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### **Task switching and response processes**

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## TASK SWITCHING AND RESPONSE PROCESSES

Stephen Cooper

University of Bangor, UK

A thesis submitted to the School of Psychology, University of Bangor, in fulfilment of  
the requirements of the Degree of Doctor of Philosophy.

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“Can you do Addition?” the White Queen asked. “What’s one and one and one and one and one and one and one and one and one and one?”

“I don’t know” said Alice. “I lost count.”

“She can’t do Addition,” the Red Queen interrupted.

“Can you do Subtraction? Take nine from eight.”

“Nine from eight I can’t, you know,” Alice replied very readily: “but—”

“She can’t do Subtraction,” said the White Queen. “Can you do Division? Divide a loaf by a knife—what’s the answer to *that*?”

“I suppose—” Alice was beginning, but the Red Queen answered for her: “Bread-and-butter, of course.”

Lewis Carroll (Author and Mathematician, 1832-1898), *Through the Looking Glass*

And the Gryphon added “Come, let’s hear some of *your* adventures.”

“I could tell you my adventures—beginning from this morning,” said Alice a little timidly; “but it’s no use going back to yesterday, because I was a different person then.”

“Explain all that,” said the Mock Turtle.

“No, no! The adventures first,” said the Gryphon in an impatient tone: “explanations take such a dreadful time.”

Lewis Carroll (Author and Mathematician, 1832-1898), *Alice’s Adventures in Wonderland*

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### Summary

When switching between tasks, participants are sometimes required to use different response sets for each task: So, task switch and response set switch are commonly confounded. Eleven experiments divided into three series examined transitions of response within a linear four-finger arrangement. The first series examined cued grouping by hand or finger equivalence in both single task and task switching designs. The second considered the effect upon transitions of response when full repetition of the stimulus was included in the design. Results showed that part of the task switch cost is associated with switching between response sets, particularly those of hand. Furthermore, when task switching and repetition trials are mixed, a bias towards switching the response and/or hand is found in task repetition trials when an element of the stimuli is altered. In this instance, response repetition is hindered when a task switch is expected, even for those trials when a switch of task does not occur. Full object repetition facilitates responding, but appears to be a special case whereby repetition of the stimulus facilitates the response previously used. However, the preferences for stimuli presentation are altered according to the type of response subset that is mapped to each task, indicating that response processes have a role in determining the operation of those related to perception. The final series mapped two stimuli to each response: The stimulus-response codes appeared to be weakened, with an increased number of response options exacerbating the influence of the double mapping. The results demonstrate executive processes involved in task set configuration closely depend upon both the assessment of the percept and the motoric processing of the response set and that the grouping of effectors



influences the response preferences that are observed. The results are also important for current theories of task set control.

## Chapter 1

### The role of motor processes in task switching

In common experience, it is often necessary to perform a number of different actions in quick succession. Flexible, goal-directed behaviour requires the suppression and activation of a number of representations in memory, including those that are perceptual and motoric. The configuration of all the information required to perform a novel task is often termed task-set. Researchers have regularly used the task-switching paradigm as a means to study the processes underlying the activation and control of different task sets. Thus, in this paradigm, the process of switching between tasks has been noted to render a delay in comparison to the repetition of a task (Rogers & Monsell, 1995). Consequently, these costs in response times are deemed to represent the functioning of neural mechanisms associated with managing shifts between different activities.

A number of researchers have tried to isolate different factors contributing to this switch cost. The theories associated with task switching tend to constitute two broad groups of interpretation. Some such as Meiran (1996) and Rubinstein, Meyer, and Evans (2001) attribute the cost of the switch to a top-down (endogenous) process of reconfiguration; this view holds that the disparity between the Reaction Times (RTs) obtained on switch and repeat trials is indicative of the operation of executive functions, and that these costs are evident for switch trials alone. The apparent cost of repeat trials in a task switch experiment compared to those using just a single task (a phenomenon termed mixing cost: Los, 1996; Meiran, 2000a) is attributed to uncertainty about the

upcoming task affecting the individual's capacity to prepare. The alternative view emphasises relationships between stimuli and responses: In this instance, the processes of response selection are similar for all trials, but those for task switching suffer from the carry-over of positive priming from the previous task. Therefore, responses during task repetition trials in a task switching experiment are slower than those of a single task block because it is proposed that the interference is experienced across all trials but becomes exaggerated during a switch, resulting in an additional delay (Allport, Styles, & Hsieh, 1994).

In support of reconfiguration theories, sufficient time to prepare for a task switch enables a decrease in response duration, a benefit that has been considered to represent the top-down alteration of task parameters prior to stimuli presentation (Rogers & Monsell, 1995). Kleinsorge and Gajewski (2007) organised each task of two components in order to assess more fully the processes occurring during preparation: They considered that preparation constituted a process of integration between the task components to form a single, unified task representation, although the associations between the components may remain asymmetrical. Furthermore, the processes did not appear to be dependent upon response execution. However, the benefit from preparation seems not to be absolute, thereby suggesting some exogenous influence: A residual element of the switch cost remains evident despite preparation (Rogers & Monsell, 1995; Meiran, 1996) and extended response to stimulus intervals (Karayanidis, Coltheart, Michie, & Murphy, 2003), so it is suggested that the advance alteration of the task set is not sufficient to manage the switch of task alone. Moreover, Sohn and Carlson (2000) noted that the extent of foreknowledge affected both switch and repeat trials equally and concluded that the benefit of task repetition was not due



to effects deriving from preparation; similarly, Los (1999) observed that preparation for category was unable to eradicate mixing costs.

De Jong (2000) contended that the residual cost represented insufficient intention of the participants to prepare for the task, so that on some trials they are unready when the stimulus is presented. Therefore, this theory rejected the influence of exogenous processes (and task set inertia, discussed later) and asserted that task switch costs derived from a failure to engage the process of reconfiguration. However, Nieuwenhaus and Monsell (2002) attempted to maximise the preparation engaged by participants through the use of a reward payment system and extended preparation intervals following the cue that adhered to a simple and predictable sequence of task alternations: While they found some improvement in the performance of their participants, the average residual costs diminished but remained present. Moreover, Lien, Ruthruff, Remington, and Johnston (2005) observed that switch costs varied between participants for different response pairs, so they argued that it was common for participants to adopt partial preparation across all tasks and that the conflict between S-R relations was responsible for the cost of switching tasks. The authors doubted that participants possessed the capacity to fully prepare for a switch of task. In regard to this issue, it is also worth noting a study by Meiran, Hommel, Bibi, and Lev (2002): They asked participants to state their readiness before each trial and found that participants possessed little conscious awareness of their preparedness for the task, thereby questioning the relationship between consciousness and cognitive control that some researchers have assumed. Intention may generate the goal settings of the task set, but the execution of the task results from the

operation of many lower level mechanisms, at least some of which are likely to be automated.

Nevertheless, preparation dependent upon internal memory cues renders less advantage than those that utilise an external cue: Koch (2003) discerned that preparation had a much pronounced effect with external cues in comparison to tasks requiring the employment of internal rules. Thus, he surmised that a non-spatial percept was able to promote the relevant Stimulus-Response (S-R) mapping for a task while this procedure was much diminished or absent when the task relied exclusively upon the free choice of the individual.

Logan and Bundesen (2003) dissociated repetitions of cue and task by using two cues for each task; if the cost of a task switch was entirely due to executive functioning then it was predicted that both forms of repetition would give equal benefit. Still, they discerned that a large advantage of cue repetition was evident, while differences between task repetition and alternation were slight. It was concluded that task repetitions involving explicit task cueing primarily reflect an advantage of stimuli encoding and so suggests that the role of executive functions is limited in this context, although it was subsequently proposed that less external influence might provoke greater demand upon mechanisms of executive control.

However, Monsell and Mizon (2006) further assessed the process of cueing and noted that switch costs were observable in many circumstances once the influence of cue change had been accommodated. Instead, they proposed that the crucial aspect was the probability of change: If participants had a high expectation of task change, or if change was clearly predicted by the cue, then

preparation for the expected task was initiated. Cue repetition facilitated preparation and reduced interference from the opposing task set. Altmann (2007a) also assessed the assertion concerning cueing that had been proposed by Logan and Bundesen (2003) in relation to a paradigm allied to task switching called backward inhibition: The term backward inhibition denotes an occurrence whereby switch costs become less prominent when a switch of task is directed toward a third task (CBA) rather than to the task that has been previously abandoned (ABA), (Arbuthnott and Frank, 2000). Again using two cues for each task, Altmann (2007a) discerned that the effects of backward inhibition were robust regardless of the cue, so he surmised that task specific representations must be dominant in explaining the switch costs that are usually obtained.

Gopher, Armony, and Greenshpan (2000) distinguished between the adoption of a task set and its execution. They proposed that the activation of a task set was time-dependent and so benefited from preparation, as the mechanisms associated with internal representations of the task can be fully reconfigured before the appearance of the stimuli. Conversely, the execution of a task was dependent upon the item and so required the actual presentation of the stimulus: Furthermore, it was argued that the process of execution was most difficult during the trial that incorporated a switch of task. Hence, two components were specified in relation to the task switch process. Mayr and Kliegl (2003) manipulated the assignment of cues in order to dissociate the effects produced by switches of cue and switches of task; two cues were assigned to each task so that a cue could be altered while the task remained constant. It was observed that changes of cue constituted a component of the task switch procedure and that this process was influenced by task preparation: Mayr and Kliegl (2003) suggested that the



temporal nature of this process indicated the retrieval from long term memory of the rules associated with the task. However, a switch of task was also affected by response priming and task-set inhibition. Therefore, it was proposed that the second component involved the automatic employment of rules upon the presentation of a stimulus. Backward inhibition was surmised to influence only the second component. Arbuthnott and Frank (2000) argued that the resolution of conflict associated with the inhibition of a previous task set may constitute an important role. Hence, Kleinsorge, Heuer, and Schmidtke (2002) contended that the residual cost comprised a component of task implementation, and appeared to be dependent upon task difficulty.

Allport, et al. (1994) suggested that a previously adopted task set was slow to decay and remained active over a number of trials, thereby producing proactive interference for the newly introduced task set. They termed this process task-set inertia. Hence, the duration of response selection on a post-switch trial is extended while the correct task set is established (Meuter and Allport, 1999). A prominent finding that supports the concept of task-set inertia is that it is often easier to switch toward the weaker task afforded by a stimulus than to a task that is stronger (for example, De Jong, 1995; Meuter & Allport, 1999). Thus, the stronger task that has been learned most well receives greater inhibition in order to accentuate performance on the task that is considered more difficult. Furthermore, Yeung and Monsell (2003) discerned that there was a greater cost for switching toward a task that had been well practiced, implying that a strong task received a greater degree of inhibition once it had been abandoned.

Lien, Schweickert, and Proctor (2003) blocked tasks into pairs of trials and found that the switch cost to the second task was additive with stimulus onset

asynchrony, the processing of the second task occurring after the first had been completed despite foreknowledge of both. Nevertheless, Monsell, Yeung, and Azuma (2000) found that the appearance of task-set inertia was not uniform, although they posited that a task of greater complexity may require an extended and more pronounced use of post-stimulus control processes in order to implement complex S-R mappings, and that this procedure could conceivably counteract and obscure any benefits obtained from the inhibition of the stronger task. However, it appears that the extent of backward inhibition is dependent upon the response-cue interval: Gade and Koch (2005) varied the response-cue interval across trials and decided that the results endorsed a theory of activation decay for the abandoned task set, with the subsequent inhibition of that task set at the response selection stage being dependent upon the degree of competition with alternative tasks.

Following the initial study by Allport et al. (1994), Wylie and Allport (2000) noted that non-switch trials also showed evidence of proactive interference and found contemporary models of task switching unable to explain the effects. In particular, they argued that the finding cast serious doubt on inferences of executive functioning associated with task reconfiguration. Instead, they proposed that switch costs were largely dependent upon the competition produced between the S-R relations of the tasks involved, with the emphasis upon the relative characteristics of those associated with the task being replaced during the switch. Moreover, the S-R relations of the abandoned task were noted to cause interference long after the initial switch had occurred, with the most recent experience of any given S-R pair influencing the manner of responding upon its following presentation.

Nevertheless, while task switch costs are common, it has been observed that when tasks are composed of different stimuli types it is possible for the costs of task switch to be eliminated entirely, as the stimuli exclusively cue the task to be executed; but if the stimuli acquire additional associations during blocks of trials for a separate experiment, those associations will then be carried back into the original test and produce interference as exhibited by continued fMRI activity related to the second study (Wylie, Javitt, & Foxe, 2004). Waszak, Hommel, and Allport (2003) contended that stimuli develop associations with the tasks in which they are experienced and these bonds can remain for more than 100 intervening trials: When activation of the desired task is weaker, such as during a switch of tasks, then the S-R bindings of the previous task create conflict. Therefore, Waszak et al. (2003) proposed that a large portion of switch costs is not attributable to mechanisms of control and reconfiguration. Mixing costs also seem to be dependent upon the ambiguity of stimuli relating to more than one task (bivalent stimuli), as the costs seem to disappear when the stimuli clearly specify the task to be implemented (univalent stimuli), so Rubin and Meiran (2005) specified the necessity to manage competing tasks in order to sustain performance.

Dreisbach, Goschke, and Haider (2006) required participants to practice eight S-R mappings, either with or without information of the associated task sets being conveyed; after transferring to a block of eight new S-R mappings, only those with knowledge of the task sets demonstrated switch and transfer costs. Therefore, knowledge of the task rules was deemed necessary to organise the S-R information before task switching effects can occur. Mayr and Bryck (2005) found that a repetition of an S-R conjunction only produced a benefit if the rule repeated also; if the rule changed then costs were obtained. Moreover, integration



between S-R mappings and a rule was strengthened through practice. Their findings supported the notion of event files that has been forwarded by Hommel (2004). According to this theory the aspects of an event, such as the presentation of a stimulus, are integrated with the event of acting and become bound to form a representation that contains all of the related facets including the task set.

Therefore, if one aspect is altered then the remaining components of the event file are also affected, and so S-R bindings become identified with the task in which they occur.

Nevertheless, the relative importance of motor processes with regard to task switching has often been overlooked, until recently. For example, Philipp and Koch (2005) contended that researchers often focussed upon the formation of sets of stimuli at the expense of considering the corresponding motor sets. They ran experiments where the response modality was switched while the stimuli group remained the same: Specifically, the participants had to give a vocal, finger, or foot response to the categorisation of digits as being odd or even. The presence of backward inhibition between modalities was evident and so Philipp and Koch (2005) stated that the inhibition of response modalities can occur in a manner similar to those of stimuli categories, with both potentially representing the capacity to constitute a task. Furthermore, Arrington, Altmann, and Carr (2003) examined the influence of the relative similarity between tasks: Similarity was defined according to either the repetition of the response modality or the continued relevance of a specific stimulus dimension for each task. It was observed that the increased similarity between tasks was sufficient to reduce the costs of a task switch

Hsieh and Yu (2003a) employed the recording of Event-Related Potentials (ERP) in order to study the neural processing associated with task switching and specified an extension of the response selection stage during the switch of task, which they supposed was due to the interference of carry-over priming from the preceding task. Examination of the ERP waves showed that external cueing affected processes that were prior to response selection for both task switch and task repeat trials and was noted to limit the interference caused by priming: Therefore, task switch and task-cueing affected two separate but linked stages and the effects were approximately additive. They subsequently proposed that the delineation of these processes strongly supported theories concerning the influence of carry-over effects upon the creation of switch costs, but that the operation of a switch specific reconfiguration mechanism was not evident (Hsieh and Yu, 2003b).

Schuch and Koch (2003) utilised Go/No-Go methodology whereby it was necessary for responses to be executed or withheld dependent upon a signal presented concurrently with the stimulus. Therefore, processes of preparation may occur for all trials but execution was sometimes withheld. The authors discerned that the costs of switching, including residual costs, were absent following a no-go trial; moreover, so were those relating to backward inhibition. Consequently, it was inferred that inhibition of the irrelevant task set occurred at the stage of response selection, and that the residual switch derived from the prolongation of this process as the continued but inappropriate activation of the S-R map from the previous task interfered with the S-R map being newly established. This proposal was further supported by a later study conducted by Koch, Gade, and Philipp (2004) that required participants to switch between three



tasks mapped to two keys, one of which consistently required a double-press of both responses. Backward inhibition was present for all three tasks, indicating that it was the response mode being inhibited: However, increased preparation by extending the cue-stimulus interval only reduced the inhibition of the double-press task, as the choice tasks still required the presentation of the stimulus in order to resolve response competition. Increasing the response-cue interval led to a reduction in the inhibition shown in all tasks, thereby demonstrating a temporal decay of the inhibition applied to the abandoned task.

Milán, González, Sanabria, Pereda, and Hochel (2006) adapted the paradigm used by Schuch and Koch (2003): The presentation of the no-go signal was delayed until 500ms after target onset in order to further encourage processes associated with response selection; the percentage of go trials was varied between experiments; and the switch was systematic rather than random, occurring after every three trials. The results were supportive of the assumptions proposed by Schuch and Koch (2003): However, Milan et al. (2006) assessed the effect of no-go trials within the trial sequence and noted that a significant difference between switch trials and second repetition trials was only evident when a high ratio of go trials was employed; it was argued that this effect represented residual costs. Thus, while Rogers and Monsell (1995) had suggested that the residual cost was dependent upon the stimulus, Milán et al. (2006) proposed that it was actually the associated mechanisms relating to the selection of the response that constituted the final component of the task switch rather than the visual processing of the percept.

Verbruggen, Liefoghe, and Vandierendonck (2006) directly dissociated response selection from response execution by the employment of selective stopping, whereby a no-go signal was only relevant under certain conditions. The

signal to stop was initially presented 250ms after presentation of the target, although subsequent trials utilised staircase-tracking procedures in order to vary the delay in accordance with obtaining a 50% probability of withholding the response. A first version of the task required participants to adhere to an auditory stop signal if the response was situated upon one hand while ignoring the signal if the response depended upon the alternative hand: Thus, it was proposed that processing of response selection was necessary so as to correctly decide the validity of the signal. The research demonstrated that switch costs were evident after all trials, including those that were correctly inhibited. Alternatively, a second version of the task entailed stopping a response dependent upon the pitch of an auditory tone: Therefore, the criterion for abstinence was perceptual and so could be assessed independently from the response process. In this instance, Verbruggen et al. (2006) discerned that the switch costs were absent following a stop signal. Consequently, it was stated that response selection rather than response execution was integral to the occurrence of switch costs.

It is apparent from these studies that response selection constitutes a crucial stage of information transfer regarding S-R relations, while response execution seems to be an extraneous factor. Philipp, Jolicoeur, Falkenstein, and Koch (2007) employed a delay of the go/no-go signal. The signal was presented either 100ms or 1500ms after the presentation of the stimulus, so participants were allowed to prepare their response to the stimulus for a duration before the signal appeared. Therefore, unlike the previous experiments that used go/no-go methodology, responding in this version of the task placed greater emphasis upon the relevance of the go signal. Moreover, in this case the effect of preparation allowed participants to not only prepare the task, but also to prepare the task-



specific response. It was observed that the opportunity to prepare resulted in the reduction of switch costs and backward inhibition, although the costs were smaller with a long signal delay if the response was not executed. Thus, the authors argued that response execution also contributed to the interference associated with switch related costs. Allowing for a specific response to be prepared illuminated the role of response execution in a manner that the design of the previous experiments had concealed: Presumably, the early stopping of a task had reduced the influence of late processes belonging to response execution and so their relevance had not been apparent.

Overall, it seems that the flexible handling of S-R mappings for different tasks requires the resolution of response competition in order that the appropriate response can be selected and performed. The mechanism resolving conflict seems particularly important in those two-choice paradigms where the mapping of the same response to different tasks maximises the conflict: In this instance, two responses for each task are mapped to the same two fingers (Altmann, 2007b; Rogers & Monsell, 1995; Ruthruff, Remington, & Johnston, 2001). However, the four-choice paradigm normally utilises four fingers with a single mapping (Miller, 1982; Reeve & Proctor, 1984), so that the stimuli pool is of the same size as that used for the two-choice paradigm but spread across a larger response set. The specific role of this mechanism in the four-choice paradigm is less clear, since different response sets are often mapped to different features (for instance, right hand for colour, left hand for shape), so minimising their relative interference. This thesis demonstrates a substantial suppression of previous responses in a four-choice paradigm of task switching when any element of the presented stimulus changes. Indeed, any system that needs to flexibly switch between actions should

possess a method of biasing the system toward new S-R mappings when the stimulus alters so as to avoid perseveration errors.

### Perceptuo-Motor Relations and Response Inhibition

Proctor, Reeve, and Van Zandt (1992) proposed that response selection was contingent upon the initial visual processing of the salient features of the percept. They delineated a three-stage model whereby response selection, termed S-R translation in their model, comprised an intermediate stage that mediates between stimulus encoding and response programming. Kornblum, Hasbroucq, and Osman (1990) specified a continuum for S-R mapping that incorporated the distinction between set-level and element-level compatibility. The former concerns the relationship between the type of stimuli, such as letters or objects, and the manner of response, which for example could be vocal or the pressing of keys; alternatively, compatibility at an element-level involves the mappings of stimulus and response according to the attribution of the members of each set. Wang and Proctor (1996) indicated that tasks that have greater correspondence between the stimulus and response sets are relatively undemanding to translate, but a lack of correspondence produces increased demands upon response selection to then render the correct reaction. Thus, an increased effect of response competition is evident when the translation of the stimulus into a response code is more difficult to accomplish. However, Adam, Paas, Buekers, Wuyts, Spijkers, and Wallmeyer (1996) assessed RTs for a four-choice task with three different forms of response modality: Pointing, vocal response, and finger-lift. Pointing, the most natural of the three actions, had RTs that were over 100ms shorter. Moreover, it was discerned that pointing showed no difference between the RTs of the four locations while the remaining modalities showed different patterns of

responding. The authors argued that the requirement for a stage of S-R translation is dependent upon the precise characteristics of the S-R relationship, while, in some instances, a direct and automatic route can be accessed.

The flanker task developed by Eriksen and Eriksen (1974) required participants to respond to a target letter while endeavouring to ignore the distracting letters that flank it to the left and right. In this circumstance, Eriksen, O'Hara, and Eriksen (1982) considered that all items within the array initially received some perceptual processing, with response competition then being responsible for the delay produced by incongruent flankers as inhibitory processes endeavoured to suppress those responses considered to be incorrect. Hommel (1998a) utilised dual-task experiments so as to assess mechanisms of S-R translation: Participants were required to produce two consecutive responses toward different dimensions of a stimulus. Further variations of the task allowed cued preparation for one dimension or removed time strictures regarding one form of response. It was subsequently discerned that primary responses were affected by the compatibility of the secondary response with either the primary stimulus or the primary response: So it was argued that, although response selection may be serial, the processing concerning S-R translation is performed in parallel, with the secondary response already generating while the primary response is still to be executed. Miller (2006) used the Psychological Refractory Paradigm, whereby two tasks are to be completed in rapid succession with a variable interval between them. He discerned that the generation of a response toward a task was affected by the preparation for a response toward the second task: The characteristics of the second-task response affected the RTs of the first, so the effect of backward



crosstalk demonstrated that response preparation for different effectors can happen concurrently.

The continuous flow model (Eriksen & Schultz, 1979) suggested that processes of response selection are initiated as soon as perceptual information begins to accumulate: So, competition between responses occurs, as all task-relevant responses are initially activated before further perceptual processing aids the selection of the most appropriate. Further study of the continuous flow model using ERP recording was conducted by Coles, Gratton, Bashore, Eriksen, and Donchin (1985): Their results led them to state the presence of three processes that affected response latencies: The accumulation of perceptual information; response priming processes independent of stimulus evaluation; and response competition. Activity of response selection is even evident when additional mental processing of the percept is required. Heil, Rauch Henninghausen (1998) used ERP recording along with examination of the Lateralised Readiness Potential (LRP): The wave patterns of the LRP illustrate hemispheric activation of the motor cortex. During the process of rotating mirror-reversed numerals it was observed that response-related activity had already been initiated before the rotation was complete.

Nevertheless, Miller (1993) amended the continuous flow model to incorporate aspects of discrete processing, thereby proposing a hybrid: Specifically, his queue-series model stated that the transfer of information for each code within a stimulus (such as colour and shape) occurred in sequence and so was discrete, but that multiple codes can be processed in parallel. Thus, each code contributes to response selection once the processing of that particular code has been completed. In support, Smid, Mulder, Mulder, and Brands (1992) employed

ERP recording in conjunction with Electromyogram (EMG) data obtained from recordings of muscle activity in the fingers: Their results suggested that response selection can be initiated on the basis of processing from one stimuli dimension, while another dimension may still not have been recognized. Furthermore, Ulrich, Rinkenauer, and Miller (1998) discerned that the intensity of the stimulus was positively correlated with the extent of response force; they also noted that an extended duration of the stimulus served to increase the duration of the response. Therefore, they surmised that the visual information from the stimulus affected the stage of response selection by degrees, rather than simply promoting a discrete activation of the response.

Schlaghecken and Eimer (2002) suggested that response activation was perhaps dependent upon exceeding a threshold of perceptual input. Previously, Neumann and Klotz (1994) had determined that stimuli displayed near or below conscious awareness is still sufficient to facilitate motor related activity. Schlaghecken and Eimer (2002) utilised masked primes and noted an asymmetry between foveal and peripheral vision, with visual information in the periphery being weaker. The perceptual strength of primes in the periphery was manipulated by delaying the onset of the mask: Effects of positive priming became negative, which they supposed to represent the activity of response inhibition. Furthermore, the gradual degradation of the peripheral primes lessened their intensity, so that negative effects of compatibility with the target became positive as the influence of the peripheral primes declined. So, it is apparent that strong perceptual traces create facilitation of the associated response followed by inhibition, but that weaker traces below a threshold are not subject to these processes.

Ridderinkhof and Van der Molen (1995) conducted a study of flanker tasks with measurements of ERP and discerned that the delayed response produced by displays featuring incongruent distractors was replicated in the latencies of the LRP wave. This disparity was assumed to derive from partial activation of the incorrect response due to associations with the distracting stimuli (Coles, Gehring, Gratton, and Donchin, 1992; Kopp, Mattler, Goertz, & Rist, 1996): Although, the activation may be insufficient to attain response execution before the S-R link between the distractors and the incorrect response activation are inhibited. Osman, Kornblum, and Meyer (1986) depicted the competition between response options in terms of a race model, with the antagonistic processes of excitation and inhibition causing the result of response selection. However, De Jong, Coles, Logan, and Gratton (1990) stated that a response could be interrupted at any time up to the point of execution, thereby arguing against the notion of unstoppable ballistic activation.

Eimer (1999) proposed that the early facilitation of the incorrect primed response that was apparent in the waves of the LRP originated from a direct perceptuo-motor link that automatically processes information before the error can be detected and inhibited. Nevertheless, Wang and Proctor (1996) argued that automatic response activation only appears to occur when a congruent mapping is apparent between the spatial arrangement of the stimuli and the response set. Additionally, the functioning of the perceptuo-motor link is absent when the experiment utilises non-spatial cues such as colour (Eimer, 1995). De Jong, Liang, and Lauber (1994) studied the Simon task, an experimental paradigm requiring responses to be made to a non-spatial dimension of a stimulus, even though the position of the target is altered for each trial: It was noted that rapid



responses produced benefits for spatially congruent responses in comparison to those that were incongruent, but that the relationship was reversed when reactions were slower, thereby indicating the late influence of response inhibition in this instance and supporting the notion of a dual-process model incorporating an early perceptuo-motor link for spatial codes with a later, more involved response process for those attributes that were non-spatial. So, the automaticity of spatial processing appears to be independent of the goals of the task. Still, some modulation of automatic processes by the task set is apparent. For instance, the influence of the perceptuo-motor link seems to be reduced if the number of non-corresponding S-R trials is increased, suggesting that probability is a factor (Stürmer, Leuthold, Soetens, Schröter, and Sommer, 2002).

However, Arbuthnott (2005) noted that the backward inhibition was absent when spatial cues were employed: Therefore, it appears that the automaticity of spatial processing is able to facilitate changes in task when spatial information is relevant to those goals. Schlaghecken, Bowman, and Eimer (2006) determined that the activation and subsequent inhibition of an incorrectly primed response also corresponded with the inhibition and later non-inhibition of the non-primed response; so, facilitation and inhibition appeared to operate in tandem in order to render the correct reaction. Nevertheless, the presence of cost or benefits for incompatible trials was mediated by the number of response options. Eimer, Schubö, and Schlaghecken (2002) employed masked priming between modalities of hands and feet, but found no carry-over of inhibition when the modality altered. Thus, they proposed that inhibition did not operate at the level of central abstract codes but instead occurred at effector-specific motor stages.

Buckolz, O'Donnell, and McAuliffe (1996) found an interaction between hand processing and the Simon effect: The cost of a spatially incompatible target was greater if the two fingers used for responding were situated on the same hand rather than separate hands. Therefore, the authors suggested that this effect represented the operation of response inhibition, as suppression of the spatially compatible response is more difficult when the hands cannot be used to separate the identity of each finger. Furthermore, Van den Wildenberg, Van Boxtel, and Van der Molen (2003) discerned that the probability of a response affected the extent of response inhibition that was observed: If response readiness was low then response force was stronger and response inhibition lasted for a greater duration, which the authors interpreted to suggest that the stopping of a response with low readiness was more demanding. Houghton and Tipper (1996) proposed that inhibition and facilitation was used to manage response competition in conjunction with similar processes applied to control the perceptual processing of target and distractor stimuli. The parallel application of inhibition and excitation by the prefrontal cortex allows the individual to manage his or her performance of different tasks (Knight, Staines, Swick, & Chao, 1999).

There have been a great many studies attempting to examine the neural basis of inhibition. For example, Hazeltine, Poldrack, and Gabrieli (2000) employed fMRI to highlight brain regions associated with the performance of a flanker task: They noted that the presence of response competition generated by distractor stimuli was associated with neural activity in the parietal and frontal lobes. Bunge, Hazeltine, Scanlon, Rosen, Gabrieli (2002) proposed that the left parietal lobe was responsible for maintaining a representation of the available responses and so constituted the origin of response competition, as responses were

activated upon presentation of the stimuli according to learnt S-R associations.

The anterior cingulate cortex was proposed to identify the presence of conflict and inform the lateral prefrontal cortex, which then resolves response competition by selecting the appropriate response while inhibiting the partial activation of the remainder.

However, inhibition does not constitute a general unitary process, but instead is local to the operation of other processes (Houghton & Tipper, 1996), so that the employment of inhibition may derive from various subsystems and mechanisms depending upon the purpose (Kok, 1999). For example, Garavan, Ross, Murphy, Roche, and Stein (2002) asserted that the implementation of response inhibition was dependent upon the difficulty of the task. They determined that the right dorsolateral prefrontal region was involved with response inhibition, in union with the parietal lobe. Moreover, it was noted that the cingulate cortex only became active for tasks where the process of inhibition was more difficult to manage, while the left dorsolateral prefrontal cortex functioned when a behavioural adjustment was required between trials. Therefore, inhibition can be fractionated into specialised sub-components, although Garavan et al. (2002) emphasised that the operation of each cortical area occurred as part of a larger framework of activation across the cortex and so warned against the simple allocation of an inhibition function to a particular region without accounting for the broader context. Thus, while the frontal lobes are often associated with processes of inhibition, the variability of findings both between and within studies has led to the assertion that the application of inhibition is task specific (Tipper, Weaver, & Houghton, 1994; Mostofsky, Schafer, Abrams, Goldberg, Flower, Boyce, et al., 2003). Interestingly, Maguire,



Broerse, De Jong, Cornelissen, Meiners, Leenders, et al. (2003) incorporated fMRI with Go/No-go tasks and discerned that the application of response inhibition in a No-go trial also increased activity of the right parietal lobe associated with the visuo-spatial processing of the environment: They interpreted this activity to suggest that response inhibition prompted heightened processing of the stimulus, indicating the close relationship between perceptual and motor processes, thereby coinciding with the pre-motor theory of attention, which states that response processes and perceptual attention affect each other because they share common mechanisms of control (Eimer, Forster, Van Velzen, & Prabhu, 2005).

#### Motor processes and response grouping

Miller (1982) developed a method of pre-cueing responses in order to assess the manner of transmission from stimulus to response. The target, a plus sign, could appear in one of four possible locations that adopted a horizontally linear arrangement and mapped spatially to the four response keys employed by the index and middle fingers of both hands. The cueing of response subsets consisted of two plus signs while the baseline used four. Thus, the subset cue allowed the participants to prepare two fingers for a response and ignore the two that remained. Subset cues that corresponded with the two fingers of the same hand (left-right cues) produced substantially faster responses than those that specified the fingers of separate hands. Miller (1982) considered that the advantage of cueing the two left or right positions represented advanced preparation of the response hand. Consequently, it was suggested that the differences of performance for the cueing of response subsets represented

differences of preparation efficiency, thereby supporting the notion that response selection was initiated before the processing of the stimulus was complete.

However, Reeve and Proctor (1984) noted that the varied cueing of separate hands also demonstrated differences of RTs. For example, the cueing of equivalent fingers of the same type produced faster responses than cues that specified a non-equivalent pairing, the middle finger of one hand and the index of the other. Moreover, extended precue intervals allowed all types of subset cue to be prepared equally well. Nevertheless, the presentation of cues at the same moment as the target rendered the subset cueing of separate hands to produce longer RTs than those of the baseline condition. Adam, Hommel and Umiltà (2005) argued that cueing the relevant hand (left-right cueing) promotes a rapid, automatic facilitation of the response, while the cueing of fingers corresponding to separate hands requires processes that are slower and more arduous. Reeve and Proctor (1984) had initially proposed a non-motoric account of the advantage of left-right cueing that emphasised the process of S-R translation during response-selection, as their research noted that the advantage remained evident even when the location of effectors was altered so that the fingers were interlaced. Thus, Reeve and Proctor (1984) contended that the S-R codes are processed during response selection according to the central location of the arrangements for the stimulus and response sets, and so criticised the assumption by Miller (1982) that advance information can influence the mechanisms of response execution. Miller (1985) replied that the advantage of hand processing may simply have been concealed by the factor responsible for causing the substantial increase in RTs.

Nevertheless, Adam, Hommel, and Umiltà (2003) later ran a similar experiment but found alternative results, whereby optimal preparation engendered an advantage for the cueing of equivalent fingers rather than left-right positions and so argued that motoric factors strongly affected the efficiency of the cue. Furthermore, the placement of the hands in close proximity upon the keyboard weakened the left-right advantage, as the grouping of hand became less distinct (Reeve, Proctor, Weeks, & Dornier, 1992); while responding with the four fingers of just one hand removed the left-right advantage entirely and instead emphasised the distinction between inner and outer cueing (Adam et al., 2003). Adam et al. (2003) reassessed the data from the studies by Reeve and Proctor (1984) and contended that the responses corresponding with the left-right advantage were still slowed in the crossed-hand conditions, so it was inferred that finger placement must constitute a role in RT performance.

Leuthold, Sommer, and Ulrich (1996) attempted to determine whether the effect of precueing had a motoric component. The research varied the advance information for responses according to hand and the movement direction of the finger in order to respond to stimuli with force sensitive keys that were able to register both the flexion and extension of each finger. They employed the recording of ERP so as to determine differences in the LRP waves related to the cues and incorporated both congruent and incongruent S-R mappings: It was subsequently discerned that the effect of cueing was at least partially due to motoric processes. Moreover, the amplitude of the LRP wave increased according to the amount of advance information that was given. Therefore, Leuthold et al. (1996) proposed that preparation involves not just the selection of abstract response codes but is also specific to groups of muscles.



Miller and Ulrich (1998) examined the impact of the response set size. They utilised the recording of ERP and examined the differences in the LRP waves produced by two-finger and six-finger response tasks: In this instance, the LRP waves demonstrated a delayed onset for incongruent trials when compared to those that were either neutral or congruent. It was observed that the six-finger tasks produced a greater delay for the LRP onset after presentation of the stimulus, but that there was also a discernable delay following the onset of the LRP wave until the key response was executed: Furthermore, increases of the total number of S-R pairs influenced the stage before LRP onset, while the duration of the wave following onset was affected by the number of competing responses on the relevant hand. Therefore, the research indicated that hand activation occurred before that of finger, as Miller and Ulrich (1998) discerned that the LRP wave began before finger selection had transpired. So, the selection and implementation of a motor response appears to develop within a series of processes that are hierarchical. Adam et al. (2003) contended that the generation of abstract codes during S-R translation is reliant upon the capacity for low-level grouping of stimulus and response related factors; in this manner, the processing of hands is normally used to group the effectors and thereby aid selection of the correct response.

Response tasks using just two fingers tend to produce faster responses when each finger is on a separate hand rather than the same hand (Reeve & Proctor, 1988; Adam, 2000), as the hand differentiation aids the selection of finger. Alain, Buckolz, and Taktak (1993) assessed the two finger responses obtained in a simple RT task; however, they manipulated the number of fingers upon keys between blocks of trials with versions of the task employing either two,

three, or four fingers, although the additional fingers were never actually required for a response and this was conveyed to the participants at the outset of the experiment. Simply placing fingers upon the keyboard that were irrelevant to the task affected responses when the two relevant fingers were upon separate hands. The addition of two fingers increased RTs further than the presence of just one. Conversely, two active fingers upon the same hand were not affected by the addition of fingers upon the other hand. Therefore, if hand is selected before finger, then the influence of fingers upon the opposing hand appears to be negligible when only one hand is used for responding; but increased response competition is evident when the active fingers are situated upon separate hands, as the hand distinction is not sufficient to negate the influence of the fingers that are irrelevant. Of course, this experiment also indicates that the production of a response is associated with the position of the body in space and is not simply dependent upon the task instructions. The implication is that exogenous feedback from the response set provides a map for the response code during response selection. Moreover, if this assumption is accurate, then it appears that the non-motoric accounts of action are incorrect in rejecting the influence of anatomy.

Adam (2008) further examined the role of anatomy. He analysed responses relating to the bowed spatial position effect in relation to variations of the four fingers used for responding. The bowed finger effect occurs for a four-finger linear response set placed in a horizontal position and demonstrates shorter RTs for the two externally placed fingers than for the two that are central. It has been suggested that the bowed finger effect produces faster processing of externally placed positions because the location possesses only one neighbour while those that are internally placed have a location situated upon either side so



they experience more interference (Adam, Paas, Teecken, Van Loon, Van Boxtel, Houx et al., 1998). Adam (2008) manipulated the fingers that were used so that the response sets were composed of either four fingers of just one hand, three fingers of one hand and one of the other, or two fingers of each hand. The stimuli and response positions remained unaltered for each version of the task. The bowed spatial position effect was consistently present, indicating that the spatial coding of the locations was responsible for its occurrence. Responses were fastest when two fingers were situated on each hand and slowest when all responding fingers belonged to one hand, indicating that grouping subsets of fingers according to hand aids response selection. However, it was noticed that the appearance of the effect altered according to the specific fingers that were used, as the RTs and error rates demonstrated a mirror-symmetry for the equivalent fingers of both hands, so the responses cannot be dictated entirely by spatial codes alone. Hence, Adam (2008) stated that anatomy may constitute a greater role in the process of response selection than had commonly been supposed, although the responses were mediated by the context of the task rather than being due to the musculature of specific fingers.

Thon and Bonneville (1996) assessed responses to a visual signal that indicated specifically either one finger or a chord of two fingers to be used for responding; the response set utilised all fingers of both hands upon a horizontal row of ten response keys. The authors surmised that, when chords were initiated, the sets of fingers of the same hand or the symmetrical fingers of both hands demonstrated a temporal overlap between response selection and motor programming, while the processing of non-equivalent fingers for both hands occurred in a serial manner. Practice served only to aid the performance of non-

equivalent finger chords. A subsequent experiment gave foreknowledge of one, two, or none of the fingers to be used during the response. Unsurprisingly, the RTs became shorter as more of the fingers were cued. However, they argued that responding with fingers upon the same hand was a holistic process, with both fingers being easily grouped; whereas chords of fingers across hands required two sets of processes, one for each finger: The processes can run in parallel if the fingers are symmetric, but must be activated serially if the fingers are non-equivalent.

Mechsner and Knoblich (2004) examined the possible relations between pairs of fingers. Participants were instructed to tap two fingers of each hand in alternation. They argued that a tendency for symmetry was dependent upon the abstract spatial codes rather than the combination of the specific fingers, as tapping appeared to be performed equally well when fingers of different types were employed upon each hand. However, the stability of this effect appeared to have a hand-centred frame of reference, as the relative position of hands altered the symmetry tendency, although the authors interpret this result as due to changes of response location rather than response execution. Nevertheless, the results of the article imply that hand processing influences S-R codes, but that the codes are enacted through an effector. The studies discussed earlier such as Philipp et al. (2007) and Adam (2008) would suggest that the processing related to specific effectors is obscured by that associated with the S-R codes to which they are directly related: Therefore, while the stage of response selection is clearly important, it is conceivable that Mechsner and Knoblich (2004) may have overlooked the importance of finger specific information as Reeve and Proctor (1984) may also have done previously.

Park and Shea (2005) examined the use of fingers when learning response sequences of 10 and 16 elements and reassessed the pattern of responses over a four day period. On the first day of research, the participants demonstrated learning of the response sequences that appeared independent of the effectors that were used: The relational pattern between the stimuli and responses could be performed equally well with different sets of fingers; but by the fourth day of practice the participants showed substantial cost when switching from the fingers that they had normally used. Hence, Park and Shea (2005) argued that effector specific information was integral to consolidating the response code in memory in order to enable fluid response sequences. Again, these results suggest that processes of response execution can be obscured if the format of the experiment is not sufficiently suited to define their activity. In a subsequent study of chord execution, Hazeltine, Aparicio, Weinstein, and Ivry (2007) noted that the re-appearance of stimuli witnessed in previous tasks was not as beneficial as repeating chord sequences that have been previously learned: Therefore, they posited that learning was primarily response based. Interestingly, observational learning of a response sequence is also effector dependent: Observers replicated patterns of response much more successfully when using the same fingers, rather than applying different fingers to the same sequence of locations (Bird & Heyes, 2005).

So, the positioning and composition of the response set appears to influence the manner of responding: The results of studies such as those previously discussed (Schuch & Koch, 2003; Wylie & Allport, 2000) suggest that the distinction between fingers may derive from the processing of abstract codes concerning S-R relations during response selection. Nevertheless, there is



sufficient evidence to suggest that the role of response execution is more prominent than commonly supposed: For instance, the findings of Alain et al. (1993) indicate exogenous feedback from the effectors and suggests that this contributes to the formation and consolidation of the abstract response codes during response selection, as well as possibly influencing processes that have become automated, such as those suggested by Adam et al. (2005). Thus, it may be that the employment of the body schema in the left parietal lobe (Bunge et al., 2002; Chaminade, Meltzoff, & Decety, 2005) emphasises responding according to processes that are perhaps either hard-wired or else learnt from experience of one's own body and promoted by cortical plasticity. However, the current thesis does not include any experiments that involve responses from arrangements of interlaced fingers: This thesis does not attempt to examine the relationship between finger placement and response location and so any anatomical distinctions that are described concerning finger and hand processing are based upon assumptions developed by others such as Miller and Ulrich (1998) and Adam et al. (2003; 2005), although for the alternative non-motoric account involving S-R coding see Proctor and Reeve (1986; 1988) and Proctor, Reeve, and Van Zandt (1992).

The results obtained from studies of response processing are important for a consideration of task switching because the task cue can also act as a response cue of the kind studied in Miller (1982). Clearly, the task cue does not only specify the perceptual dimension relevant for the next task, but also the subset of relevant responses to activate upon the presentation of the stimulus. Conceivably, the switch in response set could generate costs that mimic those observed in task switching experiments. The interaction between response set switch and task

switch could be substantial for most paradigms, although it would be expected to be critical for those four-choice paradigms where each response subset is mapped onto a different hand (for example, Arrington & Logan, 2004; Logan & Bundesen, 2003). In these paradigms the priming between different responses associated to the same hand (hand-based priming) would produce speeded and more accurate responses in task repetition trials, and would slow responses executed with the alternative hand. These hand-switch costs should be observable even without any switch in tasks, allowing the distinction between its pure effect and its interaction with task switching.

### Current Studies

The opening chapter of this thesis will delineate further the role of response processes in single task and task switch experiments with the aim of determining the influence of motor production. Specifically, these first five studies intend to examine switches of response between different fingers within a four-finger linear response arrangement that utilises the index and middle fingers of both hands, and to define processes associated with the grouping of responses when responding to non-spatial stimuli. It is expected that costs associated with shifts between fingers will signify the operation of response selection processes associated with the translation of stimuli codes, and so determine the relationship between the task set and S-R relations. Once the pattern of responding has been discerned within a single task design, the patterns of response behaviour will then be assessed within a task-switching context. Particular attention will be directed toward two response factors: a) hand-based priming, in which the previous activation of a particular finger would benefit the use of any other finger within

the same hand; and b) response repetition where, under normal circumstances, the repetition of the same responding finger would lead to speedier responses in comparison to those obtained from the use of another finger.

However, with two-choice tasks using a double mapping of stimuli to each key, it has been noted that the activity of switching between tasks produces a cost of repeating a response, but the cost associated with a switch of task is less apparent for response alternations (Rogers and Monsell, 1995; Meiran, 2000a). Still, when measuring task switching in paradigms of this kind the repetition trials are affected by hand-based priming; and further, when the task is repeated, the same finger may also be employed for the response or changed for another: These different types of response trials are not usually analysed separately, so their relative impact on the global switch between tasks has been difficult to evaluate. Therefore, the following experiments employed a four-choice arrangement, with four effectors being designated and a single mapping between each response and a feature from the stimuli pool. Analysis of these more basic S-R effects should then clarify the role of response processes that may previously have been overlooked.

The first experiment constituted a baseline, as the stimuli were presented randomly, with each block of trials associated with a single task. Then, in Experiment 2A, a letter cue of the type commonly employed in task switching experiments was used. The impact of this cue was tested on the selection of the response subset associated to the appropriate hand. Experiment 2B then introduced different tasks that switched alongside the responding hand. Thus, in this instance cueing signifies both the task to be performed and the associated



response set. By comparing the first three studies it is possible to obtain an estimation of the amount of the task switch cost that is represented by shifts between the response subsets associated with each hand. Wylie and Allport (2000) have argued that, commonly, the repeat trials of a task switch experiment are used as the baseline for assessing the switch trials and that this form of experimental design distorts the findings that are observed. However, the single task experiments employed here were designed to provide adequate comparisons for those that incorporated task switching. Consequently, the trials for task repetition and task switch can be examined with greater clarity.

The final two experiments of this chapter repeat the format of the second and third, except that the cues are used to indicate a subset of equivalent fingers (index or middle) from different hands. With these two experiments it can be tested whether these costs emerge from switching between hands or between response sets.

### Experiment 1

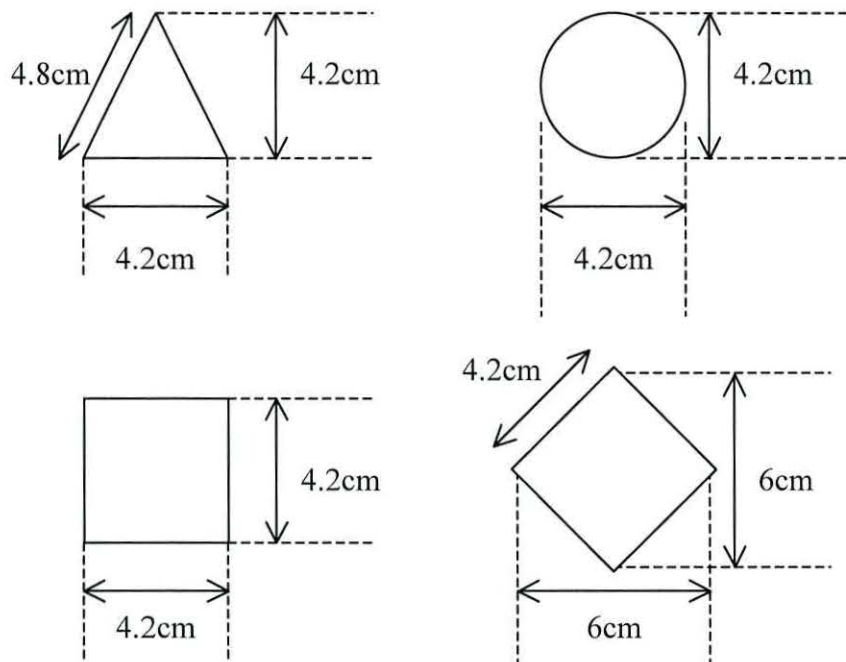
The first experiment in this first series provided the baseline whereby stimuli were presented for a response without being preceded by an instructional cue. Subsequent experiments within this first series (2A and 2B) are designed to assess response repetition against this initial baseline when different instructional cues are used to prepare for different types of switching (hand switch and task switch).

## *Method*

*Participants.* 24 students from the University of Wales Bangor voluntarily participated in this study. It was required that none of the participants were colour-blind with normal or corrected-to-normal vision. All participants were right-handed.

*Apparatus and stimuli.* The display of each trial consisted of the presentation of one of four shapes, and with one of four possible colours filling the interior of the item. The colours of the stimuli were red, yellow, blue, and green, and the shapes were comprised of diamond, square, triangle, and circle. All combinations of colour and shape were utilised to generate a total of 16 stimuli. The colours were balanced for saturation and luminance (saturation: 255; luminance: 125). At a viewing distance of 60cm, the triangle, circle, and square each had a visual angle of 4°. However, the visual angle of the diamond was 5.72° because of its tilt, although the surface area was identical to that of the square. Responses to the diamond were analysed separately to test for possible effects due to the subtended visual angle, but did not show any reliable difference with the rest of the subset. The colour and shape stimuli are illustrated in Figure 1. Apart from the stimuli, the remainder of the presentation screen remained monochromatic as the lines defining the shapes were black upon a white background. All of the lines were of ¾ pt width. The cue for each trial was invariant and comprised an asterisk symbol (\*) which provided no information regarding the nature of the subsequent stimuli: Nevertheless, the use of this cue enabled the temporal pattern of stimuli presentation to remain the same as that

adopted for the later experiments. The cue used a courier view font with a point size of 18, measured 6mm by 6mm in dimension, and had a visual angle of  $0.57^\circ$ .



Dimensions of shape stimuli.



Red: 250	Red: 250	Red: 70	Red: 70
Green: 250	Green: 70	Green: 250	Green: 70
Blue: 70	Blue: 70	Blue: 70	Blue: 250

Composition of colour stimuli.

Figure 1. Colour and shape stimuli.

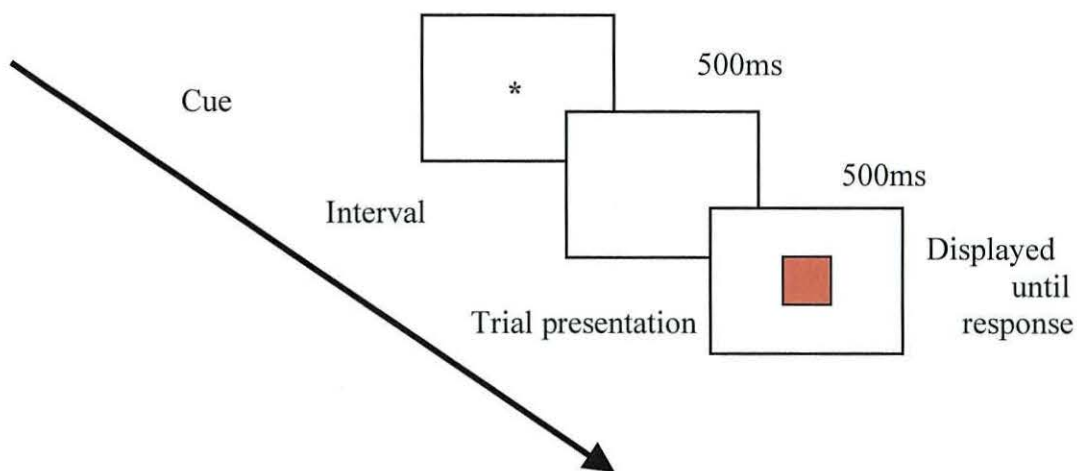


The keys employed for responding were C, V, B, and N. The keys ran concurrently so that no spatial division was apparent between the left and the right hand keys. The pressing of any key was allowed to begin each block of trials, as this enabled the participant to ready the arrangement of his or her hands before commencing. Response errors were indicated using a .WAV sound file of a buzzer. The program was developed using E-prime (Version 1.1), the presentation images were bitmap files created in PowerPoint, and an IBM-compatible PC was used to deliver instructions, present the trials, and collect the responses from the participants.

*Design.* The experiment employed two variations of the task, although the same stimuli were utilised for each. Both versions required responses to a different dimension of the centrally presented stimuli: One of the tasks required participants to report the colour of the stimuli, while the other necessitated responses to shape. The study employed a repeated-measures design, with each participant undergoing both versions of the experiment, and these were altered according to incomplete counterbalancing (Appendix III, Table A).

Responses were executed on the keyboard with the index and middle fingers of each hand. The hands were placed adjacently. The keys ran concurrently so that no division was present between those of the left hand and those of the right, forming a four-finger linear response arrangement. With regard to Reeve et al. (1992), the arrangement is surmised to minimise the left-right advantage that is obtained; if the hands were to be placed separately then the effects related to hand salience would most likely increase. In both versions of the

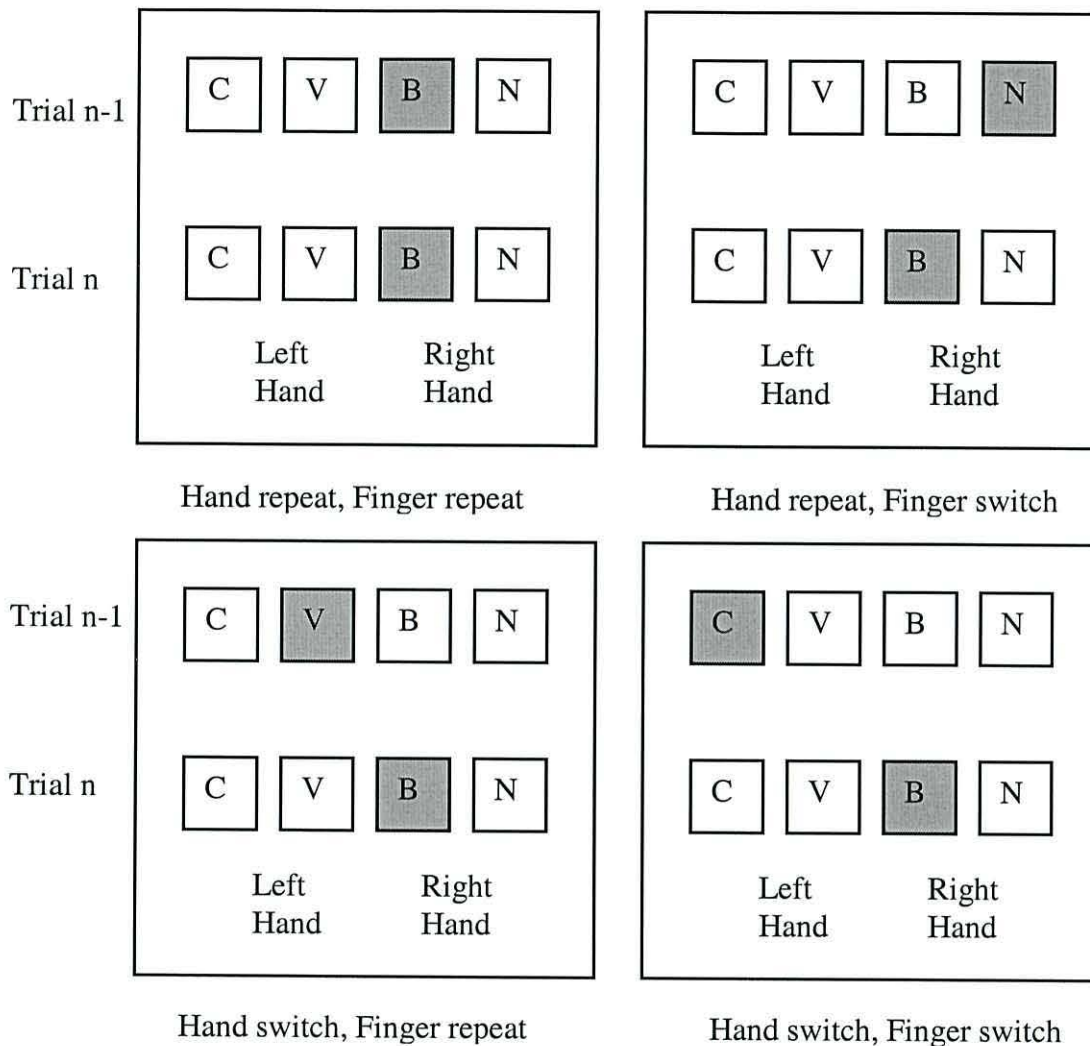
task the mapping of the different properties to each response key was varied across participants according to a balanced Latin square design (Appendix III, Table B and Table C). Stimuli order was randomised without replacement for each participant: So, in order to minimise the extent of the perceptual priming the item never fully repeated from the previous trial.



*Figure 2.* Presentation of stimulus and interval durations for studies of switching within the response set.

Each version of the experiment was comprised of two blocks of trials, enabling the participant to rest between them. Each block consisted of 24 cycles of 4 trials, with selection within a cycle being random. Consequently, each block amounted to 96 trials and the sum total of the 2 experimental blocks used to assess the performance of each participant was 192 trials. Moreover, the two blocks were preceded by 4 cycles that constituted a total of 16 practice trials, and these were used to allow the participant to become acquainted with the procedure. Thus, the additional 16 practice trials brought the entire number of trials for each

version to 208, although the practice trials were not regarded for assessment. The diagram of Figure 2 illustrates the presentation of stimuli for a typical cued trial.



*Figure 3.* Examples of the four types of finger transition. In this instance, the probe response always involves the index finger of the right hand. The only difference across the conditions concerns the response that was executed in the previous trial.

The type of response transition for each trial was encoded after the data had been collected as a function of whether the hand or the finger was identical or



different from the previous trial. Thus, responses could be encoded as 1) “Hand Repeated, Finger Repeated”, same finger repeated twice, 2) “Hand Repeated, Finger Switched”, switches of response to the alternative finger upon the same hand, 3) “Hand Switched, Finger Repeated”, switches to the same type of finger (equivalent) from the opposite hand, and 4) “Hand Switched, Finger Switched”, switches to the alternative type of finger (non-equivalent) on the opposite hand. The four different forms of response transition are illustrated in Figure 3. To encode the responses in this manner required the use of a 2x2 repeated measures design so as to evaluate the impact of both hand switch and finger switch within the same task. The results from this study constituted the baseline for subsequent experiments.

*Procedure.* At the outset, the researcher comprehensively explained the required tasks, and any queries posed by the participants were answered. Following this event, the participants were asked to complete a consent form (Appendix I). Standardised instructions were also presented on the monitor screen prior to the onset of the experiment and these emphasised the importance of both speed and accuracy (Appendix II). Each trial began with an asterisk at fixation presented for 500ms, with a subsequent interval of 500ms before the stimulus was shown (Figure 2). Once displayed, the stimulus remained on screen until a response had been produced. An error was always followed by auditory feedback (produced by a buzzer wavefile). The intertrial interval was 400ms. All participants were allowed to rest for one minute after finishing each block of experimental trials. Excluding the intervals between blocks, the duration of the experiment was approximately nine minutes in total if the participant demonstrated an average response time of 1000ms. Upon completion of the

experiment, every participant was given a debriefing form detailing the purpose of the research (Appendix IV).

### *Results*

The means of each condition were computed for each participant. The first 16 trials were considered practice trials and not included in the analyses. All errors were removed (amounting to 3.7%) as well as those responses that were not executed within 200-2000ms of duration (1.4%). As a result, 5.1% of the trials were eliminated.

Table 1a shows the mean RT, Standard Error (SE), and percentage of errors (%E) in milliseconds for each condition in the experiment. A 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA was performed on the resulting means. Of particular importance was the finding that responses were 111ms faster when the responding hand was the same as that used in the previous trial ( $F(1,23)= 41.89$ ,  $MSe=7154$ ,  $p<0.001$ ,  $\eta_p^2=0.64$ ). This pattern was shown by 23 out of 24 participants. Similarly, when the type of responding finger (index or middle) was the same as that of the previous trial, responses were overall 42ms faster ( $F(1,23)= 42.18$ ,  $Mse=986$ ,  $p<0.001$ ,  $\eta_p^2=0.64$ ), with the effect again shown by 23 participants.

Table 1. *Switches of finger response for the random (Exp 1), hand cued (Exp 2A), and hand + task cued experiments (Exp 2B). This response set coincides with transitions of hand in the first series of experiments. It should be noted that the condition in which both Hand and Finger repeats corresponds to the repetition of the exact same response. When the hand switches and the response repeats, the condition refers to the transition between equivalent fingers from different hands.*

Hand/Set	Repeat		Switch		Hand/Set	Finger type
Finger type	Repeat	Switch	Repeat	Switch	switch cost (Switch – Repeat)	switch cost (Switch – Repeat)
a) Experiment 1. Random						
Mean RT	605	674	743	758		
SE	16.26	22.76	29.17	28.23	111	42
%Error	3.80	4.75	4.31	6.81		
b) Experiment 2A. Predictable hand switch						
Mean RT	531	581	706	704		
SE	17.56	23.61	35.36	33.05	149	24
%Error	4.87	5.76	6.82	9.27		
c) Experiment 2B. Hand and Task switch						
Mean RT	775	717	912	929		
SE	35.86	38.05	46.23	43.79	174	-21
%Error	9.86	9.89	12.73	14.27		



The interaction between hand repetition and finger type repetition effects was highly significant ( $F(1,23)= 17.50$ ,  $MSe=1007$ ,  $p<0.001$ ,  $\eta_p^2=0.43$ ). Indeed, finger repetition benefits were greater (69ms) and more consistent (shown by 23 of 24 participants) when the responding hand was the same; that is, when the responding finger was exactly the same one used in the previous trial ( $F(1,23)= 34.00$ ,  $MSe=1668$ ,  $p<0.001$ ,  $\eta_p^2=0.59$ ). When the same type of finger (index or middle) was repeated with the other hand, the benefit was smaller (15ms) and less consistent (17 from 24 participants), but still reliable ( $F(1,23)= 7.77$ ,  $MSe=326$ ,  $p=0.01$ ,  $\eta_p^2=0.25$ ).

The percentages of errors per participant and per condition were analysed following the previous design. The effect of hand repetition was significant ( $F(1,23)= 20.73$ ,  $MSe<3.75$ ,  $p<0.001$ ,  $\eta_p^2=0.47$ ), since 21 out of 24 participants made more errors when the hand switched than when it repeated. However, the effect of finger type repetition was also significant, ( $F(1,23)= 22.93$ ,  $MSe<1.71$ ,  $p<0.001$ ,  $\eta_p^2=0.49$ ), with an interaction between hand and finger repetition ( $F(1,23)= 4.65$ ,  $MSe<1.39$ ,  $p=0.04$ ,  $\eta_p^2=0.16$ ). Overall, a repeat of the same type of finger was associated with fewer errors (See Table 1a), so that finger repetition produced the least, and a transition to the alternative finger of the other hand generated the most.

### *Discussion*

Both the response times and the error rates of this experiment indicate a preference for maintaining the use of the current hand, as costs are apparent when the responding hand is different to that of the previous trial. Therefore, the results reaffirm the presence of the left/right advantage previously observed (Miller,

1982; Reeve & Proctor, 1984) and are consistent with the assumption proposed by Adam et al. (2003) that hands are used to group the effectors. However, the inclination for repeated use of the same hand also suggests a sustained facilitation of that hand, and that this is further compounded by repetition of finger. An association is evident between equivalent fingers; comparative benefits were observed when a switch of hand was directed toward the equivalent finger. Nevertheless, a repeat of the same type of finger was not equal to a repeat of the same effector: Costs were still apparent, as the response of the equivalent finger did not benefit from the repetition of hand. Therefore, repetition of the actual effector is also relevant in this context. These results show the standard pattern of response transitions when responses to the same task are given in a random order. The following four experiments will measure the impact of cueing a response subset and also the cueing of a particular task against this random baseline.

### Experiment 2A

Experiment 2A was identical to Experiment 1, but in this instance the sequence of hands used for responding followed a fixed pattern. Thus, responses required of the right and left hands alternated periodically in runs of two trials. The sequence made predictable the hand switch (left, left, right, right), although it kept random the finger used for responding. The predictability of hand switch was further emphasised by an instructional cue. The letters “A” or “B” signalled each hand and were displayed instead of the asterisk employed in Experiment 1. The hand cueing experiment was intended to assess the impact of advanced selection of a reduced subset of the responses, in this case those of the responding hand, that are to be executed in the absence of a task switch. This response set

switch could be an important component contributing to the switch cost in some task switching experiments when the response subset switches alongside with the task.

### *Method*

*Participants.* 24 students from the University of Wales Bangor participated voluntarily in the experiment. All of the participants reported that they were right-handed, not colour-blind, and possessed normal or corrected-to-normal vision.

*Stimuli, Design, and Procedure.* Experiment 2A used the same stimuli, apparatus and temporal parameters as those of the previous study. However, the asterisk cue was replaced with a centrally positioned letter, A or B, which appeared at fixation at the onset of each trial. The letter was used to cue the hand that would produce the correct response. Therefore, the letter 'A' cued the keys of the left hand while the letter 'B' cued those associated with the right.

The order of the trials was such that a hand response was cued in two consecutive trials before switching to cueing the two responses of the opposing hand. With this arrangement, the first trial performed with a particular hand constituted a hand switch trial, while the second trial was used to estimate the hand repetition effects (Rogers & Monsell, 1995). Therefore, the order of cueing was a recurring sequence that ran in the following manner: A, A, B, B. As a result, the conditions used in the experimental design were identical to those used in Experiment 1. A pool of eight stimuli was associated with each letter cue and the stimuli were presented in a pseudo-random sequence, avoiding the repetition of the same stimulus twice in succession. The letters were presented in the same



font and point size as Experiment 1, but instead measured 8mm by 8mm and possessed a visual angle of  $0.76^\circ$ , rendering them slightly larger than the asterisk cue used previously. The experiment was executed according to the procedure detailed in Experiment 1, although the instructions of the title screen were altered in order to incorporate mention of cueing and are shown in Appendix II.

### *Results*

Table 1b shows the mean RTs, standard error, and error rates per condition in Experiment 2A. The initial 16 trials for each participant were allocated for practice and removed. From the experimental trials, only correct responses between 200 and 2000ms were included in the analyses. The errors amounted to 5.6%, while the outliers (those responses falling outside of the analysis window) constituted 1.1%. So, the trimming procedure resulted in a total of 6.7% of the trials being removed.

The resulting data were analysed following the same design as that of Experiment 1: A 2 (Hand Repetition: Switch, Repeat) x 2 (Finger Type Repetition: Switch, Repeat) repeated measures ANOVA. The most prominent result was an increase in RTs (149ms) when switching the responding hand ( $F(1,23)= 55.70$ ,  $MSe=9612$ ,  $p<0.001$ ,  $\eta_p^2=0.708$ ), and this was demonstrated by 100 % of the participants: However, while the cost of switching between hands increased in comparison to Experiment 1, the effect was only significantly faster from that of the previous experiment with regard to hand repetition trials ( $F(1,46)= 9.462$ ,  $MSe=8826$ ,  $p=0.004$ ,  $\eta_p^2=0.17$ ). The consideration of hand switch trials in isolation found no difference between those of the two experiments ( $F(1,46)= 1.072$ ,  $MSe=23486$ ,  $p=0.30$ ,  $\eta_p^2=0.02$ ). Following the pattern of

Experiment 1, responding with the same type of finger, inclusive of effector repetition, produced RTs that were overall 24ms faster than when it was switched ( $F(1,23)= 8.68$ ,  $MSe=786$ ,  $p=0.007$ ,  $\eta_p^2=0.27$ ). Further, this effect was modulated by its interaction with the switch in hands ( $F(1,23)= 6.13$ ,  $MSe=2568$ ,  $p=0.02$ ,  $\eta_p^2=0.21$ ). Indeed, this response repetition benefit was mainly observed in the 50ms advantage (shown by 18 participants) when the same finger from the same hand was repeated ( $F(1,23)= 11.32$ ,  $MSe=2594$ ,  $p=0.003$ ,  $\eta_p^2=0.33$ ). Contrary to the results from Experiment 1, there was no observed benefit from repeating the equivalent finger from the alternative hand (Hand Switch: Finger Repeat vs Finger Switch;  $F < 1$ ).

The error rates were analyzed following the same design: 17 out of 24 participants had an increase in error rates when the hand switched ( $F(1,23)= 12.16$ ,  $MSe=3.18$ ,  $p=0.002$ ,  $\eta_p^2=0.34$ ). In addition, 19 participants showed benefits when repeating the same type of finger ( $F(1,23)= 8.62$ ,  $MSe=4.79$ ,  $p=0.007$ ,  $\eta_p^2=0.27$ ) irrespectively of whether they belonged to the same hand or not ( $F < 1$ ).

### *Discussion*

The cueing of hand primarily facilitated the processing of the hand currently being used, and this benefit was most pronounced for the repetition of finger. It was the comparatively faster responses associated with hand repetitions that are accountable for the greater disparity (149ms) between these and the RTs for hand switch. The advantage of cueing was not significantly present for trials where the hand switched. Therefore, the results again demonstrate that response selection is affected by motor grouping factors, but that the pattern of responding

is most effective when maintaining the current response process (finger repetition trials). The apparatus specified by Miller and Ulrich (1998) would suggest that the cue aids the initial choice of hand and thereby speeds selection of the effector. Nevertheless, hand cueing accentuated the grouping of the hand subset and reduced the advantage of switching between equivalent fingers from both hands that was noted in Experiment 1. The top-down selection of the hand-based response subset (at least where no switch of task is present) seems to work through two mechanisms: a) Excitation, by speeding responses when the same response set is repeated, without increasing overall responses in hand switch trials; and b) Inhibition, by suppressing other pre-existing response groupings or links, such as those connecting the responses associated to equivalent fingers (Eimer, 1999; Band & Van Boxtel, 1999; Bowman, Schlaghecken, & Eimer, 2006).

### Experiment 2B

For this experiment, a task switching procedure was incorporated within the design of the previous experiment. Participants were required to respond to the colour of the object with the fingers of one hand and to its shape with those of the opposite hand. The order of the tasks was set in a fixed sequence, such that a task was repeated twice before switching to the other. Hence, the switches of hand were identical to those of Experiment 2A, but now the task switched along with the hand. This study was intended to finish the first series of three directed to assess the extent to which a task switch cost is associated exclusively with the configuration processes involved in the switching between tasks or with the switch between response subsets, in this instance those related to hands. This is



particularly important in studies where both the task and the response subset switch simultaneously.

### *Method*

*Participants.* The experiment engaged the participation of 24 student volunteers from the University of Wales, Bangor. The participants conformed to the criteria of eligibility stipulated by the previous experiments.

*Stimuli, Design, and Procedure.* The stimuli, visual and temporal parameters, and the basic design were similar to that of Experiment 2A. However, responses to both colour and shape were mixed within both blocks of trials, so only two colours and two shapes were utilised, these being red, blue, circle, and square. The composition of each stimulus attribute that was used remained as indicated in Figure 1. The reduction in the pool of stimuli entailed that the experiment contained only half the trials per condition of the previous two. By doing so, the total number of S-R repetitions was held constant across the experiments. The dimension appropriate for responding during each trial was indicated by the preceding letter cue. The letters A and B were changed to read S (for shape) and C (for colour), although the proportions of the cues were unaltered. Two keys of the response set were allocated to each dimension – C and V for one dimension, B and N for the other – so the cue still served to represent a subset of the possible responses. The assignation of the response keys to each dimension was balanced across participants according to the incomplete counterbalancing detailed in Appendix III, Table D. The order of Block-list selection remained systematic (S, S, C, C). Furthermore, the selection from the associated pool of stimuli was random without replacement.

## Results

The descriptive results of Experiment 2B are displayed in Table 1c. The data were filtered in the same manner as the previous experiments, with 4.9% of errors and 6.7% of outliers, thereby removing 11.6% of the trials. An early look at the results indicates that the RTs elicited by the current task switching procedure were much longer than those produced previously. Indeed, there were significant differences across the three experiments ( $F(2,69)=11.85$ ,  $MSe=21635$ ,  $p<0.001$ ,  $\eta_p^2=0.25$ ). Bonferroni post-hoc contrasts showed that RTs from Experiment 2B were significantly longer than those from Experiment 1 ( $p=0.005$ ) and 2A ( $p<0.001$ ). Global differences between Experiment 1 and 2A were not significant.

To further analyse data from this experiment, mean RTs between 200 and 2000ms to correct trials per participant and per condition for Experiment 2B were submitted to a 2 (task/hand switch: Switch, Repeat)  $\times$  2 (finger switch: Switch, Repeat) repeated measures ANOVA. Similar to the results in the previous experiments, responses were overall longer when switching between tasks and hands than when they were repeated ( $F(1,23)=72.21$ ,  $MSe=10077$ ,  $p<0.001$ ,  $\eta_p^2=0.75$ ), although the difference was extended to 174ms. However, the effect was not dissimilar in size to that observed in Experiment 2A for the predicted change in hands ( $F<1$ ). A comparison of the effect of hand switch across the three experiments showed no significant interaction ( $F(2,69)=2.64$ ,  $MSe=4474$ ,  $p=0.078$ ,  $\eta_p^2=0.07$ ). When explored further, only the transition of hands in the random condition (Experiment 1) was significantly less than that of the task

switching experiment (Experiment 2B) ( $F(1,46)= 5.42$ ,  $MSe=4308$ ,  $p=0.024$ ,  $\eta_p^2=0.10$ .)

As in the previous experiment, there was no reliable difference between switches of hand to the equivalent finger and the non-equivalent. However, contrary to the standard pattern, when the task (and hand) repeated, the repetition of the finger produced responses that were 57ms longer in comparison to a transition ( $F(1,23)= 12.46$ ,  $MSe=3185$ ,  $p=0.002$ ,  $\eta_p^2=0.35$ ), an effect that was demonstrated by 19 of the 24 participants. Indeed, only the difference between repeating the same finger or not within the same hand was significantly different to that from previous experiments ( $F(2,69)= 22.37$ ,  $MSe=2482$ ,  $p<0.001$ ,  $\eta_p^2=0.39$ ). Bonferroni post-hoc contrasts showed that the response repetition effect in the task switching experiment significantly differed from the random condition ( $p<0.02$ ) and from the predicted hand switch experiment ( $p<0.001$ ). In summary, the introduction of a task switching procedure did not substantially alter the size of the hand switch cost observed in Experiment 2A, but it changed the pattern of response repetition in task repeated trials.

The same analyses were conducted upon the mean error rates per condition and participant, only to find that participants produced more errors when executing a transition to another type of finger ( $F(1,23)= 6.59$ ,  $MSe=3.39$ ,  $p=0.017$ ,  $\eta_p^2=0.22$ ). While no main effect of switching between hands was observed, an interaction was obtained for hand and finger responses, showing a slight increase in accuracy for equivalent finger transitions, see Table 1c ( $F(1,23)= 5.02$ ,  $MSe=1.58$ ,  $p=0.03$ ,  $\eta_p^2=0.17$ ).



## Discussion for experiments 1 to 2B

This first series of three experiments were developed to study whether a portion of the switch cost observed in task switching studies, particularly those using four response keys, can be attributed to costs associated to switches in response set. To do so, a situation was examined in which the task switches along with the responding hand (Experiment 2B). In this context participants had to respond to task A with one hand and to task B with the other in runs of two repeated trials (AABBAABB). To examine the impact of switching the response subset (or hand), Experiment 2A measured a circumstance in which the responding hand switched every two trials without any change in tasks. Finally, these switch costs were measured against a baseline (Experiment 1) in which responses were performed randomly without a switch in tasks.

Interestingly, just changing the responding hand created costs (111ms) in the random condition (Experiment 1): This cost demonstrated a predisposition for the system to continue use of the same hand once it has been selected. The benefit of using the same hand in consecutive trials was not directed to a particular task goal and was observed independently of whether the responding finger was repeated or not. Therefore, this finding indicates a preference that may be structural, but could alternatively have a learning basis: For instance, it is conceivable that cortical plasticity may adapt response production if fingers were interleaved for a sufficient period. The subset grouping of hand rendered the most pronounced effect; nevertheless, an advantage was also evident for the subsets of equivalent fingers from the two hands in comparison to those that were not equivalent, a finding that coincides with the assertion of relations between

equivalent fingers (Adam et al., 2003). Reeve and Proctor (1984) had discerned that the cueing of a separate finger from each hand elicited a faster response if they were equivalent rather than not: However, they employed spatial cues, which may promote mechanisms associated with grouping of the percept, while the current experiments utilise abstract cues to achieve a similar outcome. Still, a more recent study by Ehrenstein and Proctor (1998) used letters to cue finger subsets and again noted a benefit for the cueing of equivalent fingers in comparison to those that were non-equivalent.

A situation was then tested in Experiment 2A in which the response set changed from one hand to another in a predictable way. This condition was aimed to test whether the cued grouping of two responses within each hand would have an impact upon the initial hand switching effect, either enhancing or diminishing its appearance. However, in comparison to the random condition of Experiment 1, the benefit of cueing was observed only for hand repetition trials. Thus, the data supports some tendency for the grouping of all responses belonging to the same hand, in a way that the system benefits from continuously using the same hand in consecutive trials. The initial selection of hand before finger that was specified by Miller and Ulrich (1998) clearly renders the subset grouping of fingers for each hand and signals a benefit for both hand and finger repetition. Still, the advantage of equivalent fingers over non-equivalent was no longer apparent: The facilitation of effector repetition did not exert an obvious influence upon the equivalent finger of the opposing hand. So, it appears that while the cueing of hand emphasised those related subsets, the relationship between fingers of separate hands that was observed in Experiment 1 may have been either suppressed or obscured.

Finally, when participants switch predictably between hands along with a switch in the task (Experiment 2B), overall RTs increase, but the hand switch cost obtained in this circumstance remained similar to when the hands alone are predictably switched (Experiment 2A). Actually, the hand switch cost is only significantly greater than that of Experiment 1, where responses were random. This result is of extreme relevance since it indicates that most of the switch cost in studies mapping the task to separate hands can be due primarily to the costs of switching between the two responding hands, rather than to any actual task switch. The functional bias of the motor system to keep responding with the same hand creates costs that are of similar magnitude to those observed when the task changes in addition.

At first, this may appear to contradict the findings of two finger studies (Alain, Buckolz, & Taktak, 1993; Hasbroucq, Akamatsu, Mouret, & Seal, 1995) whereby a response repertoire that comprises a single finger of each hand (such as the index fingers) tends to elicit shorter RTs in comparison to those conditions where two fingers upon the same hand are used. However, it is likely that the underlying processes are similar for two and four finger response sets. In a circumstance where just one responding finger is upon each hand, the hands can be used to differentiate between the responses and so aid in selecting the appropriate action: According to the model proposed by Miller and Ulrich (1998), it is surmised that the selection of finger would be perfunctory once the initial stage of hand selection has occurred. Hand selection cannot aid the differentiation of two responses when they are both positioned upon the same hand, so with a two-finger repertoire they are comparatively longer. Therefore, the advantage provided by hand selection seems to be sufficient to compensate for any possible



cost of hand switch. Conversely, a four-finger response set obtains faster responses when both cued fingers are upon the same hand in comparison to cues that specify fingers on opposing hands (Reeve & Proctor, 1984): In this instance, the initial selection of hand aids in removing the competition from the fingers upon the opposing hand and so facilitates responding in comparison to cues that involve fingers from both hands. Thus, the process of hand selection provides most aid with a separate hand repertoire for the two-finger response set and the cueing of a single hand for a four-finger response set. The capacity to group fingers according to hand appears to assist responding but this pattern varies depending upon the number of fingers used within the response set.

Nevertheless, a disparity is evident when analysing the effect of repeating a response from the same finger. Response repetition, when both hand and finger are repeated, consistently produces benefits when participants perform the same task throughout the block of trials. However, this benefit turns into a cost when the two tasks are mixed within the same block (Experiment 2B). In both cases the same task repeats for the trials considered, the only difference being the context in which this repetition takes place, either a pure block of the same task or a mixed block with different tasks. It is regularly assumed that the costs of response repetition are likely to represent the management of the S-R relations that promotes the responding of another effector (Kleinsorge, 1999): The influence of stimulus presentation upon response repetition will be examined in Chapter 2.

To summarise, it appears that the system is biased towards persevering whenever there is a potential benefit of so doing, indicated by the presentation of the stimulus and the task demands. Nevertheless, it is apparent that the activation

of a particular response set is especially powerful when responses are mapped onto the same hand. These three experiments have indicated that both fingers of the current hand acquire benefits in relation to a switch of response to the opposing hand. However, it is unclear whether the prominent switch costs of hand, particularly those observed in Experiments 2A and 2B, are due to the top-down selection of any kind of response set or are more specific to the selection of hand. Therefore, the following two experiments will assess the pattern of responding when each response subset is shared between hands.

### Experiment 3A

In the present experiment, the activation of a particular response set can be predicted in advance. So, in this regard the experiment is identical to Experiment 2A, but on this occasion each cued response set is mapped to a subset of equivalent fingers (index or middle). A grouping based on equivalent fingers is relatively easy to remember as spatial and body cues can be used to group the responses, thus providing a good contrast with the hand groupings used for the previous series. Moreover, Experiment 1 also discerned a preference for the cueing of equivalent fingers in comparison to those that were not of the same type. Hence, the final two experiments of this chapter will attempt to examine further this relationship while seeking to replicate the basic findings.

## *Method*

*Participants.* Experiment 3A employed 24 student volunteers from the University of Wales, Bangor in accordance with the criteria used for all of the previous experiments in this chapter.

*Stimuli, Design, and Procedure.* Experiment 3A was identical to Experiment 2A with the only difference being the subset of responses being cued in each trial. Thus, the letter A signified the subsequent use of the index fingers while the letter B referred to the middle fingers. The title page of the instructions was altered to incorporate the difference in cueing (Appendix II). Nevertheless, the particular mapping of each response to a particular property (colour or shape) was again counterbalanced across participants according to the description in Appendix III, Table B and Table C.

## *Results*

Table 2b shows the descriptive results of Experiment 3A. RTs were treated as in the previous experiments, finding 3.1% of errors and 1.4% of outliers, thereby resulting in 4.5% of the trials being removed. Again, mean RTs per participant and per condition were analysed following a 2 (Hand Repetition: Switch, Repeat) x 2 (Finger Type repetition: Switch, Repeat) repeated measures ANOVA. A substantial increase in RTs (77ms) was observed when switching the responding hand ( $F(1,23)=28.39$ ,  $MSe=4970$ ,  $p<0.001$ ,  $\eta_p^2=0.55$ ). In principle, it appears that this effect could be smaller than that of the random condition (77 vs. 111ms in Experiment 1). However, this hand-cost effect was not significantly different between the two experiments ( $F=2.43$ ). The advantage of effector repetition remained evident, with a comparison to transitions toward the



equivalent finger of the cued subset being substantially slower, ( $F(1,23)=25.19$ ,  $MSe=3218$ ,  $p<0.001$ ,  $\eta_p^2=0.52$ ). However, a comparison with Experiment 1 found no significant difference of finger repetition ( $F=2.60$ ).

Perhaps more important is consideration of the switch between the response subsets, in this instance composed of the equivalent fingers from both hands. An increase in RTs (61ms) was apparent when switching to the alternative response set and this was shown by 23 of the 24 participants ( $F(1,23)=49.55$ ,  $MSe=1826$ ,  $p<0.001$ ,  $\eta_p^2=0.68$ ). Nevertheless, this effect was only marginally greater than that of switching finger type in the random condition from Experiment 1 ( $F(1,46)=3.33$ ,  $MSe=703$ ,  $p=0.07$ ,  $\eta_p^2=0.06$ ). Furthermore, the benefit from repeating the same type of finger, involving a repeat of cue, was observed independently of whether it repeated the same finger (67ms,  $F(1,23)=29.24$ ,  $MSe=1837$ ,  $p<0.001$ ,  $\eta_p^2=0.56$ ), or changed to one that was equivalent (56ms,  $F(1,23)=39.73$ ,  $MSe=942$ ,  $p<0.001$ ,  $\eta_p^2=0.63$ ). Indeed, the interaction between Hand and Finger Type repetition was far from significant ( $F<1$ ).

Table 2. *Switches of finger response for the random (Exp 1), equivalent cued (Exp 3A), and equivalent + task cued (Exp 3B) experiments. These experiments examined switches between subsets of equivalent fingers. Note that Experiment 1, the baseline, is brought here in order to provide a comparison.*

Hand	Repeat		Switch		Hand	Finger type
Finger type	Repeat	Switch	Repeat	Switch	switch cost (Switch – Repeat)	switch cost (Switch – Repeat)
a) Experiment 1. Random						
Mean RT	605	674	743	758		
SE	16.26	22.76	29.17	28.23	111	42
%Error	3.80	4.75	4.31	6.81		
b) Experiment 3A. Predictable Equivalent Finger Subset switch						
Mean RT	581	648	663	719		
SE	18.63	22.24	31.09	32.31	77	62
%Error	3.24	5.23	4.25	5.31		
c) Experiment 3B. Equivalent Finger Subset and Task switch						
Mean RT	860	940	789	909		
SE	35.53	35.13	31.09	34.09	-51	100
%Error	15.50	19.46	10.70	17.13		

To summarize, an increase is evident concerning the costs of switching between alternative response subsets when a particular subset is activated before the stimulus appears. This cost of switching between response subsets is not confounded with either task switching or hand grouping. Instead it reflects the top-down control required to group responses within a response set. This top-down grouping effect seems to reflect a general process as it influences set-switch costs equally whether it happens between naturally grouped responses (switching between hands, Experiment 2A) or between response sets with associations that are less strong (switching between equivalent fingers, Experiment 3A). However, the grouping of equivalent fingers did not benefit from the processes associated to hand selection that were observed in Experiment 2A, as the response times were not significantly different from those of Experiment 1.

The error rates were analysed in a similar manner. 17 out of 24 participants demonstrated an increase in error rates when the response set of equivalent fingers switched rather than repeated ( $F(1,23)= 11.23$ ,  $MSe=1.23$ ,  $p=0.003$ ,  $\eta_p^2=0.32$ ). Other effects did not reach significance.

### *Discussion*

Similar effects to those discerned in Experiment 1 were again noticed here. An advantage of hand repetition was again evident; so the process of selecting hand before finger that was noted by Miller and Ulrich (1998) still promoted the hand currently being used despite the cueing of equivalent fingers. Further, the repetition of the previous response also elicited the fastest reactions, so the consistent use of the same finger obtained benefits in a single task design regardless of the cued subset arrangement. Additionally, a repeat of finger type



also demonstrated an advantage over a switch of finger type. Nevertheless, while an eye inspection of the results would suggest a comparative shift from hand processing towards the grouping of equivalent finger subsets, none of these effects were statistically different from the baseline results provided by Experiment 1. Thus, it seems that the cueing of subsets across hands attains only a marginal benefit, at least at this cue to stimulus interval, as the cue does not promote the grouping of hand. The initial hand cueing experiment conducted by Miller (1982) found no significant difference for cueing across hands in relation to a non-cued baseline. Still, it is conceivable that the cueing of equivalent fingers may have greater influence with a longer cue-to-stimulus interval: However, while Adam et al. (2003) noted a small benefit for equivalent finger cues in relation to hand cues with an extended cue to stimulus interval (3 seconds) this only appeared when the hands were placed apart. An adjacent hand arrangement, as employed in the current experiment, did not produce any benefit of equivalent finger cues over those for hand.

### Experiment 3B

#### *Method*

*Participants.* The experiment entailed the participation of another 24 student volunteers from the University of Wales, Bangor and all conformed to the criteria stated in Experiment 1.

*Stimuli, Design, and Procedure.* The stimuli, including letter cues, and format of the experiment were identical to those of Experiment 2B with one exception: The letter cues were still used to refer to colour and shape, but the response keys associated with each dimension were instead allocated to equivalent

fingers subsets. The instructions of the title screen were slightly amended from those of Experiment 2B in order to accommodate the alteration of the cueing procedure (Appendix II).

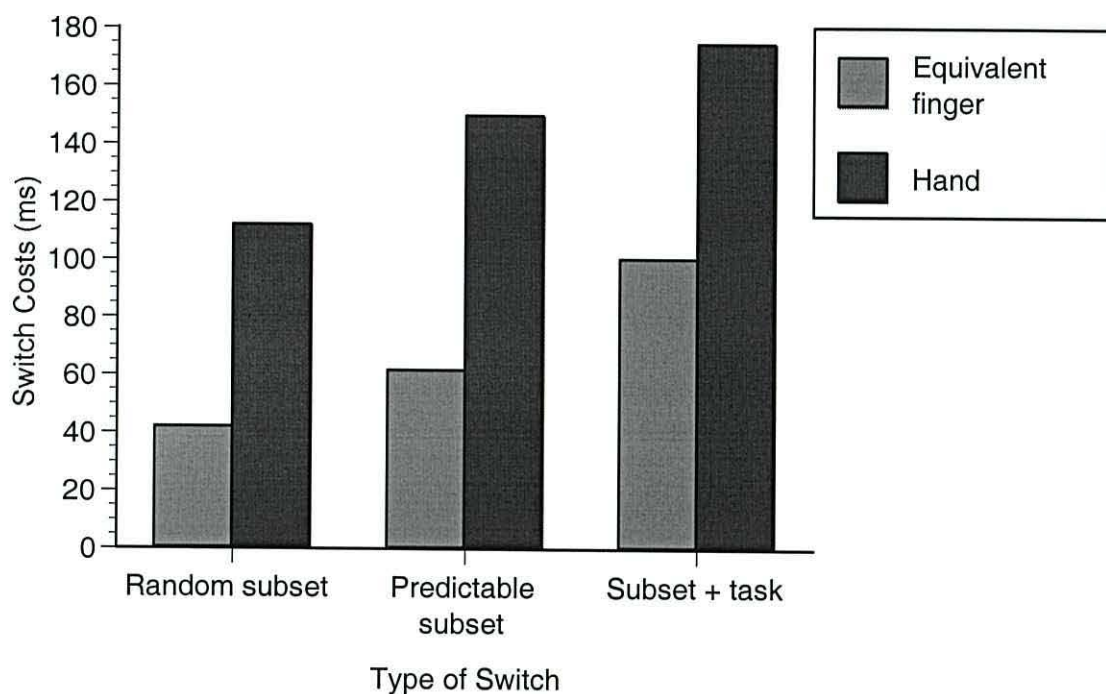
### *Results and Discussion*

Table 2c illustrates the descriptive results of experiment 3B. All RTs scores received the same treatment as in the previous experiments. This resulted in 3.8% of errors and 11.5% of outliers, with a total of 15.3% of the trials being removed. An early inspection of the data reveals that the RTs in this experiment are substantially larger than those in experiments 1 and 3A (see Table2;  $F(2,69)=20.29$ ,  $MSe=16347$ ,  $p<0.001$ ,  $\eta_p^2=0.37$ ). Bonferroni comparisons confirmed that switching between tasks produced greater response times than switching between predictable response sets (Exp 3A,  $p<0.001$ ), or those of the baseline (Exp 1,  $p<0.001$ ).

Like all of the experiments in this article, mean RTs per participant and per condition were analysed with a 2 (Hand Repetition: Switch, Repeat) x 2 (Task/Finger Type repetition: Switch, Repeat) repeated measures ANOVA. As expected, switching between tasks (which involves switching between response sets of equivalent fingers) produced greater RTs than repeating the same task twice (100ms longer;  $F(1,23)=17.60$ ,  $MSe=13621$ ,  $p<0.001$ ,  $\eta_p^2=0.43$ ). Comparison of the transition between finger type across Experiments 1, 3A, and 3B found an interaction, ( $F(2,69)=3.85$ ,  $MSe=2738$ ,  $p<0.026$ ,  $\eta_p^2=0.10$ ): Further examination with Bonferroni discerned the finger type switch cost of Experiment 3B to be significantly different to the switch between equivalent sets of fingers in Experiment 3A, ( $p<0.001$ ), and also Experiment 1 ( $p<0.001$ ). When controlling

for the predictable switch between response subsets, the resulting task switch cost is reduced to an effect of 39ms (see Figure 4), demonstrating that, without taking into account the response transitions analyzed in this article, the 100ms costs of task switching in the present experiment would have been enormously inflated.

Figure 4 illustrates the switch costs associated with the switches between response subsets for all of the five experiments described in this first chapter. The graph indicates that the predictable cueing of a response subset accentuates the switch costs that are observed, although the advantage is primarily associated with the hand cueing of Experiment 2A. However, the costs of transition are extended still further by the addition of task switch to the cued switch of the response subset.



*Figure 4.* Switch costs between response subsets for all of the experiments in this first chapter.

Another relevant result appears when analyzing the costs of hand switch.

While 2B may have demonstrated inhibition of the currently active response,



inhibition occurred at the level of finger selection rather than of hand. However, for Experiment 3B, repeating either response of the same hand was significantly *longer* than a transition to the opposing hand ( $F(1,23)= 18.36$ ,  $MSe=3423$ ,  $p<0.001$ ,  $\eta_p^2=0.44$ ). The cost of repeating the same hand is shown for task repetition trials (as in Exp 2B) and also when switching to the alternative task. These costs were of 71ms ( $F(1,23)= 15.20$ ,  $MSe=4016$ ,  $p<0.001$ ,  $\eta_p^2=0.39$ ) and 31ms ( $F(1,23)= 4.86$ ,  $MSe=2380$ ,  $p=0.05$ ,  $\eta_p^2=0.17$ ) respectively. The interaction between hand and task switching was only marginally significant ( $F(1,23)= 3.28$ ,  $MSe=2973$ ,  $p=0.09$ ,  $\eta_p^2=0.12$ ), thereby indicating that highly active responses are suppressed if the stimulus alters in order to enable a flexible switch between tasks. However, both responses of the previously used hand were still highly active, requiring their suppression so as to activate the relevant response subset.

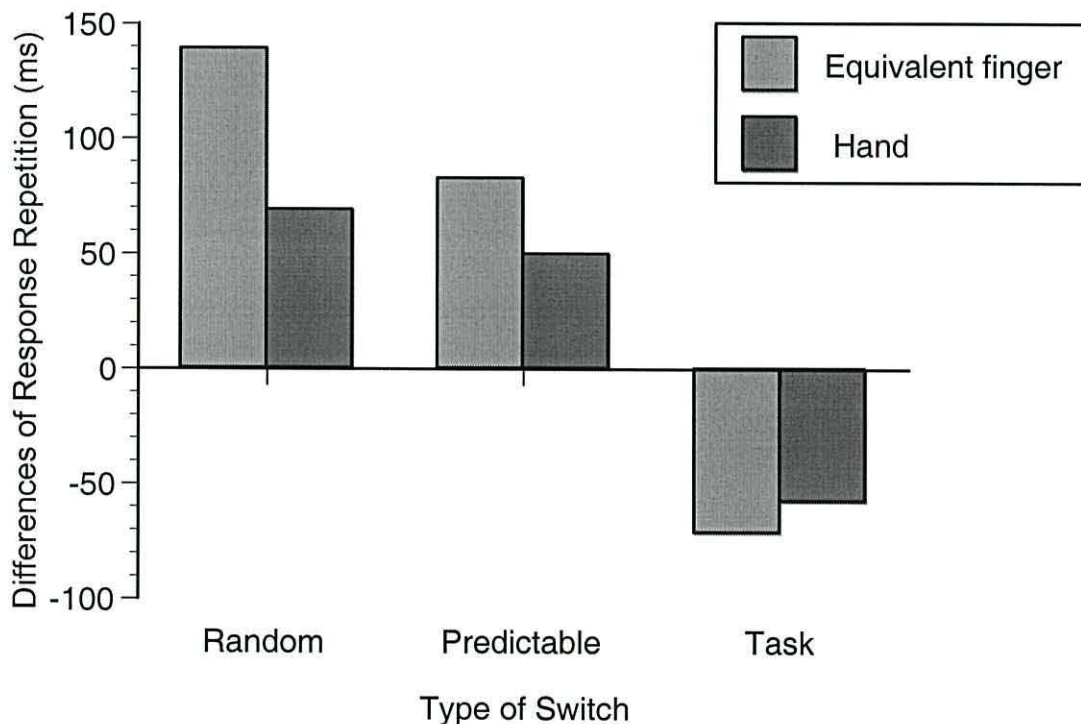
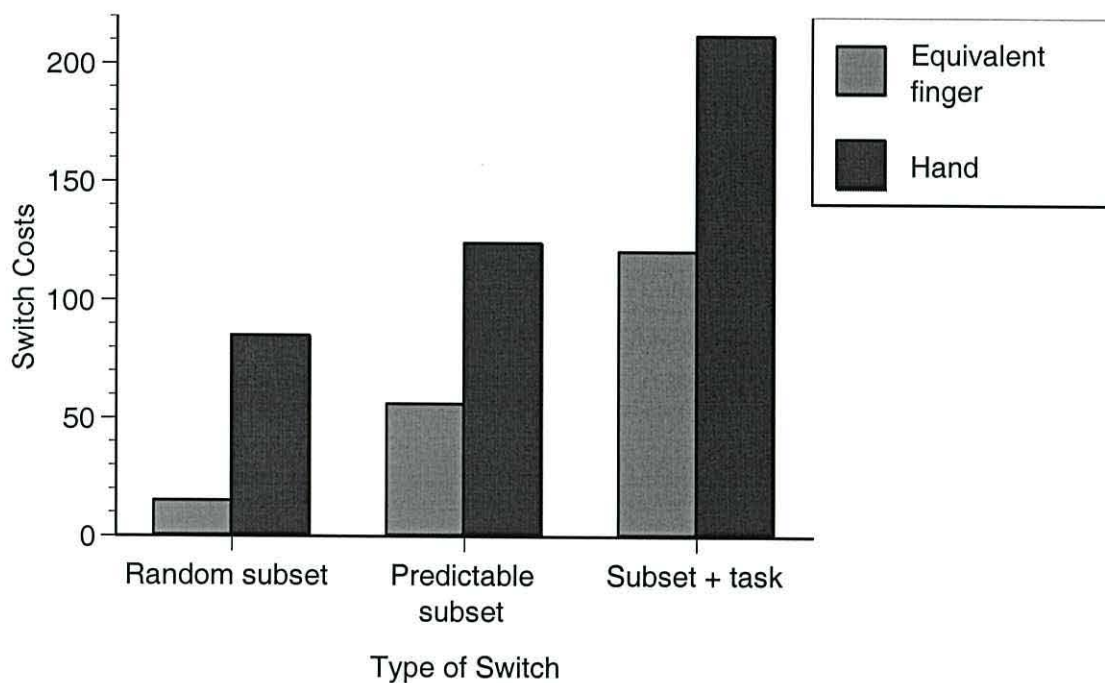


Figure 5. Effects of response repetition for hand cued and equivalent finger cued subsets.

Figure 5 shows the impact of response repetition across all the experiments in this study. The graph demonstrates the effect of repeating a response from the previous trial in relation to a response transition toward the alternative finger of the current subset (Hand cued: RTs for the other finger of the same hand minus the RTs for response finger repetition; Equivalent finger cued: RTs for the equivalent finger minus the RTs for response finger repetition). So, the graph indicates the difference between the responses produced by the two fingers, and provides an illustration of the relative advantage or cost of finger repetition. The pattern of the finger repetition effect is similar with regard to the employment of both hand-cued and equivalent fingers-cued subsets: When compared to the alternative finger, repetition of the previously used finger shows the largest difference in RTs for the random condition. The difference is reduced for the predictable cueing used in experiments 2A and 3A, but the advantage of finger repetition is still apparent. However, when task switching is introduced response repetition is slower than transferring to the other finger of the response set: Hence, the pattern is reversed and the difference becomes negative. However, it appears that the differences are exaggerated with equivalent finger pairings, as grouping according to hand is predominantly utilised by the motor system and the need for suppression may have been enhanced.

Consequently, it appears that the difference in response repetition performance may contaminate the estimation of task switch: Therefore, the elimination of the response repetition trials should provide some indication of switch costs without the influence of effector repetition. The graph of Figure 6 is founded upon a comparison of the alternative finger within the response subset

and the non-equivalent, non-anatomically related finger of the opposing subset (For the subsets of hand, the fourth column minus the second column of Table 1; for the subsets of equivalent finger, the fourth column minus the third column of Table 2): It is apparent that the removal of response repetition has slightly increased the estimation of the switch of subset when task switching is also involved; conversely, the random and cued subset experiments demonstrate a small decrease of switch costs, with the cost of equivalent transitions of response during the random trials of Experiment 1 being particularly minor. Nevertheless, the overall pattern is similar to that observed previously.



*Figure 6.* Switch costs of Experiments 1 to 3B with the effect of finger repetition excluded.

The error percentages were analysed in the same manner as the previous experiments. It was noted that a transition to another type of finger, identified



with a switch of task, produced greater errors ( $F(1,23)= 10.70$ ,  $MSe=4.95$ ,  $p=0.003$ ,  $\eta_p^2=0.31$ ). Moreover, an interaction was evident between the errors associated with responding of hand and those of finger type, ( $F(1,23)= 13.39$ ,  $MSe=1.00$ ,  $p=0.001$ ,  $\eta_p^2=0.36$ ). The other effects analysed did not reach significance.

### General discussion to Chapter 1

The traditional analysis of task switching adopts the method of comparing trials of task switch and those of repeat in order to infer the presence of executive functions. Instead, these first five experiments use a procedure that segregates response trials that are qualitatively and quantitatively different. The current research examines transitions of response occurring in both pure blocks and mixed blocks of trials. The results provide rich information concerning the management of S-R mappings when monitoring different tasks.

The results concerning the switches between hands for Experiments 1, 2A, and 2B are consistent with the assumption that finger responses are grouped according to hand, thereby supporting the previous research derived from use of the response cueing paradigm (Miller, 1982; Adam et al., 2003). The predictable cueing of both subset and task switch bolster the advantage of hand response repetition beyond that which is evident when cueing is absent. Moreover, a cost of switching between hands was still evident when the hand-based grouping was minimised by cueing a subset of equivalent fingers in Experiment 3A. Thus, it appears that hand grouping constitutes a tendency for responding and is not just dependent upon instructional cues. Conversely, the grouping of equivalent fingers from different hands seems to be weaker. While a cost for switching between the

cued response-sets was evident in Experiment 3A, such cost was not significantly different from the one observed in the random condition. Therefore, at a precue interval of 1000ms (the duration of the cue presentation and the blank screen interval combined), equivalent fingers do not appear to be grouped readily as their cueing does not produce the same benefits as exhibited by hand cued responses. Hence, it is argued that executive functions operate within the constraints of motor processes.

Still, Experiment 2A noted that the benefits of cueing principally facilitate the repetition of both hand and finger. To reiterate, Miller and Ulrich (1998) argued that a finger response involved two stages, with hand selection occurring before finger selection had begun. Consequently, the repetition of both stages will accentuate the benefits obtained in a single task experiment. A transition to the other finger of the same hand still demonstrated advantages as the same hand grouping was repeated despite the responding finger being altered. While Experiment 1 noted some relationship between equivalent fingers, their cueing did not render benefits in the same manner, as the cue did not sufficiently accommodate the primary, automatic processes associated with response production; but, the advantage of hand repetition was still discernable despite the conflict with the cueing arrangements.

Nevertheless, the results here show that the introduction of a task switch produces a reversal of the repetition effect. An advantage is no longer apparent for a repeat of response, but instead processing favours the other finger of the current response subset. Moreover, this occurrence is evident for both forms of cued subset. Thus, Experiment 2B notes an advantage for a transition to the other

finger of the same hand. Yet, understandably, both fingers maintain an advantage of hand repetition in comparison to a switch of task to the opposing hand.

However, a consideration of Experiment 3B discerns that the cueing of equivalent fingers actually favours a switch of hand regardless of whether the task is repeated or switched. So, a repetition of both hand and finger appear to be inhibited with a transition to the opposing hand becoming beneficial. It is important to highlight that, for both Experiment 2B and 3B, this result also occurs on trials where the task repeats, thereby constituting a new effect that is different from the cost of response repetition for switch trials that has been observed elsewhere (for example, Rogers & Monsel, 1995; Meiran, 2000a; Schuch & Koch, 2003; Hübner, Kluwe, Luna-Rodriguez, & Peters, 2004). The cost of response repetition (for finger or hand) is perhaps not just caused by the actual task switch, but rather the expectation of it when responding to stimuli that consistently alter across a block of trials. Moreover, because the response sets do not overlap, these response repetition costs cannot be confounded with the costs of re-mapping a different set of stimuli to the same response set. Therefore, the results depicted in this first chapter provide a strong indication that relations between stimuli and responses are integral to understanding the nature of task switching, and that these processes occur across all trials rather being restricted to the switch trials alone.

Prior explanation of response repetition has derived mostly from the use of two keys with each task mapping different attributes to the same responses (Rogers & Monsell, 1995; Meiran, 2000a). In this instance, the cost of response repetition is only evident for task switch trials and not those where the task repeats: Meiran (2000a) proposed that the cost of repetition represented a suppression of the alternative code attributed to the same response finger, so that



during the switch of task the attribute that had previously been irrelevant is more inhibited than the attribute associated with the other response finger. Meiran's account assumes that task repetition will not entail costs of response repetition. It is probable that these experiments included the repetition of the whole stimulus and that response repetition receives benefits from the repetition of the entire object from the previous trial when the task repeats; this view will be discussed further in Chapter 2. However, it is conceivable that the double mapping of tasks to responses may obscure, or even alter, the functioning of motor processes that have been discerned during these experiments. The relationship between task and response is complicated by the requirement of double mapping and creates greater uncertainty about the mapping to be applied for each trial, as a switch of task will not necessarily require a switch of response to occur. While perception of a stimulus can be directed towards different dimensions, responding with fingers or limbs is inherently location based, so the double mapping of stimuli restricts participants from using the location of the effectors to successfully govern their reactions. Therefore, it is possible that the absence of a direct single mapping of task and response set may serve to reduce the inhibition of the previous response during each trial and that this effect may also contribute to the benefits of response repetition during a repetition of task.

However, the experiments of this chapter possess a direct one to one mapping of stimuli and response sets and are more representative of everyday behaviour and experience. It has already been noted that S-R relations can be bound to specific tasks (Waszak et al., 2003). Moreover, despite only finding costs of response repetition on switch trials because of convoluted S-R mappings, both Allport et al. (1994) and Mayr and Keele (2000) presumed that a switch of

task was associated with a bias to produce a different response. This assertion is supported by the findings detailed here, as they indicate that a switch of task is associated with a de-emphasis upon the last used effector or hand and that cognitive functioning identifies the prospect of a switch with a transition to another part of the body. Furthermore, that inhibition processes were observed across all trials in the task switching experiments of this chapter represents a serious criticism of theories of reconfiguration; the double mapping used by many previous studies had led to the erroneous impression that switch trials were processed differently, but it is apparent that the results of those studies are due to the S-R mappings that were employed.

The present experiments suggest that, without any repetition of the entire object from the previous trial, the processing associated with producing a response appears to be directed toward the difficult component of the action, which is the switch of task. However, it appears that this occurs in the context of the hand and finger response processing that was delineated by Miller and Ulrich (1998), as the corresponding mapping of hand and task influences the outcome. When the task switches along with the hand as in Experiment 2B, the response that is most highly active is the effector that has been previously activated. So, its suppression will ensure that it does not interfere with the activation of the task/response set to be established. Nevertheless, in Experiment 3B the hand is not grouped within a task/response set. The preference for hand grouping renders active all of the responses within a hand following its selection in the previous trial. Thus, the same control process will come to suppress this activation of hand in order to allow the relevant task/response set to be activated.

Consequently, it appears that the response repetition costs noticed during these task switching experiments reflect the inhibition of highly active responses that may conflict with the new goals of the task. This top-down process seems to be applied over the entire block of trials rather than on a trial-by-trial basis. As a result, the presence of this process will be revealed even in the paradoxical situation of having to correctly repeat the same response twice to the relevant dimension of the stimulus in a task repeated trial. The overall benefit that such a process would have upon task switch trials could compensate for the relative disadvantage observed upon response (and task) repetition trials.

The employment of response inhibition promotes flexibility when a participant is aware that a switch of task is anticipated, but can occur at the expense of responses that remain highly active from the previous trial. The requirement of flexibility is determined by the task switching context of the experiment. The reason for selection influences how the S-R relations are utilised. However, while hand processing can be modulated by executive processes, either exaggerated or reversed, it still remains present. So, the instructions given to participants will influence their implementation of the task, but performance must still be enacted through a motor network with specific characteristics and constraints. Although, the repetition of a cue has been noted to produce benefits (Mayr & Kliegl, 2003), it is apparent that the influence of the cue upon the priming of the response is not straightforward, but rather is dependent upon the context. Previous research (Adam et al., 2003, 2005; Reeve & Proctor, 1984) has demonstrated that factors affecting hand grouping, such as the relative distance of hands upon the keyboard and the angle of hand placement, will influence the formation of S-R relations. These effects may reflect a switch of response set



rather than task set, but as the results of these experiments have shown, the two processes are related.

It is interesting to compare the examination of response repetition detailed here with research on backward inhibition. Mayr and Keele (2000) discerned that a switch to a previously adopted task (ABA) renders costs in relation to a switch to a new third task (ABC). Thus, it has been proposed that backward inhibition denotes the inhibition that is applied to a previous task set in order to prevent its perseveration (Hübner, Dreisbach, Haider & Kluwe, 2003). Mayr and Keele (2000) suggested that the processes associated with response repetition were probably separate from those of backward inhibition, and that set-specific response repetition “sits on top of backward inhibition but does not account for it” (p. 20). However, their experiments were founded upon the use of a single finger and so did not require any transitions to another effector: Thus, they obtained response repetitions that demonstrated benefits within the context of task switching rather than costs, as the effector was employed repeatedly regardless of the task. Mayr and Keele (2000) also suggested that backward inhibition operated at set level rather than upon S-R factors. Still, Schuch and Koch (2003) subsequently argued that the role of response processing had been underestimated and proposed that backward inhibition was related to response selection, albeit indirectly, as S-R readiness constituted a component of the absolute activation of a task rule set. Therefore, it is conceivable that, while backward inhibition and response repetitions could reflect different processes, they are quite possibly linked, with response repetitions reflecting the element level processing of specific S-R relations and backward inhibition representing the organisation of task sets. This assumption would coincide with the continuum for S-R mapping

suggested by Wang and Proctor (1996), as they specified a distinction between set-level and element-level processing. Moreover, Schuch and Koch (2003) speculated that backward inhibition occurred on two levels, with one level related to the processing of perceptual information and the other operating upon response codes.

As previous research with two fingers and a double mapping noted benefits for persevering with the prior response, this may have exaggerated the perceived difference between response repetition and backward inhibition. It appeared that the former emphasised perseveration, while the latter was anti-perseverative. Yet the findings detailed here indicate that the prior results for response repetition had been distorted by the employment of the double mapping of stimuli: Instead, it seems that both response repetition and backward inhibition demonstrate a tendency for anti-perseveration once the task or stimulus has been altered. Therefore, it may be that the processes associated with each may be more closely allied than had formerly been realised.

The first chapter assessed the manner of responding when perceptual priming was limited and found patterns of responding that provide a crucial insight into motor-related mechanisms and the influence of the task set. The following chapter will now consider the role of stimuli presentation in guiding the response process.

## Chapter 2

### Selective attention and stimuli features

The first chapter limited perceptual priming that may have derived from repetition of the complete stimulus item from the previous trial: Therefore, examination of the role of stimuli presentation could not be easily conducted. So, the current chapter will assess the salience of the stimuli features as directed by the task set, especially those of the irrelevant dimension, in order to comprehend the relationship between stimulus and response processes.

### Attention and perceptual grouping

Luck and Ford (1998) proposed that attention was necessary to resolve conflict when multiple objects or dimensions are processed concurrently. Initial definitions of attentional selection emphasised the role of the target: Hence, the excitation model (Allport, 1989) asserted that an internal representation of the focal point is activated so as to enhance the mental awareness of the target in comparison to other irrelevant distractor items. Posner (1980) proposed the metaphor of a spotlight when defining the functioning of attention, suggesting that an area of the neural representation of a scene is illuminated for detailed processing. However, Tipper (1985) contended that, although excitation of the target occurred, it was the active inhibition of irrelevant information that constituted the foremost method of attentional selection.

The assertion that inhibitory mechanisms are essential to attentional functioning was subsequently summarised by the theory of selective inhibition (Houghton & Tipper, 1994). This model suggested that the percepts of target and distractor are compared against target specifications that then inhibit those that are



unmatched. Therefore, attention is assigned to certain features in order that they can be processed further, but distracting stimuli can be automatically processed to the point of semantic awareness: The degree of distractor interference affecting the processing of the target will contribute to the difficulty of the task by potentially lengthening RTs and increasing the rate of errors, so requiring inhibition to remove the conflicting influence (Tipper, Bourque, Anderson, & Brehaut, 1989). Consequently, perceptual attention is proposed to be a combination of facilitatory and inhibitory processes. Inhibition is applied to those properties of the distractor that are most salient to the task; positive priming is apparent for other qualities that were not previously considered to be significant, although increased difficulty for target selection demonstrates that inhibition becomes more broadly applied so that positive priming is lost (Tipper, Weaver, & Houghton, 1994). Moreover, inhibition appears to be object-centred, so that if the item is in motion the degree of inhibition it receives remains consistent (Tipper, Brehaut, & Driver, 1990). Therefore, inhibition is a flexible process, with those elements of the distractor most identified with the action to be conducted towards the target being inhibited. Duncan and Humphreys (1989) stated that search difficulty increased with both greater similarity between targets and distractors and decreased similarity between distractors, so defining the efficiency of visual search in terms of a continuum and indicating the extent of interference that is likely to be encountered.

Machado, Wyatt, Devine, and Knight (2007) presented a distractor prior to the target with a varied temporal interval; the position and location of the target and distractor were chosen randomly before each trial. It was found that if the distractor preceded the target by more than several hundred milliseconds, then

congruency between the two stimuli led to slower responses. The researchers inferred that the representation of the distractor was inhibited before the target appeared, entailing greater costs if the two stimuli matched. Berti and Schröger (2003) suggested that it is beneficial to apply less inhibition to perceptual information when the task is easier, as it may be necessary to alter the task at short notice, thereby enabling greater flexibility for shifting attentional priorities. Alternatively, when the task is more difficult to accomplish, increased inhibition is necessary to limit interference from irrelevant information.

However, while continued variance in the presentation of distractors serves to sustain inhibition (Tipper, Weaver, Kirkpatrick, & Lewis, 1991), the repeated presentation of a distracting stimulus is liable to reduce the interference that it creates due to habituation: The individual's internal representation of the environment eventually accommodates the presence of the distractor so that selective attention is no longer hindered (Lorch & Horn, 1986). Nevertheless, Danziger, Kingstone, and Ward (2001) determined that an item serves as a point of reference for the spatial coding of other stimuli within a display, even after the spatial code for that item is no longer motivating a response.

Lowe (1979) identified the importance of task context in determining performance. The study used a paired-trial Stroop task: This task involves responses to coloured words, where incongruency between the written colour and the presented colour leads to costs. It was noted that participants would attempt to exploit information from the first trial if it was considered likely to be a reasonable predictor of the subsequent trial. Furthermore, if it was assumed that the second trial of each pairing would be difficult, then only mild facilitation was apparent when the task was easier than anticipated. Thus, it appears that the



extent of facilitation and inhibition is moderated by expectation and that the mental set adopted by the participants would adjust the performance of the task.

Eriksen and Eriksen (1974) noted that, with the employment of their flanker task, parallel processing of the flanking stimuli was unavoidable within a visual area of one-degree around the target. Interference was inferred from the presence of the distractors, as incongruent flankers slowed responses compared to those that were congruent. The effect of incongruency was reduced as the distance between the target and the distractors was increased. Consequently, it was suggested that the location of surrounding stimuli is a primary factor in determining the relative difficulty of finding the target and so supports the spotlight theory proposed by Posner (1980). Tsal and Lavie (1993) conducted an experiment that required participants to respond to one of three properties: location, colour, and identity. They determined that participants responded most rapidly to stimuli presented near to the target on a probe trial, regardless of which dimension was most relevant to the task. Therefore, they stated that location constituted the principal dimension for visual processing. Beck and Lavie (2005) proposed that effects of perceptual load relating to attentional capacity influenced equally central and peripheral distractors, but that those displayed at fixation had preferential access to attention. However, while proximity around the target may exacerbate the influence of distractors, Tsal and Makovski (2006) discerned that, when the location of distractors is invariant, all stimuli in the display are processed, even if this is likely to entail greater interference. They inferred that expectancies of participants concerning the location of stimuli encouraged the processing of distractors according to a 'process-all' mechanism that operated regardless of the demands of the task.



Nevertheless, the impact of location is not unqualified. Harms and Bundesen (1983) used a flanker task with letter stimuli, but varied the colour of the distractors between trials, sometimes being congruent with the target and at other times not: It was found that different coloured distractors of incongruent letters created less interference than those of an identical colour, as they were more readily grouped and inhibited. Hence, the non-spatial features of the distracting stimuli also appeared to affect the extent of interference obtained. Similarly, Fox (1998) noticed that the principle of increased interference for near distractors was lost if they were presented in a different colour to the target while those further away were coloured congruently. Pratt and Hommel (2003) found that a centrally placed arrow elicited involuntary shifts of attention if it shared the same colour as the target, regardless of whether colour was the relevant dimension for producing a response: Attention was guided within the visual field by features associated to the target, so promoting other symbols sharing similar properties and indicating the functioning of feature-based stimulus codes held by the task set.

Driver and Baylis (1989) suggested that perceptual grouping could be encouraged by the congruent motion of stimuli: Increased interference was apparent from a remote distractor if it was moving in the same direction as the target, in contrast to a static distractor sited at a closer location. Conversely, the motion of distracting stimuli close to a static target showed less interference when compared to distant distractors that were stationary. Moreover, Baylis and Driver (1992) proposed that stimuli alignment could promote perceptual grouping: A distractor of a similar orientation was responsible for rendering greater interference in comparison to a distractor that was angled differently but situated at an equivalent distance from the target. Therefore, while the importance of

location was accepted, Baylis and Driver (1992) contended that the common features of different stimuli could allow those disparately positioned to be grouped endogenously.

Jiang, Chun, and Olson (2004) examined the detection of a location change for any black dot amongst a selection of eight. However each black dot was intersected by a white line that was irrelevant to the task. If a black dot altered position between the memory display and the probe display but the associated line changed orientation, then the target was much more difficult to determine. The authors argued that the elements of an object are grouped to form a composite representation and so responding will be affected by the change of a component even if an element is irrelevant. Thus, it is apparent that the primacy of location processing is modulated by other factors.

However, Van der Heijden (1993) proposed that non-spatial features only serve to mark a location in a display, with the position of the item being the dominant code. Kim and Cave (2001) asked participants to respond to a cued target letter flanked by two other letters: The flankers were coloured, sometimes being congruent with the colour of the target. Following some letter trials, a dot appeared in the location of one of the distractors, which required a spatially compatible response. It was observed that responses were faster to a dot that appeared in the location previously occupied by a congruently coloured flanker letter. The authors suggested that target-colour locations obtained further attention and that increased attention produced greater interference. Therefore, it was contended that, while non-spatial dimensions may direct attention, spatial processing was the primary determinant for selection.

It is worth noting that perceptual grouping is a complex procedure incorporating all elements of an object. Palmer, Brooks, and Nelson (2003) proposed that perceptual grouping constitutes both the early processing of two dimensional characteristics as well as the later processing of three dimensional properties, such as binocular depth and shape constancy: Consequently, it was stated that perceptual grouping does not represent a single stage, but is instead a continuous process, accommodating each feature representation while the information from a percept is being analysed. Treisman (1988) proposed that each object derives from a feature map, with the allocation of attention to a particular location being required to unite those components in order that the object can be perceived.

Nevertheless, it appears that attention can be specific to objects regardless of location. Duncan (1984) briefly displayed two objects, a line and a box, in the same location: Participants were then asked two of a possible four questions after each trial. If asked about the properties of two separate objects, the participants were less accurate, but demonstrated few errors for characteristics belonging to the same stimulus. Therefore, Duncan (1984) stated that the discrepancy regarding the processing of single and multiple objects indicated that features were grouped into objects by attentional processes without the aid of location, as the placement was identical for both objects. However, Kramer and Jacobson (1991) re-examined the effect of distance in the flanker task. They noticed that interference was exaggerated if the target and distractors was encased within the same object, but that the interference of a distractor was substantially reduced if it was presented within a separate object to the target, even if the stimuli were placed in close proximity. Objects are not just considered in isolation, but are



assessed in relation to the other characteristics of the display: Thus, the exogenous figural grouping of stimuli will affect the extent of inhibition that is required.

Humphreys and Riddoch (1995) assessed a patient with unilateral visual neglect and determined dissociations of the side where neglect appeared for different types of task: The researchers inferred from the performance of the patient that the visual system develops codes separately for the relations of features within an object and the relations between objects and that these two processes occur in parallel. Shalev and Algom (2000) concurred following a comparison of costs for the cueing of locations of a spatially variable Stroop task. Similarly, Wolfe, Cave, and Franzel (1989) discerned that visual search was more efficient if searching for a target composed of three conjunctions rather than two: They proposed that each feature appropriate to the target was processed in parallel, so that increased information about the features of the target enabled faster recognition and aided response selection.

Scholl (2001) proposed that the apparent emphasis upon the processing of objects or locations was affected by the task: For instance, the assessment of grouped arrays are related to spatial cueing tasks, while the processing of objects is evident in divided attention tasks such as that utilised by Duncan (1984). Therefore, the processing of objects and locations may be complimentary. Vecera and Farah (1994) replicated the study by Duncan (1984), but also found no additional costs for attending to the same stimuli when the objects were sited at separate locations, so supporting the assertion that the associated processing activated representations of objects that were spatially invariant. Nevertheless, further use of the stimuli in a cued location task found that correctly cued responses were faster when the object appeared at the specified position,

signifying that location coding was prevalent in this instance. Hence, Vecera and Farah (1994) stated that the prevailing frame of reference is not invariant but instead is reliant upon the goals of the task, with both object representations and location codes being relevant.

Gibson and Egeth (1994) delineated a continuum that included both object and spatial associations: The task set can accentuate processing for the locations of the various elements that comprise an object, or can focus upon the location of an object in relation to others. Consequently, the authors suggested that processing based upon objects and locations is interconnected, with the emphasis altering according to the context. Of course, the model implies that the features of an object are also spatially-focussed, but on a smaller scale. Fox (1998) observed that a distractor presented within the same object as a target did not show an effect of distance. Davis, Driver, Pavani, and Shepherd (2000) discerned that costs for assessing two objects instead of one occurred only if the two objects covered a wider spatial area. They concluded that participants did not demonstrate a fixed ability to attend to only one object, but instead, suggested that attention toward an object automatically spreads across the entire percept even when only one portion of the item is relevant. Therefore, the spatial processing within an object can be differentiated from the spatial processing across the array, supporting the assertion by Humphreys and Riddoch (1995).

#### Dimensional relevance and response repetition

The primary supposition of any theory of object processing is that the irrelevant features of an item will be selected in conjunction with those that are relevant (O'Craven, Downing, & Kanwisher, 1999). Mapelli, Cherubini, and Umiltà (2002) required participants to judge same-different comparisons between

two targets. If some features of the object containing the target were irrelevant to the task then costs were apparent and these increased if the target was composed from the conjunctive elements of two distinct objects that both contained distracting information. A distractor will create greater interference if combined with the target within an object rather than being placed separately, so the researchers suggested that attendance to an object was most beneficial if the features contained were relevant to the task, but that irrelevant information included within the object will entail a cost. Fischer, Dreisbach, and Goschke (2008) proposed that the apparent level of control per trial was dependent upon both the extent of the interference from the features irrelevant to the task and the processing demands of the relevant feature. Hence, preparation for the relevant dimension represented a beneficial strategy when switching tasks (Meiran & Marciano, 2002). However, Hommel and Colzato (2004) considered that the emphasis upon a particular feature was dependent upon the relevance to the task: So, the procedure of feature binding is not uniform but is directed by the task set. Thus, an object does not appear to constitute an absolute collection of features: Instead, the binding of features seems to be relatively loose, enabling the information to be directed according to its salience.

Hommel and Colzato (2004) proposed that the integration of stimulus features created an object file, while the additional pairing of a stimulus with a response will lead to an event file: Hence, actions can also be bound to features, as well as the features of an object being bound to each other. Hommel (2005) considered that the formation of object and response codes occurred locally, with these S-R codes becoming integrated during a successful event. So, during the performance of a single task, the effects of response competition are generally less



evident if a stimulus and the response is repeated from the previous trial (Bertelson, 1961). Moreover, the effect of response repetition tends to be more pronounced with tasks comprising greater than two choices (Kornblum, 1967). Horner and Henson (2008) proposed that priming from a previous association between a stimulus and response would promote the automatic activation of the response if the stimulus was displayed again, thereby avoiding the need to use some of those mechanisms that were initially involved in the selection of the response during the first trial presentation.

Similarly, Pashler and Baylis (1991) suggested that S-R repetition allowed the operation of links able to provide a shortcut for the stage of response selection. The facilitation associated with a repetition of response is absent if the criteria for responding are altered compared to Trial  $n-1$  (Pollman, Weidner, Müller, Maertens, & von Cramon, 2005). Thus, if it is necessary that the response becomes mapped to a different dimension of the stimulus, the S-R relations are disturbed: Pollman et al. (2005) observed that, in the event of responding to a different dimension, a preference was apparent for executing the response with another effector. Conversely, if the relevant stimulus feature recurred on a consecutive trial, Hommel (1998b) discerned a cost if the response was altered to another finger rather than repeated: Furthermore, non-spatial elements of the stimulus were found to interact, so that RTs are shorter if the various dimensions such as colour and shape are either replicated or altered in unison. However, the advantages of repeating an element from a non-spatial dimension are also dependent upon the repetition of the location of the stimulus; otherwise alternation of the response appears to again be favoured. Thus, Hommel (1998b) argued that aspects of a stimulus are bound to a particular response, with alterations of the

stimulus leading to a preference for a shift of response to another effector, although the relative location of the stimulus and response remains paramount.

Campbell and Proctor (1993) discerned that the benefit of response repetition was also dependent upon the mapping of category: That is, one category of stimulus may be mapped to one response subset, for instance the fingers of one hand, while another category is mapped to another subset, such as the fingers of the opposing hand. So, they indicated that a non-identical stimulus to that presented during Trial  $n - 1$  could still render a benefit when mapped to the same effector if the relevant category for responding remained unaltered; a red triangle and a red square would still produce facilitation if the effector is to respond to the colour red. It was discerned that the benefit of response repetition remained present if the succeeding trial was mapped to the same type of finger on the opposing hand while the category was unaltered: Thus, they considered that the use of the same effector is not necessary if the two hand subsets directly correspond although, during the experiments conducted by Campbell and Proctor (1993), the switches of hand response were systematic and therefore predictable. It should be noted that alternating the S-R mapping according to hand accommodates the response apparatus specified by Miller and Ulrich (1998). Moreover, Campbell and Proctor (1993) discerned that the orthogonal placing of hands, with one arranged vertically and the other horizontally, removed the benefit of response repetition across hands as the mappings of each do not correspond. Nevertheless, Pashler and Baylis (1991) found that the response repetition advantage was limited when different categories, letters and digits, were mapped to responses conducted by the same three fingers of one hand. In this instance, they contended that the S-R mappings were non-categorisable, as the

fingers were not easily assigned to a single dimension or type of stimuli. Only the repetition of the previous stimulus and response pairing was sufficient to produce benefits of response repetition.

Responses conducted in the context of task switching find that the benefit of response repetition is also reversed (Rogers & Monsell, 1995; Meiran, 2000a): So, the activity of switching between tasks produces a cost of repeating a response, but these costs are less apparent for response alternations. Waszak et al. (2003) observed that switch costs were greater for stimuli that were presented during both tasks: It was inferred that following the instigation of a new task set, occurrence of a stimuli displayed in the course of the previous task will then promote associations with the task that had been replaced and so increase interference. Moreover, Schuch and Koch (2004) demonstrated that costs of repetition are evident for compatible responses, sharing some overlap of S-R features, which are not dependent upon the same response modality. Their study required vocal responses of “left” or “right” to be given before a keypress was executed by one of either index finger; the RTs were longer for switches of modality and the relative costs of cross-modal response repetition were reduced, but still present, in comparison to the use of just one response modality. It was suggested that the benefits of response repetition derived from the operation of abstract response codes during response selection rather than an association with an explicit motor action. However, the findings of studies such as those conducted by Alain et al. (1993) and Adam (2008) suggest that this view may underestimate the influence of the response apparatus upon the generation of these response codes, and the reduction of the response benefit found by Schuch and Koch (2004) implies that response execution occupies a role. Mayr and Bell



(2006) allowed participants to choose freely whether to switch or repeat a task for each trial. Generally, it was noticed that a change of stimulus was more likely to be associated with a switch of task, whereas a repetition of the previous stimulus was liable to sustain a repetition of the task. Kleinsorge (1999) contended that the alteration of a stimulus category and of a switch of task rendered similarly adverse effects for response repetition. Accordingly, it was argued that a change of a feature related to the task disrupts the task set and thereby promotes response alternations; the benefit of response repetition is dependent upon the abstract features of the task remaining constant. Preparation may reduce switch costs, but is not sufficient to diminish the interference from the irrelevant feature (Monsell, Sumner, & Waters, 2003).

#### Experiment 4

With reference to the available literature, the patterns of response repetition obtained in the Experiments 1 to 3B could be related to the processing of the two dimensions used for the tasks. In the single task designs, the irrelevant dimension remains irrelevant for the entire block of trials, but this is not the case for those experiments requiring the switching of tasks. As the irrelevant dimension is more salient during task switching experiments, it appears that the change of the irrelevant dimension hinders response repetition due to increased conflict, to the extent that it becomes a cost, with a transition to another effector then being promoted. The first series of experiments did not incorporate repetition of the whole stimulus, mainly to limit perceptual priming deriving from repetition of the object: Without the inclusion of full object repetition, it is not possible to compare the repetition and change of the irrelevant dimension in

relation to the processing of the relevant target feature. This chapter will consider responding when full object priming is allowed.

Consequently, the following three experiments aim to test the influence of processing related to dimensions of the percept by comparing trials in two contexts: Firstly, the experiments will aim to replicate the response processes obtained previously; secondly, they will be used to examine the influence of the stimulus upon the production of the response. The processing of the stimulus will be considered with four conditions: The repetition of the whole object; the repetition of the relevant property; the repetition of the irrelevant property; and the alteration of both dimensions of the object (the whole object changes). So, Experiments 4, 5A, and 5B are similar to those of Experiments 1, 2B, and 3B, but instead incorporate full object repetition in order to enable greater analysis of the possible influence from the irrelevant dimension upon the occurrence of response repetition costs.

### *Method*

*Participants.* A further 24 students from the University of Wales, Bangor were employed according to the criteria stated in Experiment 1.

*Stimuli, Design, and Procedure.* Experiment 4 used the same stimuli, temporal parameters and response arrangements of Experiment 1, but instead the selection from the trial-list was random with replacement: Thus, the same item could now appear repeatedly without alteration. The previous experiment always rendered a change of at least one dimension of the stimuli between trials. Experiment 4 requires participants to respond to the same dimension across whole blocks of trials and so does not incorporate task switching. Consequently, it

provides the baseline comparison for the analysis of task switching provided by Experiments 5A and 5B.

### *Results*

The data of Experiment 4 were trimmed in exactly the same manner as that of Experiment 1: The practice trials were removed followed by the errors (2.9%) and any response faster than 200ms and slower than 2000ms (0.4%). In total, 3.3% of the trials were excluded from the analysis.

Table 3a contains the mean RTs, standard error, and percentage of errors in milliseconds for each response condition and also for each type of stimuli presentation. Also presented in the table are the descriptive statistics for Experiments 5A and 5B. As before, a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA was used to assess the data. The experiment replicated all of the major findings that were observed in Experiment 1: A main effect of hand was obtained, ( $F(1,23)= 58.66$ ,  $MSe=3414$ ,  $p<0.001$ ,  $\eta_p^2=0.71$ ) and the advantage of hand repetition was demonstrated by all 24 of the participants. Nevertheless, although the advantage was reduced to 91ms from the 111ms obtained in Experiment 1, the difference between them was not significant ( $F<1$ ). An effect of finger type was also discerned, ( $F(1,23)=23.49$ ,  $MSe=2196$ ,  $p<0.001$ ,  $\eta_p^2=0.50$ ), with the general advantage of finger type repetition being 46ms. This pattern was shown by 21 of the 24 participants, mirroring the effect obtained in Experiment 1, as the difference of the finger repetition effect across the two experiments was  $F<1$ .



Table 3. *Global results for stimuli presentation and transitions of response for the random (Exp 4), hand cued (Exp 5A), and hand + task cued experiments (Exp 5B). The results represent hand transitions obtained with a one to one mapping and full object repetition.*

Response Processing					Perceptual Processing				Hand	Finger type
<u>Response Hand</u>	Repeat		Switch		Object Repeat	Relevant repeat	Irrelevant repeat	Object change	switch cost	switch cost
Finger type	Repeat	Switch	Repeat	Switch					(Switch – Repeat)	(Switch – Repeat)
a) Experiment 4. Random										
Mean RT	570	663	708	707	534	576	697	697		
SE	10.46	19.32	23.34	22.70	17.16	9.44	22.45	21.27	91	46
%Error	0.99	1.45	1.64	2.53	0.10	0.52	1.49	4.51		
b) Experiment 5A. Hand and Task switch										
Mean RT	712	724	803	831	734	797	767	767		
SE	36.62	36.59	38.59	39.13	32.85	37.32	40.46	37.59	99	20
%Error	1.06	1.67	1.25	1.71	1.41	1.77	1.32	1.19		
c) Experiment 5B. Finger Type and Task switch										
Mean RT	698	805	758	832	743	812	766	788		
SE	30.68	35.91	34.77	41.67	32.56	33.53	34.27	37.74	43	90
%Error	1.56	1.88	1.25	2.08	1.86	2.10	1.41	1.41		

There was an interaction between the two main effects of hand and finger type, as the fastest response was that which repeated exactly the response from the previous trial, ( $F(1,23)=41.06$ ,  $MSe=1283$ ,  $p<0.001$ ,  $\eta_p^2=0.64$ ). The repetition of the specific effector showed the shortest RTs compared to a transition to the other finger of the same hand, ( $F(1,23)=37.85$ ,  $MSe=2755$ ,  $p<0.001$ ,  $\eta_p^2=0.62$ ), with the advantage being 93ms, greater than the 69ms of Experiment 1 but not significantly so ( $F<2$ ). This advantage of finger repetition was also shown by all of the participants. The only effect not to be replicated from Experiment 1 was the comparison between the transition to the equivalent finger and the non-equivalent finger of the opposing hand ( $F<2$ ). Examination of the global RTs found no difference between those of Experiment 1 and the RTs of Experiment 4 ( $F<2$ ).

More importantly, analysis of the properties of the stimuli discerned that repetition of the whole object produced faster responses than merely a repeat of the relevant dimension, ( $F(1,23)=12.60$ ,  $MSe=1849$ ,  $p=0.002$ ,  $\eta_p^2=0.35$ ). This effect was found for 22 of the participants. It should be noted that repetition of both the whole object and the relevant dimension alone coincided with the repetition of the finger response. Still, benefits for the repetition of the irrelevant dimension of the stimuli appeared to be absent when the feature of the relevant dimension altered: A comparison of repetition of the irrelevant dimension and a complete change of the item found that the difference between them was extremely slight at just 0.6ms, ( $F(1,23)=0.01$ ,  $MSe=448$ ,  $p=0.92$ ,  $\eta_p^2<0.001$ ). These two perceptual conditions also represent transitions of response: For example, the current experiment did not contain a condition where only the irrelevant dimension repeated along with a repeat of the finger response (this

occurrence will be assessed later, in Experiments 6, 7A, and 7B). So, comparison of the repeat of the irrelevant dimension and the switch of the object were founded upon totals derived from the means associated with the three remaining types of response transition (hand repeat, finger switch; hand switch, finger repeat; and hand switch, finger switch). Therefore, unsurprisingly, when repetition of the relevant dimension and whole object was contrasted with repetition of the irrelevant dimension and whole object change, the responses for the former perceptual conditions were faster and the effect was demonstrated by all 24 participants, ( $F(1,23)=78.16$ ,  $MSe=3340$ ,  $p<0.001$ ,  $\eta_p^2<0.77$ ). This demonstrates how closely can be bound the repetition of the stimuli and the repetition of the response. Moreover, it indicates the default preference for stimuli presentation and provides a useful comparison for the subsequent analysis in Experiments 5A and 5B.

The details for response transitions according to the manner of stimuli presentation are shown in Table 4a. The table also contains the information for the following two experiments. It should be understood that the values in Table 4 may not exactly match those of Table 3: In order to aid clarity, some trials have been excluded from Table 4 where the trials following an error have produced a combination of stimulus presentation and response transition that was not anticipated by the design of the experiment. During those instances following an error, the type of transition might be unusual: For example, in Table 4, the repeat of the equivalent finger may occur along with whole object repetition when the previous response was incorrect, so promoting a transition that was unexpected. However, there are too few of these post-error trials to conduct a meaningful analysis of them.



Table 4. *The effect of stimuli dimension upon response transitions for the random (Exp 4), hand cued (Exp 5A), and hand + task cued experiments (Exp 5B). The results were obtained with a one to one mapping of stimuli to response and full object repetition.*

Hand		Repeat								Switch						
<u>Finger</u>		Repeat				Switch				Repeat				Switch		
Percept	Object	Rel	Irrel	Switch	Object	Rel	Irrel	Switch	Object	Rel	Irrel	Switch	Object	Rel	Irrel	Switch
a) Experiment 4. Random																
Mean RT	527	572	N/A	N/A	N/A	N/A	646	665	N/A	N/A	706	708	N/A	N/A	711	706
SE	16.58	9.27					15.29	20.98			26.78	22.55			25.65	22.15
%Error	0.02	0					0.17	0.58			0.17	1.12			0.67	1.62
b) Experiment 5A. Hand and Task switch																
Mean RT	662	752	N/A	N/A	N/A	N/A	699	719	793	829	818	767	806	841	836	847
SE	34.19	42.97					41.24	38.91	37.51	39.54	46.15	41.08	41.78	41.19	47.60	47.87
%Error	0.36	0.04					0.28	0.26	0.23	0.41	0.19	0.41	0.43	0.56	0.28	0.43
c) Experiment 5B. Finger Type and Task switch																
Mean RT	643	739	N/A	N/A	860	861	767	782	N/A	N/A	721	754	848	870	806	819
SE	28.73	35.17			49.63	42.03	35.73	41.40			36.39	37.95	46.93	47.23	44.59	42.57
%Error	0.71	0.13			0.39	0.86	0.19	0.43			0.26	0.23	0.52	0.58	0.39	0.58

Analysis of the errors again utilized a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA: It was discerned that a transition to the opposing hand created more errors, ( $F(1,23)=19.45$ ,  $MSe=0.93$ ,  $p<0.001$ ,  $\eta_p^2<0.45$ ). A repeat of the equivalent type of finger was also associated with less errors, although the effect was not so large as that obtained for hand, ( $F(1,23)=6.33$ ,  $MSe=1.71$ ,  $p=0.01$ ,  $\eta_p^2<0.21$ ). Nevertheless, there was no interaction between these two effects, ( $F<2$ ). When considering the influence of the perceptual properties, it was found that most errors were committed when the whole object changed in comparison to a repeat of the irrelevant dimension, ( $F(1,23)=29.02$ ,  $MSe=3.76$ ,  $p<0.001$ ,  $\eta_p^2<0.55$ ). However, both the repeat of the relevant dimension and of the whole object produced far fewer errors in comparison to the repeat of the irrelevant dimension and the change of the whole object, ( $F(1,23)=38.39$ ,  $MSe=2.76$ ,  $p<0.001$ ,  $\eta_p^2<0.62$ ). Still, again it should be reminded that these perceptual conditions are also those associated with a repetition of the response finger. Actually, only one error was produced for a trial incorporating both a repeat of object and a repeat of response across all of the 24 participants, while the repeat of the relevant dimension and the previous response only led to two.

### *Discussion*

The results of Experiment 4 demonstrate that the main effects obtained in Experiment 1 are robust: The benefits for hand and finger repetition are both evident, as is the repetition of equivalent finger type. Participants always responded to the same dimension throughout a block of trials so little difference was anticipated, although the advantages of full object repetition were not

sufficient to enhance the main effects compared to those of Experiment 1. As predicted, repetition of the irrelevant dimension did not have a direct effect upon the responses, as the RTs were not dissimilar from those of a full change of the stimulus. Therefore, the view is supported that the irrelevant dimension was not salient for the participants, as it was not assigned to a response set and so was consistent in not providing information explicitly associated to the task. The irrelevant dimension did not appear able to capture attention automatically in any meaningful way. However, when the irrelevant dimension repeated along with the relevant dimension (full object repetition) then benefits were obtained (45ms) in comparison to a repetition of the relevant stimulus alone. Hence, the complete repetition of the stimuli appeared able to promote responding beyond the RTs achieved for a repeat of the relevant dimension: This finding supports the notion proposed by Horner and Henson (2008) that full object repetition represents a special case whereby a number of the normal S-R processes are bypassed automatically.

Nevertheless, while the RTs showed no difference between irrelevant repetition and object change, consideration of the errors found those for object change are more substantial. It appears that repetition of the irrelevant dimension creates more stability, and so less interference, when shifting the focus of attention to process the new relevant feature and the associated response transition. Therefore, while the repetition of the irrelevant dimension in isolation does not appear to be directly beneficial upon RTs, it serves to aid the accuracy of responses when the relevant dimension changes and to promote the response when its repetition coincides with that of the relevant dimension. Conversely, a change of the irrelevant dimension prevents automatic activation of the previously



associated event file and increases instability during the creation of a new event file.

### Experiment 5A

Experiment 4 constituted the baseline for the analysis of full object repetition and its influence upon processes associated with response. Experiment 5A incorporates full object repetition within a task switching paradigm. The experiment is similar in design to Experiment 2B, with each hand being assigned to a separate task so that cueing specifies both the hand and task to be employed. The experiment will assess the same response effects that were obtained from Experiment 2B in relation to changes in the target stimuli.

#### *Method*

*Participants.* An additional 24 students from the University of Wales, Bangor participated in the study and each conformed to the criteria stated in Experiment 1.

*Stimuli, Design, and Procedure.* Experiment 5A used the same stimuli, temporal parameters and response arrangements of Experiment 2B, but akin to Experiment 4, the selection from the trial-list was altered to become random with replacement, thereby enabling an item to repeat entirely from the previous trial. Consequently, the experiment was able to assess perceptual priming when the different tasks were allocated to each hand.

## Results

The first 16 trials for each participant were allocated for practice and so were removed from the analysis, along with the errors (5.7%) and those responses committed faster than 200ms or slower than 2000ms (3.8%). Overall, 9.5% of the trials were eliminated from the analysis of the main effects.

Table 3b illustrates the global descriptive results for stimuli presentation and response transitions that were obtained for the current study. It should be remarked that, due to the incorporation of task switching, for this experiment each type of stimuli is associated with three types of finger transition. Repetition of the whole object and the relevant dimension occurred for finger repetition, equivalent finger switch, and non-equivalent finger switch while the repetition of the irrelevant object and the change of the object were both related to a transition to the other finger of the same hand, equivalent finger switch and non-equivalent finger switch. However, for trials involving a switch of task, the repetition of the relevant dimension concerns the feature that is now relevant but was irrelevant on the previous trial, whereas repetition of the irrelevant dimension concerns the feature that was previously relevant.

Table 4b displays the influence of stimuli presentation upon the mean RTs for response transitions. An analysis of the perceptual properties found a general advantage of repeating the whole object in comparison to repeating only the relevant dimension, ( $F(1,23)=15.35$ ,  $MSe=2223$ ,  $p=0.001$ ,  $\eta_p^2<0.40$ ). This effect was the same for task switch and task repeat trials ( $F<2$ ). Similar to the findings of Experiment 4, no difference was observed in the overall performance related to a change of the whole stimuli and a repeat of the irrelevant dimension, ( $F<1$ ) and,

again, this effect did not alter when the task switched or repeated ( $F < 1$ ). Still, unlike Experiment 4, the repeat of the relevant dimension actually rendered slower responses in comparison to a change of the whole object, ( $F(1,23)=5.83$ ,  $MSe=2330$ ,  $p=0.02$ ,  $\eta_p^2 < 0.20$ ): Therefore, an alteration of the irrelevant dimension seemed to have a greater influence than in the previous experiment. Furthermore, overall, either a change or a repeat of the whole object led to faster responses than a partial change or repeat associated with just one dimension, ( $F(1,23)=13.09$ ,  $MSe=1882$ ,  $p=0.001$ ,  $\eta_p^2 < 0.36$ ) and this effect did not alter according to whether the trial involved the repeat or the switch of task ( $F < 1$ ). These differences appeared to be more pronounced for comparisons associated with responses of hand repetition, primarily because of the benefits of full object repetition and the exacerbated cost for the repeat of the relevant dimension; analysis of stimuli for responses of hand switch alone found that the advantage of whole object change or repeat achieved only marginal significance, ( $F(1,23)=3.46$ ,  $MSe=5209$ ,  $p=0.07$ ,  $\eta_p^2 < 0.13$ ). However, the change of the whole object created a benefit of 80ms for a switch to the equivalent finger in comparison to the non-equivalent finger, ( $F(1,23)=5.69$ ,  $MSe=13342$ ,  $p=0.02$ ,  $\eta_p^2 < 0.19$ ): Therefore, it seems that full object change was beneficial for a change of task, but only for the symmetrically equivalent finger rather than the responses of the entire hand. Overall, a comparison of the repetition of the whole object and the relevant dimension in relation to a repeat of the irrelevant dimension and complete change found no significance ( $F < 1$ ).

Again, a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA was employed to assess the patterns of response transitions. Firstly, analysis of the current data replicated the main



effects of response transition that were obtained for Experiment 2B. Responses were faster when the hand and task were repeated than when the response switched to the opposing hand and task, ( $F(1,23)=25.98$ ,  $MSe=9086$ ,  $p<0.001$ ,  $\eta_p^2<0.53$ ). However, the effect produced by the introduction of object repetition reduced the cost of hand and task switch to just 99ms, only 8ms more than that obtained for Experiment 4 when no task switch was required or cueing employed. Actually, there was no significant difference of hand switch between Experiment 4 and 5A ( $F<2$ ), although the global RTs of Experiment 4 were shorter ( $F(1,46)=5.36$ ,  $MSe=19619$ ,  $p=0.02$ ,  $\eta_p^2<0.10$ ).

Unlike Experiment 2B, the current data finds a significant difference between a switch to the equivalent or non-equivalent fingers, with a switch to the equivalent finger being faster by 29ms, ( $F(1,23)=5.86$ ,  $MSe=1724$ ,  $p=0.02$ ,  $\eta_p^2<0.19$ ). This effect of finger transition was shown by 17 of the participants. Conversely, no difference was discerned between the repetition of the previous effector and a transition to the other finger of the same hand, ( $F<1$ ), so no effect of finger repetition was obtained when examining all response repetition trials collectively. Consequently, the manner of response repetition in Experiment 5A was significantly different to that of Experiment 4 ( $F(1,46)=16.47$ ,  $MSe=2401$ ,  $p<0.001$ ,  $\eta_p^2<0.26$ ), as the earlier experiment had obtained an advantage for repetition that was absent here. Nevertheless, the removal of trials for full object repetition reduced the data to those types of trials used in Experiment 2B: Following this procedure, it was revealed that the remaining trials again showed a cost for response repetition in relation to the other finger of the same hand, ( $F(1,23)=10.05$ ,  $MSe=3671$ ,  $p=0.004$ ,  $\eta_p^2<0.30$ ). The benefits of full object repetition disguised the costs of repeating finger when the stimulus altered. Still,

the benefits of full object repetition were not as pronounced as those obtained in Experiment 4 when task switching was not required, ( $F(1,46)=12.55$ ,  $MSe=17336$ ,  $p=0.001$ ,  $\eta_p^2<0.21$ ), suggesting an occurrence of response suppression that is perhaps not directly founded in the presentation of the irrelevant property.

Experiment 5A was compared with Experiment 2B: Both were identical in design except for the inclusion of full object repetition in Experiment 5A. As previously noted, the inclusion of full object repetition removed the trend for costs associated with repetitions of response so that they were no longer apparent. However, while response repetitions were 62ms faster compared to Experiment 2B, the overall benefits for response repetition were not significantly greater, ( $F<2$ ). Nevertheless, the use of full object repetition did affect the processing of hand between the two experiments, ( $F(1,46)=7.03$ ,  $MSe=4791$ ,  $p=0.01$ ,  $\eta_p^2<0.13$ ), and this interaction increased if the object repetition trials were removed from the mean RTs of Experiment 5A, ( $F(1,46)=9.46$ ,  $MSe=11231$ ,  $p=0.004$ ,  $\eta_p^2<0.17$ ): It appears that the main source of benefits deriving from the inclusion of full object repetition actually seemed to be for transitions to the opposing hand, with a transition to the equivalent finger being 108ms faster than the same type of transition in Experiment 2B, although in isolation this comparison achieved only minor significance, ( $F(1,23)=3.06$ ,  $MSe=44590$ ,  $p=0.08$ ,  $\eta_p^2<0.62$ ). Conversely, a transition to the alternative finger of the same hand gained the least from the inclusion of object repetition, with just 7ms difference ( $F<1$ ).

The errors of response transition were also analysed using a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) ANOVA. It was found that substantially more errors were produced by a transition to the

opposing type of finger, ( $F(1,23)=6.86$ ,  $MSe=0.98$ ,  $p=0.01$ ,  $\eta_p^2<0.23$ ). There was no significant difference produced by the grouping of hand ( $F<1$ ). No differences were observed for the errors associated with the repetition and changes of the stimuli dimensions ( $F<2$  for each of the comparisons).

### *Discussion*

Like the previous experiment, there was no overall difference between a change of the whole stimuli and a repeat of the irrelevant dimension only: So, the irrelevant dimension did not appear to have a direct influence when the relevant dimension changed, regardless of whether the task switched or repeated. However, during task repetition trials, a change in the irrelevant dimension when responding to the relevant feature led to the longest RTs of any form of stimulus presentation; the expectation of a switch increased the salience of the irrelevant dimension, thereby confirming that a change in the irrelevant dimension disrupted the S-R bonds of the event file and so was considered by participants to signal a change of task and effector. Moreover, a partial change of the stimulus regardless of the dimension rendered costs in relation to a complete repetition or change. So, less interference was obtained if the features of the current stimulus did not overlap with the event file previously established, thereby allowing a new event file to be more readily determined, while an absolute replication of the stimulus encouraged the same bypassing of some S-R processes that was noticed in the previous experiment. This effect was most apparent when the task repeated, suggesting greater differentiation at the element level of specific S-R codes. Conversely, when the task changed the difference between the whole and partial repeat or change of the stimulus was marginally significant but less pronounced,



indicating that the element level processing of specific S-R codes still occurred to some degree but that the alteration of the task set possibly reduced their discriminability during the switch. Only a complete change of the stimulus elicited faster RTs for the equivalent finger compared to the non-equivalent, suggesting that the greater certainty of a transition from the previous response that was associated with the change of item may in this instance have a focus directed by symmetry when the task also altered.

The benefits for hand and task repetition are evident, as they were for Experiment 2B, but now the advantage has reduced to 99ms; just 8ms more than the difference obtained in the non-cued baseline of Experiment 4. So, the results from inclusion of full object repetition into the experimental design reinforce the assertion that the allocation of tasks to separate hands is not sufficient to provide a good indication of executive functioning. Response repetition costs were absent, but only for those trials where the whole object repeated: A change of the irrelevant dimension was sufficient to produce the costs that were noted in Experiment 2B. Therefore, the increased salience of the irrelevant feature of the stimulus appeared to promote a transition of response to the other finger of the task set when the feature altered. In this instance, the advantage of response repetition was dependent upon the replication of the entire stimulus from the previous trial. Furthermore, a switch of hand and task entailed responses that were generally slower, including the RTs for those trials where the full object repeated: The reappearance of the previous stimulus does not provide any obvious benefit if the effector and the task both alter. However, indirectly, the greatest advantage of introducing full object repetition into the design appeared to be for those trials involving a transition of task and hand, as the task switch trials

showed the greatest benefits compared to those of Experiment 2B: It is possible that full object repetition serves both to reinforce the response repetition effects and also to promote stability across all trials, as there is then greater certainty that a change of the stimulus is more likely to correspond with a change of the response. Thus, repetition of the irrelevant dimension and of the whole object both allow for greater control of S-R associations.

Nevertheless, repetition of the whole stimulus along with the previous response still produced substantially longer RTs than the same occurrence in Experiment 4, with the difference being 135ms. Therefore, while repetition of the previous S-R codes may allow the bypass of some processes, those that remain to be executed still appear to be more effortful, as they are affected by the context of the surrounding trials. It is arguable that the expectation of task switch is sufficient to slow the responses to all stimuli, even when the stimulus does not alter; so the results support the assertion from the first chapter that the anticipation of a switch affects all trials regardless of their form, with response suppression representing the likely component.

### Experiment 5B

Experiment 5B again considers S-R processes within a task switching context, but instead applies the two tasks to response subsets of equivalent fingers. Hence it is similar to Experiment 3B, but includes the full object repetition of the stimuli.

### *Method*

*Participants.* The criteria listed in Experiment 1 were again used to employ another 24 student volunteers from the University of Wales, Bangor.

*Stimuli, Design, and Procedure.* Experiment 5B employed the same stimuli, temporal parameters and response arrangements as those used in Experiment 3B, but similar to the previous two experiments, the selection from the trial-list was changed to become random with replacement. So, unlike Experiment 3B, an item was able to repeat entirely from the previous trial. The current experiment examined the influence of perceptual priming when the tasks were allocated across hands to subsets of equivalent fingers; one task being assigned to the index fingers and the other related to the middle fingers.

### *Results*

The 16 practice trials for each participant were removed from the analysis, along with the errors (6.7%) and the responses that were produced outside of the temporal window of 200 to 2000ms (6.0%). Following this procedure, a total of 12.7% of the trials had been eradicated from the analysis of the primary data. Examination of the global RTs for Experiments 4, 5A, and 5B found that Experiment 4 had significantly faster responses, ( $F(2,69)=3.67$ ,  $MSe=21801.15$ ,  $p<0.03$ ,  $\eta_p^2<0.09$ ): Bonferroni comparisons verified that the RTs of Experiment 5B were generally longer than those of Experiment 4 ( $p=0.04$ ) but not of those for Experiment 5A ( $p=1.00$ ).

Table 3c displays the descriptive results that were obtained for Experiment 5B. In this instance, the relations between stimuli and response transitions were



as follows: Repetition of the whole object and the relevant dimension occurred for finger repetition, a transition to the other finger of the same hand, and a transition to the non-equivalent finger of the opposing hand; repetition of the irrelevant dimension and a change of the whole object were associated with transitions to the equivalent finger, the non-equivalent finger, and the alternative finger of the same hand. The relations between each type of stimuli presentation and response transition are shown in Table 4c along with the accompanying statistics.

Similar to the findings of Experiments 4 and 5A, analysis of the perceptual properties of the stimuli discerned that whole object repetition was associated with faster responses than merely the repeat of the relevant dimension, ( $F(1,23)=21.84$ ,  $MSe=2589$ ,  $p<0.001$ ,  $\eta_p^2<0.48$ ). However, this effect altered according to whether the task repeated or changed: When the task switched, responses for the repetition of the whole object became approximately 100ms slower whereas the RTs for the repeat of the dimension currently relevant were relatively unaltered, ( $F(1,46)=18.83$ ,  $MSe=3865$ ,  $p<0.001$ ,  $\eta_p^2<0.29$ ). There was no significant difference between a repeat of the irrelevant dimension and a complete change of the object ( $F<2$ ) and this remained unaltered regardless of whether the task repeated or switched ( $F<2$ ). Moreover, responses for a repeat of the relevant dimension were slower than those for a repeat of the irrelevant dimension, ( $F(1,23)=6.98$ ,  $MSe=3530$ ,  $p=0.01$ ,  $\eta_p^2<0.23$ ), and this was also unchanged by a switch of task. Generally, the repetition or change of the whole object produced faster responses than an alteration of just one dimension, ( $F(1,23)=6.23$ ,  $MSe=1052$ ,  $p=0.02$ ,  $\eta_p^2<0.21$ ).

However, this effect was not significant when the task switched: For these trials alone, there was no difference for the repetition or change of the whole of the stimuli or just a part, as there was in Experiment 5A ( $F < 1$ ). Instead, for the switch trials alone, repetition of the object or the relevant dimension produced slower responses than a repeat of the irrelevant dimension or a change of the whole object, ( $F(1,23)=8.03$ ,  $MSe=3305$ ,  $p=0.009$ ,  $\eta_p^2 < 0.25$ ). This effect did not appear in Experiment 5A, although the difference between the two experiments achieved only marginal significance, ( $F(1,46)=3.76$ ,  $MSe=3556$ ,  $p=0.059$ ,  $\eta_p^2 < 0.76$ ). Unlike Experiment 5A, no significant difference was discerned between the two fingers associated with the opposing task when the whole stimulus changed, ( $F(1,23)=2.78$ ,  $MSe=5799$ ,  $p=0.109$ ,  $\eta_p^2 < 0.10$ ). Still, for the current experiment, equivalent transitions of response are only associated with a repeat of the irrelevant dimension or a change of the whole stimuli, as a repeat of the relevant dimension and of the whole object were both identified with repeating the other, previously used, finger of the subset. So, analysis of the transitions to the non-equivalent finger in isolation gives an indication of how response transitions are affected when the hand is switched. For the non-equivalent transitions of response, all forms of stimuli appearance could occur. If the non-equivalent transitions are assessed alone then the effect of costs for the repeat of the whole object or of just the relevant dimension remains significant, ( $F(1,23)=6.22$ ,  $MSe=4176$ ,  $p=0.02$ ,  $\eta_p^2 < 0.21$ ) and this effect was not present for the non-equivalent transitions of Experiment 5A ( $F < 1$ ). In this instance, the comparison of the non-equivalent transitions between the two experiments found that the difference is fully significant, ( $F(1,46)=4.15$ ,  $MSe=6061$ ,  $p=0.04$ ,

$\eta_p^2 < 0.83$ ). The comparison achieved minor significance for a transition to the other finger of the same hand, ( $F(1,23)=3.68$ ,  $MSe=8240$ ,  $p=0.06$ ,  $\eta_p^2 < 0.13$ ).

As before, a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA was used to assess the response related effects. The responses were faster when the task and equivalent finger subset repeated compared to a switch, ( $F(1,23)=15.93$ ,  $MSe=12197$ ,  $p=0.001$ ,  $\eta_p^2 < 0.40$ ), and this effect was demonstrated by 22 of the participants. A repeat of task and equivalent finger subset was 90ms faster, while the same contrast was only 43ms more rapid for Experiment 4: However, a comparison of the effects of subset switch for the two experiments found that the 47ms difference achieved only marginal significance, ( $F(1,46)=3.17$ ,  $MSe=7196$ ,  $p=0.08$ ,  $\eta_p^2 < 0.65$ ). Moreover, the effect of finger repetition was not dissimilar to the result produced for Experiment 3B ( $F < 1$ ).

The differences of switching between response subset and/or task for the three experiments of this chapter are displayed in Figure 7: The two bars to the left represent the costs of switching between response subsets of hand and equivalent finger when a meaningful cue is absent (Experiment 4); the two bars to the right show the costs obtained when participants switched between tasks associated with either subsets of hand (Experiment 5A) or equivalent finger (Experiment 5B). The graph illustrates that the cost of switching between response subsets when the task remains invariant can accommodate much of the switch cost that is obtained even when no cue is used, particularly for those experiments that employ transitions between subsets of hand.



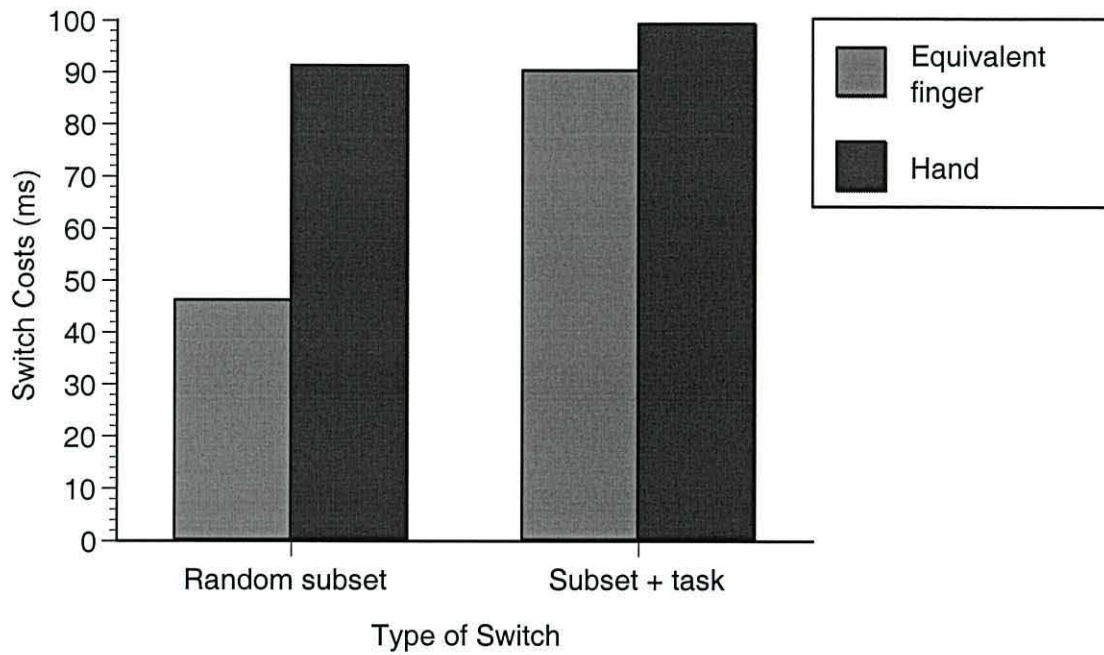
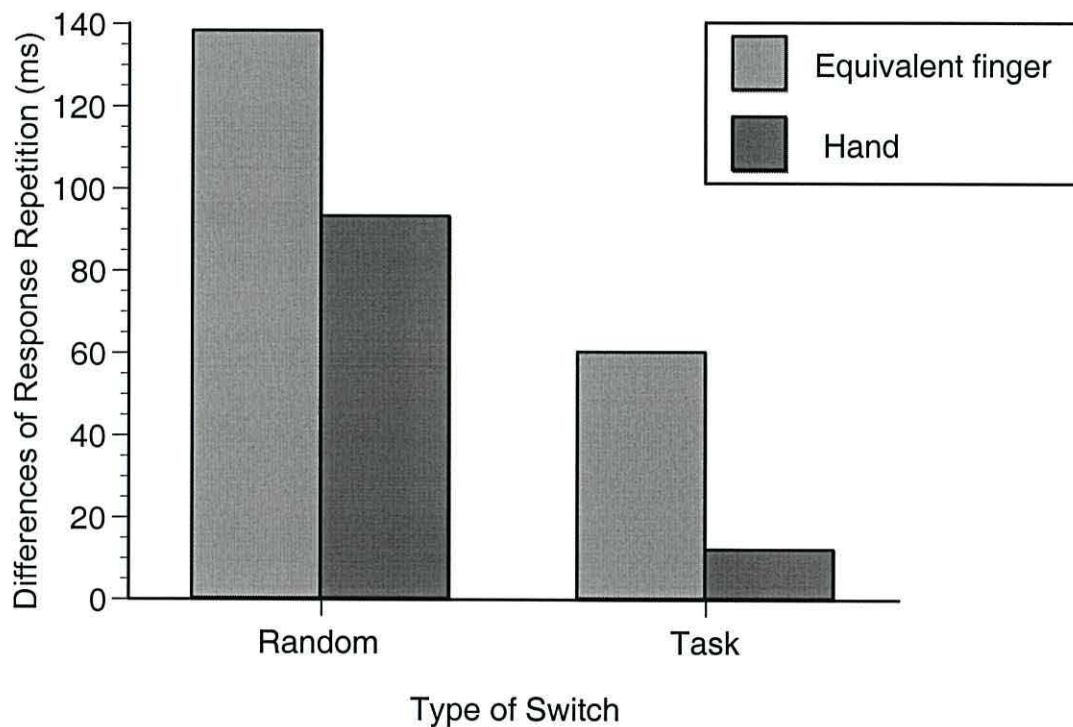


Figure 7. Switch costs between response subsets for all of the three experiments in this second chapter.

An effect of hand processing was also obtained with, in this instance, a repeat of hand being faster than a transition to the opposing hand, ( $F(1,23)=65.23$ ,  $MSe=3337$ ,  $p<0.001$ ,  $\eta_p^2<0.58$ ): The effect was demonstrated by 20 of the participants and was significantly different from that obtained in Experiment 3B, ( $F(1,46)=32.08$ ,  $MSe=3341$ ,  $p<0.001$ ,  $\eta_p^2<0.41$ ). However, closer examination found that this effect was primarily due to the benefits produced by response repetition: When the finger repeated the associated RTs were significantly shorter than those for a transition to the equivalent finger, ( $F(1,23)=6.34$ ,  $MSe=6731$ ,  $p=0.01$ ,  $\eta_p^2<0.21$ ). Conversely, when the task switched, comparison of non-equivalent transitions with those to the alternative finger of the same hand found the difference to be only of marginal significance, ( $F(1,23)=3.23$ ,  $MSe=2705$ ,  $p=0.08$ ,  $\eta_p^2<0.12$ ). Removal from the analysis of the trials containing full object

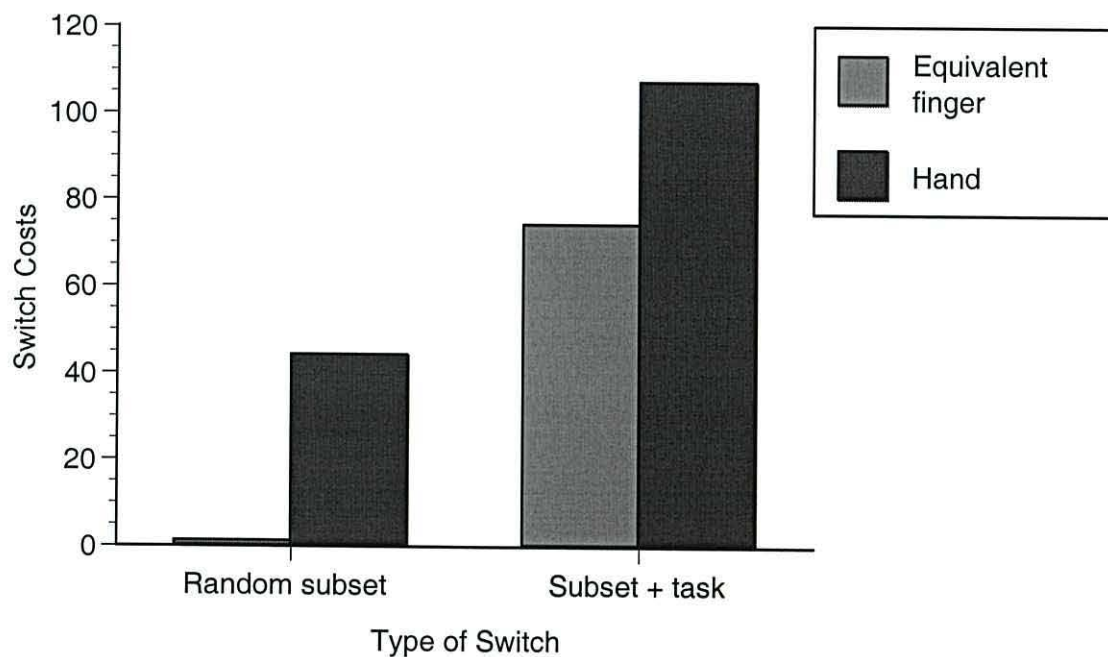
repetition found that the benefit for response repetition was lost when compared to the equivalent finger ( $F < 2$ ) and the advantage for hand repetition disappeared also, ( $F < 2$ ). Similar to Experiment 5A, the response repetition trials for full object repetition produced longer RTs than those of Experiment 4, ( $F(1,46)=12.11$ ,  $MSe=13208$ ,  $p=0.001$ ,  $\eta_p^2 < 0.20$ ). For Experiment 5B, there was no interaction between the effects of hand and finger type ( $F < 2$ ).



*Figure 8.* Effects of response repetition for hand cued and equivalent finger cued subsets with full object repetition employed.

The effects of response repetition when full object repetition is included are shown in Figure 8. The graph defines the effect of repeating a response from the previous trial in comparison to a transition towards the other finger of the active subset. The pattern of results is similar for the use of hand and equivalent

finger subsets, but as with Experiments 1 to 3B the subsets of equivalent finger show differences that are exaggerated in relation to those of hand. It is apparent that the benefits of repeating the finger are greater for the random experiment, when the task is invariant and there is no meaningful cue, particularly so for a transition to the equivalent finger. Conversely, when task switching is introduced along with the associated cues then the benefit of finger repetition appears to be substantially reduced, with the cueing of hand and task almost eliminating the advantage of response repetition entirely. However, with the trials for full object repetition included the repetition of finger does not render a cost in the manner that was evident for Experiments 2B and 3B where full object repetition was excluded from the design.



*Figure 9.* Switch costs of Experiments 4, 5A, and 5B excluding the effect of finger repetition.



In order to consider the possible contamination of task switch estimates, the differences of task switch were again assessed with the response repetition trials removed. The graph of Figure 9 was calculated by subtracting the alternative finger of the current subset with the non-equivalent finger of the opposing hand. It is evident that the removal of the response repetition effect reduces the differences of switch obtained for the random condition of Experiment 4, but that the costs of task switch for Experiments 5A and 5B remain similar to their previous state.

The graph of Figure 10 illustrates figures for repetition and change of the irrelevant dimension for each of the three experiments in this second chapter. For the experiments incorporating task switching, only trials involving task repetition were used in the calculation. The object repetition of the repeated response was subtracted from the mean obtained for the presentation of the irrelevant dimension associated with the alternative finger of the current response set: The difference obtained from this procedure was used to represent the effect of irrelevant repetition and the associated motor transition for those trials when the task repeats. Thus, for Experiment 4 the figure 527ms was subtracted from 646ms, thereby ascertaining that the advantage of irrelevant repetition was 119ms. Alternatively, subtracting the mean of the relevant dimension from the mean for the whole object change that was associated with the other finger of the response set gives a figure for irrelevant change, as it indicates the relative benefit or cost of repeating the finger when the critical condition is affected by the mismatch of the irrelevant property. For Experiment 4, this was obtained by removing the 572ms from 665ms to leave a total 93ms. The means used for the calculations of all three experiments are detailed in Table 4.

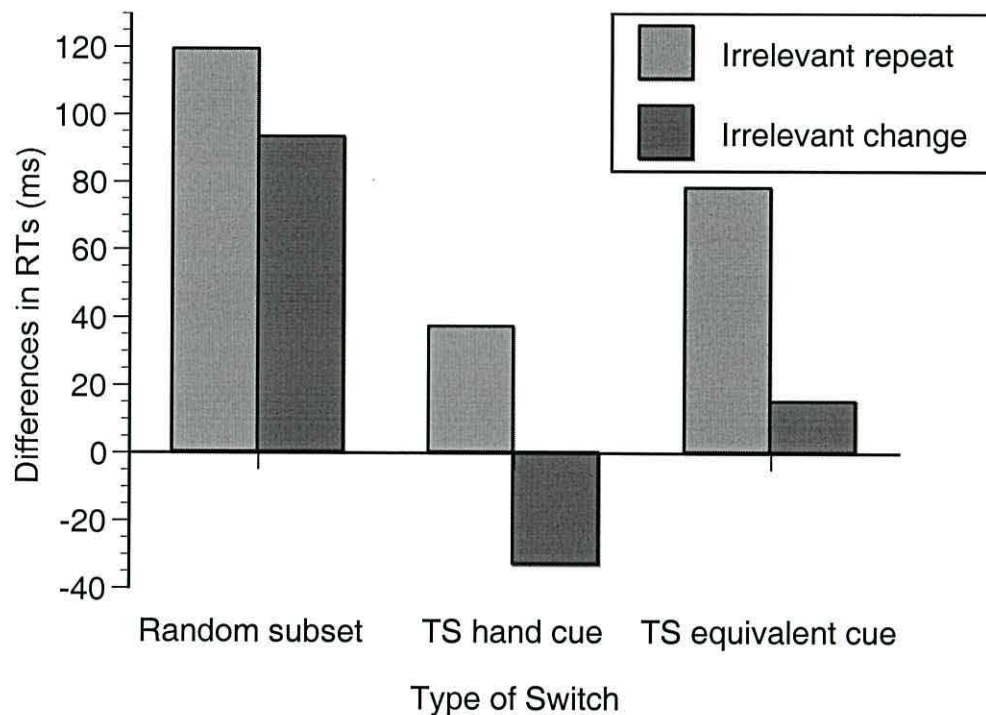


Figure 10. Evaluation of S-R repetition effects when the irrelevant dimension repeats or changes for Experiments 4, 5A, and 5B.

The graph of Figure 10 indicates that the effects of both the repetition and change of the irrelevant dimension are most substantial for the single task design of Experiment 4, whereas these conditions are most reduced for the task switch design of Experiment 5A, when the tasks are mapped to separate hands. When task switching is introduced repetition of the irrelevant feature does not create costs but, generally, the benefits are much diminished. Therefore, this demonstrates that, in a task switching context, the irrelevant dimension is still salient and influencing responding even when the irrelevant feature was shown on the previous trial and the dimension that is currently relevant presents a new feature: Participants are less able to focus upon the relevant target even when it is repeated along with the task. For Experiments 4 and 5A the difference for

irrelevant repetition is 82ms while that for irrelevant change is 126ms. The details of Experiment 5B also demonstrate a reduction of both irrelevant repetition and irrelevant change, but not as much as that obtained for Experiment 5A when the tasks were grouped according to hand. However, the effects tend in the same direction as those for Experiment 5A, with 41ms of difference between Experiments 4 and 5B for irrelevant repetition and 78ms difference for irrelevant change.

The error percentages of Experiment 5B were analysed in a similar fashion to the analysis of the primary data. A 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA found no difference in the number of errors associated with hand processing ( $F < 2$ ). However, analysis of finger type discerned a benefit of repetition, with a transition of finger type being allied to a switch of task, ( $F(1,23)=10.19$ ,  $MSe=0.77$ ,  $p=0.004$ ,  $\eta_p^2 < 0.30$ ). There was no interaction between hand and finger type ( $F < 2$ ). Analysis of the stimuli found no significant difference between repetition of the whole object and of the relevant dimension only ( $F < 1$ ). Moreover, there was no significant difference between a repeat of the irrelevant dimension and a change of the whole object ( $F < 1$ ). However, comparison of these two groups (whole object repetition and relevant repetition vs whole object change and irrelevant repetition) found a difference, with a change of the relevant dimension being associated with more errors, ( $F(1,23)=10.68$ ,  $MSe=0.37$ ,  $p=0.003$ ,  $\eta_p^2 < 0.31$ ).



### General discussion

The experiments of this second chapter assessed the influence of stimuli presentation upon the pattern of response preferences discerned in the first chapter. In all three experiments the presentation of the entire stimulus that had appeared on the previous trial was able to elicit the fastest responses, but only in those circumstances where it was paired with a repeat of the response. For Experiment 5B it was particularly noticeable that whole object repetition created substantial costs if the task and response were changed. This finding supports the contention by Horner and Henson (2008) that repetition of an event file allows some mechanisms to be bypassed: Nevertheless, the results of Experiment 5B support the claim derived from those of the previous experiment, whereby the increased length of the RTs for full object repetition suggests that these trials are also affected by the task switching context. So, the procedure associated with event file repetition does not appear to be purely automatic, although it may rely upon some automatic processes.

The single task experiment encouraged benefits of response repetition when the relevant dimension repeated, but greater influence of the irrelevant dimension was evident when participants were required to respond to multiple dimensions. In this instance, when the irrelevant dimension changed then the dominant event file was disrupted and participants expected a transition to another effector or hand. Experiment 5B again supported the findings of the previous experiment by finding that a repeat of the relevant dimension alone (with a change of the irrelevant dimension) rendered the longest RTs. Therefore, in the context of task switching, the irrelevant dimension does become more salient. During

task switching experiments, the repeat of what becomes the relevant dimension promotes longer RTs for response repetition both when the task repeats and when it changes: For task repetition trials, a change of the irrelevant dimension promotes a change to another effector, whereas when the task changes the repeat of the relevant dimension, which was irrelevant before, is disrupted by changes of both the task and the feature for the dimension that was previously established. Thus, for those task switching experiments that use a double mapping of stimuli to two responses (Rogers & Monsell, 1995; Meiran, 2000a) it is possible that the advantage of response repetition during task repetition trials may derive from the appearance of full object repetition, as it is only with the repetition of both task and response that the repeat of the object can produce a benefit. Therefore, the proposal by Meiran (2000a) that the cost of response repetition for switch trials derives from suppression of the alternative code is plausible, as the current experiments have noted that the dimension becoming relevant tends to be associated with greater costs. However, in most research articles regarding task switching, it is not often stated whether full object repetition has been used: Consequently, the influence of perceptual processing can be difficult to ascertain. The issue of double mapping of stimuli to responses will be examined further in Chapter 3.

The preference for a response transition when an element of the stimulus alters appears to be adaptive, as the system becomes flexible in order to accommodate the changes that are anticipated. These findings demonstrate that the balance of facilitation and inhibition of response set mechanisms can influence the overall responses in task switching experiments. Nevertheless, it should be clear that the reference to adaptation specifies context-dependent alterations of the

S-R process in order to produce the most advantageous result. It does not mean to say that the participants are actively aware of inhibiting their previous response during each trial: In this instance, the cost of response repetition related to the repeat of the relevant dimension during the task switching experiments of the first chapter derives from processes associated with the manipulation of S-R codes and so represents a consequence of the task set that had been adopted. However, the response processes described here are probably automated to some extent as they represent the operation of lower-level mechanisms (Adam, Hommel, & Umiltà, 2005). In essence, the body can demonstrate adaptations in the processes that are employed; adaptations which have developed through the passage of evolution, but of which the individual is unaware. The processes that have been delineated in these two chapters represent preferences of response selection, with interference being discerned when those preferences are in conflict with the goals of the current task. Therefore, interference is not an arbitrary phenomenon, but derives from perceptual and motor operations associated with the task set and is especially evident for responses when those processes must function according to S-R relations that are not intuitive.

The costs of task switch were minor compared to the random non-cued baseline experiment: Assigning a task to each hand entailed an additional cost of just 8ms. Therefore, the findings of this chapter strongly reassert the contention of the first chapter that the processing of hand is often being confounded with goal setting reconfiguration. However, the graphs of Figures 7-9 illustrate that the removal of the response repetition effect much reduces the switch costs of Experiment 4 while those of the task switching experiments remain similar to their previous state. Thus, the costs of switching hand for the baseline experiment



are bolstered by the addition of full object repetition for response repetition trials, as this effect exaggerates the benefit of hand repetition. It is worth recalling that the results of the first chapter demonstrated that the cueing of hand without task switching further encourages the grouping of hand and facilitates hand repetition trials, so that the dissimilarity in relation to a transition of hand becomes greater (Figure 4): Without the inclusion of full object repetition in the experimental design, the costs for all of the experiments of the first chapter were more robust to removal of the response repetition effects. Consequently, it is to be expected that the cueing of hand in a single task design will create costs of hand transition that are more comparable to those obtained for task switching when the response repetition trials are removed.

The benefit of response repetition in Experiment 5A returns to a cost similar to that shown by Experiment 2B when the full object repetition trials are removed. Therefore, it appears that processing at the element level is relatively speedy, especially when the hand repeats and the hand processing is easily managed by congruency with the task allocation. Nevertheless, the results show that processing at the element level of S-R codes also has an affect upon hand processing: For Experiment 3B of the first chapter, the change of the irrelevant dimension encouraged both a change of finger and of hand. That response inhibition is applied to all of the fingers of the responding hand, regardless of their task associations, as well as to the specific finger that was used indicates that change of the irrelevant dimension alone is unlikely to provide a fully sufficient explanation without accounting for motor processes. However, it is the processing of the specific element level associations that seems to determine the manner of hand processing, as hand selection precedes and augments that of the

responding finger. Overall, processes associated with dimensional salience appear to operate in conjunction with those of response suppression.

For Experiment 5B, hand processing does not drop back to the negative position obtained for Experiment 3B. Instead, the effect of hand becomes neutral when trials containing full object repetitions are removed, showing neither benefits nor costs. Consequently, it is proposed that transitions between fingers of the same hand appear to be more easily accommodated within a shorter time frame, while the processing of hand is more sustained, bolstered by the response repetition benefits associated to full object repetition, so that hand activation requires a longer duration to become inhibited. This would also provide explanation of why the cost of a transition to the opposing hand is normally so much larger than a transition to another finger of the same hand. Therefore, the results for the task switching experiments of Chapter 1 demonstrate that a transition of response is more readily executed when the stimuli alter consistently for every trial and the additional facilitation caused by full object repetition is absent. These findings demonstrate how easy it is for researchers to make misattributions concerning the role of executive functioning when using the task switching paradigm, especially if the tasks are assigned to each hand, as the patterns of RTs clearly show a strong role for motor processes that has previously been overlooked. It is necessary to understand the operation of the motor processes before the influence of the task set can be considered with clarity.

The preferences for stimuli vary according to the response subsets that are used for each task. Apart from the combination of full object with response repetition, Experiment 4 shows little difference for the RTs of the forms of stimuli

presentation that occur for each type of finger transition. Experiment 5A finds an advantage during the switch of task for either the repeat or change of the whole object: A change of stimulus is related to a change of hand and a repeat of the object is associated with a repeat of the finger. The congruency between hand and task means that whole object repeat or change are more easily assigned, although whole object change shows a preference for the equivalent finger in comparison to the alternative finger of the other hand. However, for Experiment 5B, the switch to the other task is affected differently: the presentation of the dimension that is now irrelevant and the change of the whole object produce shorter RTs during a switch. These two forms of stimulus presentation are associated with a transition to the equivalent finger of the current subset: The presentation of the whole object and the relevant dimension would only associate with this transition as errors. Conversely, whole object repetition and relevant repetition are most readily identified with a repeat of the previously used effector, as the response is more isolated, contained by both the grouping of hand and the allocation of task and hindering the capacity for the effector to be easily grouped with others. So, for each trial the response executed represents the only finger of the current hand that is mapped to the dominant task. This effect of stimuli preference is most prominent for the transition to the non-equivalent finger of the opposing task set, although the effect was marginally significant for the other finger of the same hand, so the switch of task appears to be influenced by the stimuli associated with the transition of hand to the equivalent finger. Thus, the result indicates an influence of the S-R relations of the task to be switched from, as it is evident that both task allocation and response subset formation influence the processing of stimuli.



The second chapter examined the influence of perceptual processes upon the pattern of responding when full object priming was incorporated into the experimental designs. The results delineated the changing nature of S-R relations according to the current goals. However, these experiments do not separate the priming of the relevant dimension from response repetition. The subsequent and final chapter will dissociate perceptual and motor processes by providing a double mapping of stimuli to each response so that perceptual and motor factors can be isolated.

## Chapter 3

## Dissociating S-R relations: Evidence from a 2:1 mapping paradigm

The experiments of this final chapter employ the same four-finger response set, but apply two stimuli to each effector. The double mapping of stimuli should enable the dissociation of stimulus and response processes, as the response is able to repeat while the stimulus changes. Therefore, the relative contribution of perceptual and motor processes will be more evident. In task switching experiments, researchers have regularly employed a two-finger response set to which the stimuli are double mapped (Rogers & Monsell, 1995; Meiran, 2000a). In this instance, it is proposed that repetition of task creates benefits for response repetition while the switch of task leads to a preference for a response transition (Rogers & Monsell, 1995). Meiran (2000b) suggested that a response was weighted in favour of the stimulus feature to which it was previously paired: Therefore, identification with one feature reduces the association of the same response to the alternative dimension and so the RTs demonstrate an advantage for the opposing finger. However, as mentioned previously, the benefit of response repetition is dependent upon both the complete repetition of the stimulus and the task (Kleinsorge, 1999), otherwise the event file is disturbed.

The double mapping of stimuli is much less common when the response set incorporates four fingers. Dreisbach, Haider, and Kluwe (2002) employed this S-R format in order to assess the effect of probability cues upon the RTs for a task switch. The results demonstrated that the probability of a task being required facilitated preparation for that task and inhibited other tasks, regardless of whether

the task had repeated or switched from the previous trial. However, the cost associated with the activation of a task was not affected by preparation. Later Dreisbach, Goschke, and Haider (2006) again used the same S-R arrangements to determine the formation of S-R categories in relation to the switching of tasks. The large number of S-R associations enables an improved capacity for researchers to examine variations in the S-R codes according to the task. However, increasing the number of stimuli and responses will also render a greater memory load. Oberauer, Lange, and Engle (2004) utilised the dual-task paradigm whereby participants were required to conduct two tasks in sequence, but with it being necessary to retain some information from the first in memory: They found that, in this experimental arrangement, participants were unable to resist the interference from the opposing task while attempting to handle the tasks concurrently. Therefore, it is likely that greater interference will be observed for the experiments of this chapter, as compared to those considered earlier in the thesis.

Visual short term memory is involved with the binding of the features of an object in order to maintain them independently from the features of other objects: Allen, Baddeley, and Hitch (2006) discerned that the memory load of a single feature did not appear to entail greater load effects than conjunctions of features, but that the binding of conjunctions was weakened by the subsequent presentation of stimuli. Therefore, while the binding of features of an object was relatively automatic, the resulting S-R code was fragile. Nevertheless, Pösse, Waszak, and Hommel (2006) determined that event files could still be retrieved following two intervening task switches, so the memory trace of an event is strong enough to endure the alteration of task, although Wylie and Allport (2000) also



noted interference from S-R associations across more than 100 intervening trials. However, Liefoghe, Barrouillet, Vandierendonck, and Camos (2008) suggested that the introduction of a task switch hindered the maintenance of items held in short term memory, as further demands were produced by changing the task set: The increased attention necessary to instigate the new task weakened the current S-R memory codes. Therefore, it was considered that a larger stimulus set may be more difficult to maintain in working memory, although the authors propose that this effect is not specific to the switch of task, but represents more general costs associated with attentional demands. Thus, it was found that the load of working memory, defined by the number of items to be retained, did not serve to extend the global switch cost that was obtained, implying that task repetition trials were also influenced by the increased instability of S-R relations.

### Experiment 6

The final series of three experiments examined the processing associated with a four-finger response set when each response key has a double mapping with the stimuli. Therefore, the stimuli pool is larger than that used in the previous experiments, as those studies incorporated a direct one to one mapping between each stimulus and a response key. In this instance, examination of the processes associated to S-R translation will enable a greater understanding of those two-finger tasks with a double mapping that are commonly used within the task switching paradigm (Rogers & Monsell, 1995; Meiran, 2000a). It is intended that the final series of experiments will dissociate the relative contribution of the repetitions for the relevant stimulus feature and the response when the task repeats. The roles for the repetition of stimulus and response could not be

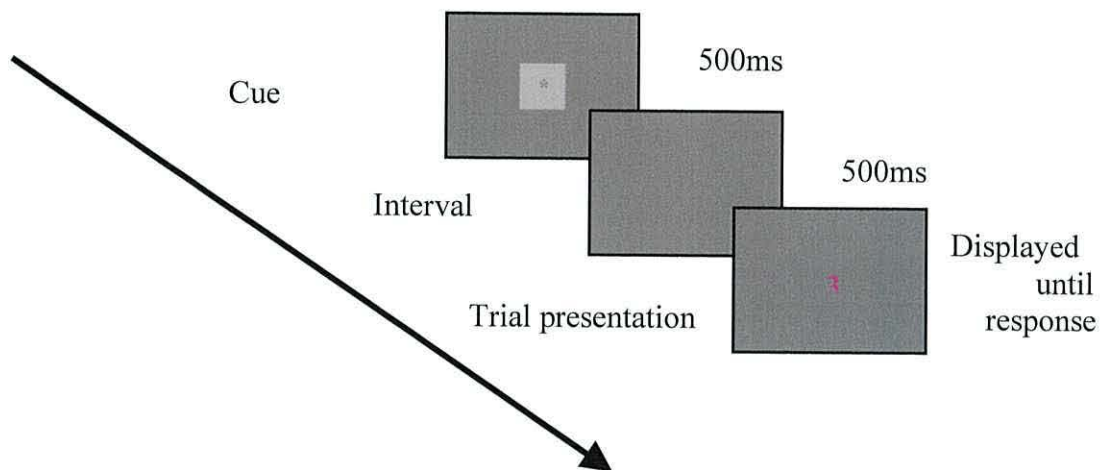
dissociated for the previous experiments due to the single mapping that was employed.

### *Method*

*Participants.* The experiment employed 24 undergraduate students from the University of Wales, Bangor according to the criteria stated for the previous experiments.

*Stimuli, Design, and Procedure.* Experiment 6 applied the same temporal parameters of the previous experiments and used the same response set (C, V, B, N) for participants to respond to the appearance of a centrally presented digit. The order and timing of presentation is displayed in Figure 11. The response to cue interval was again 400ms. However, the stimuli pools were created anew, as the current task required a double mapping of stimuli to each of the four response keys. Thus, two versions of the task were created, one involving responses to colour and the other entailing responses to number. Each dimension was composed of 8 stimuli: The numbers ran from 1 to 8 while the colours were black, red, yellow green, cyan, blue, magenta, and white. A coloured number was presented for each trial, so that both dimensions were always presented despite only one being relevant. The Arial font was used for each of the number stimuli with a font size of 36. Each coloured number measured approximately 10mm wide and 15mm high, with a visual angle of  $0.95^\circ$  horizontally and  $1.43^\circ$  vertically. Accounting for all combinations of colour and number entailed a total of 64 stimuli, with a pool of 32 allocated to each hand. The mapping of the stimuli attributes to the responses were in a fixed order, so that the numbers always ran from 1 to 8 starting from the left side, with 1 and 2 attributed to the left

middle finger, 3 and 4 to the left index, 5 and 6 to the right index, and 7 and 8 given to the right middle. The colours were ordered from black to white, with black and red allied to the left middle, yellow and green to the left index, cyan and blue to the right index, and magenta and white to the right middle. The pool of colours was balanced according to the relative composition of each, the primary constituents in PowerPoint being red, green, and blue. The composition of the colours is illustrated in Figure 12.



*Figure 11.* Presentation of stimulus and interval durations for studies of switching within the response set.

The written instructions for the experiment, as well as the inter-block and post-experiment displays, were all presented on a white background. The initial instructions presented on the computer screen also included a diagram depicting the relevant stimuli and the associations with the response keys. Including the diagram, the instructions constituted a total of three pages of information, all of which are displayed in Appendix II. However, the trials for the experiment were presented entirely on a grey screen, including the cue to stimulus interval and the response to cue interval. The shade of grey was composed in order to reside half



way between black and white. Consequently, neither tone was favoured according to contrast.

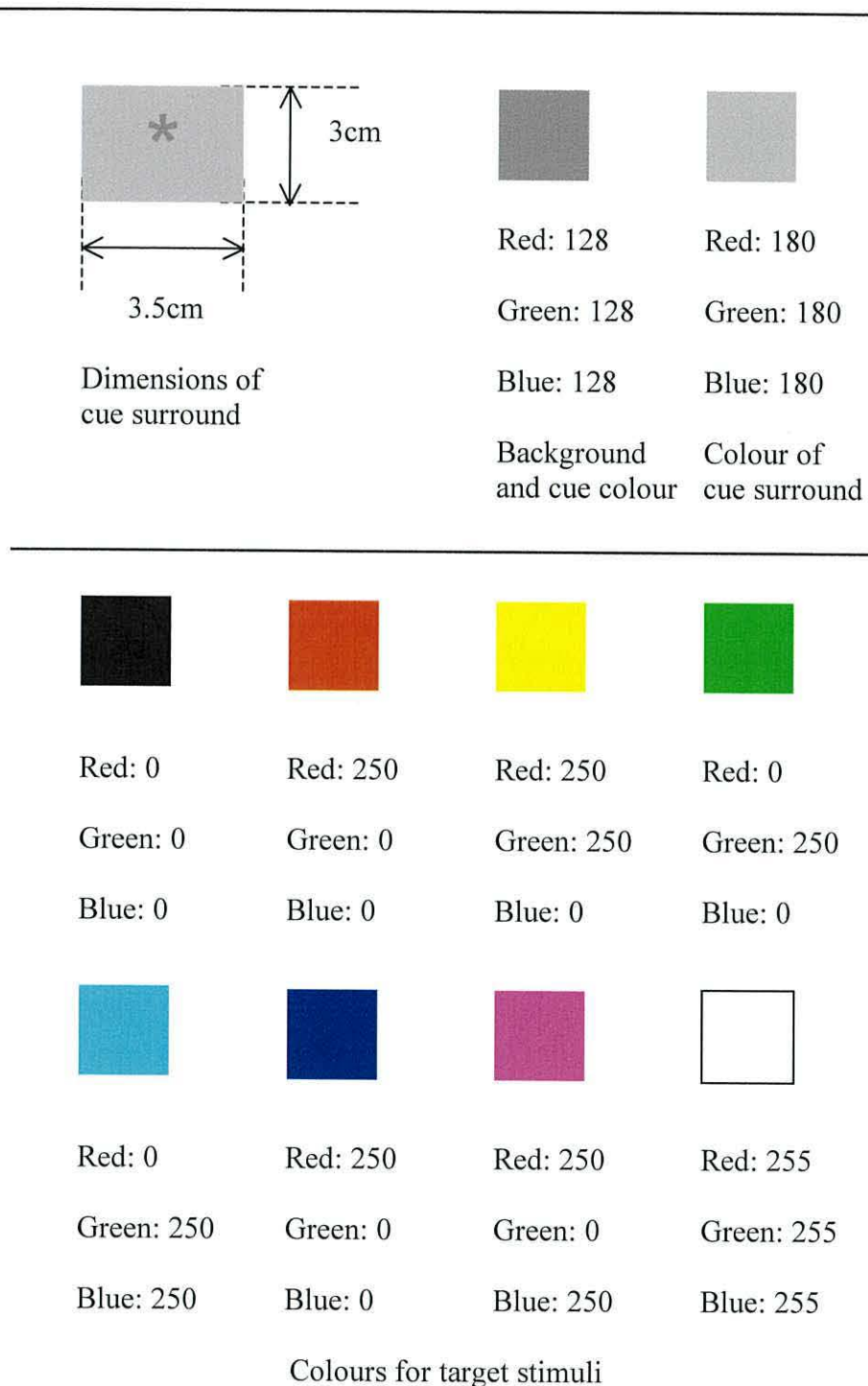


Figure 12. Composition of colour stimuli, background, and cues.

Each trial was preceded by an asterisk cue, the dimensions and visual angle of which matched that used in experiment 1 (6mm by 6mm, with a visual angle of  $0.57^\circ$ ). However, the cue was the same shade of grey as the background so that the item of fixation would also be balanced according to its relation to the target stimuli: Instead, the cue was illuminated by a small square surround, which was grey, but of a lighter shade than that used for the background and the cue. The two shades of grey are also shown in Figure 12 along with a depiction of the cue. The grey rectangle was 35mm wide by 30mm high, and had a visual angle of  $3.3^\circ$  horizontally and  $2.8^\circ$  vertically when viewed from 60cm distance. Like those for the previous experiments, all stimuli and diagrams were bitmap files produced in PowerPoint.

Every participant sat both versions of the task. The sequencing of the two versions was alternated between participants in order to eliminate order effects. Each version was comprised of two blocks of trials, and each block contained 64 cycles of four trials, with two trials of each cycle being allocated to each hand. This allowed each target stimulus to appear four times within each block. In total, each block consisted of 256 trials (128 trials for each hand), totalling 512 for the pair. The blocks were preceded by 4 cycles of 4 trials so that the participants could practice the task, leading to 16 in all. Therefore each version of the task was comprised of 528 trials. Like Experiment 1, the Block-list cycle constituted two responses of the left hand and two of the right, with selection being random within each cycle. The Trial-list selection was random without replacement. By utilising a 2:1 mapping, it was intended that the experiment would dissociate the processing of the relevant and irrelevant dimensions, so in this instance full object repetition was not considered to be essential to the design. Overall, the duration

for each version of the task was approximately 21 minutes if the average response was 1000ms.

Analysis of the response related processes relied upon the same 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA that had been employed for the previous experiments. The identical analysis of responses was reapplied in this chapter so as to provide close comparison with the previous experiments and ascertain whether the increased memory load had an impact on the interference across tasks, which would reflect in the salience of the irrelevant dimension. However, to test for perceptual priming from the irrelevant dimension, the data were analysed using a 2 (Irrelevant Feature Change, Irrelevant Feature Repeat) x 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures factorial ANOVA. This allowed for an examination of hand and finger repetition effects in relation to changes in the dimension to be ignored (whether the irrelevant dimension was relevant on the previous trial or if it had remained irrelevant from before).

More importantly for the purposes of this chapter, it is also possible to test the perceptual priming associated with the property that is relevant to the task. This property is determined by its relationship to the S-R binding of the previous trial. To do so, the conditions in which the relevant property repeated (and therefore the response repeated as well) could be compared with instances where the response was repeated but all of the perceptual properties changed. This comparison was performed with a t-test. The results from this experiment



represent the baseline for the following two experiments (Experiment 7A and Experiment 7B).

### *Results*

Like every experiment in this thesis, the first 16 trials were removed from the data obtained from each participant in order to exclude those assigned for practice. Responses that were faster than 200ms or slower than 2000ms were removed (2.1% of the trials) as well as those responses conducted in error (4.9% of the trials). As a result, 7% of the original data were omitted from the analysis.

The global statistics for response transitions and stimuli presentation for Experiment 6 are displayed in Table 5a. The table displays both the data representing the transitions of response and those for the alterations of the stimuli, along with the statistics for the following two experiments of this chapter. A 2 (Hand Switch, Hand Repeat)  $\times$  2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA was used to assess the mean RTs of the motor effects. Concurring with the results from all of the experiments in this dissertation, it was noted that there was a significant 56ms of costs for making a transition of response to the opposing hand ( $F(1,23)=80.34$ ,  $MSe=952$ ,  $p<0.001$ ,  $\eta_p^2=0.77$ ). The size of the cost for hand transition was significantly smaller than that obtained for Experiment 1, which also excluded full object repetition but used only a single mapping of stimuli to the response set, ( $F(1,46)=9.04$ ,  $MSe=2026$ ,  $p=0.004$ ,  $\eta_p^2=0.16$ ). The results also presented a highly consistent 66ms of benefit for repeating the equivalent type of finger ( $F(1,23)=96.47$ ,  $MSe=1069$ ,  $p<0.001$ ,  $\eta_p^2=0.80$ ). Repetition of the previous finger produced an overall advantage of 104ms in relation to the other finger of the same hand,

( $F(1,23)=91.62$ ,  $MSe=1430$ ,  $p<0.001$ ,  $\eta_p^2=0.79$ ) and this benefit was demonstrated by all 24 of the participants.

As mentioned earlier, to examine the influence of the irrelevant dimension upon the response transitions, the resulting mean RTs per participant and per condition were analyzed with a 2 (Switch of Irrelevant Dimension of Stimuli, Repeat of Irrelevant Dimension of Stimuli)  $\times$  2 (Hand Switch, Hand Repeat)  $\times$  2 (Finger Switch, Finger Repeat) repeated measures ANOVA. Importantly, a repetition of the irrelevant feature from the previous object produced neither benefits nor costs in the overall RTs ( $F<2$ ) and, furthermore, this repetition did not interact with any of the other transition effects.

Table 5. *Global results for stimuli presentation and transitions of response for the random (Exp 6), hand cued (Exp 7A), and hand + task cued experiments (Exp 7B). The results were obtained with a double mapping of stimuli to the four finger response set.*

Finger type	<u>Response Hand/Set</u>				<u>Perceptual Dimensions</u>			Hand/Set	Finger type
	Repeat		Switch		Relevant	Irrelevant	Whole Stimulus	switch cost	switch cost
	Repeat	Switch	Repeat	Switch	Repeat	Repeat	Change	(Switch – Repeat)	(Switch – Repeat)
a) Experiment 6. Random									
Mean RT	663	767	758	785	577	764	768		
SE	14.98	21.27	21.45	21.02	11.62	21.56	20.49	56	66
%Error	2.13	3.74	3.75	4.41	0.36	1.69	11.98		
b) Experiment 7A. Predictable hand switch									
Mean RT	629	706	741	756	559	727	728		
SE	17.78	22.20	22.23	23.47	16.66	21.92	21.95	81	46
%Error	2.53	4.19	3.70	4.63	0.47	1.72	12.85		
c) Experiment 7B. Hand and Task switch									
Mean RT	808	821	872	876	845	819	853		
SE	37.75	41.19	35.36	32.65	34.73	33.52	36.87	60	9
%Error	4.42	6.10	4.32	5.72	2.18	5.59	12.04		



When analysing the priming from the relevant property, the results showed quite a different scenario. A t-test discerned that there was 179ms of highly robust benefit when participants responded to the same perceptual property twice in succession, ( $F(1,23)=177.42$ ,  $MSe=2164$ ,  $p<0.001$ ,  $\eta_p^2=0.89$ ) when compared to responses with the same finger conducted toward a complete change of the object (Finger Repeat, Relevant Repeat vs Finger Repeat, Relevant Switch). Indeed, 100% of the participants showed this effect, and only three of them had a benefit of less than 100ms. Repetition of the relevant dimension with the response was also significant when compared to the whole stimulus change associated with the other finger of the response set, ( $F(1,23)=228.23$ ,  $MSe=2061$ ,  $p<0.001$ ,  $\eta_p^2=0.90$ ), a comparison equivalent to those of the experiments of the previous chapter.

The impact of the alterations of the stimuli upon the response transitions can be observed in Table 6a. The table details the means, standard error, and percentage of errors for each type of finger transition according to the repetition or change of the stimuli properties. Analogous to the tables of Chapter 2, the data contained in Table 6 may be slightly dissimilar to that of Table 5: Again, to avoid confusion some trials have been excluded from Table 6 where the post-error trials have resulted in a combination of stimulus presentation and response transition that was not accommodated by the experimental design.

Table 6. *The effect of stimuli dimension upon the transitions of response for the random (Exp 6), hand cued (Exp 7A), and hand + task cued experiments (Exp 7B). The results derived from a double mapping of stimuli to the four finger response set.*

Response Hand		Repeat				Switch						
Finger type		Repeat			Switch		Repeat			Switch		
Dimension repeat	Relevant	Irrelevant	Change	Irrelevant	Change	Relevant	Irrelevant	Change	Relevant	Irrelevant	Change	
a) Experiment 6. Random												
Mean RT	568	732	747	772	766	N/A	759	758	N/A	773	786	
SE	12.13	21.86	19.80	24.81	21.10		21.90	21.56		23.73	20.86	
%Error	0.03	0.15	0.80	0.15	1.16		0.18	1.04		0.19	1.25	
b) Experiment 7A. Predictable hand switch												
Mean RT	548	678	697	726	703	N/A	730	743	N/A	751	756	
SE	16.39	22.71	20.27	24.43	22.31		22.08	22.92		26.15	23.31	
%Error	0.02	0.22	0.74	0.12	1.37		0.16	1.20		0.19	1.53	
c) Experiment 7B. Hand and Task switch												
Mean RT	780	778	842	803	825	874	866	874	927	843	884	
SE	43.52	36.19	40.42	39.80	42.97	38.37	34.22	37.39	39.47	33.27	32.99	
%Error	0.13	1.02	0.97	0.66	1.8	0.21	0.26	1.12	0.34	0.69	1.36	

The errors were assessed using the same process of a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA for the response transitions with a 2 (Irrelevant perceptual priming) x 2 (Hand repetition) x 2 (Finger repetition) repeated measures factorial ANOVA to assess changes of the irrelevant dimension. It was noted that there was an effect of hand, with a switch of hand rendering more errors ( $F(1,23)=20.20$ ,  $MSe=0.39$ ,  $p<0.001$ ,  $\eta_p^2=0.46$ ). An effect of finger type was also present; a repeat of finger type produced less errors than a transition to the opposing type, ( $F(1,23)=21.10$ ,  $MSe=0.36$ ,  $p<0.001$ ,  $\eta_p^2=0.47$ ). An interaction was evident between hand and finger type, ( $F(1,23)=13.14$ ,  $MSe=0.10$ ,  $p=0.001$ ,  $\eta_p^2=0.36$ ), as less errors were produced when both the hand and finger repeated compared to the other finger of the same hand, ( $F(1,23)=30.63$ ,  $MSe=0.25$ ,  $p<0.001$ ,  $\eta_p^2=0.57$ ).

The percentages of errors for the irrelevant dimension were analysed with a 2 (Switch of Irrelevant Dimension of Stimuli, Repeat of Irrelevant Dimension of Stimuli) x 2 (Hand Switch, Hand Repeat) x 2 (Finger Switch, Finger Repeat) repeated measures ANOVA, the same form of ANOVA analysis that was used to assess the primary data. The effect of hand interacted with the effect of the irrelevant stimulus, ( $F(1,23)=5.38$ ,  $MSe=0.44$ ,  $p<0.03$ ,  $\eta_p^2=0.19$ ), as a change of hand produced more errors if the irrelevant dimension also altered. Moreover, the effect of finger type also interacted with the effect produced by the irrelevant stimulus, ( $F(1,23)=18.27$ ,  $MSe=0.36$ ,  $p<0.001$ ,  $\eta_p^2=0.44$ ): Again, more errors were produced if the finger type altered along with the irrelevant dimension than if the finger type repeated and the irrelevant dimension changed alone. An interaction was also evident between hand and finger, ( $F(1,23)=4.65$ ,  $MSe=0.26$ ,  $p<0.04$ ,  $\eta_p^2=0.16$ ). A repeat of the finger type rendered fewer errors if the hand



also repeated. However, the global interaction between the three factors achieved only marginal significance, ( $F(1,23)=3.76$ ,  $MSe=0.39$ ,  $p<0.06$ ,  $\eta_p^2=0.14$ ).

Overall, this suggests that responding was speeded by repetition of the irrelevant dimension, but that repetition of hand and finger type also reduced errors. The differences between the errors associated with each transition were more obvious when the irrelevant dimension changed; it may be that repetition of the irrelevant dimension reduces errors to the point where a floor effect is apparent.

Finally, it was discerned that there was a benefit for a repetition of the irrelevant dimension of the percept, as more errors were committed when the property altered, ( $F(1,23)=61.66$ ,  $MSe=2.52$ ,  $p<0.001$ ,  $\eta_p^2=0.72$ ). However, the repetition of the relevant dimension was associated with the least errors in comparison to a repeat of the irrelevant dimension, ( $F(1,23)=68.45$ ,  $MSe=0.07$ ,  $p<0.001$ ,  $\eta_p^2=0.74$ ). Furthermore, a repeat of the irrelevant dimension produced far less errors in comparison to a change of the whole stimulus, ( $F(1,23)=79.15$ ,  $MSe=4.01$ ,  $p=0.001$ ,  $\eta_p^2=0.77$ ). Still, it should be remembered that repetition of the relevant dimension is also associated with response repetition while the other perceptual conditions are mostly associated with response transitions to other fingers.

### *Discussion*

Similar to Experiment 4, without the requirement of switching task the irrelevant dimension did not demonstrate a benefit in relation to a complete change of the object. Therefore, despite the increased pool of stimuli, the RTs suggest that the information from the irrelevant dimension was not used by participants to aid responding: The irrelevant dimension was not salient and so

was not attended. However, consideration of the error rates showed that fewer errors were produced if the irrelevant dimension was repeated from the previous trial, an effect that was also noted in Experiment 4. Again, it appeared that a change of the relevant feature for responding was more stable if the irrelevant dimension remained unaltered.

The results demonstrate a large advantage for the combined repetition of the response and the relevant dimension. This effect was not evident if the response was repeated but the relevant dimension altered. Once more, the advantage of hand repetition was evident, thereby reasserting that the hands are used to group the fingers together even if the grouping is not promoted by a cue. Repetition of the equivalent finger subset also demonstrated an advantage, suggesting that the parallel processing of symmetrical fingers specified by Thon and Bonneville (1996) produces some benefit when the S-R mappings are complex. However, the benefit of hand repetition was substantially smaller than that obtained in Experiment 1, which used single mappings of stimuli to the response set. In combination, these two effects suggest that the double-mapping of stimuli features to each response leads to indecision for trials where the major S-R elements of the previous trial do not repeat: The reduction of the hand repetition benefit indicates difficulty in attributing each stimuli feature to the appropriate response, with the grouping of hand providing less assistance, as the location of the effectors is dissociated from the stimuli by the double mapping. Therefore, the findings support the assertion that the inhibition and facilitation of hand is generally less evident when a double mapping of stimuli is employed. Only the repetition of the relevant dimension enables a relatively rapid response by association with the finger that was previously used.

It could be argued that the number of options produced by the double mapping of stimuli may be primarily responsible for the effects obtained, rather than the double mapping directly. However, it is apparent from the research detailed in this thesis, as well as the findings of others such as those concerning event files (Hommel, 1998b; 2004), that specific S-R relations are important to the execution of a response. The binding and manipulation of different S-R codes is dependent upon recent experience; the effects are not simply due to the quantity of stimuli and responses. However, it is likely that the increased number of S-R options will intensify difficulties of determining the correct S-R combination during response selection when a double mapping is applied.

### Experiment 7A

Experiment 7A was similar to Experiment 6, but instead cued each hand before the target appeared. Like Experiment 2A, the letter “A” was used to identify the left hand and the letter “B” was used to signal the use of the right. These letters replaced the asterisk cue that was used in Experiment 6. In this instance, it was intended that the cueing of hand would allow for an examination of advanced selection processes when the experiment incorporates a double mapping of stimuli to the four-finger response set. This experiment does not incorporate task switching, so will demonstrate the impact of cueing a subset of the responses when the task is invariant.

### *Method*

*Participants.* The criteria listed in Experiment 1 were again used to employ another 24 student volunteers from the University of Wales, Bangor.



*Stimuli, Design, and Procedure.* Experiment 7A used the same stimuli, apparatus, and temporal parameters of Experiment 6, except that the asterisk cue was replaced by a letter A or B. The letters were centrally positioned at fixation and shared the same grey shade as the background. The letters appeared within an identical grey surround to that employed for the asterisk in the last experiment. The letter “A” signalled the coming use of the left hand and the letter “B” indicated the use of the right. The transitions between hands were systematic, with two responses of the left hand followed by two of the right. Therefore, the order of cueing was a recurring sequence that allowed for a repeat of a hand subset before a transition to the opposing hand. The letters were presented in the same font and point size as Experiment 2A (8mm by 8mm, with a visual angle of  $0.76^\circ$ ). Two versions of the task were used, one requiring responses to numbers and the other to colours, although the same stimuli were used for both. Participants sat for both versions of the task. The instructions were similar to those of Experiment 6, but the first page was altered to accommodate mention of the letter cues (Appendix II).

### *Results*

The practice trials were removed, as well as those responses that were faster than 200ms and slower than 2000ms (1.7%) and the responses that were incorrect (5.7%). Excluding those allocated for practice, overall 7.5% of the trials were removed before the analysis.

The descriptive statistics for Experiment 7A are presented in Table 5b. Like Experiment 6, the initial analysis of the response processes was conducted using a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type

Repeat) repeated measures ANOVA for the mean RTs per participant and per condition. The response related processes that were discerned in Experiment 6 remained and were even magnified: A large effect of hand was noticed ( $F(1,23)=136.70$ ,  $MSe=1150$ ,  $p<0.001$ ,  $\eta_p^2=0.85$ ), with a repeat of hand leading to responses that were 81ms faster than a transition to the opposing hand, an effect that was significantly larger than that of Experiment 6, ( $F(1,46)=6.84$ ,  $MSe=525$ ,  $p=0.01$ ,  $\eta_p^2=0.12$ ). However, this was significantly smaller than the benefit of hand repetition discerned in Experiment 2A, which excluded full object repetition but used only a single mapping between each stimulus and response, ( $F(1,46)=10.43$ ,  $MSe=2690$ ,  $p<0.002$ ,  $\eta_p^2=0.18$ ). An effect of finger type was also present ( $F(1,23)=76.11$ ,  $MSe=662$ ,  $p<0.001$ ,  $\eta_p^2=0.76$ ), as a repeat of finger type was 46ms speedier than a transition, significantly more substantial than the 24ms obtained for Experiment 2A, ( $F(1,46)=5.18$ ,  $MSe=558$ ,  $p=0.02$ ,  $\eta_p^2=0.10$ ). Nevertheless, the effect of finger repetition was less prominent than that shown by the previous experiment, ( $F(1,46)=5.39$ ,  $MSe=432$ ,  $p=0.02$ ,  $\eta_p^2=0.10$ ). Thus, for both effects a transition to the opposing subset, either hand or finger type, served to increase the RTs of the participants. Like Experiment 6, a repetition of the previously used finger was faster than a transition to the alternative finger of the same hand, ( $F(1,23)=82.63$ ,  $MSe=864$ ,  $p<0.001$ ,  $\eta_p^2=0.78$ ).

The details for alterations for the relevant and irrelevant dimensions of the stimuli are shown in Table 6b. A 2 (Switch of Irrelevant Dimension of Stimuli, Repeat of Irrelevant Dimension of Stimuli) x 2 (Hand Switch, Hand Repeat) x 2 (Finger Switch, Finger Repeat) repeated measures ANOVA was used to analyse the influence of the irrelevant dimension upon the response transitions. Following the pattern observed in the previous experiment, it was discerned that changes of

the irrelevant dimension of the stimuli did not produce a significant effect ( $F < 1$ ). However, an interaction between equivalent finger type and the irrelevant dimension was noticed but achieved only minor significance, ( $F(1,23)=3.49$ ,  $MSe=2123$ ,  $p=0.07$ ,  $\eta_p^2=0.13$ ). When the irrelevant dimension repeated there was a significant difference between the responses of finger type, with the repetition being faster, ( $F(1,23)=7.28$ ,  $MSe=1936$ ,  $p=0.01$ ,  $\eta_p^2=0.24$ ). Nevertheless, a change of the irrelevant dimension reduced the difference between types of finger so that it was no longer significant ( $F(1,23)=2.98$ ,  $MSe=356$ ,  $p=0.09$ ,  $\eta_p^2=0.11$ ). All other interactions were not significant.

When the finger repeated, the priming from the relevant property again displayed a substantial advantage for a repetition of the same dimension when compared to a complete change of stimulus identity ( $F(1,23)=339.61$ ,  $MSe=783$ ,  $p < 0.001$ ,  $\eta_p^2=0.93$ ). Nevertheless, the effect was smaller than before, reduced to 149ms from the 179ms observed in Experiment 6, although the effect was still sufficiently robust for it to be demonstrated by 100% of the participants and the occurrence of the effect was not significantly different between the two experiments, ( $F < 2$ ). The benefit of repetition for response and the relevant dimension was also present for a comparison with the other finger of the hand when the whole object changed, ( $F(1,23)=177.56$ ,  $MSe=1624$ ,  $p < 0.001$ ,  $\eta_p^2=0.88$ ).

A 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA assessed the percentages of errors produced by response transitions. Generally, more errors were produced when the response transferred to the opposing hand, ( $F(1,23)=14.17$ ,  $MSe=0.27$ ,  $p=0.001$ ,  $\eta_p^2=0.38$ ).



A repeat of finger type also led to less errors being made by the participants, ( $F(1,23)=28.58$ ,  $MSe=0.35$ ,  $p<0.001$ ,  $\eta_p^2=0.55$ ). There was an interaction between hand and finger type ( $F(1,23)=4.70$ ,  $MSe=0.17$ ,  $p=0.04$ ,  $\eta_p^2=0.17$ ), primarily due to less errors being produced by response repetition in relation to the other finger of the same hand, ( $F(1,23)=24.74$ ,  $MSe=0.33$ ,  $p<0.001$ ,  $\eta_p^2=0.51$ ).

The percentages of errors associated with changes in the irrelevant dimension were analysed in the same manner as the mean scores, with a 2 (Switch of Irrelevant Dimension of Stimuli, Repeat of Irrelevant Dimension of Stimuli) x 2 (Hand Switch, Hand Repeat) x 2 (Finger Switch, Finger Repeat) repeated measures ANOVA. Changes in the irrelevant dimension led to more errors, ( $F(1,23)=85.70$ ,  $MSe=2.42$ ,  $p<0.001$ ,  $\eta_p^2=0.78$ ), although overall, repetition of the relevant dimension was associated to the production of less errors in comparison to the repetition of the irrelevant dimension, ( $F(1,23)=54.39$ ,  $MSe=0.08$ ,  $p<0.001$ ,  $\eta_p^2=0.70$ ). Nevertheless, like Experiment 6, most errors were associated with a complete change of the stimulus when compared to a repeat of the irrelevant dimension, ( $F(1,23)=113.59$ ,  $MSe=3.27$ ,  $p<0.001$ ,  $\eta_p^2=0.83$ ). There was an interaction between the irrelevant dimension and the processing of hand, ( $F(1,23)=12.74$ ,  $MSe=0.34$ ,  $p=0.002$ ,  $\eta_p^2=0.35$ ): In this instance, the transition of hand was more affected by a change in the irrelevant dimension than was a repeat of hand. An interaction was also evident between finger type and the irrelevant dimension, ( $F(1,23)=43.14$ ,  $MSe=0.30$ ,  $p<0.001$ ,  $\eta_p^2=0.65$ ): When the irrelevant dimension altered, more errors were produced if the finger type also changed than if it did not. However, while the interaction between the errors of hand and finger type was not significant ( $F<2$ ), there was a global interaction between all three of the factors, ( $F(1,23)=4.33$ ,  $MSe=0.50$ ,  $p=0.04$ ,  $\eta_p^2=0.15$ ). Both perceptual

repetition and response repetition appeared to reduce errors, although the differences between the errors produced by motor responses were more apparent when the irrelevant dimension altered. This global interaction is similar in pattern to that of Experiment 6, but the significance is greater.

### *Discussion*

Concurrent with the findings of the previous experiment, an advantage was evident when the response repeated along with relevant dimension; the benefit was lost if the primary target feature or dimension altered. The advantage of hand repetition was again evident, with the benefit produced from the repetition of hand being accentuated by the use of hand cueing in relation to Experiment 6, and the advantage of finger type repetition becoming comparatively reduced. Therefore, the cueing of hand served to promote hand grouping and partially restricted processes associated to the equivalent fingers. However, further comparison with the single mapping experiments of the first chapter suggest that grouping of hand is generally hindered when a double mapping of stimuli is employed. It is curious that, while the benefit of hand repetition declined in relation to the single mapping of Experiment 2A, the overall advantage of equivalent finger repetition increased. This pattern was also evident for the previous experiment in relation to Experiment 1. Conceivably, as the employment of S-R codes becomes more effortful, then the relation of equivalent fingers is accentuated due to the parallel processing of this response arrangement (Pashler & Baylis, 1991). Furthermore, it is possible that inhibition and facilitation for subsets of hand and equivalent finger operate antagonistically, with the relations of equivalent fingers becoming stronger as hand grouping is

weakened. Adam, Hommel, and Umiltà (2003) varied the cue to stimulus interval with a response arrangement that positioned the hands at either end of the keyboard: In this instance, it was discerned that a long cue to stimulus interval of three seconds rendered an advantage of equivalent finger cues while shorter intervals favoured the cueing of hand. However, the increased benefit of finger type repetition for the current experiments cannot be attributed to exogenous factors, as this subset arrangement is not cued or promoted by the spatial location of the stimuli. Therefore, the effect appears to reflect the operation of mechanisms associated to response selection and execution and so is likely to be identified with the parallel processing of equivalent fingers specified by Thon and Bonneville (1996).

Generally, it was noted that repetition of the irrelevant dimension did not produce any advantage over the change of the whole stimulus. However, in this instance repetition of the equivalent finger subset demonstrated an advantage if the irrelevant dimension also repeated. Moreover, it was again evident from consideration of the error rates that repetition of the irrelevant feature from the previous trial promoted stability: Fewer errors were produced if the irrelevant dimension was consistent, with a change of the irrelevant feature creating most difficulty during a transition of response. Subset transitions of hand and equivalent finger both demonstrated increased errors, thereby indicating the advantage produced by the processes associated to these finger relations.

### Experiment 7B

This experiment introduced task switching into the design of the previous experiment. Therefore, it allowed for an examination of task switching effects in



relation to the patterns of hand processing that were noted previously. This experiment concludes the final series of three assessing S-R configuration processes with a double mapping and a four-finger response set.

### *Method*

*Participants.* The experiment employed another 24 participants from the University of Wales, Bangor in accordance with the criteria listed in Experiment 1.

*Stimuli, Design, and Procedure.* This experiment used a similar design and temporal structure to that of experiment 7A, but introduced task switching. Responses to both colours and numbers were mixed within blocks of trials. Responses to colour were signified by the cue “C” and responses to number were indicated by the cue “N”. While the letter cues were altered from those of the previous experiment, the dimensions were not. The stimuli dimensions to be attended were mapped to separate hands, so that the cue served to specify both the dimension to respond and the associated response subset. As the dimensions were mixed within blocks of trials, the pool of stimuli was only half the size of that used for the previous two experiments. Therefore, the numbers 1 and 2 were assigned to the leftmost finger of one hand and the numbers 3 and 4 were allocated to the remaining finger of the same hand. For the opposing hand, the leftmost finger was to respond to the colours yellow and green and the rightmost responded to cyan and blue. This arrangement of colours and numbers replicated half of the individual S-R associations for finger that had been used in the past two experiments, rather than combining stimuli previously associated with different fingers. The composition of each stimulus that was used remained

unaltered to the description given in Figure 12. The assignment of dimensions to the hands was counterbalanced between participants. The order of Block-list selection was systematic (C, C, N, N,), with a repeat of one dimension before a switch to another, although selection from the Trial-lists was again randomised without replacement.

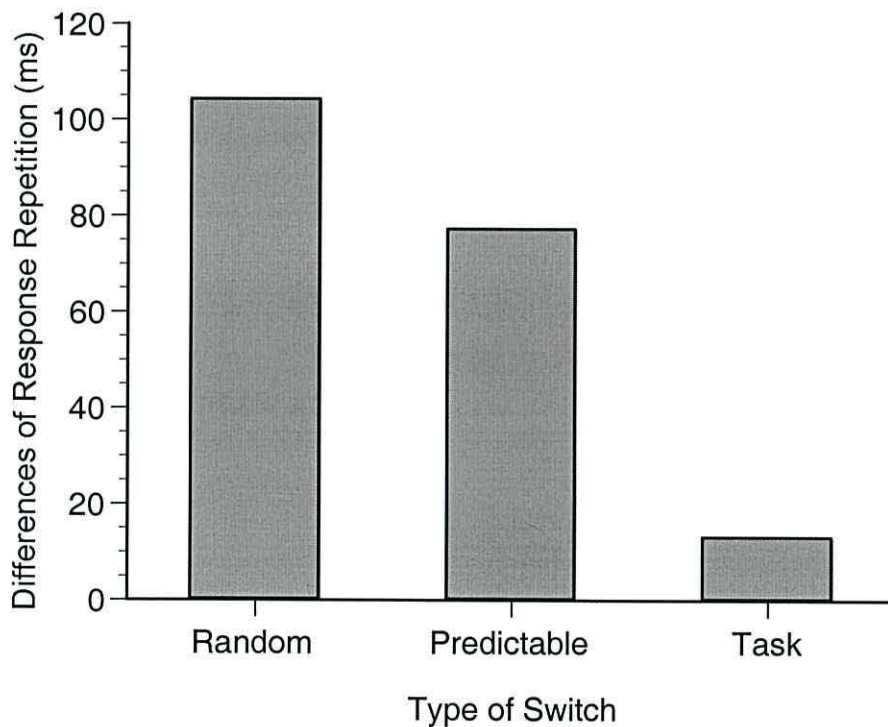
The instructions were similar to those of Experiment 7A, but the first page was altered in order to state the need to switch tasks and the meaning of the cues, while the second page displayed a figure illustrating the relations between the stimuli and the response set. The instructions are described in Appendix II.

### *Results*

As before, the practice trials were removed, followed by the errors (4.6%) and those responses that were executed faster than 200ms and slower than 2000ms (5.6%). In total, 10.2% of the trials were removed before the analysis of the data.

The descriptive statistics for the presentation of the stimuli and the transitions of response are shown in Table 5c. Following the pattern of analysis for the previous two experiments, the response effects were again assessed with a 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA. An effect of hand repetition was significant, although in this instance a switch of hand also represented a switch of task, ( $F(1,23)=9.85$ ,  $MSe=8728$ ,  $p=0.005$ ,  $\eta_p^2=0.30$ ). However, the cost of switching hand and task was not significantly different from Experiment 6 ( $F<1$ ) or Experiment 7A ( $F<2$ ). A switch of hand and task produced costs of 60ms, significantly less than that obtained for Experiment 2B, where full object repetition was excluded and a single mapping of stimuli was used for the response

set, ( $F(1,46)=16.67$ ,  $MSe=4701$ ,  $p<0.001$ ,  $\eta_p^2=0.26$ ). No effect of equivalent finger type was discerned ( $F<2$ ). While there was an advantage of hand repetition, there was no significant difference between the two associated finger responses ( $F<1$ ), so benefits for response repetition were absent.



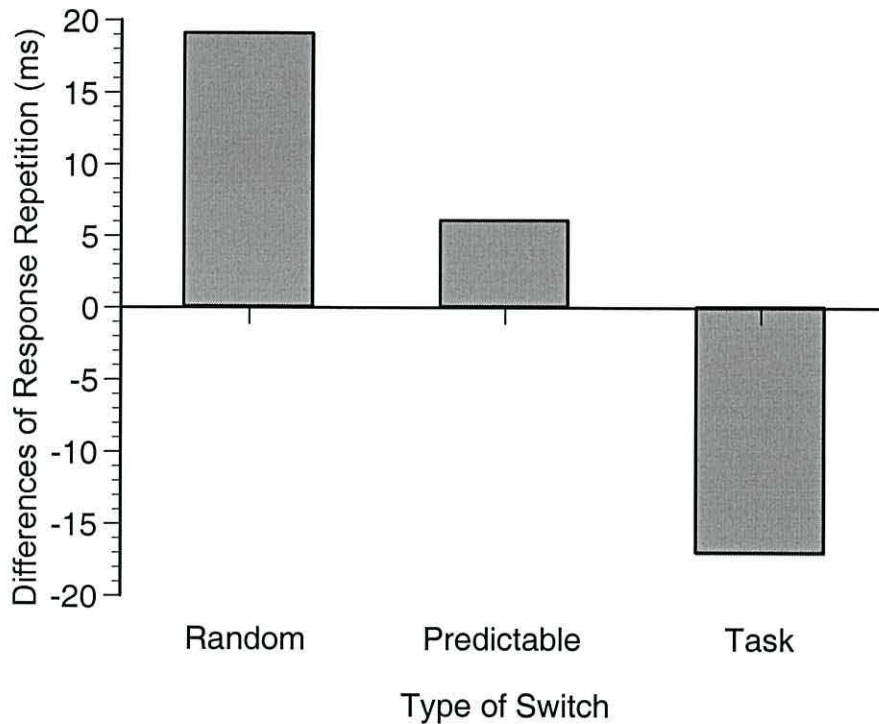
*Figure 13.* Effects of response repetition for hand subsets with a 2:1 mapping of stimuli to each response.

The global effects for response repetition are shown in Figure 13. The graph depicts the relative benefit or cost of repeating a response from the previous trial in relation to the other finger of the same hand. A similar pattern is evident to that displayed in the previous two chapters: Response repetition is largest for the random baseline of Experiment 6, is reduced for the predictable cueing of Experiment 7A, and becomes slight when task switching is introduced for



Experiment 7B. However, the incorporation of task switching with a 2:1 mapping does not produce the cost for response repetition that was obtained in the first chapter when the experiments used a single mapping between stimulus and response.

The means for response repetition and a transition to the alternative finger of the same hand were also compared for those trials where only the whole stimulus changed (see Table 6), thereby removing any obvious effects of perceptual priming. For Experiment 6 it was observed that the advantage of response repetition was reduced to 19ms, an effect that only just obtained marginal significance, ( $F(1,23)=2.96$ ,  $MSe=1478$ ,  $p<0.098$ ,  $\eta_p^2=0.11$ ). Experiment 7A found that the same comparison between these two types of response reduced the effect of response repetition to just 6ms and so did not obtain a level of significance, ( $F<1$ ). Examination of response repetition along with the alternative finger of the same hand was also conducted for the stimulus change trials of Experiment 7B and in this instance discerned that repeating the finger was just 17ms slower than a transition, not achieving significance ( $F<2$ ). Figure 14 illustrates the effects of response repetition when perceptual priming is removed. In this circumstance all of the figures lessen, so that the effect of task switch causes response repetition to demonstrate costs.



*Figure 14.* Effects of response repetition for hand subsets with a 2:1 mapping of stimuli to each response when perceptual priming is absent.

So, for the three experiments of this chapter, the removal of trials associated with perceptual priming led the response repetition effect to become much reduced or absent. Nevertheless, it is clear that the effect of response repetition is being hidden by this comparison. The full change of the stimulus has caused participants to also expect a change of effector for the response; it is less natural to repeat a response when the item changes. Hommel (2007) noted that participants were more likely to repeat a response in a single task design when some or all of the features of the stimulus are repeated. Therefore, this manner of examining response repetition will render a bias in favour of the transition as the previously employed response becomes inhibited. Comparison of the two types of finger response for stimulus change trials between Experiments 6 and 7B finds

an interaction bordering on significance, with Experiment 6 tending to have faster RTs for response repetition and Experiment 7B showing costs, ( $F(1,46)=3.91$ ,  $MSe=2040$ ,  $p=0.054$ ,  $\eta_p^2=0.07$ ). Thus, the interaction appears to confirm that the advantage of response repetition is not merely perceptual, but is also dependent upon the repeat of the previous effector, although the general size of many of the effects obtained in these experiments is less extensive than those of the first two chapters due to interference generated by the double mapping of stimuli. However, with this comparison, the task switching of Experiment 7B demonstrates a cost for response repetition comparable to that obtained in the first chapter. Therefore, it is apparent that inhibition of the previous response does occur in a task switching context and that the cost does not have a purely perceptual basis.

The descriptive statistics for response transitions according to changes of the relevant and irrelevant dimensions of the stimuli are shown in Table 6c. The data concerning the irrelevant dimension of the stimuli were analysed using a 2 (Switch of Irrelevant Dimension of Stimuli, Repeat of Irrelevant Dimension of Stimuli)  $\times$  2 (Hand Switch, Hand Repeat)  $\times$  2 (Finger Switch, Finger Repeat) repeated measures ANOVA. When the finger repeated, an effect of the irrelevant dimension was evident, with a repeat of the irrelevant dimension generally producing responses that were 62ms faster than if the whole object changed, ( $F(1,23)=17.29$ ,  $MSe=3114$ ,  $p<0.001$ ,  $\eta_p^2=0.42$ ). There were no interactions between each of the pairs of factors, but the global interaction verged closely upon significance, ( $F(1,23)=4.18$ ,  $MSe=3959$ ,  $p=0.052$ ,  $\eta_p^2=0.15$ ). With further examination, it was found that, while a change of the irrelevant dimension elicited longer RTs for response repetition, this was also evident for a transition to the



non-equivalent finger ( $F(1,23)=8.26$ ,  $MSe=2412$ ,  $p=0.009$ ,  $\eta_p^2=0.26$ ). For, the remaining two types of response transition the influence of the irrelevant dimension was not significant ( $F<2$ ).

Similar to the finding of the previous two experiments, response repetition trials found that the priming from the relevant property demonstrated speedier responses than when the whole item changed, ( $F(1,23)=8.47$ ,  $MSe=5465$ ,  $p=0.008$ ,  $\eta_p^2=0.27$ ). However, while significant, the effect was much reduced compared to the single task designs, as the difference between a repeat of the relevant dimension and a complete change of item was only 62ms (Experiment 7A vs Experiment 7B,  $F(1,46)=14.47$ ,  $MSe=3124$ ,  $p<0.001$ ,  $\eta_p^2=0.23$ ). Furthermore, the effect was not universal, as it was shown by only 18 of the 24 participants. For response repetition trials, the repetition of the relevant dimension did not create greater benefits than if the irrelevant dimension repeated, ( $F<1$ ). Repetition of the response along with the relevant dimension also remained faster compared to when the stimuli fully changed but the response was executed by the other finger of the same hand, ( $F(1,23)=6.12$ ,  $MSe=3920$ ,  $p=0.02$ ,  $\eta_p^2=0.21$ ).

The differences of switching between response subset and/or task for the three experiments of this chapter are shown in Figure 15. The bar to the left illustrates the cost of switching between subsets of hand when the cue is simply an asterisk (Experiment 6); the following bar in the centre shows the cost obtained for the meaningful cueing of hand (Experiment 7A); and the bar on the right depicts the cost obtained when task switching is incorporated (Experiment 7B). The graph shows that the greatest cost of switching hand is observed for the

predictable hand cueing of Experiment 7A, which is 21ms larger than that produced by the task switching of Experiment 7B; the incorporation of task switching reduced the switch cost obtained to a level similar to that produced by the baseline experiment.

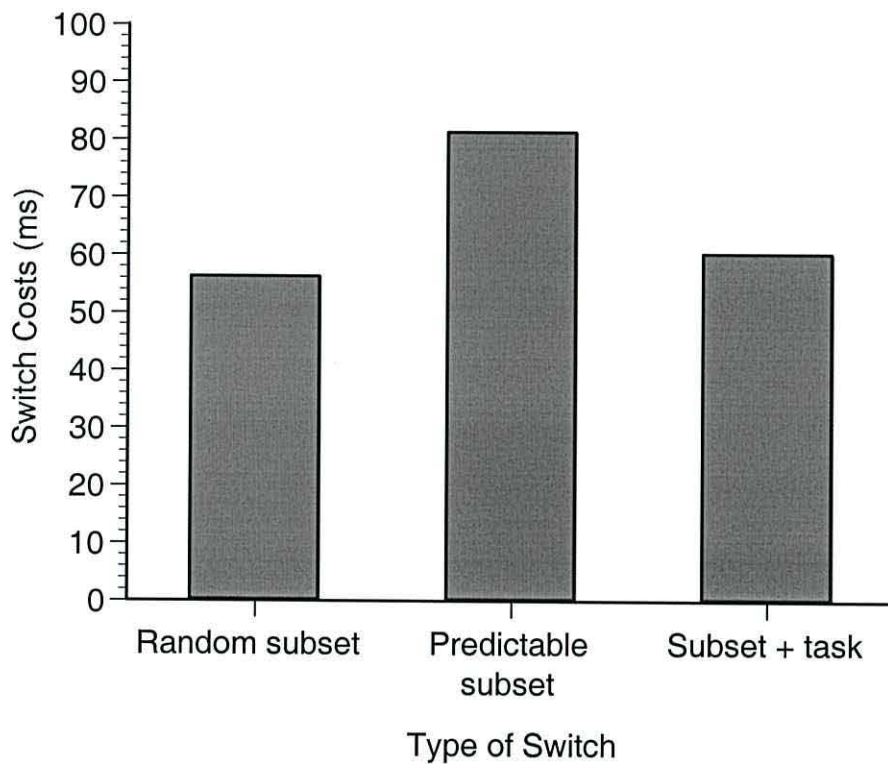
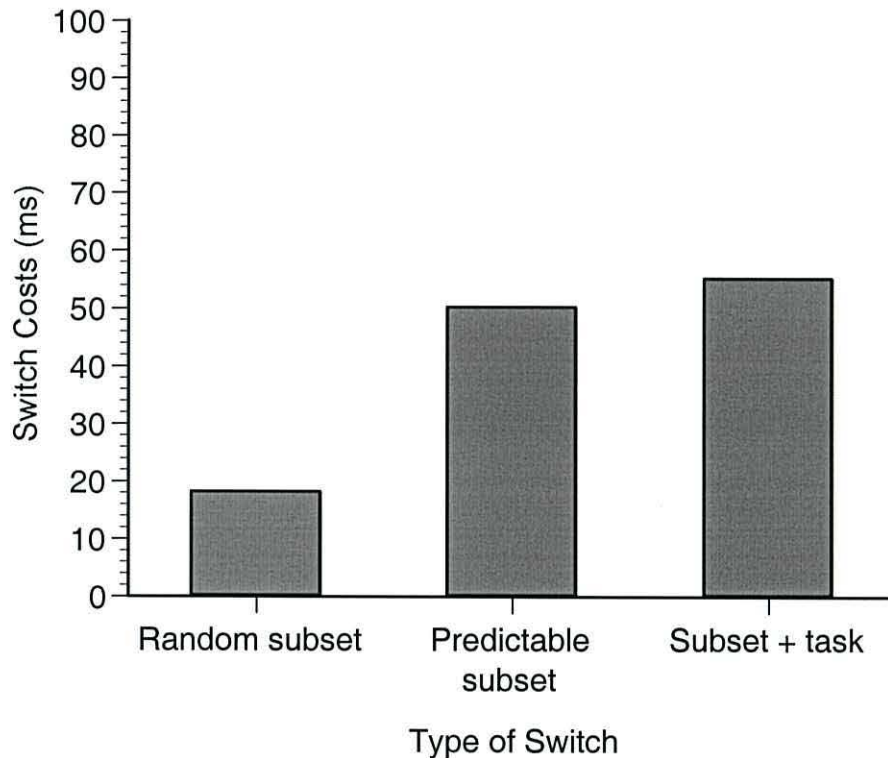


Figure 15. Switch costs between response subsets for Experiments 6, 7A, and 7B.

To examine the contamination of task switch estimates, the difference of switch costs were examined when the response repetition trials had been excluded. The graph of Figure 16 was calculated by subtracting the mean RTs for transitions to the alternative finger of the current subset from those of the non-equivalent finger of the opposing hand. As was noted in the previous chapter, the graph indicates that the removal of response repetition trials most affects the switch costs of the random experiment, while those of the task switching

experiment are the most resilient. The switch cost for the predictable cueing of Experiment 7A was marginally reduced, but appeared little different to that of Experiment 7B.



*Figure 16.* Switch costs of Experiments 6, 7A, and 7B excluding the effect of finger repetition.

The percentages of errors related to response transitions were assessed using the same 2 (Hand Switch, Hand Repeat) x 2 (Finger Type Switch, Finger Type Repeat) repeated measures ANOVA that was employed for the main analysis. It was discerned that there was no difference between the errors produced by hand repetitions and transitions ( $F < 1$ ). However, assessment of finger type showed that the difference attained borderline significance, with a repetition of the type of finger leading to less errors than a transition to the



opposing type, ( $F(1,23)=4.19$ ,  $MSe=3.38$ ,  $p=0.05$ ,  $\eta_p^2=0.15$ ). The interaction between the errors of hand and finger type was not significant ( $F<1$ ).

The percentages of errors associated with changes of the irrelevant dimension were assessed in the same manner as the primary data, by using a 2 (Switch of Irrelevant Dimension of Stimuli, Repeat of Irrelevant Dimension of Stimuli)  $\times$  2 (Hand Switch, Hand Repeat)  $\times$  2 (Finger Switch, Finger Repeat) repeated measures ANOVA. Despite the introduction of task switching, it was found that, in general, more errors were produced when the irrelevant dimension altered than when it repeated, ( $F(1,23)=12.74$ ,  $MSe=0.40$ ,  $p=0.002$ ,  $\eta_p^2=0.35$ ). Similar to the previous two experiments, repetition of the relevant dimension produced less errors than a repeat of the irrelevant dimension, ( $F(1,23)=32.59$ ,  $MSe=1.07$ ,  $p<0.001$ ,  $\eta_p^2=0.58$ ). Moreover, a comparison with the irrelevant dimension found a change of the whole stimulus to render substantially more errors, ( $F(1,23)=27.95$ ,  $MSe=4.45$ ,  $p<0.001$ ,  $\eta_p^2=0.54$ ).

There was no interaction between hand and the irrelevant dimension of the stimuli ( $F<1$ ), but the irrelevant dimension did interact with finger type, ( $F(1,23)=5.26$ ,  $MSe=0.14$ ,  $p=0.03$ ,  $\eta_p^2=0.18$ ): When the irrelevant dimension changed there were more errors if the subset of equivalent finger also changed. As stated previously, there was no interaction between hand and finger, but the analysis showed a three-way interaction between all three of the factors, ( $F(1,23)=7.00$ ,  $MSe=0.20$ ,  $p=0.01$ ,  $\eta_p^2=0.234$ ). Overall, excluding response repetition trials, the least errors were produced when the irrelevant dimension repeated but the hand switched to the equivalent finger; most errors occurred

when the irrelevant dimension altered along with the relevant dimension while the hand repeated with a transition to the alternative response.

### General discussion

This series of experiments used a design that employed a double-mapping between perceptual features and responses: each response was associated to two different visual properties. The design enabled further examination of the separate contributions of perceptual and motor processes to the overall switch cost in task switching experiments. It was speculated that the increased memory load required by the experimental design would render the tasks more difficult for the participants to accomplish, although the error rates did not show a general increase compared to those of Experiments 1 to 3B: Actually, it was Experiment 3B that demonstrated the largest rates of error for all of the experiments of the thesis, where a single mapping for two tasks was applied to subsets of equivalent fingers without full object repetition. However, for the current series of experiments, it is conceivable that the increased number of trials in each block could have allowed the participants more time to become accustomed to the tasks, so this may have countered the task difficulty to some extent. Nevertheless, despite differences in the design, the results from the present series of experiments provided a good replication of the motor effects that had been obtained from the first series, while providing additional insight regarding their interaction with perceptual priming.

The advantage for the repetition of the relevant dimension coupled with the repetition of the response did not render the benefit that had been obtained in the previous two experiments. Therefore, the change of the irrelevant dimension

appears again to be capturing attention due to increased salience. However, the extent of the response inhibition was not as great as was noted previously, as this S-R arrangement did not produce the cost that had been observed in Chapter 1, at least not at the cue to stimulus interval of 1000ms. Repetition of the irrelevant feature of the object did not produce any priming effect with blocks of single task trials (Experiments 6 and 7A): Only when two different tasks were intermixed in the same block of trials did repetition of the irrelevant property produce a benefit when the response repeated in relation to a change of the whole object. These benefits of the irrelevant dimension are comparable to those observed from the repetition of the relevant property (64ms and 62ms respectively, see Table 6), reaffirming that when switching between tasks, both dimensions become salient.

Consequently, it is conceivable that, in a task switching context, attention may be more likely to spread to all aspects of an object and so be less selectively applied. Interestingly, this would imply that changes of a dimension that remained irrelevant throughout a block of task switching trials may also capture attention: Examination of this occurrence would help to determine whether specific dimensions of the object are attended according to their relevance to the tasks, or whether the task set initiates a global analysis of the item when a task switch is anticipated, particularly during featural changes. However, the benefit for the repetition of the irrelevant dimension was not present in the previous chapter, where the repeat of the irrelevant feature entailed a transition of response: Therefore, it is arguable that the benefit of irrelevant repetition obtained here for response repetition trials may be associated with the double mapping of stimuli, as the previous two experiments also discerned that the increased complexity of S-R associations promoted the processing associated with the previous response.



Unsurprisingly, a repeat of hand and task entailed significant benefits, although the cost of switching task was less than that of the previous experiment where hand cueing was employed. It is likely that the greater advantage of hand repetition for Experiment 7A derived from the increased facilitation of hand that was noted with the single mapping design of Experiment 2A. Conversely, the increased salience of the irrelevant dimension was perhaps responsible for reducing the benefits of hand repetition, as a switch of task is promoted by regular alterations of the stimuli being presented, although the results of Experiment 2B noted a minor increase in the costs of transitions between the response subsets of hand when they were directly matched to different tasks. However, in comparison to the single task experiments, the double mapping of the current series caused the effect of task switching to be completely eliminated: There was certainly no evidence of any additional cost of switching between tasks that could be dissociated from the costs of switching between hands. It is possible that the double mapping weakened the links between the S-R codes and that the selection between these S-R links might constitute the basis of the task switching costs, so supporting the suggestion by Wylie and Allport (2000) that switch costs derive from the management of competition between the S-R relations for the separate tasks. In any case, the reduction in the switch cost compared to Experiment 7A reasserts that the allocation of tasks to hands does not provide a good indicator of executive functioning and that motor functioning should be accommodated before abstract processes associated with the task set can be considered meaningfully.

Nevertheless, the hand switch cost for the task switching of Experiment 7B was more resilient to the removal of response repetition effects in relation to the other experiments of this chapter that involve only a single task, although the

cueing of hand bolstered the switch cost for Experiment 7A compared to the random presentation of Experiment 6. When compared to a transition to the other finger of the current hand subset, Experiment 6 demonstrated the greatest advantage of response repetition, as the discrepancy between the RTs of the two types of response was largest. The cueing of hand during Experiment 7A served to group the responses together so that the advantage of response repetition was less prominent, and the effect of grouping was compounded by the addition of separate tasks for Experiment 7B. However, for this experiment, it is apparent that the lack of discrepancy between the two responses of the current task was also influenced by inhibition of the previous response; even if the cue to stimulus interval did not demonstrate a cost for response repetition, the same processes of inhibition are likely to occur as those described in the first chapter, albeit in a more muted fashion as the indecision caused by the double mapping appears to reduce or delay the inhibition that is applied.

In this instance, when considering the RTs the introduction of task switching removed the benefit of repeating the subset of equivalent fingers that had been noted in the previous two experiments. However, fewer errors were produced when repeating the subset of equivalent fingers while no difference was discerned for a switch or repeat of hand and task, although this effect was also present for the single mapping design of Experiment 2B. Generally, the reinforcement of hand grouping by the attribution to different tasks appears to reduce much of the processing for subsets of equivalent fingers that had been apparent in the previous two experiments.

For all three of the experiments of this chapter, the removal of perceptual priming from response repetition trials found that any benefit of repeating the response was lost when compared to the alternative finger of the same hand. However, it is apparent that the interpretation of a stimulus is dependent upon its relation to the previously established S-R code: The presentation of the stimulus varies in meaning for different responses according to the recently established event files. A complete change of the stimulus from that presented during the previous trial is likely to also promote a transition of response. During this event a transition of response will demonstrate a relative advantage, as a new S-R code will be easier to form with a different response whereas a repetition of the previous response is bound more closely to another stimulus, and so will be hindered if the stimulus completely alters. Therefore, it is clear that the processes determining the RTs are not purely perceptual, but are dependent upon the close relationship between the S-R codes.

Figure 14 shows that, for the task switching design of Experiment 7B, there are substantial costs associated to repeating the same response during task repetition trials when the impact of any perceptual priming is removed. While the second chapter emphasised the role of perceptual processes, this result clearly indicates the occurrence of response inhibition. The effect replicates those of the first chapter and confirms the assertion that the previous response is inhibited in order to promote an alternative when acting within a task switching context. So, it again appears that, without full object repetition, a general preference for response transition is apparent despite the double mapping of stimuli: However, in this instance the increased stimuli pool caused by the double mapping promoted the repetition of response when the relevant dimension repeated, as the salience for



the repetition of the target feature was increased when a greater number of options were included in the design.

### Overview of the main effects

#### *Response repetition benefits and costs*

Chapter 1 excluded full object repetition from the design of each experiment: For a single task design, repetition of the previous response produced an advantage compared to a transition towards another finger. However, costs of response repetition were evident when participants were required to switch between tasks: Instead, a switch to the other finger of the current response set demonstrated shorter RTs. It appeared that the expectation of a task switch promoted the inhibition of the response that was previously employed. The experiments of the second chapter utilised full object repetition and the results indicated that the complete repetition of the stimulus previously presented facilitated further the repetition of the response. In this instance, Horner and Henson (2008) specified the bypassing of some neural mechanisms when the entire event file is repeated. When all forms of stimulus presentation were considered, it was apparent that a change of the irrelevant dimension hindered response repetition during task switching experiments, as the expectation of a switch of task increased the salience of the opposing dimension. Generally, for those experiments with just a single task design a change of the irrelevant dimension had a negligible influence upon the RTs. Nevertheless, repetition of the irrelevant feature often promoted stability during a transition, thereby leading to fewer errors.

However, the final chapter employed a double mapping of stimuli to each response key and noted that a repetition of response to a different target stimulus was sufficient to render costs. So, a partial repetition of the event file that was established during the previous trial extends the RTs, as a change of stimulus will then promote a transition to another finger. Uncertainty caused by the double mapping accentuated the comparative benefit of repeating the response along with the relevant target dimension, especially for single task designs. However, during task switching (Experiment 7B), once perceptual priming had been removed from the analysis consideration of the response repetition trials determined the presence of costs in relation to a transition towards the alternative finger of the same hand: This cost was not apparent for the single task designs. Therefore, the assertion of the first chapter was supported: The cost of response repetition for a task switching experiment is not solely due to the change of stimulus, but is also formed by inhibition of the previous response.

#### *Hand repetition and hand switch*

Miller and Ulrich (1998) discerned that response selection constituted a two stage process, with hand being selected before finger: The results of Chapter 1 showed that the facilitation and inhibition of hand is tied to the management of S-R relations for the desired effector as well as to the formation of the subsets of response. The experiments of the first chapter discerned that, in a single task design with a single mapping between the stimulus and response, repetition of the hand previously used rendered an advantage in relation to a transition to the opposing hand. This was apparent without meaningful cues being employed (Experiment 1), but was accentuated by the addition of hand cueing (Experiment

2A). When tasks were assigned to separate hands (Experiment 2B), the combined repetition of hand and task retained an advantage, but the benefits were not much greater than those for the cueing of hand in a single task design. The advantage of hand was still evident even when the cues were assigned to subsets of equivalent fingers (Experiment 3A), although a marginal effect of cueing was also apparent. A repetition of hand and cued subset produced the fastest responses. However, in the context of task switching, the repetition of hand became slower regardless of whether the task repeated or changed, indicating that the hand was inhibited when a switch was expected (Experiment 3B).

For Chapter 2, the general costs of hand switch across all three experiments were smaller, as full object repetition served to speed all responses, not just those of repetition, due to better differentiation between the S-R relations. Nevertheless, response repetition trials still held the shortest RTs by a substantial degree. The advantage for hand repetition noted in the task switching study (Experiment 5A) was not significantly larger than that obtained for the random baseline with non-meaningful cues (Experiment 4). Therefore, the effect of hand switching was robust, so representing a major confound for those task switching experiments that assign tasks to hands and then produce inferences regarding executive functioning (Arrington & Logan, 2004; Logan & Bundesen, 2003). Experiment 5B assigned the tasks to subsets of equivalent fingers: In this instance, unlike Experiment 3B, the repetition of hand retained an advantage, although the benefit was lost when full object trials were removed. It appeared that additional facilitation from the S-R link associated with full object repetition was sufficient to also affect the processing of hand, thereby removing the cost that had been noted previously.



The final chapter incorporated a double mapping of stimuli to each response key. While an advantage for hand repetition was evident for both single task and task switch designs, it was found that the costs for switching hand were reduced from those obtained in the previous two chapters; with the benefit of hand cueing in a single task design (Experiment 7A) being greater than that obtained when task switching was required (Experiment 7B). Greater uncertainty appeared to be apparent when participants were required to switch between dimensions alongside management of the double mapping of stimuli, so the facilitation associated with hand repetition was subdued, except where hand grouping was reinforced by the allocation to separate tasks.

#### *Equivalent finger transitions*

The baseline experiment of the first chapter (Experiment 1) noted an advantage when the fingers of the same type were repeated from the previous trial. However, the cueing of hand eliminated this benefit (Experiment 2A) and the effect was also absent when separate tasks were assigned to each hand (Experiment 2B). Therefore, the reinforcement of hand grouping appeared to be responsible for suppressing the differentiation of equivalent fingers. The cueing of equivalent finger subsets (Experiment 3A) served to marginally increase the associated processing, as the repetition of a finger similar to that used in the previous trial produced shorter RTs. Nevertheless, the advantage of hand repetition was still present, albeit subdued. Generally, at a cue to stimulus interval of 1000ms, the benefits of equivalent finger repetition were not as prominent as those obtained when hands were cued. The allocation of tasks to equivalent fingers (Experiment 3B) entailed a cost for both response repetition and hand

repetition, but the benefit of repeating the equivalent finger subset and of task was still present.

The inclusion of full object repetition for the baseline condition of Chapter 2 (Experiment 4) did not alter the advantage of repeating the subset of equivalent fingers that was noted in Experiment 1. However, in this instance, the allocation of task switching to each hand (Experiment 5A) did not remove the benefit of repeating the subset of equivalent fingers: Possibly, the greater stability produced by the inclusion of full object repetition was sufficient to reduce the inhibition involved with managing the separate hands and tasks. Allocating task to subsets of equivalent fingers reinforced the grouping of these effectors, but the inclusion of full object repetition removed the cost of repeating hand that had been obtained in Experiment 3B.

None of the experiments of the final chapter involved the cueing of equivalent fingers, yet processing for these subsets was readily apparent. While hand grouping was generally less prominent, the association between equivalent fingers was accentuated. The baseline study (Experiment 6) discerned that the cost of transitions between subsets of equivalent fingers was as great as that obtained for hand grouping. The cueing of hand accentuated the benefit of hand repetition at the expense of repetition for equivalent fingers, but both effects were still evident (Experiment 7A). For these single task experiments, the benefits for the processing of the subsets of equivalent fingers seemed to increase as the advantage of hand repetition was reduced: Therefore, it is proposed that the facilitation of the two forms of grouping occur antagonistically, with the increased complexity of the S-R mappings serving to limit hand grouping and so promote

the grouping of equivalent fingers. However, the addition of task switching (Experiment 7B) removed the occurrence of benefits for equivalent finger repetition, as the allocation of a separate task to each hand reinforced the grouping of those subsets.

### *Implications for task switching*

The processing of hand is closely linked to the S-R relations of the current and previously used effectors, as well as being influenced by the expectations directed by the task set. The assignment of a different task to each hand is confounded by the costs of transitions between hands that are apparent during single task experiments. Furthermore, the facilitation of equivalent fingers when hand grouping is less strong indicates that other motor processes are of relevance. Thus, for manual responses the task set cannot be considered in isolation, as the enactment of the goal must occur through a motor apparatus with specific characteristics and these should be accommodated before the influence of the task set can be inferred.

The results considered throughout this thesis clearly demonstrate that the management and execution of single or multiple tasks is dependent upon the S-R relations, with the processing of tasks and stimuli being affected by their associations to the response set. The results do not directly contradict the concept of task reconfiguration, but nevertheless are strongly supportive of the arguments proposed by Wylie and Allport (2000) who specified the particular importance of the S-R relations associated with the trial being replaced. Furthermore, the double mapping of stimuli to response keys does not remove the influence of perceptual and motor processes, but merely alters them: Therefore, it is argued that this



manner of assessing task switching does not render executive functions more accurately and is not sufficient to avoid the issue of S-R relations.

#### *Future research and conclusion*

The preference for hand grouping was common across all of the experiments to a varying degree: However, the relationship between equivalent fingers is of interest and could be examined further, particularly in instances such as those of Experiment 6 and 7A where the grouping of equivalent fingers is apparent regardless of the cueing of hand. As the suppression of hand processing may facilitate that for equivalent fingers, the nature and function of this occurrence should also be considered. This new paradigm for assessing a response in relation to that previously executed would yield additional information of interest upon manipulation of the cue-stimulus interval, a procedure that was applied to the cueing paradigm by Adam et al. (2003). It is highly likely that the extent of facilitation and inhibition for both hand and finger processing may vary depending upon the interval that is given, with the time course affected by the number of tasks and the formation and placement of the response subsets. Certainly, assessment of the response processes should be examined in relation to the size of the global switch cost from various task switching paradigms. The current studies were not designed to assess residual switch costs: However, it would be of interest to investigate the effect of alterations to the cue type and the extent of preparation. All of the experiments of this thesis employ a four finger linear response set, with the effectors positioned adjacently: The placement and size of the response set could be manipulated to determine the influence upon response transitions between subsets of hand and

equivalent finger. Moreover, special attention should be paid to the double-mapping of stimuli to a two finger response set, as this formation is often employed within task switching experiments (Rogers & Monsell, 1995; Meiran, 2000a). Finally, none of the experiments described here use spatial cues or stimuli: It is conceivable that the automaticity of spatial processing may influence the patterns of response transition. Therefore, the paradigm introduced here offers many opportunities for assessing S-R relations and the operation of the task set.

To conclude, the analysis of general switch costs in task switching paradigms may not be the only index of executive processing. Instead, a more analytical approach can reveal the kind of computations that are required to execute goal directed behaviour. The specific details of S-R relations are important for determining a greater degree of information about the processes that occur during the switching of tasks; a general analysis is not sufficient to explain the mechanisms involved as the stimuli pool, response set, and task set interact. Therefore, the nuances concerning the configuration of each will serve to render the outcome represented by the RTs. Only by considering the task set in the context of the S-R relations for each experiment can the relevant neural functioning be most effectively understood.

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List of appendices

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Appendix I  
Consent form



This is to certify that I, ....., hereby agree to participate as a volunteer in a scientific investigation, authorised by the School of Psychology at University of Wales, Bangor, under the supervision of Paloma Marí-Beffa.

The investigation, and my part within the investigation, has been fully explained to me by ..... and I understand his/her account. Queries concerning the procedures of this investigation, and any associated risks, have been answered to my satisfaction.

I understand that all data will remain confidential with regard to my identity.

I also understand that I am free to withdraw my consent and terminate my participation at any time without penalty.

I am aware that I may request a summary of the results of this study.

In the case of any complaints concerning the conduct of research, these should be addressed to Professor R. Hastings, Acting Head, School of Psychology, University of Wales, Bangor, Gwynedd, LL57 2DG.

.....  
Date

.....  
Participant's Signature

I, the undersigned, have fully explained the investigation to the above individual.

.....  
Date

.....  
Investigator's Signature

## Appendix II

Standardised instructions for Experiment 1 and Experiment 4.

Initial title screen:

**The task requires responses to a centrally presented colour\*. Responses are to be conducted with the index and middle fingers of each hand. The key**

**responses are as follows:**

**If blue\*, then press "C"**

**If green\*, then press "V"**

**If red\*, then press "B"**

**If yellow\*, then press "N"**

**It is emphasised that your responses should be as fast and as accurate as possible.**

**Please press any key in order to begin a block of practice trials.**

\*The shape version of the experiment substituted a list of shapes for the colours stated above, these being diamond, triangle, square, and circle. The lists of colours or shapes were altered according to the relevant key attributions determined by Appendix III, Table B and Table C.

Display upon completion of practice trials:

**The practice trials have been completed.**

**The first experimental block of trials  
will begin once you press any key.**



Display upon completion of first block and second block of experimental trials:

**Please rest.**

**When ready, press a key to continue with the experiment.**

Display upon completion of experiment:

**The experiment has ended.**

**Thank you for participating.**

**The experimenter will now debrief you  
upon the nature of the task.**

Standardised instructions for Experiment 2A.

Initial title screen:

The instructions for Experiment 2A were identical to those of Experiment 1 except that a description of the letter cues was added following the list of key responses. The explanation read as follows:

**Each trial will be preceded by a letter indicating the hand to which the following response is to be allocated. The letter "A" represents the left hand while the letter "B" refers to the right.**

Standardised instructions for Experiment 2B and 5A.

Initial title screen:

**The task entails responses to a centrally presented item. Responses are to be conducted with the index and middle fingers of each hand. Each trial will be preceded by a letter indicating the dimension to which the following response is to be allocated. The letter "C" necessitates a response to colour while the letter "S" requires a response to shape. Thus, one dimension is assigned to the responses of the left hand while the other is attributed to the right.**

**The key responses are as follows:**

**If blue\*, then press "C"**

**If red\*, then press "V"**

**If square\*, then press "B"**

**If circle\*, then press "N"**

**It is emphasised that your responses should be as fast and as accurate as possible.**

**Please press any key in order to begin a block of practice trials.**

\*The order of stimuli attribution was altered with regard to the incomplete counterbalancing detailed in Appendix III, Table D.

The instructions subsequent to the title screen were identical to those of Experiment 1.

Standardised instructions for Experiment 3A.

Initial title screen:

The instructions for Experiment 3A were the same as those of Experiment 2A barring the description of the letter cues which was altered:

**Each trial will be preceded by a letter indicating whether the response is to be allocated to an internal or external subset. Thus, the letter "A" represents the index fingers while the letter "B" refers to the middle fingers.**

Standardised instructions for Experiment 3B and 5B.

Initial title screen:

The instructions for Experiment 3B were identical to those of Experiment 2B except that the description of the letter cues was altered:

**The task entails responses to a centrally presented item. Responses are to be conducted with the index and middle fingers of each hand. Each trial will be preceded by a letter indicating the dimension to which the following response is to be allocated. The letter "C" necessitates a response to colour while the letter "S" requires a response to shape. Thus, one dimension is assigned to the responses of the index fingers while the other is attributed to the middle fingers.**

The order of stimuli attribution detailed in the title screen of Experiment 3B was changed according to the incomplete counterbalancing detailed in Appendix III,



Table E.

Standardised instructions for Experiment 6.

Initial title screen:

**The task requires responses to the colour of a centrally presented digit.**

**Responses are to be conducted with the index and middle fingers of each hand. The key responses are as follows:**

**If black or red, then press "C"**

**If yellow or green, then press "V"**

**If cyan or blue, then press "B"**

**If magenta or white, then press "N"**

**The following screen presents a diagram of this arrangement.**

**Press any key to continue.**

According to the task, the second screen of the instructions displayed one of the following two diagrams:

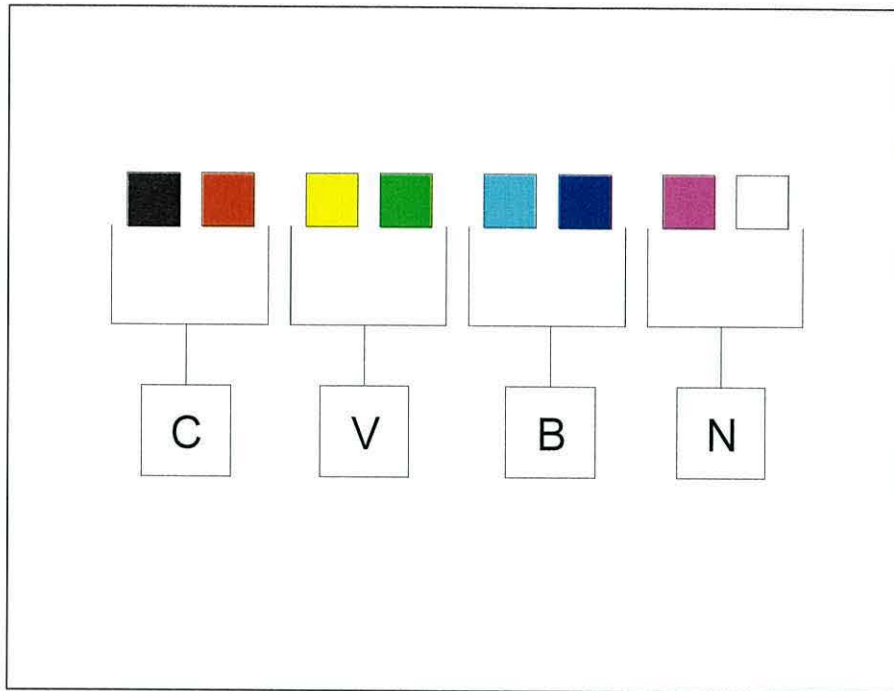


Figure 17. Second instruction page for Colour\*<sup>2</sup>

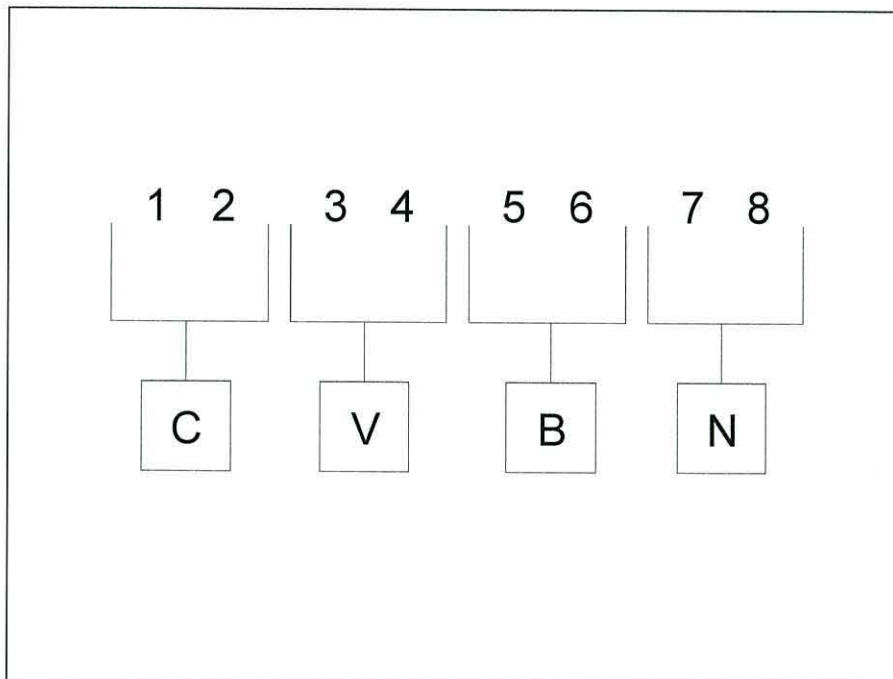


Figure 18. Second instruction page for Shape\*<sup>2</sup>

\*<sup>2</sup> For Figure 17 and Figure 18, the appropriate screen was displayed according to whether the task concerned colour or shape

Third instruction page:

**It is emphasised that your responses should be as fast and as accurate as possible.**

**Please press any key in order to begin a block of practice trials.**

Following the initial instructions, the inter-block screens and the final screen were identical to those used in Experiment 1.

Standardised instructions for Experiment 7A.

Initial title screen:

The instructions for Experiment 6A were identical to those of Experiment 5 except that a description of the letter cues was inserted following mention of the keys and their associations with the stimuli:

**Each trial will be preceded by a letter indicating the hand to which the following response is to be allocated. The letter "A" represents the left hand while the letter "B" refers to the right.**

All of the remaining display screens were identical to those used in Experiment 5.



Standardised instructions for Experiment 7B.

Initial title screen:

The first page of the instructions was altered to specify the changes in cueing and the S-R relations:

**The task requires responses to a centrally presented item. Each trial will be preceded by a letter indicating the dimension to which the following response is to be allocated. The letter "C" necessitates a response to colour while the letter "N" requires a response to the number.**

**Responses are to be conducted with the index and middle fingers of each hand. The key responses are as follows:**

**\*<sup>3</sup> If 1 or 2, then press "C"**

**\*<sup>3</sup> If 3 or 4, then press "V"**

**\*<sup>3</sup> If yellow or green, then press "B"**

**\*<sup>3</sup> If cyan or blue, then press "N"**

**The following screen presents a diagram of this arrangement.**

**Press any key to continue.**

\*<sup>3</sup> The attribution of dimension to hand was counterbalanced between participants.

According to counterbalancing the second screen of the instructions displayed one of the following two diagrams:

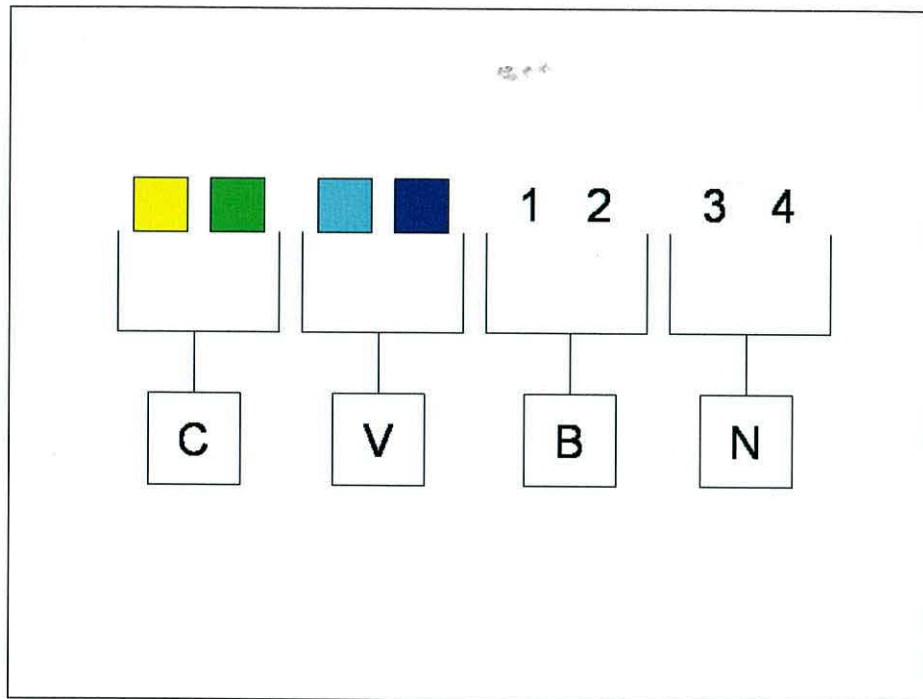


Figure 19. Second instruction page for mixed blocks version1\*4

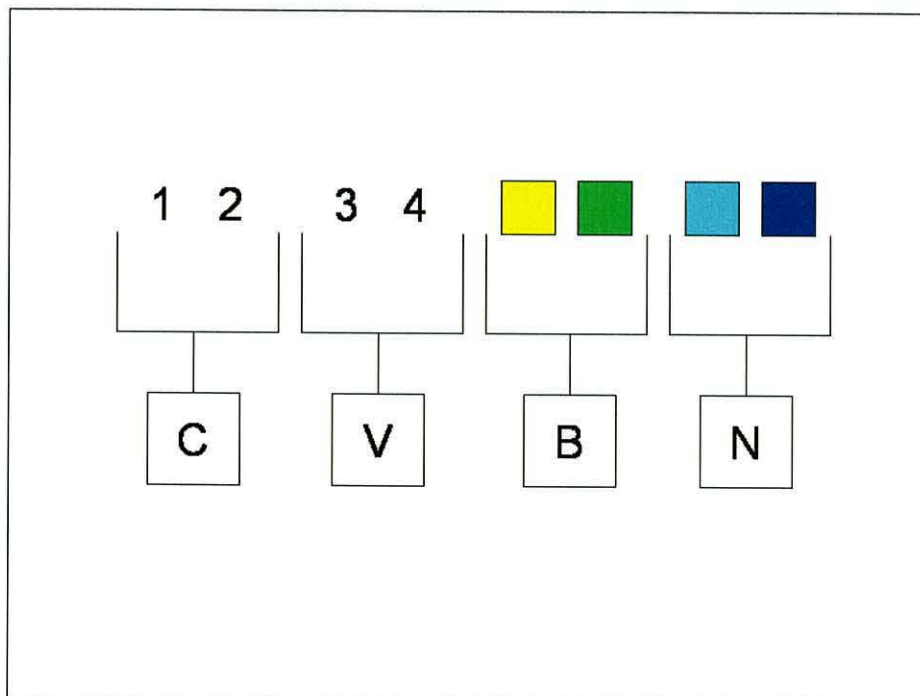


Figure 20. Second instruction page for mixed blocks version2\*4

\*4The appropriate figure was displayed according to the S-R relations specified in the first instruction page.

The remaining display screens for Experiment 7B were identical to those used in Experiment 6.



## Appendix III

Table A. *Assignment order for experimental conditions.*

Participant	Task Sequence	
	First task	Second task
1	C1	S4
2	C1	S3
3	S2	C1
4	S1	C1
5	C2	S2
6	C2	S1
7	S4	C2
8	S3	C2
9	C3	S1
10	C3	S3
11	S2	C3
12	S4	C3
13	C4	S2
14	C4	S4
15	S1	C4
16	S3	C4
17	C1	S4
18	S2	C1
19	C2	S3
20	S1	C2
21	C3	S4
22	S1	C3
23	C4	S3
24	S2	C4

Table B. *Assignment order for key attributions: Colour.*

Colour Arrangement	Key			
	C	V	B	N
C1	blue	green	red	yellow
C2	red	blue	yellow	green
C3	yellow	red	green	blue
C4	green	yellow	blue	red

Table C. *Assignment order for key attributions: Shape.*

Shape Arrangement	Key			
	C	V	B	N
S1	circle	triangle	square	diamond
S2	square	circle	diamond	triangle
S3	diamond	square	triangle	circle
S4	triangle	diamond	circle	square

Table D. *Assignment order for key attributions: Colour and shape attributed separately to responses of the left hemisphere and the right hemisphere.*

Task Switch Arrangement	Key			
	C	V	B	N
TS1	blue	red	square	circle
TS2	red	blue	circle	square
TS3	circle	square	red	blue
TS4	square	circle	blue	red



Table E. *Assignment order for key attributions: Colour and shape allocated to homologous fingers.*

Task Switch Arrangement	Key			
	C	V	B	N
TS1	blue	square	circle	red
TS2	red	circle	square	blue
TS3	circle	blue	red	square
TS4	square	red	blue	circle

Appendix IV

Debriefing form

Thank you for contributing to this research.

The topic of task-switching involves consideration of the neural mechanisms associated with regulating the shifts between different activities: Thus, a current activity must cease in order that it can be replaced by another task set suitable for the adoption of a new behaviour. However, research regarding task switching has tended to emphasise the role of executive functions in this process, while perceptual and motor related mechanisms have been comparatively overlooked. The present series of studies intends to examine switches of response between different fingers: It is expected that costs associated with shifts between fingers will signify the operation of motor attention within the left parietal, and so demonstrate a cost associated with the shifting of a response to another finger or hand. However, Mayr and Kliegl (2003) discerned that the pattern of costs between fingers was altered in a task switch context, most likely due to backward inhibition of the previous task set. Consequently, the current research intends to delineate the relationship between motor mechanisms and task set.

If you have any further queries about this study, or would like to view your results, then please contact Stephen Cooper – [pspe20@bangor.ac.uk](mailto:pspe20@bangor.ac.uk)

Supervisor: Dr Paloma Marí-Beffa – [pbeffa@bangor.ac.uk](mailto:pbeffa@bangor.ac.uk)