocate attention to focus specifically on the objects within the stimulus display, no relationship between the precue object and the location of the matching target in the stimulus set occurred. In order for the precue to have an effect on response selection processes, it is necessary for attention to be re-focused on to the stimulus set before response selections takes place. An effortful decision making process is required before the influence of a precue on free choice responses can be investigated. Under the current conditions, this is not the case, with responses simply triggered by stimulus presentation, with little decision making required.

A simple change in the methodology used in Experiment 1 should resolve this issue. A similar paradigm was used, with the same set of objects used as targets. The alteration occurred when participants were placed in a free choice situation. Only two of the three targets on the non-precued side were now be emboldened. In Experiment 1; it was possible that participants were able to detect the presentation of an invalid precue due to a lack of stimulus presentation at the precued object location. Attention shifts were not required under invalid precue conditions, leading to a lack of perceptual feature effect. This was due to all three objects in the non precued group being contained within the stimulus set. No decision making process was therefore required as participants could select any of the three objects. In the present experiment it will be necessary to re-focus attention on the stimulus objects to detect which of the two objects are available for selection. It is hoped that this change to the experiment will yield the results we expected to find in Experiment 1, namely an effect on object selection under free choice conditions. Specifically, it is hypothesised that response selection is governed, at least to some degree, by the object presented as the precue. The grouping of visual targets by features such as colour and shape has been established in a significant number of studies (see Triesman, 1982 and Duncan & Humphries, 1989 for reviews). It is expected that similar grouping effects will be seen in the current experiment between the precue object and the matching object in the response set (when available). This grouping should lead to increased activation levels when during response selection and should be evident in response frequency levels.

Method

Participants

10 university students with normal or corrected to normal vision served as participants in the study. All participants were naïve to the hypothesis being tested and inexperienced in the experimental task. Informed consent was obtained prior to participation in the study. The experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, University of Wales-Bangor for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

The apparatus was the same as that used in Experiment 1.

Procedure

At the start of each trial the 6 target objects appeared on the screen. A precue was then presented which consisted of one of the objects being emboldened with a black outline for 1000msec. Participants were again told to prepare the response corresponding to the precue. The stimulus was then presented following a randomised ISI of between 1000 and 2000msec. It consisted of either all three objects on the same side as the precue being emboldened, or two targets from the group on the opposite side to the precue being emboldened (see Figure 4.2). If the stimulus set contained the precue object the participants were required to produce the prepared response (i.e. a forced choice trial). If the stimulus set did not contain the precue object participants could choose either of the two highlighted objects. Each object on a particular side was precued in each of the 3 locations. For each individual object precue position the stimulus could indicate 3 pairs of objects on the non-precued side, or the precue set itself could be indicated. For each object this gave a total of 12 trials, therefore a total of 36 trials for all 3 objects. The three objects could also occur at any of the three positions on the opposing side, resulting in 108 trials. Each trial was produced 3 times giving a final total of 324 trials per participant.

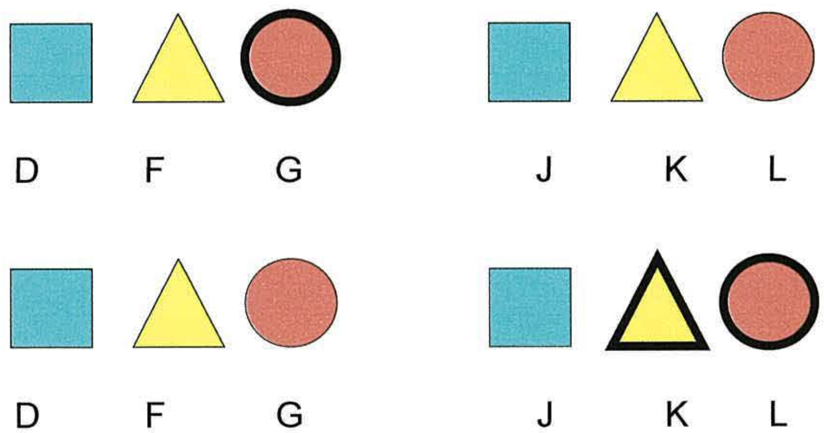

Figure 4.3; Layout of display and mapping of key placement in current Experiment; Precue (top pane) followed by free choice stimulus (bottom pane)

Data analysis

For each precue object (circle, triangle, square), the proportion of trials in which participants chose the same and different object to that of the precue was analysed. This was performed using a 3 precue (circle; triangle; square) x 2 response type (same object; different object) one-way ANOVA.

A separate analysis for each finger precue (Index, middle, ring) and whether participants chose the same or different finger to that of the precue was also performed. This analysis was performed using a 3 precue (Index; Middle; Ring) x 2 response type (same finger, different finger) repeated measures ANOVA.

Reaction time data was analysed using the same sets of ANOVA's for both object and finger precues. Thus 3 precue (Circle, Triangle, Square) x 2 precue/response relationship (same object; different object) repeated measures ANOVA's were performed for each precue object. Additionally 3 precue (Index, Middle, Ring) x 2 precue/response relationship (same finger; different finger) repeated measures ANOVA's were performed for each finger precue.

Results

Response frequencies

Analysis of the object precue data revealed significant main effects for precue $F(2,18) = 3.571$ $p < .05$ and precue/response relationship $F(1,9) = 41.5$ $p<.01$. There was also a significant interaction between precue and precue/response relationship, $F(2,18) = 14.5$ $p<.01$. Post hoc analysis of this interaction revealed that in each precue condition, participants responded with a 'same' object more often than a 'different' object. This effect was stronger for the square and triangle compared to the circle (see Figure 4.3)

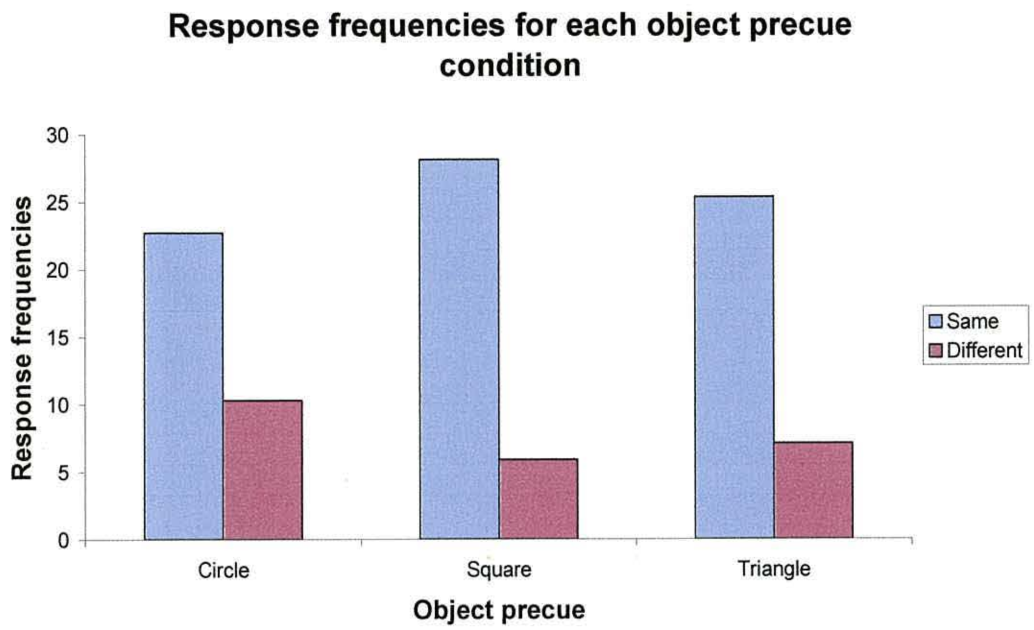

Figure 4.4; Mean response frequencies for precue matched (Same) and unmatched (Different) responses following each object precue n=10.

Reaction Time

Analysis of the reaction time data for the object precues revealed a significant precue main effect, F (2,18) = 5.459, p<.05 Post hoc analysis revealed triangle stimuli reaction times to be faster than circle stimuli. There was no difference between any other response object reaction times.

A significant main effect was also found for response relationship, with precue matched responses being faster than non-matched F (1,9) = 18.1, p<.05.

Analysis of the RT data for the finger precues revealed no significant effects. (Precue: F(2,18) = 2.5, p>.05, Response; F(1,9) = 0.0, p>.05) There was no difference in reaction times for same finger and different finger responses for index, middle or ring finger precues (see Tables 4.4 and 4.5).

Response Object	Object Precue Circle	Square	Triangle
Precue matched	449	438	449
	(7)	(6)	(6)
Precue unmatched	460	497	515
	(5)	(10)	(8)

Table 4.3; Mean reaction times for each Object precue condition n=10. Standard error in parenthesis

Response finger	Finger Precue Index	Middle	Ring
Precue matched	453	457	488
	(8)	(8)	(7)
Precue unmatched	483	454	468
	(9)	(7)	(7)

Table 4.4; Mean reaction times for each finger precue condition n=10. Standard error in parenthesis

Errors

Errors in the current Experiment did not show any significant effects. Error responses were produced on less than 5% of all trials

Discussion

The hypothesised results that were not seen in Experiment 1 were this time evident. Response frequencies showed that matching precue/stimulus objects were selected more often than non-matched. The grouping of responses by features such as shape and colour has been shown in many investigations. These have often explored the effect of distractor similarity on search capabilities. Results have reliably shown that increased similarity between targets and distractors leads to increased reaction times. It appears that there is a tendency to group together visual presented objects presented based on features such as colour (Carter, 1982). Activation of an object through its presentation as a precue increases its prominence in short term memory. When attention is then switched to a separate group of targets and selection of one of these is required this previous activation of the object influences response selection.

In the current Experiment, when placed in a free choice situation, selection of either a precue matched object or an unmatched object both equated to correct responses. Under these conditions, it appears a preference for selecting a matched object exists. It is worth noting that in the current study, placement of the three objects on either hand was randomized across all trials. This meant that while on some trials selecting a precue matched object meant selecting a homologous finger to the precue, on two thirds of the trials this would not be the case.

Analysis of the data also revealed that the results seen in the previous chapters of this thesis concerning finger activation in free choice responses have been replicated. Activation of a response finger led to an increased likelihood that, if placed under similar free choice conditions as in our previous investigations, the homologous finger to the location of the precue would be selected.

Additional factors now need to be considered in terms of response selection under free choice conditions. In this Experiment the colour and shape of the 3 objects used was maintained throughout. Previous studies have indicated that individually these factors influence reaction time during visual search investigations. We will now investigate their effects in our free choice paradigm separately in order to further examine whether colour or shape influence response selection process independently of each other. We investigated whether either of these perceptual factors produced an overriding influence on response selection, or do both have similar effects and are simply seen in combination.

4.4 Experiment 3

Introduction

The final two experiments in the current study were designed to further investigate the effect of precue colour and shape on response selection. Investigations into these factors as separate entities have shown evidence for grouping of visual targets by their similarity to distractor targets. Trials where speeded locating of a target amongst a set of distractors have been carried out where the number of distracting objects and their similarity to the response object has been varied (Beck, 1974; Carter 1982; Quinlan and Humphreys, 1987). Reliable findings have shown that increased similarity (in terms of shape/structure and colour) of distractors slows visual search speed. It is hypothesised that the close similarity of targets and distractors makes it difficult to organise them quickly into separate groups in line with Gestalt principles of selection. When number of distractor targets is high, yet their similarity to a target object is low (either in terms of shape/structure or colour) then reaction times in terms of locating the target object remain fast.

As has been discussed earlier, the methodology being used in our Experiments differs significantly to these visual search paradigms. Where previous examinations have focused on the effect on factors such as feature and conjunction searches (Quinlan and Humphreys 1987), extrafoveal discriminability of letters (Beck 1974) and involuntary attention shifts (Folk et al 1992), we focused on the impact that precue features and stimulus similarity had on response selection processes. Whilst the indication from existing data is that both colour and shape of the precue will have an effect on response selection (as seen in Experiment 2), it will be interesting to note if either of these factors have a larger effect on target selection than the other.

Method

Participants

10 university students with normal or corrected to normal vision served as participants in the study. All participants were naïve to the hypothesis being tested and inexperienced in the experimental task. Informed consent was obtained prior to participation in the study. The experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, University of Wales-Bangor for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki

Apparatus

The apparatus set up was the same as that used in the previous Experiments.

Procedure

The six target objects consisted of the same three object shapes as the previous experiments. However each was now coloured differently. The same 6 colours (figure) were used for the entire experiment, however the colour assigned to each shape was randomised across each trial. The procedure was identical to that used in Experiment 2. Each shape on a particular side was precued in each of the 3 locations. For each individual shape-precue position, the stimulus could indicate 3 pairs of shapes on the non-precued side, or the precue set itself could be indicated. For each shape this gave a total of 12 trials, or a total of 36 trials for all 3 shapes. The three shapes could also occur at any of the three positions on the opposing side, resulting in 108 trials. Each trial was produced 3 times giving a final total of 324 trials per participant.

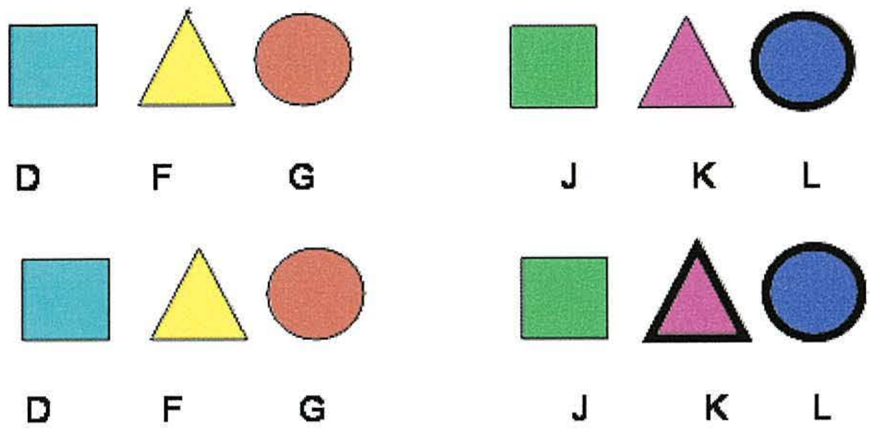

Figure 4.5 Layout of display and mapping of key placement in current Experiment; Precue (top pane) followed by free choice stimulus (bottom pane)

Data Analysis

For each precue shape (Circle, triangle, square) the proportion of trials in which participants chose the same and different object to that of the precue was analysed. This was carried out using a 3 precue (Circle; Triangle; Square) x 2 precue/response relationship (same shape; different shape) repeated measures ANOVA.

A separate analysis was performed for each finger precue (Index, middle, ring) and by the proportion of trials in which participants chose the same and different object to that of the precue. This analysis was carried out using a 3 precue (Index; Middle; Ring) x 2 precue/response relationship (same finger; different finger) repeated measures

ANOVA. Response reaction times were submitted to the same two shape and finger precue repeated measures ANOVAs.

Reaction time data was analysed using the same sets of ANOVA's for both shape and finger precues. Thus 3 precue (Circle, Triangle, Square) x 2 precue/response relationship (same shape; different shape) repeated measures ANOVA's were performed for each precue object. Additionally 3 precue (Index, Middle, Ring) x 2 precue/response relationship (same finger; different finger) repeated measures ANOVA's were performed for each finger precue.

Results

Response Frequencies

Analysis of the shape precue data revealed a significant main effect for response, $F(1,9) = 24.07$ $p<.01$. Participants selected same shape responses more than different shape responses. This effect did not differ across precue shape however.

Analyses of the finger precue data also revealed a significant main effect for response, $F(1,9) = 7.691$ $p<.05$. Participants selected same finger responses more often than different finger responses.

Reaction Time

Analysis of the finger precue reaction time data revealed a significant main effect for precue, with index finger precues resulting in longer reaction times than either middle or ring finger precues. This is likely to be to due to two participants having longer reaction times when producing unmatched precue responses (see Table 4.6)

Analysis of the shape precue reaction time data revealed no significant main effects or interactions.

	Finger Precue		
Response finger	Index	Middle	Ring
Precue matched	419	403	412
	(6)	(4)	(7)
Precue unmatched	452	416	403
	(7)	(6)	(6)

Table 4.5; Mean reaction times for each finger precue condition n=10. Standard error in parenthesis

Errors

Errors in the current Experiment did not show any significant effects. Error responses were produced on less than 5% of all trials

Discussion

The current Experiment was undertaken in order to investigate the influencing effect that precue shape has on response selection. In conjunction with Experiment 4 in this chapter, we hoped to examine whether the response grouping effects found in Experiment 2 were due to the individual influence of either shape or colour, or whether it was a combination of these features that resulted in higher response frequencies for precue matched targets under free choice conditions. We found very similar results in the current examination as were found in the Object precue experiment. Response frequencies were significantly higher for target shapes that matched the precue shape than those that did not. The indication is therefore that the relationship between the shape of a precue and the available target shapes in a response subgroup have at least a contributing effect to response selection decisions. We were now interested in examining the effect of colour on response selection. The final Experiment in this chapter was undertaken in order to investigate this element of response features, and in a similar way to the current Experiment, the influence of precue/response shape was removed from the paradigm.

4.5 Experiment 4

Method

Participants

10 university students with normal or corrected to normal vision served as participants in the study. All participants were naïve to the hypothesis being tested and inexperienced in the experimental task. Informed consent was obtained prior to participation in the study. The experimental protocols were approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, University of Wales-Bangor for research involving human participants in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Apparatus

The apparatus set up was the same as that used in the previous Experiments.

Procedure

The six target objects consisted of six different object shapes, coloured using the same three colours as in Experiment 1. The layout therefore consisted of two groups of

3 coloured targets. The procedure was identical to that used in the Experiment 2. Each colour on a particular side was precued in each of the 3 locations. For each individual colour precue position the stimulus could indicate 3 pairs of colours on the non-precued side, or the precue set itself could be indicated. For each colour this gave a total of 12 trials, therefore a total of 36 trials for all 3 colours. The three colours could also occur at any of the three positions on the opposing side, resulting in 108 trials. Each trial was produced 3 times giving a final total of 324 trials per participant.

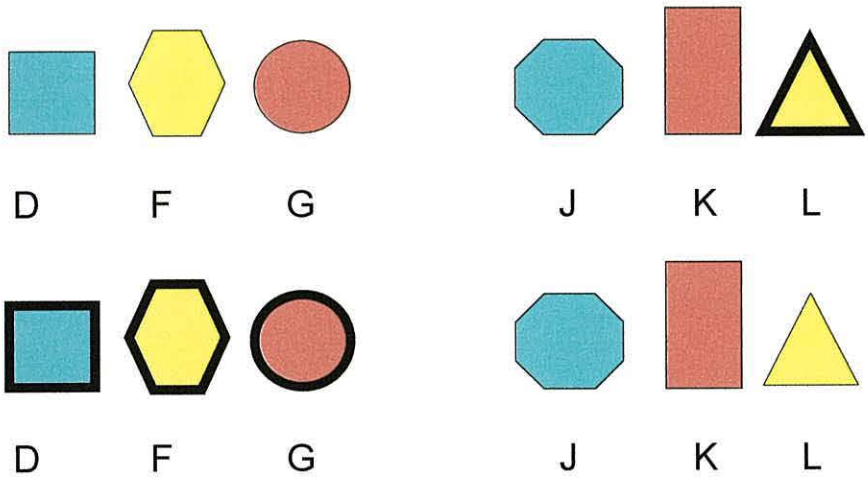

Figure 4.6 Layout of display and mapping of key placement in current Experiment; Precue (top pane) followed by free choice stimulus (bottom pane)

Data Analysis

Participant response frequencies were analysed under two separate precue conditions. For each of the 3 colour precue conditions (Red, yellow, turquoise), the proportion of trials in which participants chose the same and different object to that of the precue was analysed. Similarly each response finger condition (Index, middle, ring) was analysed by the proportion of trials in which participants chose the same and different finger to that of the precue was analysed. Both these analyses were carried out by submitting participants' means to separate 3 precue condition x 2 response/precue relationship repeated measures ANOVAs.

Reaction time data was analysed using the same sets of ANOVA's for both colour and finger precues. Thus 3 precue (red, yellow, turquoise) x 2 precue/response relationship (same colour; different colour) repeated measures ANOVA's were performed for each precue object. Additionally 3 precue (Index, Middle, Ring) x 2 precue/response relationship (same finger; different finger) repeated measures ANOVA's were performed for each finger precue.

Results

Response Features

Analysis of the colour precue data revealed a significant main effect for response, $F(1,9) = 15.427$ $p<.01$. Participants selected same colour responses more than different colour responses.

Analyses of the finger precue data also revealed a significant main effect for response, $F(1,9) = 6.142$ $p<.05$ as well as a precue by response interaction, $F(2,18) = 5.165$, $p<.05$. Participants selected same finger responses more often than different finger responses when looking at all three fingers combined. Post hoc analysis revealed this was due to a very large index finger effect, with ring and middle finger have no selection bias between responses.

Reaction Time

Analysis of the reaction time data revealed no main effects or interactions for either the finger or colour precues.

Errors

Errors in the current Experiment did not show any significant effects. Error responses were produced on less than 5% of all trials

Discussion

The final set of experiments were designed to isolate the 'colour' and 'shape' factors that influenced response selection in Experiment 2 of the current chapter. In studies designed to test the effect these factors have during visual search paradigms, significant impact has been noted both when these features are manipulated separately and in conjunction. As discussed earlier, we have significantly altered the protocol used in these investigations, with the focus being switched to response selection processes. It was important to identify if this change in experimental focus had impacted on the effect and inter-relationship that these features have on selection processes. The results from Experiment 3 (Shape) indicated that the tendency for selection of a precue matched object seen in Experiment 2 occurs when the shape of the precue and response targets is the only grouping factor. Participants were more likely to select a shape matched target from a pair of free-choice targets than a non-matched shape. Randomization of location of precue and target shapes again ensured that any effect found in the 'Shape' analysis could not be influenced by the tendency for effector matched responses as seen in the previous experiments. Analysis of the finger responses

indicated however that matched finger responses were produced more often then non-matched. The indications are therefore that the effect shape has on response selection is additional to the influence of effector selection. Neither the influence of 'Finger' nor that of 'Shape' is so powerful that it overrides the other.
Similarly, Experiment 4 (Colour) also produced results parallel to those seen in Experiment 2. The influence of precue colour was strong enough to encourage selection of a colour matched stimulus on the non precued hand under free choice conditions. Likewise an effect for precue effector was found, although interestingly, this seems largely due to a very high influence of index finger. This result will be discussed at greater length in the general discussion.

Analysis of the data provided by these final two experiments provide additional evidence for the influence of precue features seen in the 'Object' experiment. It appears that the preference to select a precue matched target when placed under free choice selection conditions is due to grouping of various features of the precue. We have demonstrated that both the colour and the shape of a precue will influence response selection processes, and will do so to a level that is comparable to the grouping strength of precue/response effector that has been demonstrated in the previous chapters of this thesis.

Chapter 5

General Discussion

The investigations contained in this thesis were intended to explore the influence of a free choice paradigm on the response selection process. Historically, there has been an underlying similarity between investigations into the processes involved in response selection. Experiments have been altered to involve multiple effectors, multiple limb movements, or a combination of these; however the relationship between the final stimulus and the movement to be performed has always been maintained. This has generally involved direct 1-1 stimulus/response mappings. Therefore, regardless of any additional information presented during a trial (e.g. precue) there is, in effect, no choice for the participant to make. Under these 'Forced Choice' conditions, response selection is externally determined by the stimulus. This are no decision making processes to be carried out by the participant. However under 'Free Choice' conditions, the response selection process is internally driven by the individual. For accurate assessment of the principles involved in response selection it is necessary for participants to be able to actively select for themselves a response from a set of available options. It is important that this 'Free Choice' nature of response selection is included, therefore allowing comparisons to be made between response choices following the provision of additional information during a trial.

Investigations previously undertaken in the area of response programming and selection through the use of precues have highlighted the apparent grouping of responses. The location within response selection and movement programming that this grouping occurs within appears to be a matter of debate (Miller 1982, 1985; Reeve and Proctor 1984, 1985, 1990). However what appears highly replicable is the effect that sets of targets, either defined spatially, or by response effectors, can be grouped by participants and this will subsequently have beneficial effects on RT's when a response on the same limb is required. Detrimental effects are seen however, when a response is required to a stimulus matched to an effector on the opposite limb. This effect is seen under conditions when gross motor movements are required (e.g. arm movements) and when single finger button press responses are required. Rosenbaum's (1980) results indicated that the exclusion of precue information concerning the arm with which a response was to be produced in a forthcoming trial had most influence on RT. This indicates that preparation of multiple responses on a single limb is easier than preparing responses on multiple limbs.

Studies involving single finger responses have found corroboratory evidence for this ease in same-limb performance following invalid precues. Precueing a response on the right hand index finger, for example, will result in faster responses to a stimulus presented at a location mapped to the right middle finger than the left middle finger (Reeve and Proctor 1984). However, manipulation of the stimulus/response relationship (overlapping fingers and hands) meant that spatial grouping of targets occurred. Precuing a target in the leftmost set of targets facilitated RT to a stimulus presented at the alternate target in the leftmost target set, whilst detrimental effects were seen in response times to stimuli presented in the rightmost set (Reeve and Proctor 1986, Experiment 1). The so called 'Hand Advantage' (Adam 1994) is a consistent finding in studies utilizing the spatial precue paradigm when hands are placed adjacently.

A significant portion of recent research into perceptual motor behaviour, especially that into response cueing, have used finger responses to targets presented visually to participants. The use of these paradigms allows key press responses to be measured very accurately in terms of RT from stimulus onset. Additionally, the relationship between visual stimuli, effectors and the mapping between them can be easily manipulated (Reeve and Proctor 1986). Rosenbaum's (1980) initial investigation into the specification of defining body movements used arm, direction and extent as the variables involved in a basic motor task. A similar set of parameters can be utilized in finger response tasks. For example Chapter 3 in this thesis used hand, finger and direction as the variables that were manipulated. Finger-press response experimental designs were selected for this thesis for these two contributing factors; due to the manner in which they provide data that can be in-directly compared to that of previous examinations, and allowing efficient manipulation of experimental paradigms to vary stimulus/response mappings. The experimental data presented in Chapter 1 involved a simple free-choice paradigm which served as the basis for all subsequent experiments undertaken in this thesis. The initial questions posed by these experiments were what effect would a Go-to precue have on response selection under free choice conditions? Would the 'Hand Advantage' noted in previous spatial precuing experiments effect response selection, and would there be an associated 'Finger Advantage'? The results showed that following preparation of a response on one finger of a specified hand, response selection was biased towards a second finger on the precued hand over any response on the non-precued hand. The implications are that the influence on response grouping that was described in Adam's Grouping Model is also present under the free choice conditions and experimental paradigm used here. Under the 'Hand' precue conditions in Experiment 1, the grouping of responses occurred between homologous fingers on either hand. Experiment 2 involved the presentation of a stimulus that would cue either inner or outer fingers following presentation of a precue. Here the grouping of responses occurred between fingers on the same hand. This implies that the process of grouping responses depends on factors such as location and relationship of precues, stimuli, targets and effectors. Depending on these relationships, grouping may occur in a 'Bottom-up' manner, where grouping of targets occurs without cognitive requirements being placed on the participant. In other cases grouping may occur in a 'Top-down' manner, where effortful processes must be undertaken in order to effectively group responses. In Experiment 1, a stimulus that precued one or other hand clearly led to grouping processes that linked homologous fingers on either hand. The manipulation of the procedure for Experiment 2 clearly altered this process to make the grouping of matching fingers on either hand an easier process and one more beneficial to optimum performance in the current task.

Chapter 3 detailed a set of experiments designed to investigate further the effects found in the preceding experiments. The successful inclusion of the 'Free Choice' paradigm in the experiments in chapter 2 allowed us to extend our examinations by investigating the role that response production of specific actions has on programming. Whilst a similar precue paradigm was used, responses were required that involved flexion and extension movements of both the index and middle fingers on the right and left hands. It was found that the grouping effect observed under free choice conditions in the experiments detailed in Chapter 2 also occurred under the new flexion/extension protocol. The second experiment in Chapter 3 sought to identify more clearly the location for the grouping effect seen in flexion/extension movements. Reeve and Proctor (1984, 1986) had previously discussed the variable-order processes involved in response specification, and the exception to this conclusion demonstrated by Miller (1982). They presented data that indicated that the hand advantage could be manipulated into a 'Side' advantage by the overlapping of effectors. This indicates that the grouping seen in previous studies may have been a result of the spatial location of targets/effectors rather than due to motoric processes. A manipulation of the experimental design used in experiment 1 of Chapter 3 was undertaken, allowing us to examine our findings in a similar way. Rotating one of the hands by 180 degrees altered the mapping between effectors and actions on opposing hands. It was found that a precue at a specific location on one hand biased selection of a spatially matched response on the non-precued hand. The indications are that the interpretation of the grouping of responses as being due to spatial factors seems to hold true for free choice responses. The prevalence of precue-matched responses under free choice conditions is due to the matched spatial properties of the precue and response targets rather than being a artefact of matching effectors on which a precue is presented and a response is selected and produced.

Chapter 4 continued to focus on the grouping of precues and responses, focusing predominantly on feature similarity. Of interest was the specific characteristics of precue/response similarity on response selection and grouping. The grouping effect seen in the previous chapters was investigated using colour and shape of targets as grouping variables. The first experiment presented participants with 2 matched groups of 3 targets. We investigated the effect of precueing one of these targets and then giving participants a choice of targets in the non-precued group. The features of the precued target had a significant influence on response selection processes. When the matched precue object was available for selection under free choice conditions, it was selected more often than any other target. Grouping of precues and responses therefore appears to be influenced not only by their spatial location, as seen in the previous experiments, but also by specific features shared between them. Studies have shown the influence of shape and colour of distractor targets on visual search performance (Quinlan and Humphreys, 1987; Duncan and Humphreys 1989) and highlighted the difficulty in rapidly disassociating targets and distractors when they share common features. In separate experiments, the influence of colour and shape individually were investigated.

Results showed that the effect seen in the combined colour and shape experiment was also found when each of these features was isolated.

In summary, the data provided by all the studies undertaken in this thesis show evidence for the grouping of response and target features in free choice conditions. Response frequencies as well as reaction times, indicated that when a subgroup of targets was presented from which an individual response must be selected, precue features have a significant effect on selection. Adam and colleagues (2003) have forwarded a grouping model to account for the effects of precues on reaction time. They suggested that if a presented cue indicates a subgroup of stimuli that correspond strongly and closely to a similar group of responses then fast, automatic activation of the cued responses occurs. If a cue indicates a set of stimuli from a different subgroup and mismatching occurs between the precue and response groups, then a slow effortful process is required to create a strong subgroup. This requires a time consuming top-down process, resulting in slower responses.

The data obtained by Adam and colleagues over a number of studies supports this Grouping model, with reaction times seen to be significantly slower when a strong stimulus/response subgroup had to be created. These studies have predominately utilized a paradigm involving a precue of 2 responses. This would then be followed by one of these two precued responses being presented as the stimulus. In this experimental design, the subgroup from which the stimulus is to be selected is defined by the precue set. The effortful process of creating a strong subgroup may be affected by this, with fewer requirements on cognitive processing by the participant to create this group. It is possible that more automatic processes take place under these circumstances, a factor which can be investigated through the use of a single precue and a free choice paradigm. In the research carried out in this thesis, a single precue was presented, allowing preparation of only one response. Production of a subgroup of possible responses prior to stimulus presentation would therefore require cognitive processes on the part of the participant. Regardless of whether this process required complex and conscious grouping of targets, or grouping was of the simpler kind that Adam and colleagues stated was less effortful, no *automatic* grouping could occur on presentation of a precue.

Through the use of a single precue and the novel free choice paradigm, we have provided evidence that supports the theory that grouping of responses takes place. What has not yet been investigated fully is the effect specific features of a response have on selection processes. Chapter 3 highlighted the effect that the spatial locations of a precue and stimulus had on response selection. Further investigation on the influence on the remaining responses that were not homologous to the precue needs undertaking. Alternating the available responses by manipulating the stimulus from a simple left/right split, whilst also preventing selection of the precue matched location on the non-precued hand, would allow dissection of the individual components of this task (i.e. Hand, effector, direction). The similarity between this potential experimental design and the early precue paradigm studies performed by Rosenbaum is significant. The data from a study such as this would provide information on the potential hierarchical nature of these response features. It would be interesting to note whether the reaction time benefits noted in the studies by Rosenbaum and colleagues are mirrored by response selection biases under our free choice paradigm.

Within every experiment carried out in this thesis, a single factor was relatively unchanged across all paradigms, namely the length of time a precue was presented. Precue presentation times of up to 1 second could allow response strategies to be utilized by participants. Under no-go to conditions, sufficient time may have been available to not only inhibit the presented precue, but also activate a response on a non precued effector. This could subsequently alter the response grouping that took place in the period between precue and stimulus presentation. In order to reduce the available time for response strategy planning, precue presentation times could be reduced. The cognitive processes that are possible contributing factors in the results obtained in the current investigations could be discounted with an experimental design that employed significantly less precue presentation times.

The possibility of increased complexity of responses should also be investigated in future studies. Utilization of a paradigm involving index, middle and ring finger, in a similar flexion/extension design as that used in the studies in Chapter 3 would achieve this. In a similar way that reduced precue presentation times could prevent response inhibition strategies to be used, increased complexity would also reduce the possibility of pre-definition of response groups prior to stimulus, or even precue, presentation. With a limited number of response choices available, participants may adopt a strategy along the lines of 'If X occurs then I will do Y'. However this pre-selection would not be possible under conditions where a larger number of precue/stimulus options are possible. These more complex paradigms would give further insight into the response grouping and selection strategies that take place when we are suddenly placed in a situation where our preparation for a particular response suddenly becomes unnecessary and we are required to select from a new set of response possibilities.

In conclusion, through the Experiments contained within this thesis, an investigation into the influence of a free choice paradigm on response selection processes has been undertaken. Support for the grouping of responses has been found, with response effectors appearing to be grouped together in basic motor tasks. Evidence has also been shown for the non-motoric theory of response grouping (Reeve and Proctor, 1984) under these free choice conditions. Finally, evidence for the grouping of response features between precues and response targets has been found. It is hoped that the results from these free choice Experiments will provided a starting point, from which the way in which our decision making process can be influenced will be investigated further.

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