The role of stimulus-response bindings in priming: multiple routes and multiple stages

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Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

Experiments 1, 2, 4-8 in Chapters 1-3 were reported in the paper by Horner, A.J. & Henson, R.N. (2009). *Bindings between stimuli and multiple response codes dominate long-lag repetition priming in speeded classification tasks*. Journal of Experimental Psychology: Learning, Memory and Cognition, 35(3), 757-779.

I hereby state that this dissertation does not exceed the work limit set by the Degree Committee for the Faculty of Biology (300 single-sided pages of double spaced text, not including the bibliography and appendices).

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Abstract

Humans are remarkably adept at recognising, categorising and interacting with objects in their environment, an ability that is strongly modulated by prior experience. Behaviourally, such experience-dependent facilitation can manifest as an increase in response accuracy and/or a decrease in response time on a given task for repeated compared to experimentally novel stimuli. This behavioural *priming* effect is often accompanied by decreases in neural activity, as measured by functional magnetic resonance imaging (fMRI) and/or electroencephalography/magnetoencephalography (EEG/MEG), within distinct cortical regions – a phenomenon known as *repetition suppression*. Priming and repetition suppression (RS) are often thought to reflect the facilitation of psychological (component) processes engaged during initial and subsequent presentations of a stimulus. These phenomena however can also reflect the formation of direct, stimulus-response (S-R) bindings, retrieval of which can bypass many of the processes engaged during the initial presentation.

This thesis presents evidence that S-R learning contributions dominate in long-lag repetition priming of semantic classification of visual stimuli (Chapters 2-3). Furthermore, S-R bindings can form at multiple levels of both stimulus and response representation, suggesting S-R learning is a highly flexible process (Chapter 4). Whereas RS, as measured by fMRI, is shown to be sensitive to the retrieval of S-R bindings in inferior prefrontal regions, it is shown to be insensitive to such retrieval in posterior ventral visual regions (Chapter 5). Using sensor-level analyses of EEG, repetition effects that are sensitive to the retrieval of S-R bindings are shown to be time-locked to response-onset whereas repetition effects that are unaffected by such retrieval are time-locked to stimulus-onset (Chapter 6). As such, both fMRI and EEG point to a dissociation between possible S-R learning and component process contributions to priming and RS. Finally, the formation of S-R bindings is shown to be dependent upon attention, with no significant S-R learning effects present for stimuli either unattended at initial or subsequent presentation (Chapter 7). Given dominant theories of repetition priming are incapable of incorporating many of these results, a multiple-route multiple-stage (MR-MS) framework is proposed (Chapter 8). This framework attempts to incorporate known component process contributions to priming and RS with the S-R learning contributions presented in this thesis.

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Chapter 1

Introduction

1.1 Repetition priming

Humans are remarkably adept at recognising, categorising and ultimately interacting with objects in their environment, seemingly oblivious to the computational complexities involved. Importantly, such abilities are modulated by experience – in general, we become more efficient with increased exposure to a particular stimulus. Experimentally, such increased efficiency can manifest as an increase in response accuracy and/or a decrease in response time (RT) on a given task for subsequent compared to initial presentation of a stimulus, a phenomenon known as *repetition priming*. Repetition priming is a robust phenomenon, and has been shown across a range of visual (e.g., Roediger & McDermott, 1993), auditory (e.g., Schacter & Church, 1992), haptic (e.g., Easton, Greene & Srinivas, 1997) and olfactory (e.g., Schab & Crowder, 1995) stimuli, as well as across short (i.e., msecs; e.g., Ratcliff, Hockley & McKoon, 1985) and long (i.e., months to years; e.g., Cave, 1997) time-lags between stimulus presentations.

Interest in priming began in earnest following the revelation that amnesic patients, who demonstrate profound impairments in standard tests of long-term declarative memory, show intact priming (Scoville & Milner, 2000; Warrington & Weiskrantz, 1974). In contrast, lesions to occipital (Keane, Gabrieli, Mapstone, Johnson & Corkin, 1995) and temporal (Bondi & Kaszniak, 1991) regions have been shown to result in the disruption of priming, but not declarative recognition memory (though see Kinder & Shanks, 2003; Kroll et al., 2003). These results drew a clear distinction between assessing memory using *direct* memory tasks (i.e., those that make explicit reference to, or require explicit knowledge of, stimulus repetition) and *indirect* memory tasks (i.e., those that do not refer or relate to stimulus repetition).

In the realm of indirect memory tasks, a distinction can be made between *identification* tasks (e.g., Jacoby, 1983a; Roediger, Srinivas & Weldon, 1989a) and *classification* tasks (e.g., Dennis & Schmidt, 2003; Schnyer et al., 2007; Schnyer, Dobbins, Nicholls, Schacter & Verfaellie, 2006). Whereas identification tasks simply require the participant to identify/recognise a particular stimulus, classification tasks require a further, often binary, classification. For example, following the presentation of a picture of a common object, participants might be required to name the object or classify it as being "man-made" or "natural". Whereas the former naming task requires only identification of the stimulus (and subsequent naming), the latter man-made/natural task requires a further binary classification. The present thesis concentrates primarily on these latter indirect classification tasks, though I will return to identification tasks in the final chapter.

A further reason for the interest in priming is that it has been used for many years as a tool to investigate the nature of mental and neural representations. By testing the degree to which priming generalises over some change in the stimulus (e.g., when presenting pictures of the same object but from different viewpoints), one can infer the degree of abstraction of the mental representations assumed to underlie the priming. In this way priming has been used to investigate the view-dependence of object representations (Biederman & Gerhardstein, 1993) and the separate existence of morphological representations of words (Marslen-Wilson, Tyler, Waksler & Older, 1994). The same logic has more recently been combined with functional neuroimaging, examining where priming effects are observed in the brain when repeating stimuli at various levels of abstraction, and hence inferring the nature of neural representations in certain brain regions (Henson, 2003). The alternative explanation of behavioural and neural priming effects explored in this thesis, however, questions such a use of priming.

1.2 Theories of repetition priming

1.2.1 Modification accounts

1.2.1.1 Abstractionist accounts

Early studies of priming typically interpreted priming as a *modification* of pre-existing mental representations (Bowers, 2000; Tenpenny, 1995) (see Figure 1.1). For example, presentation of a picture of a familiar object is likely to entail activation of a pre-existing representation of that object. This activation may lead to temporary or long-lasting changes in the representation's baseline level of activation such that re-activation of that representation in the future occurs more rapidly (e.g., Morton, 1969). Alternatively, activation of specific representations may lead to the strengthening of connections between such representations, perhaps related to synaptic or neural changes in the brain – the "greased tracks" metaphor (e.g., Henson, 2003). Evidence in favour of such "abstractionist" accounts comes from studies that show priming regardless of the task or context in which a stimulus is initially presented. For example, priming has been shown for low-frequency words when the task was switched between presentations (Bowers & Turner, 2003) and even for words embedded within prose passages at initial presentation (i.e., when stimuli were presented in a different context/task to subsequent presentation; Nicolas, 1998).

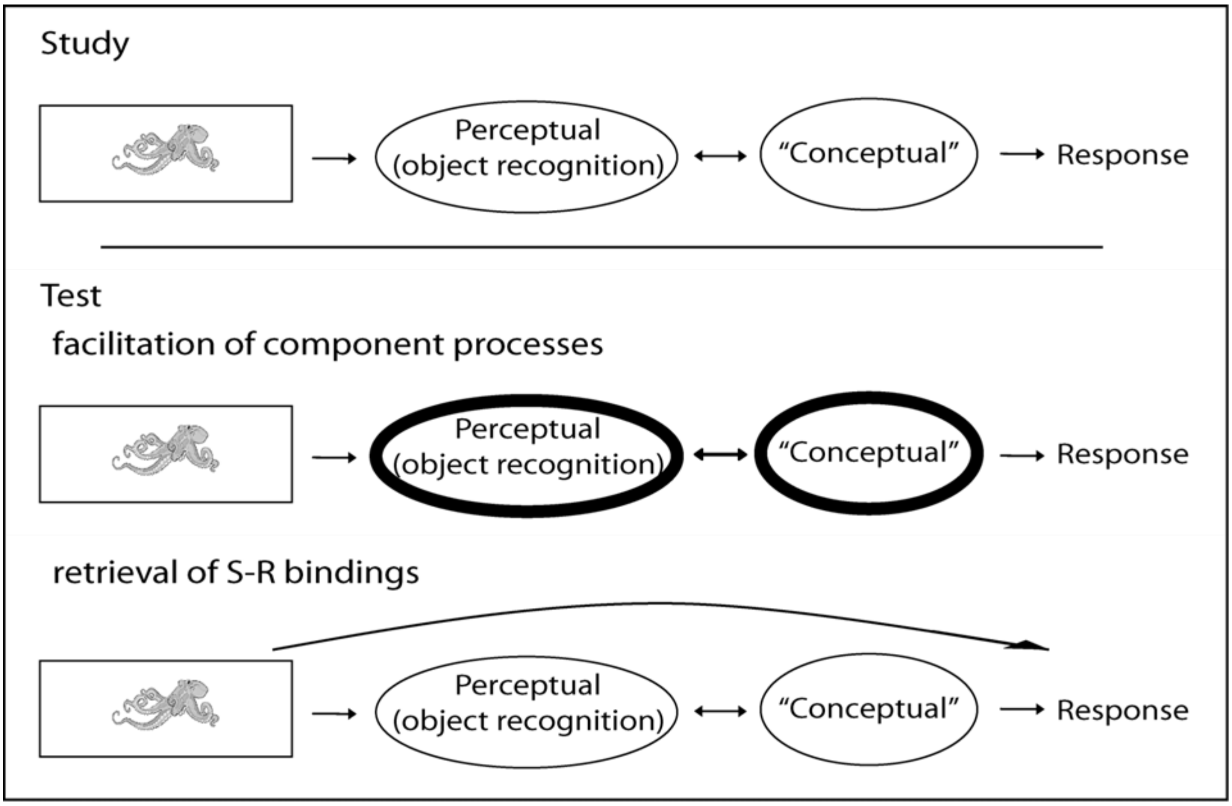

Figure 1.1. At Study, the presentation of a visual object entails the recruitment of specific processes involved in the perceptual identification of the object as well as the extraction of particular (possibly semantic) task-relevant information prior to the generation of an appropriate response. Under the component process account, one or more of these process are facilitated at Test (i.e., when a stimulus is repeated) therefore resulting in priming. Alternatively, a previously encoded Stimulus-Response (S-R) binding is retrieved, resulting in the effective by-passing of previously engaged component processes.

1.2.1.2 Perceptual representation systems

Such priming need not depend on pre-existing representations however. Instead, facilitation could arise from the construction of novel stimulus representations, for example within a Perceptual Representation System (PRS) (e.g., Schacter, 1990). Here priming is thought to reflect the activation of a representation that was constructed on initial presentation. Such activation is thought to be less time consuming than the processes involved in the construction of a new representation, resulting in faster RTs. Consistent with the specialised role of a PRS, priming has been shown for novel 2D pictures of 3D "possible", but not "impossible", objects, suggesting that priming can reflect the construction (and subsequent activation) of 3D "structural" representations of objects (Schacter, Cooper & Delaney, 1990). Indeed, the mechanisms involved in the learning of new representations may be the same as the modifications thought to occur in standard abstractionist accounts, as illustrated for example by weight changes in connectionist models (Bowers, Damian & Havelka, 2002; Marsolek, Schnyer, Deason, Ritchey & Verfaellie, 2006; Stark & McClelland, 2000).

1.2.2.3 Component process theories

A different, though related, conception is that priming involves the facilitation of specific processes or procedures entailed by a task (Kolers & Roediger, 1984; Logan, 1990; Roediger, Weldon, & Challis1989b). Such processes might be thought of as task-specific computations and/or mappings between representations. Although this conception would seem to make similar predictions to abstractionist theories, the procedural conception does not focus on individual representations of stimuli. Thus it can explain practice effects in tasks like reading inverted or mirror-reversed text. With practice, participants are able to rapidly read such text despite a change in stimulus set (i.e., prose passage) between practice and test (Kolers & Perkins, 1975). In other words, such practice effects can generalise to new items. Procedural theory therefore offers greater explanatory flexibility in that it can accommodate highly task-specific novel processes. At the same time however, the procedural conception makes few *a priori* predictions regarding the specific types of processes that are engaged by tasks or that can demonstrate facilitation.

Though having few *a priori* predictions about the types of processes that can be primed, one useful heuristic within the procedural framework has been the broad distinction between *perceptual* and *conceptual* processes (Blaxton, 1989; Roediger & McDermott, 1993). Such a distinction is primarily based on studies that show a dissociation between data-driven tasks thought to engage primarily perceptual processes, such as word identification, and conceptually-driven tasks thought to engage more conceptual processes, such as word generation when presented with an antonym (e.g., Jacoby, 1983b; though see Tenpenny & Shoben, 1992 for a critique of the data-driven/conceptually-driven distinction). More generally however, it is likely that there are multiple different computations that can be facilitated during any one task, the so-called *component process* (CP) view of priming (Tenpenny & Shoben, 1992; Witherspoon & Moscovitch, 1989) (see Figure 1.1). For example, priming in word-stem completion paradigms has been shown despite changes in modality between presentations (Richardson-Klavehn & Gardiner, 1996), suggesting a conceptual locus for such effects. However, word-stem completion priming is also reduced following graphemic versus phonological study tasks (Richardson-Klavehn & Gardiner, 1998), suggesting a perceptual component. Such results are therefore difficult to characterise with the broad perceptual vs. conceptual distinction, suggesting facilitation can occur at a lexical level too. Note though that not all component processes necessarily make a significant contribution to the final amount of priming, in that the critical ones that can be facilitated significantly by repetition are likely to be those that are not already maximally efficient (Henson, 2003).

According to the CP theory, the amount of priming reflects the degree of overlap between processes performed on initial and repeated presentation of a stimulus (analogous to Transfer Appropriate Processing - TAP; Morris, Bransford & Franks, 1977). In favour of such an account, priming (particularly for high-frequency words) has been shown to be sensitive to switches in task between presentations

(Franks, Bilbrey, Lien & McNamara, 2000), with the transfer of priming dependent on the similarity of semantic information retrieved by tasks at initial and subsequent presentation (Xiong, Franks & Logan, 2003).

Critically, both abstractionist and CP accounts are what have been termed “modification” accounts of priming. They both predict that the same mental representations and/or psychological processes are activated or engaged at initial and subsequent presentations of a particular stimulus, and that these representations/processes are in some way modified resulting in facilitation. In short, assuming that task demands remain constant, the “qualitative” representations/processes engaged in the generation of a response remain constant regardless of repetition. Given CP theory has become the modal theory of repetition priming, the present thesis uses this theory as the primary example of a modification account of repetition priming.

1.2.2 Episodic accounts

An alternative view to such modification theories of priming suggests that priming reflects the formation and retrieval of unique “episodes” (Hintzman, 1976). Such episodes would encode, at a minimum, the stimulus presented and response made (Dennis & Schmidt, 2003; Hommel, 2004), but may also include additional contextual information (McKoon & Ratcliff, 1986) (note however that such episodes are not necessarily related to the idea of conscious "episodic" memory; Tulving, 1972). In support of such a conception, priming has been shown to be sensitive to changes in contextual detail between presentations (Tenpenny, 1995). Furthermore, episodic representations would seem necessary to explain priming for novel associations between stimuli (Goshen-Gottstein & Moscovitch, 1995; Paller et al., 1992). Within the broad domain of episodic accounts of priming, theories that focus on the binding of stimuli and responses are often referred to as “response learning” or “Stimulus-Response” (S-R) theories. The focus of the present thesis is on such S-R theories of priming.

1.2.2.1 S-R theories

One specific example of an S-R theory of priming is the "instance theory" proposed by Logan (1990), as an extension of his theory of expertise (Logan, 1988). This theory assumes that the response to the initial presentation of a stimulus is generated by an algorithmic processing route (i.e., the engagement of specific component processes), but that this response also becomes stored together with the stimulus in a separate "instance" (i.e., episode/S-R binding). When the stimulus is repeated, there is a race between the algorithmic route and retrieval of any previous instances. If the retrieval of a previous instance wins the race, the RT will be shorter, producing priming (see Figure 1.1). Importantly, stimulus repetition is not thought to result in the speeding up of the algorithmic route (e.g., facilitation of component processes); priming instead results from a qualitative shift in processing, from the generation of a response via an algorithmic route to one of instance retrieval. By assuming that each stimulus-response repetition (i.e., trial) leads to the formation of a new instance, Logan's theory provides an elegant account of the change in both the mean and variance of RTs as a function of the number of repetitions.

Critically, Instance Theory predicts that priming should only be present when a response is repeated between initial and subsequent presentation. When a response is changed between presentations of a stimulus, the theory predicts that no priming should occur as the system reverts to the algorithmic route that does not show facilitation. Note that the two routes to response generation are independent in Logan's model, with the fastest route winning the race for response selection. In situations where the response should be reversed between presentations (e.g., following a task-switch), the successful retrieval of an inappropriate/incorrect response code should cause both an error and a speeding up of RTs. Alternatively, if the algorithmic route wins the race and is not itself error-prone, RTs should show no change. As such, RTs should never be slower than the time taken for the algorithmic route to produce a response. This lack of interference predicts that RTs for correct responses to repeated stimuli should never be slower than for novel stimuli when a response is changed between presentations (i.e., negative priming cannot occur).

The encoding of S-R bindings is also consistent with the Event File theory proposed by Hommel (1998). This theory can be seen as an extension of the object-file theory (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992) originally proposed as a system that binds together visual information relating to a single object. These bindings were thought to include, though not exclusively, information relating to the stimulus shape, colour and location. The Event File theory extends this proposal to include bindings between stimuli and information relating to the task performed and response made, as well as additional contextual information. This theory has thus far focussed on interfering effects of prior encounters with a stimulus, whereby discrepancies between the present circumstances and retrieved Event Files tend to slow RTs compared to novel stimuli (Hommel, 2004). Given this focus on interference, it is presently unclear how the theory predicts positive priming (i.e., a speeding of RTs) as a result of response repetition (though see Waszak & Hommel, 2007).

Note that in the above discussion of S-R theories of repetition priming I have not given a precise definition of what constitutes a “response” or a “stimulus”. For example, the question of whether responses in S-R bindings relate to specific motor-actions (e.g., left/right finger-press) or more abstract task-dependent decisions (e.g., “yes”/“no” in a binary classification task) is still disputed in the literature (e.g., Dobbins, Schnyer, Verfaellie & Schacter, 2004; Logan, 1990; Schnyer et al., 2007), as is the question of whether or not S-R effects are “hyper-specific” to repetition of exactly the same stimulus (e.g., identical pictures of an object) (Denkinger & Koutstaal, 2009; Schnyer et al., 2007). I address these issues directly in Chapter 4.

1.2.3 Predictions of S-R versus CP theories

To summarise, the Instance Theory predicts positive priming (shorter RTs) only when a response is repeated between presentations (i.e., when response retrieval wins the race). When a response is changed/reversed, Instance Theory predicts that no nett priming should occur. This is because the system reverts back to the algorithmic route, that does not show facilitation. The Event File Theory predicts that the reversal of a response between presentations results in slowing of RTs (i.e., negative priming). Although it is unclear what the theory predicts when a response is repeated, it is plausible to suggest the theory predicts no nett priming. More importantly, the Instance and Event File Theory predict a difference in priming dependent upon the repetition/reversal of response between presentations. In contrast to these S-R theories, the CP account of priming predicts that positive priming should occur regardless of response repetition/reversal – as long as the same component processes are engaged at initial and subsequent presentation. This is because CP theories predict that priming can only result from the facilitation of processes that are stimulus specific. Although response-selection processes may show facilitation, if they are not bound to a specific (repeated) stimulus, facilitation will occur for both repeated and novel stimuli and therefore no priming will occur. Thus, repeating/reversing a response between repetitions should have no effect on priming.

In light of these predictions, S-R and CP accounts of priming are typically assessed by means of a response switch (versus response repetition), usually effected by a switch in task between initial and subsequent presentation of a stimulus. Using this manipulation, S-R learning has been shown to contribute to repetition priming of RTs and/or errors in long-lag classification tasks (e.g., Dennis & Schmidt, 2003; Schnyer et al., 2007), though its contribution is normally believed to supplement that from facilitation of component processes. Importantly, if priming does reflect such a qualitative shift in processing, and a "by-passing" of previously engaged processes, these S-R learning effects question the commonly held assumption that priming can be used as a tool with which to investigate the nature of stimulus representations, and question the nature of memory processes that are intact in amnesia.

1.2.4 S-R learning across numerous paradigms

1.2.4.1 Task-switching paradigms

S-R effects have been studied extensively within the context of task-switching (Allport & Wylie, 1999; Koch & Allport, 2006; Waszak, Hommel & Allport, 2003). These experiments show that RTs are usually slower after a task-switch, the so-called task-switch cost (Rogers & Monsell, 1995). More importantly for present purposes, RTs are also modulated by the prior task and/or response history of a repeated stimulus (Allport & Wylie, 1999; Koch & Allport, 2006; Waszak et al., 2003). In particular, RTs tend to be slower (relative to novel stimuli) when a stimulus is repeated in a task that is incongruent with the task performed on its prior presentations. Such stimulus-specific task-switch costs are thought to result from the retrieval of information relating to the previous task and/or response, which interferes with the selection of a new response. Note however that such research has focussed primarily on the behavioural costs associated with switches in response between stimulus presentations, rather than the benefits (e.g., faster RTs) associated with response repetition as shown in long-lag repetition priming paradigms (though see Koch & Allport, 2006; Waszak et al., 2003).

1.2.4.2 Masked priming paradigms

S-R learning has also been used to explain aspects of short-lag subliminal priming (Abrams, Klinger & Greenwald, 2002; Damian, 2001; Kiesel, Kunde & Hoffmann, 2006; Kiesel, Kunde & Hoffmann, 2007; Klauer, Eder, Greenwald & Abrams, 2007; Kunde, Kiesel & Hoffmann, 2003). Subliminal priming paradigms typically assess priming for a “probe” stimulus that is immediately preceded by a “prime” stimulus. This prime stimulus is rendered subliminal by brief presentation accompanied by some form of masking. Facilitation is normally seen when the prime and probe are the same stimulus (Forster & Davis, 1984). Recently however there has been much debate as to whether “semantic” effects can be seen, where a stimulus is preceded by a semantically related masked prime (e.g., Hodgson, 1991).

Although such effects have been seen, it has been argued that they are due solely to S-R learning (Damian, 2001). This is because such subliminal semantic priming has typically been found in paradigms in which the stimuli are repeated across trials, such that a stimulus used as the probe on one trial can be used as a prime in later trials. This raises the possibility that stimuli can become associated with a response when they generate that response as a probe, and that this response can be triggered when that stimulus is presented briefly as a prime in a subsequent trial (causing priming), without that prime stimulus necessarily being processed semantically.

Although more recent studies have controlled for S-R contributions and still found evidence for subliminal semantic priming, there is little doubt that S-R learning plays a dominant role in such paradigms if not controlled (see Van den Bussche, Van den Noortgate & Reynvoet, 2009 for a meta-analysis). Such results are theoretically interesting in that they suggest that, whereas the encoding of S-R bindings requires conscious awareness of the stimulus (i.e., they are only formed when the stimulus is shown as a probe), such bindings are retrieved automatically with no need for conscious awareness (i.e., when previous probe stimuli are repeated as subliminal primes), as tested empirically by recent studies of masked categorical priming (e.g., Eckstein & Henson, submitted). Note however that further studies have shown that, while awareness for the prime may not be necessary to see masked priming effects, spatial (e.g., Lachter, Forster & Ruthruff, 2004) and temporal (e.g., Naccache, Blandin & Dehaene, 2002) attention are necessary. The issue of attention is revisited in the next section.

1.2.4.3 Negative priming paradigms

S-R learning has also been used as an explanation for negative priming effects (Frings, Rothermund & Wentura, 2007; MacDonald & Joordens, 2000; Rothermund, Wentura & De Houwer, 2005). Negative priming refers to a slowing of RTs when previous non-target (unattended) stimuli are repeated as targets (attended) (see Fox, 1995; Tipper, 2001 for reviews). This effect is often thought to reflect the inhibition of task-irrelevant stimulus representations (Tipper, 1985). Such inhibition is thought to produce carry-over effects from initial to subsequent presentation, resulting in a slowing of RTs. Alternatively, unattended task-irrelevant stimuli might be tagged with a “do-not-respond” code that interferes with response generation on subsequent presentation (Neill, 1997). Again however, a third type of explanation for negative priming has appealed to S-R learning. According to such accounts, the response given to an attended stimulus becomes bound to the critical task-irrelevant unattended stimulus. In other words, a response becomes bound to any co-occurring stimulus, regardless of attention. When the unattended stimulus is repeated (and attended) negative priming can manifest if the response previously bound to the stimulus is incongruent to the newly generated response. Studies showing such effects therefore suggest that attention is not a necessary condition in the encoding of S-R bindings. I return to the issue of attention in Chapter 7.

1.2.5 Limitations of S-R theories of repetition priming

Although S-R contributions to priming have been seen across the range of paradigms described above, certain results are more difficult to explain in terms of the encoding and retrieval of unique S-R bindings. In particular, although long-lag classification paradigms have shown clear S-R learning effects (e.g., Dennis & Schmidt, 2003; Logan, 1990; Schnyer et al., 2007), the results from studies using identification tasks would seem less explicable in terms of S-R learning (e.g., Jacoby, 1983a; Roediger & McDermott, 1993; Roediger et al., 1989a). For example, tasks requiring the identification of a degraded or fragmented stimulus at test (e.g., word-stem completion) are difficult to reconcile with S-R accounts, particularly given that the type of response made between study and test phases can be dissimilar (e.g., counting syllables at study and completing a word-stem at test, Schott et al., 2005). Although the present thesis focuses on the role of S-R binding in classification paradigms, I return to the differences between classification and identification paradigms in the final chapter.

1.3 S-R theories and repetition suppression

More recently S-R theories have been offered as a means to explain the reductions seen in neural activity following stimulus repetition, as measured by functional magnetic resonance imaging (fMRI) and magneto/electro-encephalography (M/EEG). In the case of fMRI, these repetition-related reductions in certain (but not all) cortical regions has been termed *repetition suppression* (RS; Grill-Spector, Henson & Martin, 2006). For example, when a visual object is repeated in the context of a given task, reductions in neural activity are often seen in lateral occipital and inferior temporal visual regions (i.e., the ventral visual stream) as well as distinct regions in prefrontal cortex (PFC). Given the co-occurrence of behavioural priming and these reductions in cortical activity, RS is often thought of as a neural analogue of behavioural priming. RS may therefore represent a fundamental form of long-term stimulus-specific neural plasticity, reflecting more efficient neural processing. In turn, such increased neural efficiency may contribute to analogous improvements in behavioural performance, such as priming (e.g., faster reaction times to make a categorisation; see Henson, 2003; Schacter & Buckner, 1998).

As in the behavioural priming literature, such RS is often attributed to the facilitation of certain processes engaged at both initial and subsequent presentation (i.e., component process accounts; Henson, 2003). In the previous example, the RS seen within ventral visual regions following repetition of a visual stimulus is often thought to result from the facilitation of visual identification processes. RS within inferior PFC however is often thought to result from the facilitation of task-specific semantic/conceptual and/or phonological processes (e.g., Poldrack et al., 1999; Wagner, Desmond, Demb, Glover & Gabrieli, 1997; Wagner, Koutstaal, Maril, Schacter & Buckner, 2000). Under this conception (as in the priming literature), RS can be used as a tool to investigate the nature and localisation of neural representations. For example, RS has been used to investigate the nature of object (e.g., Eger, Henson, Driver & Dolan, 2004; Kourtzi & Kanwisher, 2001; Vuilleumier, Henson, Driver & Dolan, 2002) and face (e.g., Eger, Schweinberger, Dolan & Henson, 2005; Eger, Schyns & Kleinschmidt, 2004; Winston, Henson, Fine-Goulden & Dolan, 2004) representations within the ventral visual processing stream.

S-R accounts however suggest that RS results not from the facilitation of particular component processes, but from the by-passing of such processes. Whereas an experimentally novel stimulus will still recruit certain component processes (i.e., the algorithmic route) in the generation of a task-appropriate response, a repeated stimulus no longer requires the engagement of such processes. In other words, a previously encoded S-R binding is automatically retrieved enabling the rapid execution of a response. This results in the effective by-passing (or curtailing) of previously engaged component processes, causing a reduction in activity in the neural implementation of the algorithmic route. In support of such an explanation, an influential paper by Dobbins et al. (2004) (which prompted many of the experiments herein, and which informed the present paradigms) recently presented evidence suggesting that the RS effect, even within "early" perceptual regions, is dependent upon response repetition between stimulus presentations. Whereas they saw robust RS in ventral visual and inferior prefrontal regions for repeated stimuli when a response was repeated, RS was significantly curtailed (and no longer reliable) when a response was reversed between presentations. These results are striking in that they suggest that RS, even in supposed "visual" regions, simply reflects the retrieval of an S-R binding (though see Horner & Henson, 2008; Race, Shanker & Wagner, 2009 and Chapter 5 of the present thesis). Importantly, these results undermine the use of RS as a tool with which to investigate particular neural representations.

1.4 Pitting CP versus S-R theories

Although I have detailed a number of studies in favour of either CP or S-R accounts of repetition priming, it is plausible that priming results from the combination of both the facilitation of repeated component processes as well as the retrieval of S-R bindings. Indeed, a recent study suggested that contributions to priming from S-R learning – but not from component processes – are disrupted in amnesic patients (Schnyer et al., 2006). Specifically, amnesic patients did not demonstrate greater priming following response repetition than response reversal (that the controls did, and as S-R theories predict). Nonetheless, amnesics did show reliable priming for repeated objects that received either the same or a reversed response between repetitions. This significant priming was attributed to the facilitation of component perceptual and/or conceptual processes that are assumed to be intact in these amnesics (e.g., occurring in cortical regions unaffected by their brain damage, which was primarily to MTL regions). This finding therefore suggests a possible dissociation between S-R and CP contributions to behavioural priming.

If indeed priming can result from the facilitation of component processes and the retrieval of S-R bindings, a theory of priming is needed that incorporates both contributions. In particular, such a theory would need to explain how these independent contributions ultimately interact to effect a response. In the development of such a theory, several issues regarding S-R learning need to be addressed. I next introduce several questions that the present thesis will attempt to answer. In the final chapter the answers to these questions will be used in the development of a novel framework designed to incorporate S-R and CP contributions to behavioural and neural repetition effects. Specifically, this framework will aim to relate the repetition-related changes in neural activity, as measured by fMRI and EEG in Chapters 5 & 6 with the behavioural priming effects seen in Chapters 2, 3, 4 & 7.

1.4.1 Question 1: How dominant are S-R contributions within long-lag classification paradigms?

As previously stated, S-R learning contributions to priming have been seen within long-lag classification paradigms (Dennis & Schmidt, 2003; Dobbins et al., 2004). Such S-R learning has been generally thought to supplement contributions from facilitation of component processes. For example, in the Dobbins et al. (2004) study, the authors saw greater priming when stimuli and responses were repeated between presentations compared to when responses were reversed. Significant positive priming was still present despite reversal in responses however. This significant positive priming following response reversal is not predicted by any current S-R theory and was therefore proposed to reflect the facilitation of component processes.

Although these data support the idea that both component process and S-R contributions can be seen within the same experimental paradigm, the relative magnitude of these effects is still unclear. The Dobbins et al. (2004) study manipulated response repetitions/reversals by means of between-block repetitions/reversals in task. During a “Start” phase, participants classified pictures of objects as to whether they were “bigger than a shoebox” in real life. Repetitions of stimuli in this block therefore required completion of the same task and as a result the same response. In a subsequent “Switch” phase, participants were asked the opposite question, viz. whether the object was “smaller than a shoebox”. As such, any stimulus that was initially presented in the Start phase required a reversal of response during the Switch phase (e.g., an item that is “bigger than a shoebox” will receive a “yes” response in the Start phase and a “no” response in the Switch phase).

One issue with the Start/Switch response manipulation is it remains unclear whether the retrieval of S-R bindings are increasing priming in the Start phase or decreasing priming in the Switch phase. In other words, is the retrieval of S-R bindings facilitating processing when a response is repeated or interfering with processing when a response is reversed? Although positive priming is seen in the Switch phase, it is possible that this could be the nett result of facilitation from repeated component processes and interference from S-R learning (presuming facilitation outweighs interference). As such, the Start/Switch paradigm does not offer a means to assess the baseline level of component process facilitation within an experiment.

In the experiments described in Chapters 2-3, I utilised a similar design to that of Dobbins et al. (2004) in order to replicate and extend their previous results. At Study, I asked participants whether pictures of objects were “bigger than a shoebox”. In two of the conditions at Test, I either asked them the same question (i.e., “bigger than a shoebox?”) or the reverse question (i.e., “smaller than a shoebox?”). One half of the stimuli at Test are repetitions of those at Study (Repeated), the other half are experimentally novel (Novel), comparison of which gives the basic measure of priming. These Same and Reverse conditions are analogous to the Start and Switch phases of Dobbins et al. (2004), but within a more conventional “Study-Test” design that equates the lag between initial and repeated presentations across the conditions; a confound of the Dobbins et al. study (see Chapter 2 for more details). To address the baseline issue outlined above, I introduced a third Test condition in which I asked a question at Test (e.g., “is the object man-made?”) that was unrelated to that at Study. Here the stimuli were chosen so that responses made at Test were, on average, orthogonal to those made at Study (i.e., 50% of stimuli required the same response, 50% required a reversal of response). This condition was designed to act as a baseline measure against which possible facilitatory and/or interference effects in the Same/Reverse condition could be measured. I therefore used this design to assess the relative contribution of S-R learning compared to facilitation of component processes (Chapters 2-3).

1.4.2 Question 2: At what level are stimuli and responses represented within S-R bindings?

Whereas Chapters 2-3 were concerned with measuring both S-R and CP contributions to priming, in Chapter 4 I turned my attention to the type of information encoded within S-R bindings. Specifically, I asked: at what level(s) of representation are stimuli and responses encoded in S-R bindings? Although some previous research has attempted to address this issue, it has led to contradictory conclusions about whether S-R binding occurs at highly specific motor-action representations (e.g., right/left finger press; Dobbins et al., 2004) or more abstract decision representations (e.g., "yes"/"no"; Logan, 1990; Schnyer et al., 2007). Research focussing on the level of stimulus representation has led to similar contradictory conclusions, with evidence for S-R bindings at highly specific representations that are tied to the specific visual format of the stimulus (Schnyer et al., 2007) or representations that are able to abstract across different object exemplars (e.g., two differing pictures of a lion; Denkinger & Koutstaal, 2009).

One possibility however is that S-R bindings can occur at multiple levels of stimulus and response abstraction. Here I can distinguish at least two levels of stimulus representation: a specific depiction of an object and an abstract representation of the identity of that object, and three possible levels of response representation: a particular motor Action (e.g., left/right finger-press), a particular binary Decision (e.g., yes/no) and a particular task-dependent Classification (e.g., bigger/smaller) (see Figure 1.2). Each of these levels of stimulus and response abstraction have been proposed in previous research (Abrams et al., 2002; Damian, 2001; Denkinger & Koutstaal, 2009; Dobbins et al., 2004; Koch & Allport, 2006; Logan, 1990; Schnyer et al., 2007), but normally when contrasting one with another, under the assumption that only one true level of stimulus or response representation needs to be identified.

This issue of multiple response codes is particularly pertinent to the results of Dobbins et al. (2004). Specifically, whereas the Start/Switch design results in the reversal of response at the level of both Action (e.g., left/right finger-press) and Decision (e.g., yes/no), it does not require a reversal at the level of a task-dependent Classification (e.g., a lion is always “bigger” regardless of the direction of the question). If responses are coded at such an abstract level of representation, it is possible that the Start/Switch design fails to control appropriately for S-R learning. Indeed, this may explain why residual priming was present in the Switch phase of the Dobbins et al. experiment, a result previously thought to reflect the facilitation of component processes. In Chapter 4 I address the issue of the level of both stimulus and response representation within S-R bindings.

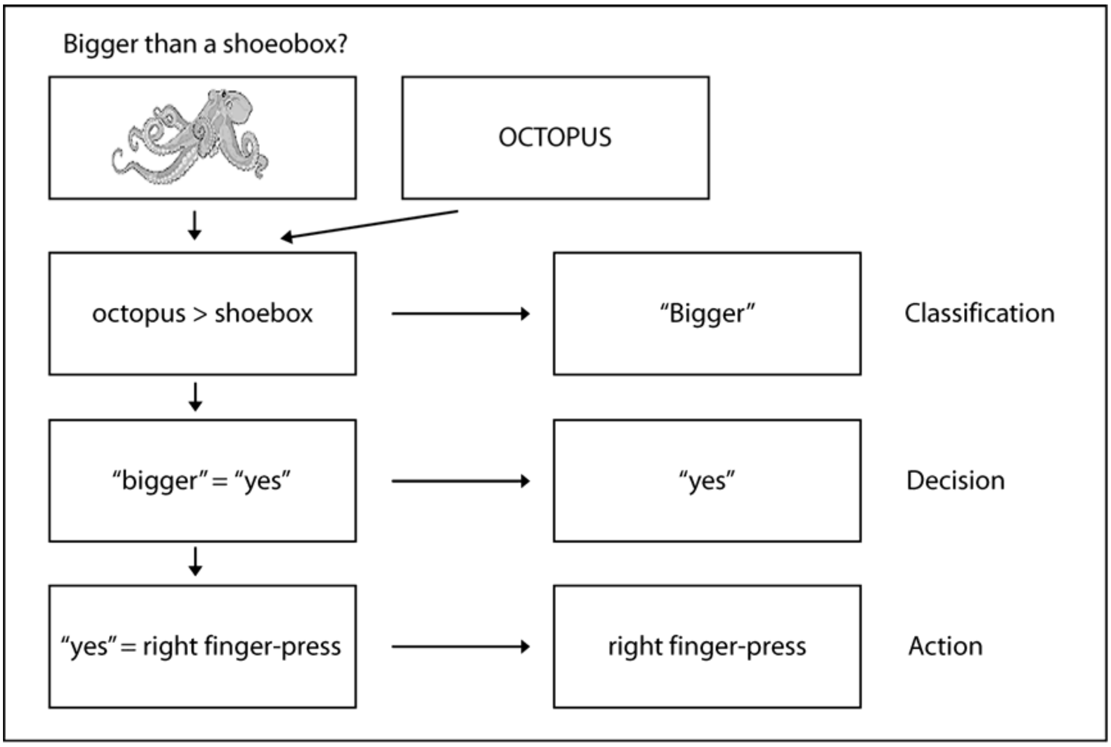

Figure 1.2. Two possible levels of stimulus representation ("specific" and "abstract") and three possible levels of response representation (Classification, Decision and Action). Either stimulus representations are specific to repetition of the same visual stimulus between presentations (e.g., a picture of an octopus), or they form at an abstract level and can be retrieved despite a change in visual format between presentations (e.g., a picture of an octopus and the word "octopus"). With regard to response representations, when a stimulus is presented in the context of the "bigger-than-shoebox" task the participant must first compare the size of the stimulus to that of a shoebox, resulting in a size-classification of "bigger". Due to the particular direction of the question (i.e., "bigger-than"), a "bigger" Classification is mapped to a "yes" decision. This "yes" decision is then mapped to the appropriate motor-response, resulting in a right finger-press Action.

1.4.3 Question 3: Does retrieval of S-R bindings result in facilitation when a response is repeated, and/or interference when a response is reversed?

Although S-R learning has been clearly demonstrated within long-lag classification paradigms (Dennis & Schmidt, 2003; Dobbins et al., 2004; Schnyer et al., 2007; Schnyer et al., 2006), these effects have largely been thought of as facilitatory in nature. Within the task-switching literature however, such task/response reversals have been shown to result in a slowing of RTs, suggesting that retrieval of S-R bindings can interfere with current response selection (Koch & Allport, 2006; Waszak et al., 2003). To date, no long-lag classification experiment has demonstrated both facilitation and interference effects owing to the retrieval of S-R bindings. This issue is particularly important given the predictions of Instance Theory, where a slowing of RTs should not occur. Specifically, when a trial requires a change or reversal in response between presentations, Instance Theory predicts that priming should not occur if a correct response reversal is made (as the system reverts to algorithmic processing). Alternatively, response retrieval could win the race, resulting in faster RTs but an incorrect response. Thus, Instance Theory predicts a trade-off between RTs and accuracy. In situations where a reversal of response is required, priming should not be seen when a "correct" response is made. Using a variety of manipulations to effect repetitions/reversals in response I address the issue of facilitation/interference across Chapters 2-6.

1.4.4 Question 4: Are repetition-related changes in neural activity, as measured by fMRI and EEG, related to S-R learning or component process contributions to behavioural priming?

Whilst the results of Dobbins et al. (2004) suggest that RS effects, as measured by fMRI, are sensitive to the retrieval of S-R bindings, other studies have found robust RS, particularly within occipital/temporal ventral visual regions, under conditions deliberately chosen to limit the occurrence of S-R learning. For example, RS in inferior temporal regions has been seen when using tasks that had no explicit response requirements for the critical stimuli (Henson, Shallice & Dolan, 2000), when changing tasks such that the response on repetition of a stimulus was (on average) orthogonal to its previous response (Henson et al., 2003; Horner & Henson, 2008), and when changing both the stimulus and response, resulting in no obvious S-R binding, such as in identification paradigms that involve different tasks at study and test (e.g., word-stem completion Schacter, Alpert, Savage, Rauch & Albert, 1996; Schott et al., 2005). Thus S-R bindings would not appear sufficient to explain RS in all brain regions, particularly parts of the ventral visual processing stream.

In Chapter 5, I present an fMRI experiment designed to assess the relative roles of S-R and CP contributions in RS. The design of the experiment was based on the behavioural results presented in Chapters 2-4. Specifically, it controlled for S-R bindings at the three levels of response representation that I proposed above, and simultaneously examined changes in both response and stimulus representation. With this “optimised” experimental design, I was able to test for S-R and CP contributions to RS in a more rigorous manner than the design of the Dobbins et al. (2004) study allowed.

One problem with fMRI is it lacks the resolution to temporally dissociate particular effects that could occur within-trial. Indeed, it is possible that fMRI RS may reflect changes in activity post-response and therefore may not be behaviourally relevant (see General Discussion – Chapter 5). I therefore present the results of an EEG study, using the same experimental design as the fMRI study, in Chapter 6. Although previous studies have demonstrated repetition-related changes in event-related potentials (ERPs) (Henson, Rylands, Ross, Vuilleumeir & Rugg, 2004; Schendan & Kutas, 2003) and induced responses in the gamma frequency (Gruber & Muller, 2002, 2006) using pictures of common objects (as used in the present thesis), these studies have not addressed whether such effects are related to S-R learning or facilitation of component processes. Using the experimental design introduced in

Chapter 5, I directly assessed whether the repetition-related changes seen in these previous studies were specific to the repetition of responses between presentations.

1.4.5 Question 5: Is attention necessary for both the encoding and retrieval of S-R bindings?

The final question focuses on the role of attention in both the encoding and retrieval of S-R bindings. Previous research has suggested that negative priming can result from the binding of a particular response with an unattended stimulus on an immediately preceding trial (Rothermund et al., 2005). These short-lag interference effects mirror those of Hommel (2005), who presented evidence to suggest that Event Files can form in the absence of attention, even when a particular stimulus is task-irrelevant. It is presently unclear whether such effects can be seen in long-lag paradigms such as those in the present thesis. Interestingly, negative priming has been shown across long-lags (Grison, Tipper & Hewitt, 2005), however the issue of whether such effects were due to the binding of a response to a unattended stimulus were not explored. In Chapter 7 I therefore assessed whether bindings can form between responses (to task-relevant stimuli) and co-occurring though unattended (task-irrelevant) stimuli. Furthermore, I asked whether previously encoded S-R bindings are automatically retrieved when a repeated stimulus is unattended (task-irrelevant). In other words, I tested whether spatial attention (like awareness in masked priming) is necessary for the encoding and/or retrieval of S-R bindings in long-lag designs.

1.5 General methods

In Chapters 2-7, I present the results of several long-lag classification priming experiments. All experiments used a Study-Test design. At Study, a number of stimuli were presented; at Test, the same stimuli were repeated (Repeated) along with experimentally novel stimuli (Novel). The lag between Study and Test presentations of a particular stimulus were in the order of minutes (e.g., approx. 5-10mins), but “long-lag” in the sense that there were many trials between initial and repeated presentations of the same stimulus (Henson et al., 2004), and as distinct from the “immediate” repetition across trials that is typical of negative priming studies, or the “within-trial” repetition in masked priming studies. I used speeded classification tasks (e.g., “is the object bigger than a shoebox?”) throughout, inline with previous behavioural and neuroimaging research in this area (e.g., Denkinger & Koutstaal, 2009; Dennis & Schmidt, 2003; Dobbins et al., 2004; Franks et al., 2000; Horner & Henson, 2008, submitted; Koutstaal et al., 2001; Schnyer et al., 2007; Schnyer et al., 2006; Wig, Buckner & Schacter, 2009)

To ensure response reptitions/reversals between presentations I manipulated the task between Study and Test blocks. Although I used several manipulations throughout Chapters 2-7, in Chapters 2-3 I used a similar design to that introduced by Dobbins et al. (2004). Whereas at Study I asked: “is the object bigger than a shoebox?”, at Test I either asked the same question (“bigger than a shoebox?”; the Same condition), the opposite question (“smaller than a shoebox?”; the Reverse condition), or an unrelated question (e.g., “is the object man-made”; the Orthogonal condition).

Stimuli in all experiments were taken from a set of 400 colour images of common objects. These were generated from the sets used by Dobbins et al. (2004) and Koutstaal et al. (2001). To confirm their suitability for British participants, the objects were named and rated independently by six participants according to several different classifications (e.g., “is it bigger than a shoebox?” and “is it man-made?”). Object names and classifications were chosen by taking the modal response across raters. High naming agreement was present across raters (>80% of objects given the same name across all six subjects) with most names corresponding to the “basic category” level (Rosch, Mervis, Gray, Johnson & Boyes-Braem, 1976).

Nonetheless, given a high degree of inter-subject variability of responses in the classification tasks used, accuracy was defined according to the modal response across participants within each separate experiment. Thus, although I report analyses of accuracy data in Appendix A, these results should be interpreted with caution given there is some subjectivity in the definition of an “error”. Reaction times (RTs) for correct trials at Test constituted the main dependent variable. An additive and proportional priming measure was calculated for all experiments. Additive priming was defined as the difference in RTs for Repeated vs. Novel stimuli (Novel – Repeated). Proportional priming was defined as the difference in RTs for Repeated vs. Novel stimuli divided by Novel RTs (Novel – Repeated / Novel). Though the appropriate measure depends on one’s theory of priming, the proportional measure can be useful to rule out “range effects”, particularly if Novel RTs vary across conditions (i.e., in case the amount of priming scales linearly with overall RT). Nonetheless, given the additive measure of priming is more conventional in the priming literature, I report analyses of additive priming in the main text of each experiment, and the analyses of proportional priming in Appendix A.

1.6 Outline of thesis

The present thesis therefore aims to assess modification versus episodic theories of repetition priming introduced above. In particular, it is concerned with the relative S-R and CP contributions to repetition priming and associated repetition-related neural changes (e.g., RS). In Chapter 2 I outline an experimental design that seeks to replicate and extend the results of Dobbins et al. (2004). Here I assessed priming across three conditions: (1) when the task (and response) was repeated across Study and Test (the Same condition), (2) when the task (and response) was reversed across Study and Test (the Reverse condition) and (3) when the task at Test was unrelated to that at Study (the Orthogonal condition). This design revealed several important signatures of S-R learning. Surprisingly, little evidence of residual priming was found that might be attributable to the facilitation of component processes (Question 1).

Given the lack of evidence for CP contributions to priming in Chapter 2, the experiments presented in Chapter 3 aimed to increase the chances of seeing such contributions. Here I used the same task manipulations outlined in Chapter 2, however I attempted to boost potential perceptual and/or conceptual facilitation using other tasks and stimuli. Mirroring the results of Chapter 2, these experiments failed to reveal any priming effects that could be unequivocally attributed to the facilitation of component processes (Question 1).

However, in order to explain the results of Chapters 2 and 3 fully in terms of S-R learning, it was necessary to presume that S-R bindings form at multiple levels of response representation. In Chapter 4 I present two experiments that directly tested this assumption. These experiments revealed that S-R bindings can form simultaneously at three distinct levels of response representation, from a particular

Action (e.g., right/left finger-press) to a Decision (e.g., “yes/no”) to a task-dependent Classification (e.g., “bigger/smaller”) (Question 2). I also present evidence that S-R bindings form at an abstract level of stimulus representation, with evidence consistent with S-R learning at two levels of stimulus representation (Question 2). Throughout Chapters 2-4, I saw evidence for both facilitation, resulting from response repetition, and interference, resulting from response reversal, suggesting that the retrieval of S-R bindings can both facilitate/interfere with component processes at Test (Question 3).

In Chapter 5, I outline an experimental design, based on the results of Chapters 2-4, that appropriately controls for S-R learning at all levels of response representation. This design allows proper separation of S-R from CP contributions to priming. Using this design in Chapter 5, I present an fMRI study that assessed S-R and CP contributions to RS. This study suggests that both S-R and CP contributions can be seen within separate cortical regions (Question 4). Specifically, I present evidence for a dissociation between occipital/temporal regions, where RS is robust to response repetitions/reversals, and inferior prefrontal regions, where RS is sensitive to response repetition/reversals. In Chapter 6, I present an EEG experiment using the same design that again showed both S-R and CP contributions to repetition-related changes in ERPs (Question 4). These effects are shown to be topographically distinct, suggesting that they are produced by differing neural generators (in line with the fMRI results) and, importantly, at different times prior to response onset. The latter result helps rule out alternative explanations of the fMRI results, for example that the fMRI RS reflects reduced attention to stimuli after a behavioural decision is made (given the poor temporal resolution of fMRI).

Finally, in Chapter 7 I address the last question posed in this chapter concerning the role of attention in both the encoding and retrieval of S-R bindings within long-lag classification paradigms. Contrary to previous studies (using immediate repetition designs) that suggest that S-R bindings can form between responses and unattended stimuli (Rothermund et al., 2005), I found no evidence for S-R learning when repeating previously unattended stimuli over multiple trials in the present Study-Test design. I also found no evidence for S-R learning when a previously attended stimulus was unattended (task-irrelevant) at Test. The results of Chapter 7 therefore suggest that attention is necessary for both the encoding and retrieval of S-R bindings (Question 5), at least within the present long-lag classification paradigms.

The results presented in Chapters 2-7 present a challenge for current S-R and CP accounts of priming and repetition-related changes in neural activity (e.g., RS). In particular, the existence of both S-R and CP contributions to priming (i.e., in classification and identification paradigms) suggests that a framework is needed that integrates these two contributions to priming. In Chapter 8 I focus on the limitations of previous theories of priming, identifying specific results from Chapters 2-7 that a future theory of priming would need to accommodate. In light of this appraisal I propose a novel framework that attempts to explain the present priming and RS effects. This framework incorporates multiple routes (i.e., component process and S-R retrieval routes) with multiple stages (e.g., perceptual vs. conceptual component processes) to response generation and is better able to explain the present data than any existing S-R or CP theory of priming.

1.7 Chapter Summary

Priming, a change in response times and/or accuracy following stimulus repetition, is a robust phenomenon seen across a range of paradigms. These behavioural changes have been associated with repetition-related changes in neural activity, particularly repetition suppression (RS), as measured by fMRI and EEG. Priming and RS are often thought to reflect the facilitation of one or more cognitive processes during initial and subsequent presentations of a stimulus. Alternatively, priming could also reflect the formation of stimulus-response (S-R) bindings, retrieval of which can bypass many of the processes engaged during the initial presentation. In this chapter, I have introduced CP and S-R theories of repetition priming, focussing on the specific predictions of each theory in relation to response repetition versus response reversal. I then posed a number of questions that have not been answered fully by the present literature. I next introduced the basic methodology used to address these questions, namely long-lag classification priming of common objects. In the next chapter, I use this methodology to address the first question posed in the present chapter: just how important are S-R contributions within long-lag classification paradigms?

Chapter 2

S-R versus CP contributions to repetition priming

As described in the preceding chapter, stimulus-response (S-R) and component process (CP) theories of priming make differing predictions under conditions that require either a repetition or a reversal in response between stimulus presentations (i.e., response-congruency). Whereas CP theories predict priming should occur regardless of response-congruency, as long as the same processes are engaged at Study and Test presentations, S-R theories predict priming should be greater following a response repetition than a reversal.

The present chapter outlines an experimental paradigm designed to assess possible CP and S-R contributions to repetition priming. The design was based on the Start/Switch manipulation first introduced by Dobbins et al. (2004). At Study, pictures of common objects were presented and participants were asked “is the object bigger than a shoebox?” in real life. At Test, the stimuli seen at Study were repeated along with experimentally novel stimuli. In line with Dobbins et al. (2004), participants performed the same task (“bigger than a shoebox” – the Same condition) or the reverse task (“smaller than a shoebox” – the Reverse condition) at Test. Critically, responses at the level of Action (right/left finger-press) and Decision (yes/no) will be repeated in the Same condition but reversed in the Reverse condition.

In the present experiments, a further condition was also added, whereby an unrelated question was asked at Test (e.g., “is the object man-made?”) such that any “bigger” or “smaller” Classification responses that are bound to stimuli in the Study task would be irrelevant to the Test task. This condition was carefully constructed such that responses (Action and Decisions) at Study were on average orthogonal to those at Test. Thus it was assumed that any effects of S-R learning at the level of

Actions or Decisions would cancel on average. This Orthogonal condition was therefore an attempt to control for possible facilitation and/or interference in the Same/Reverse condition respectively. The Orthogonal condition also presented an opportunity to assess S-R contributions within-block, by comparing priming for stimuli that received the same Action/Decision response between Study and Test (response-congruent) versus stimuli that received the opposite Action/Decision response (response-incongruent). The present experiments also utilised a manipulation introduced by Dobbins et al. (2004) where stimuli at Study were either presented once (Low-primed) or three times (High-primed). This manipulation was included to increase possible SR and CP contributions to priming by increasing the number of Study repetitions, thus increasing the amount of exposure participants had with particular stimuli. This experimental design is presented in Figure 2.1.

Importantly, the present Study-Test design equates for lag between presentations, a potential confound in the Dobbins et al. (2004) study. In this study, the first presentation for all primed stimuli occurred during the Start phase. A certain proportion of these stimuli were repeated in this same block, and priming was assessed as the difference in RTs between first and subsequent presentations. In the later Switch phase (where the task was reversed) a certain proportion of the stimuli seen during the Start phase were repeated along with Novel stimuli and priming was assessed as the difference in RTs between these Repeated and Novel items. As such, the lag between presentations was greater for repeated stimuli in the Switch than Start phase. Given priming has been shown to decrease with increasing lag (Henson et al., 2004), the reductions in priming seen in the Switch phase may have been due to increased lag rather than resulting from a switch in response between presentations.

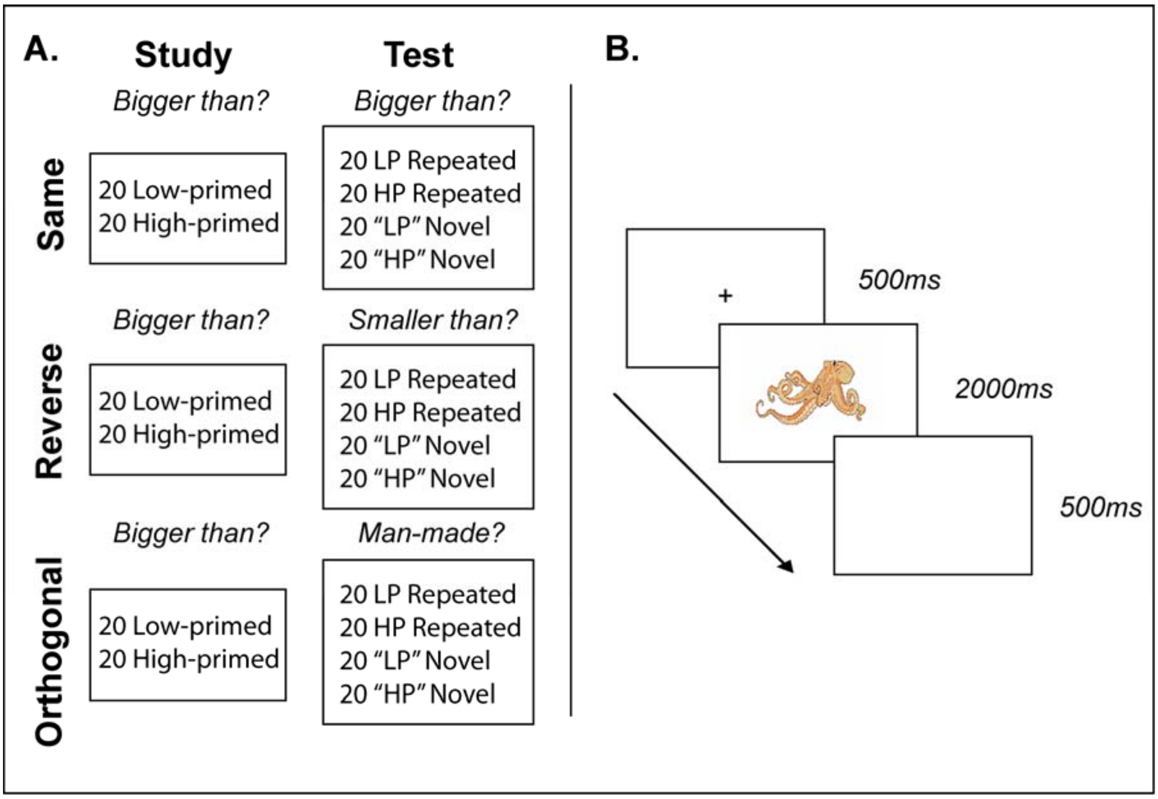

Figure 2.1. (A) Experimental design of Experiment 1. Stimuli were presented once (Low-primed) or three times (High-primed) at Study. Participants were asked "is the object bigger than a shoebox?". At Test the stimuli presented at Study were repeated (Repeated) intermixed with experimentally novel stimuli (Novel). Participants were either asked the same question (Same condition) the reverse question (Reverse condition) or an unrelated question (Orthogonal condition). (B) Trial sequence in both Study and Test blocks. A fixation cross was presented for 500ms followed by stimulus presentation for 2000ms. Each trial ended with a 500ms blank screen. Participants were free to respond at any point prior to the start of the next trial.

Before presenting the experimental results it is worth outlining the predictions that CP and S-R theories make. These predictions are presented in Figure 2.2. Firstly, if priming is solely a consequence of facilitation of perceptual processes, equivalent positive priming would be expected across all three task conditions (Figure 2.2-A). This is because all three tasks are likely to recruit similar object identification processes. A similar pattern of results might be expected from facilitation of conceptual processes. Here though, one might expect reduced priming in the Orthogonal condition if the Test task does not engage all the same conceptual processes as the Study task (a question addressed in Chapter 3) (Figure 2.2-B). In both cases, priming should generally increase for High-primed compared to Low-primed stimuli (i.e., facilitation should generally increase with increased stimulus exposure).

The predictions of an S-R theory depend on the nature of the response (R) representation. If responses are coded at the level of Actions (right/left finger-press) or Decisions (yes/no), positive priming should be seen in the Same condition. The Reverse condition should show significantly reduced priming compared to the Same condition. This is because the response given at Study is not repeated at Test in the Reverse condition (see below). In the Orthogonal condition, the mean amount of priming should be intermediate between that in the Same and Reverse conditions. This is because the same numbers of stimuli require a response repetition ("Congruent trials") as require a response reversal ("Incongruent trials"). Furthermore, if Congruent and Incongruent trials in the Orthogonal condition are split, greater priming should be seen for Congruent than Incongruent trials.

The exact nature of the priming effects seen in either the Reverse condition or for Incongruent trials in the Orthogonal condition depend on the degree to which retrieved S-R bindings can cause interference. If retrieved incongruent S-R bindings are effectively ignored, as predicted by Instance Theory, then no nett priming should be seen in either the Reverse condition or for Incongruent trials in the Orthogonal condition (Figure 2.2-C). This is because the retrieved response is simply ignored and the system reverts to algorithmic processing. If, however, retrieved S-R bindings actively interfere with processing, then negative priming (i.e., a slowing of RTs compared to baseline) should be seen in both conditions (Figure 2.2-D). Indeed, if the amount of facilitation for Orthogonal Congruent items owing to response repetition matches the amount of interference for Orthogonal Incongruent items owing to response reversal, there should be zero nett priming in the Orthogonal condition.

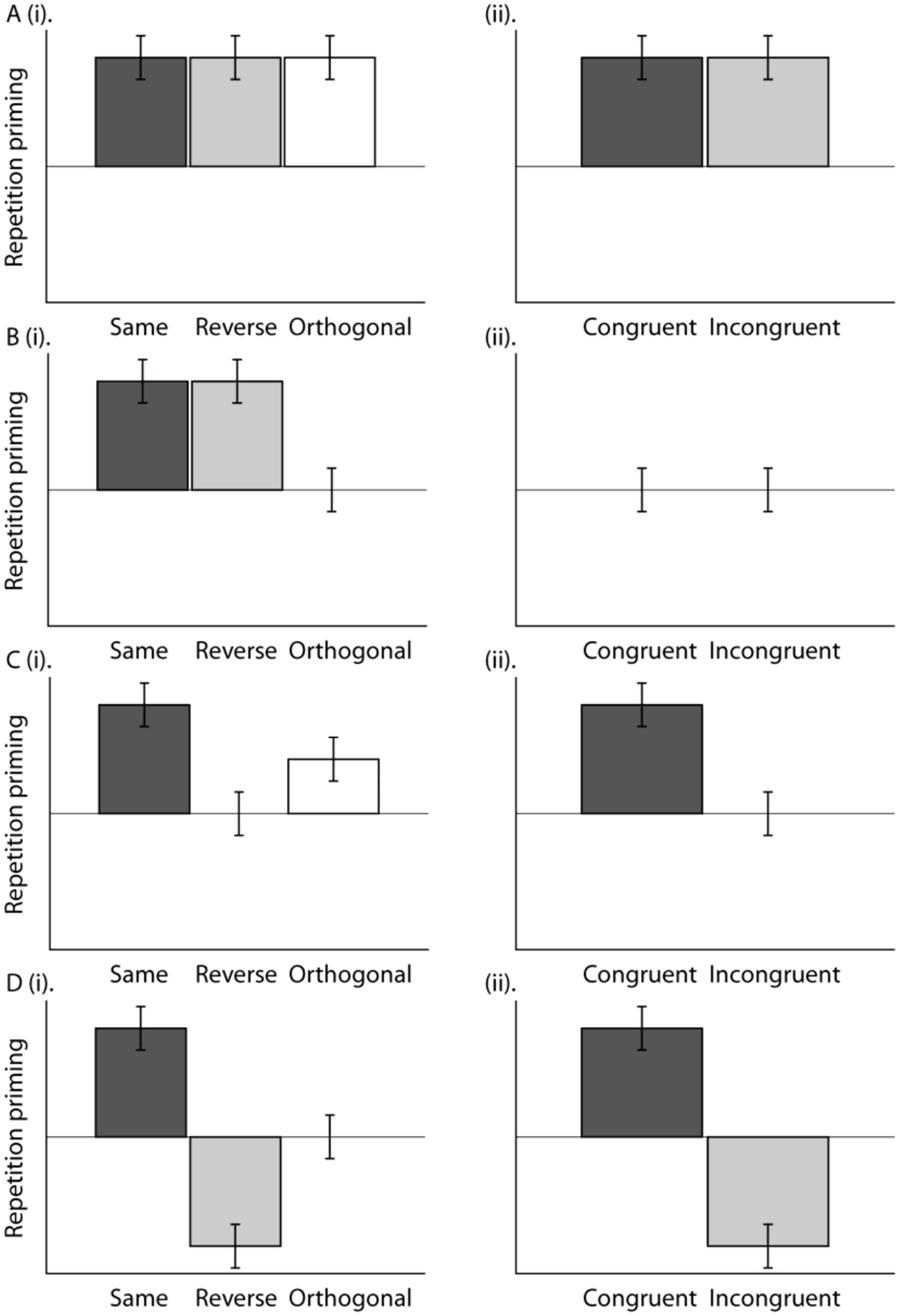

Figure 2.2. Predictions made by various CP and S-R theories of priming in (i) the Same, Reverse and Orthogonal conditions and (ii) for Congruent and Incongruent trials in the Orthogonal condition. (A) CP theory solely predicting perceptual facilitation, (B) CP theory solely predicting conceptual facilitation and S-R theory predicting S-R bindings are coded solely at the level of Classifications (e.g., “bigger”/”smaller”), (C) S-R theory predicting that retrieval of S-R bindings facilitates, but does not interfere, with processing and (D) S-R theory predicting that retrieval of S-R bindings both facilitates and interferences with processing.

If multiple Study presentations lead to the formation of more S-R episodic bindings, or a strengthening of an S-R association, High-primed stimuli should produce greater priming in the Same condition compared to Low-primed stimuli. In the Reverse condition, High-primed stimuli should show equivalent or even reduced priming, owing to greater interference, compared to Low-primed stimuli. As a result, the High-primed vs. Low-primed manipulation should interact with the Same vs. Reverse tasks. This pattern should also be present when comparing Congruent vs. Incongruent trials in the Orthogonal condition.

If, on the other hand, responses are only coded at the more abstract level of the Classification, then S-R theories would predict similar priming for the Same and Reverse conditions, but no priming in the Orthogonal condition for either Congruent or Incongruent trials. Note that this is the same prediction made for conceptual CP contributions to priming (Figure 2.2-B), and as such the present design is unable to distinguish between these two possible contributions to repetition priming (though see Chapter 4).

Of course, the actual pattern of priming could be a combination of several of the above causes. Given the relative importance of CP theories of priming (e.g., for inferring the nature of psychological and neural representations; see Chapter 1), the present chapter concentrates on trying to refute S-R theories of priming. The finding of reliable positive priming in the Orthogonal condition, particularly for Incongruent trials, would be particularly informative in this regard. If positive priming for Incongruent trials in the Orthogonal condition were seen, such a result would be difficult to explain in terms of the retrieval of an S-R binding.

2.1 Experiment 1

Experiment 1 was designed to assess the relative contributions of S-R and CP accounts of long-lag repetition priming of visual objects, as outlined above. The experimental design of Experiment 1 is shown in Figure 2.2-A. At Study, participants performed the “bigger-than-shoebox” task. At Test, participants performed the “bigger-than-shoebox” task (the Same condition), the “smaller-than-shoebox” task (the Reverse condition) and the “man-made” task (the Orthogonal condition) in separate Study-Test blocks. Specifically, I was interested in comparing: (1) the Same vs. the Reverse condition and (2) Congruent vs. Incongruent trials in the Orthogonal condition. I was also interested in whether reliable priming would be seen in the Orthogonal condition, particularly for Incongruent trials, as this would be strong evidence for facilitation of component processes.

2.1.1 Method

2.1.1.1 Participants

Participants in all experiments were recruited from the MRC-CBU subject panel, or from the student population of Cambridge University; all participants had normal or corrected to normal vision. All experiments were of the type approved by a local research ethics committee (CPREC reference 2005.08). Note that the number of participants in each experiment across Chapter 2-7 does vary in order to fully counterbalance each individual experiment. Participation was predominantly confined to a single experiment; however on occasions when individuals participated in multiple experiments, I ensured a minimum of six months between testing.

Twelve participants (7 male) gave informed consent to participate in Experiment 1. The mean age across participants was 23.3 years (σ = 4.5). By self-report, all participants were right-handed.

2.1.1.2 Materials

Stimuli were 240 images taken from the main stimulus set. They were selected so that 25% were "bigger than a shoebox" and "man-made", 25% were "bigger than a shoebox" and "natural", 25% were "smaller than a shoebox" and "man-made", and 25% were "smaller than a shoebox" and "natural". Each picture was randomly assigned to one of 12 groups relating to the 12 experimental conditions (3x2x2; Task x Repetition x Prime-level), resulting in 20 stimuli per group. The assignment of groups to experimental condition was rotated across participants.

2.1.1.3 Procedure

Prior to the experiment, participants performed a practice session using the "bigger than a shoebox" task, where it was made clear that this comparison referred to the object's typical size in real life. They responded using a "yes" or "no" key with their right or left index finger respectively. Although participants were told the question may change during the course of the experiment, the other test tasks were only explained to the participants prior to each test block. They were told to respond as quickly as possible without sacrificing accuracy. No error feedback was provided either in the practice session or the main experiment.

The experiment consisted of three alternating study-test cycles, with each cycle lasting approximately 10mins. During each Study phase, 40 stimuli were shown; 20 were presented once (Low-primed) and 20 were presented three times (High-primed), resulting in 80 trials (Figure 2.2-A). Apart from ensuring no immediate repetitions, the stimulus presentation order within each Study block was randomised so that High-primed stimuli were approximately evenly distributed throughout. During each Test phase, the 40 stimuli from the Study phase (Repeated) were randomly intermixed with 40 novel stimuli. The order of the three test conditions (Task) was counterbalanced across participants.

An example trial sequence is shown in Figure 2.2-B. A central fixation cross was presented for 500ms, followed by a stimulus for 2000ms, followed by a blank screen for 500ms. Images subtended approximately 6^{o} of visual angle. Participants were able to respond at any point up to the start of a new trial (i.e., the presentation of another fixation cross).

2.1.1.4 Behavioural analyses

Trials in which reaction times (RTs) were less than 400ms, or two or more standard deviations above or below a participant's mean for a given task, were excluded. Given that there is some subjectivity in the “bigger-than-shoebox?” and “man-made?” questions (i.e., some variability of opinions across participants for some stimuli), accuracy was defined by the modal response across participants for each object. Although analyses of such “errors” are reported in Appendix A, these results should be interpreted with caution given the definition of an “error” is less clear than in some other priming experiments. RTs for correct trials at Test constituted the main dependent variable. Given the focus on S-R learning, RTs were further restricted to objects also given a correct judgment on every occurrence at Study. Repeated-measures Analysis of Variance (ANOVA) was applied to mean RTs, with a Greenhouse-Geisser correction for all F-values with more than one degree of freedom in the numerator. All statistical tests had alpha set at .05; T-tests were two-tailed except where stated otherwise.

Priming was defined as the difference in mean RTs between Novel and Repeated trials. To control for possible Novel RT differences across Task conditions, an additional proportional measure of priming was calculated by dividing the difference between Novel and Repeated trials by the mean RT for Novel trials (Schnyer et al., 2006). Analyses of proportional priming scores are reported in Appendix A.

To investigate whether responses made at Study had a significant effect on RTs at Test, Repeated trials in the Orthogonal condition were split further according to whether the participant had given the same (“Congruent”), or opposite (“Incongruent”), response at Study, regardless of accuracy. For High-primed stimuli, such trials were restricted to objects for which the same response was given across all three Study presentations. Note that this means that effects in this response congruency analysis of the Orthogonal condition (such as effects of High- versus Low-primed) can differ from those in the main analysis, because “incorrect” (as defined by modal response over participants) trials may be included in the former but not latter.

2.1.2 Results

After excluding 0.3% of trials with outlying RTs, the percentages of errors are shown in Table 2.1. Note that most "errors" were likely to reflect a degree of subjectivity, particularly for the “shoebox” task (see Methods). Analyses of errors revealed no significant effects of repetition (Appendix A-1), suggesting the RT priming effects reported below are unlikely to reflect a speed-accuracy trade-off. A further 4.1% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study (see Methods).

Table 2.1. *Mean percentage errors and error priming (plus standard deviations) across Task (questions denote Tasks carried out at Test), Prime-level, and Repetition for Experiments 1-3. LP = Low-primed; HP = High-primed; N = Novel; R = Repeated; P = Priming (Novel-Repeated). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Task /		Same		Reverse		Orthogonal	
Prime-level		LP	HP	LP	HP	LP	HP
% Errors							
		Bigger than shoebox?		Smaller than shoebox?		Man-made?	
Experiment 1	N	13.3 (3.9)	12.9 (7.5)	9.6 (4.5)	10.8 (5.6)	2.9 (3.3)	1.3 (2.3)
	R	8.3 (4.9)	10.8 (7.9)	12.5 (6.9)	14.6 (7.8)	2.1 (2.6)	2.1 (4.5)
	P	5.0 (7.4)	2.1 (11.0)	-2.9 (8.9)	-3.8 (10.0)	0.8 (3.6)	-0.8 (4.2)
		Man-made?		Natural?		Bigger than shoebox?	
Experiment 2	N	2.8 (3.9)	2.8 (2.6)	1.7 (4.9)	1.7 (2.4)	9.7 (6.1)	13.1 (7.1)
	R	0.8 (2.6)	1.7 (3.0)	3.9 (4.0)	2.2 (3.9)	10.0 (6.4)	11.4 (5.1)
	P	1.9 (3.5)	1.1 (2.7)	-2.2 (5.2)	-0.6 (3.8)	-0.3 (9.3)	1.7 (7.1)
		Bigger than shoebox?		Bigger than shoebox?		Bigger than shoebox?	
Experiment 3	N	10.0 (5.6)	15.4 (9.4)	12.9 (5.4)	11.2 (9.3)	11.2 (4.3)	10.4 (5.4)
	R	7.5 (4.5)	8.3 (4.9)	15.4 (9.9)	12.5 (8.7)	10.0 (4.8)	14.6 (8.7)
	P	2.5 (8.1)	7.1 (10.3)	-2.5 (10.3)	-1.3 (13.0)	1.3 (6.4)	4.2 (9.0)

Table 2.2 displays mean RTs, together with subtractive (Novel-Repeated) and proportional ((Novel-Repeated)/Novel) measures of priming. A 3x2x2 (Task x Repetition x Prime-level) ANOVA on RTs revealed a significant Task x Repetition interaction, *F*(1.5, 17.0) = 7.15, p<.01 (plus main effects of Task, *F*(1.9, 21.0) = 14.39, p<.001, and Repetition, *F*(1, 11) = 21.82, p<.001). Given no reliable effects involving Prime-level (*F*'s<2.0, p's>.16), subsequent tests collapsed across this factor. Pairwise tests of priming across tasks revealed significantly greater priming in the Same relative to Reverse, *t*(11) = 2.48, p<.05, and Same relative to Orthogonal, *t*(11) = 3.90, p<.01, conditions (Reverse vs. Orthogonal, *t*(11) = 1.57, p=.14). Furthermore, although priming was significantly greater than zero in the Same and Reverse conditions, *t*'s>2.92, p's<.01, it was not reliable in the Orthogonal condition, *t*(11) = 0.60, p=.56. Thus, switches in task decreased priming in the Reverse condition and prevented reliable priming in the Orthogonal condition. This pattern of results is

presented in Figure 2.3-A. Analogous ANOVAs on the proportional measure of priming showed the same pattern of results (Appendix A-1), suggesting that the difference in priming between the Same/Reverse and Orthogonal conditions was not a range effect owing to the shorter overall RTs in the Orthogonal ("man-made") task.

Table 2.2. *Mean reaction times (RT), RT priming and proportional priming (plus standard deviations) across Task (questions denote Tasks carried out at Test), Prime-level, and Repetition for Experiments 1-3. LP = Low-primed; HP = High-primed; N = Novel; R = Repeated; P = Priming (Novel-Repeated); PP = Proportional Priming ((Novel-Repeated)/Novel). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Task /		Same		Reverse		Orthogonal	
Prime-level		LP	HP	LP	HP	LP	HP
RT							
		Bigger than shoebox?		Smaller than shoebox?		Man-made?	
Experiment 1	N	914 (161)	903 (157)	1021 (228)	1018 (215)	882 (165)	863 (184)
	R	781 (154)	758 (192)	956 (210)	923 (191)	834 (202)	874 (228)
	P	133 (75)	145 (99)	65 (118)	94 (102)	48 (75)	-11 (157)
	PP	.15 (.07)	.16 (.11)	.06 (.10)	.09 (.10)	.06 (.08)	-.02 (.16)
		Man-made?		Natural?		Bigger than shoebox?	
Experiment 2	N	757 (154)	759 (135)	773 (148)	781 (176)	960 (209)	969 (214)
	R	677 (138)	651 (128)	746 (150)	754 (160)	946 (180)	935 (194)
	P	79 (60)	108 (77)	27 (72)	27 (79)	13 (91)	34 (165)
	PP	.10 (.08)	.14 (.09)	.03 (.09)	.03 (.10)	.00 (.10)	.02 (.16)
		Bigger than shoebox?		Bigger than shoebox?		Bigger than shoebox?	
Experiment 3	N	888 (193)	841 (193)	861 (128)	839 (152)	912 (113)	896 (153)
	R	768 (170)	739 (129)	804 (122)	782 (138)	862 (122)	901 (149)
	P	120 (104)	103 (121)	57 (86)	57 (97)	50 (86)	-5 (81)
	PP	.14 (.11)	.11 (.11)	.06 (.09)	.06 (.10)	.05 (.09)	-.01 (.10)

The Orthogonal trials were split according to Response-congruency between Study and Test (i.e., objects given the same "yes" or "no" response at Study and Test, regardless of accuracy, versus those given differing responses). The resultant priming data were entered into a 2x2 (Response-congruency x Prime-level) ANOVA. Only the main effect of Response-congruency was reliable, *F*(1, 11) = 7.73, p<.05, demonstrating greater priming for Congruent (+50ms) than Incongruent (-6ms) trials.

Despite this main effect, priming did not reach significance for either Congruent, *t*(11) = 1.48, p=.17, or Incongruent, *t*(11) = .25, p=.81, trials alone (see Figure 3.2-B).

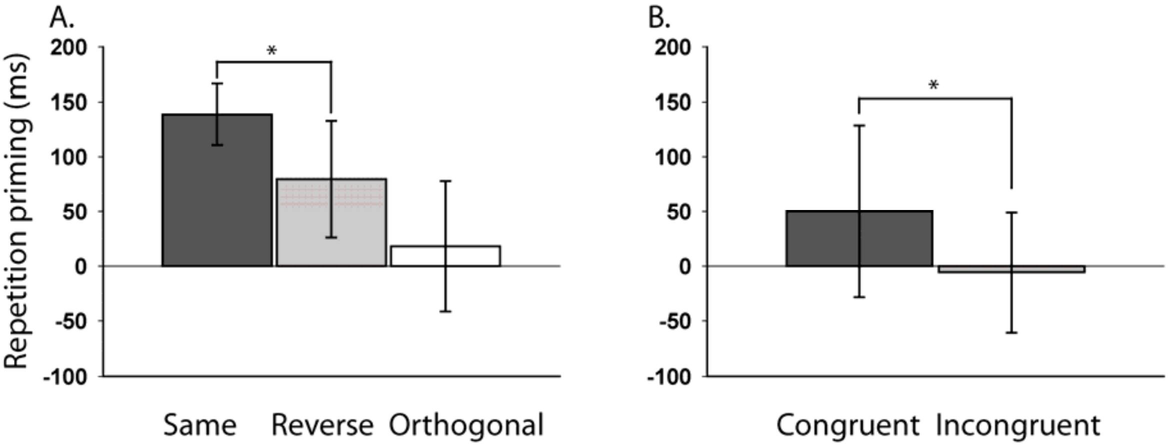

Figure 2.3. Mean repetition priming (Novel-Repeated) across (A) the Same, Reverse and Orthogonal conditions (collapsed across Prime-level) and (B) Congruent and Incongruent trials in the Orthogonal condition in Experiment 1. Error bars represent 95% two-tailed confidence intervals of priming effect. * p<.05.

2.1.3 Discussion

The results of Experiment 1 suggest that the retrieval of S-R bindings plays an important role within the present paradigm. The binding of stimuli to a particular response is apparent from two reliable effects: (1) a reduction in priming for the Reverse condition relative to Same condition and (2) greater priming for Congruent than Incongruent trials in the Orthogonal condition. It is also consistent with the lack of reliable nett priming in the Orthogonal condition, where there were approximately equal numbers of Congruent and Incongruent trials. The lack of priming in the Orthogonal condition was surprising, and suggests that other causes traditionally linked to perceptual priming (such as faster object identification for repeated pictures) play a negligible role in the present paradigm (see also Bruce, Carson, Burton & Ellis, 2000). The lack of evidence for any modulation of priming by High vs. Low primed stimuli was also surprising, though there was a numerical pattern consistent with S-R learning that was reproduced and reached significance in subsequent experiments (see inter-experimental analysis of Chapter 3).

2.2 Experiment 2

Experiment 1 used the "shoebox" task on the basis of previous work by Dobbins et al. (2004) and Schnyer et al. (2006). Such a task is likely to represent a rather "ad hoc" categorisation (Barsalou, 1983). In other words, it is likely to involve a considerable strategic/executive component, which may encourage, or leave greater scope for, S-R learning. Experiment 2 therefore switched to the "man-made" categorisation task as the main task. It was thought this categorisation was a more natural categorisation, in that it is more likely to be a distinction represented within semantic memory (Farah & McClelland, 1991). This is consistent with the faster RTs for this task than the shoebox task in Experiment 1. The man-made task is also one that has been used in many previous priming studies (Bruce et al., 2000; Franks et al., 2000; Vriezen, Moscovitch & Bellos, 1995; Zeelenberg & Pecher, 2003). Thus the design of Experiment 2 was a mirror-reflection of Experiment 1, in the sense that the man-made and shoebox tasks were swapped (i.e., the man-made task was used in all phases, except the Orthogonal Test phase, when the shoebox task was used). Again, it was of interest whether significant priming would be seen in the Orthogonal condition, particularly for Incongruent trials.

2.2.1 Method

The experimental design of Experiment 2 was identical to Experiment 1, with the following exceptions.

2.2.1.1 Participants

18 participants (5 male) gave informed consent to participate in the experiment. The mean age across participants was 22.6 years ($\sigma = 3.0$). By self-report, 3 participants were classified as left-handed, 15 right-handed.

2.2.1.2 Design

Participants were always asked "is the object man-made?" at Study. At Test, in the Same condition, the man-made task was repeated; in the Reverse condition, the opposite question was presented ("is the object natural?"); in the Orthogonal condition, the "bigger than a shoebox?" question was asked.

2.2.2 Results

After excluding 0.6% of trials with outlying RTs, the percentage of errors are shown in Table 2.1. Consistent with expectations, RTs for Novel stimuli were faster in the Man-made task (i.e., Same and Reverse conditions) than the Shoebox task (i.e., Orthogonal task). Analyses of errors revealed no significant effects of Repetition (Appendix A-2). A further 1.9% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study (see Methods).

Table 2.2 displays mean RTs and priming effects. A 3x2x2 ANOVA revealed a significant Task x Repetition interaction, $F(1.6, 26.5) = 5.29$, $p<.05$ (plus main effects of Task, $F(1.4, 23.5) = 42.57$, $p<.001$, and Repetition, $F(1, 17) = 18.85$, $p<.001$). Given no reliable effects involving Prime-level (F's<.84, p's>.37), subsequent tests collapsed across this factor. These tests revealed significantly greater priming in the Same relative to the Reverse, $t(17) = 3.80$, $p<.01$, and Same relative to Orthogonal, $t(17) = 2.83$, $p<.05$, conditions (Reverse vs. Orthogonal, $t(17) = 0.12$, p=.91). Furthermore, although priming was significantly greater than zero in the Same and Reverse conditions, *t*'s>2.0, p's<.05, it was not reliable in the Orthogonal condition, *t*(17) = 0.94, p=.36 (see Figure 2.4-A). The proportional priming measure revealed a similar pattern of results (Appendix A-2).

A 2x2 (Response-congruency x Prime-level) ANOVA for the Orthogonal condition showed only a main effect of Response-congruency, *F*(1, 17) = 23.18, p<.001, with greater priming for Congruent (+73ms) than Incongruent (-18ms) trials. Indeed, priming was reliable for Congruent trials, *t*(17) = 3.42, p<.01, but not Incongruent trials, *t*(17) = .71, p=.49 (see Figure 2.4-B).

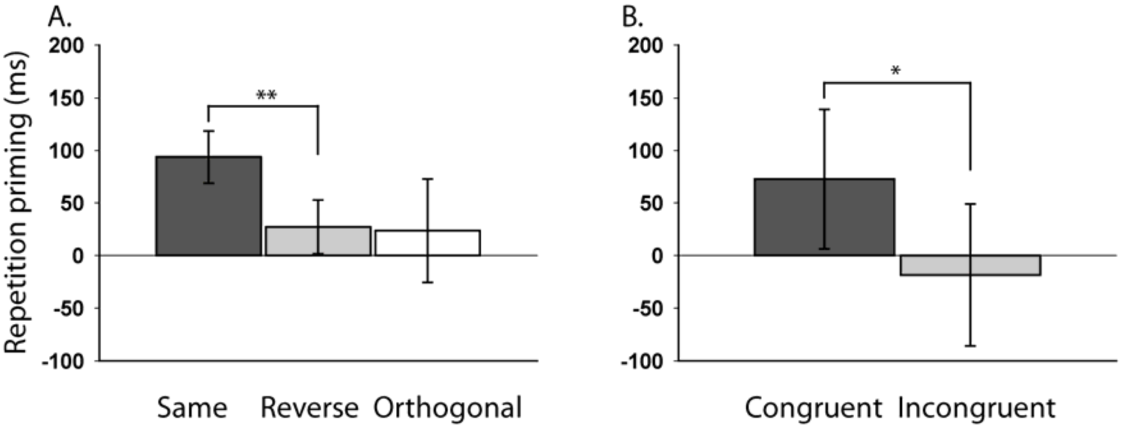

Figure 2.4. Mean repetition priming (Novel-Repeated) across (A) the Same, Reverse and Orthogonal conditions (collapsed across Prime-level) and (B) Congruent and Incongruent trials in the Orthogonal condition in Experiment 2. Error bars represent 95% two-tailed confidence intervals. ** p<.01; * p<.05.

2.2.3 Discussion

The priming results of Experiment 2 replicate those of Experiment 1, most notably with an absence of reliable priming in the Orthogonal condition. Again, most of the results appear explicable in terms of S-R learning: (1) greater priming in the Same condition than Reverse condition, and (2) greater priming for Congruent than Incongruent trials in the Orthogonal condition. This suggests that S-R learning plays an important role even with the relatively easier (and less “ad hoc”) decisions required by the man-made categorisation task (relative to the shoebox task).

2.3 Experiment 3

The results of Experiments 1 and 2 demonstrated clear S-R effects using both the “bigger-than-shoebox” and “man-made” classification tasks. Such S-R effects would therefore seem to be replicable across tasks that demonstrate clear differences in response accuracy and RTs (see later inter-experimental analysis). Experiment 3 further tested the robust nature of these effects by switching the tasks undertaken at Study and Test. In Experiments 1 and 2 the Study task was held constant, whilst the Test task was varied. As such, priming differences at Test may have resulted from overall differences in task difficulty (consistent with overall task differences in RTs and accuracy). To control for such differences at Test, Experiment 3 varied the Study task whilst maintaining a constant Test task. At Test, participants always undertook the “bigger-than-shoebox” task. At Study, either the Same (“bigger-than-shoebox”), Reverse (“smaller-than-shoebox”) or Orthogonal (“man-made”) tasks were performed.

2.3.1 Method

The experimental design of Experiment 3 was identical to Experiment 1, with the following exceptions.

2.3.1.1 Participants

12 participants (5 male) gave informed consent to participate in the experiment. The mean age across participants was 20.8 years ($\sigma = 3.5$). By self-report, 1 participant was classified as left-handed, 11 right-handed.

2.3.1.2 Design

Participants were always asked “is the object bigger than a shoebox?” at Test. At Study, in the Same condition, the “bigger-than-shoebox” task was performed; in the Reverse condition, the opposite question was performed (“is the object smaller then a shoebox?”); in the Orthogonal condition, the “man-made” task was performed.

2.3.2 Results

After excluding 1.0% of trials with outlying RTs, the percentage of errors are shown in Table 2.1. Analyses of errors revealed no significant effects of Repetition (Appendix A-3). A further 3.2% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

Table 2.2 displays the mean RTs and priming effects. A 3x2x2 ANOVA revealed a significant Task x Repetition interaction, *F*(1.9, 20.9) = 4.98, p<.05 (plus main effects of Task, *F*(2.0, 21.9) = 11.27, p<.001, and Repetition, *F*(1, 11) = 17.89, p<.001). Given no reliable effects involving Prime-level (*F*’s<2.26, p’s>.16), subsequent tests collapsed across this factor. These tests revealed significantly greater priming in the Same relative to the Reverse, *t*(11) = 2.58, p<.05, and Same relative to the Orthogonal, *t*(11) = 2.74, p<.05, condition (Reverse vs. Orthogonal, *t*(11) = 1.14, p=.28). Furthermore, although priming was significantly greater than zero in the Same and Reverse conditions, *t*’s>2.4, p’s<.05, it was not reliable in the Orthogonal condition, *t*(11) = 1.08, p=.31 (see Figure 2.5-A). The proportional priming measure revealed a similar pattern of results (Appendix A-3).

A 2x2 (Response-congruency x Prime-level) ANOVA for the Orthogonal condition showed only a main effect of Response-congruency, *F*(1, 11) = 12.28, p<.01, with greater priming for Congruent (+70ms) than Incongruent (-40ms) trials.

Indeed, priming was reliable for Congruent, *t*(11) = 2.97, p<.05, but not Incongruent, *t*(11) = 1.16, p=.27, trials (see Figure 2.5-B).

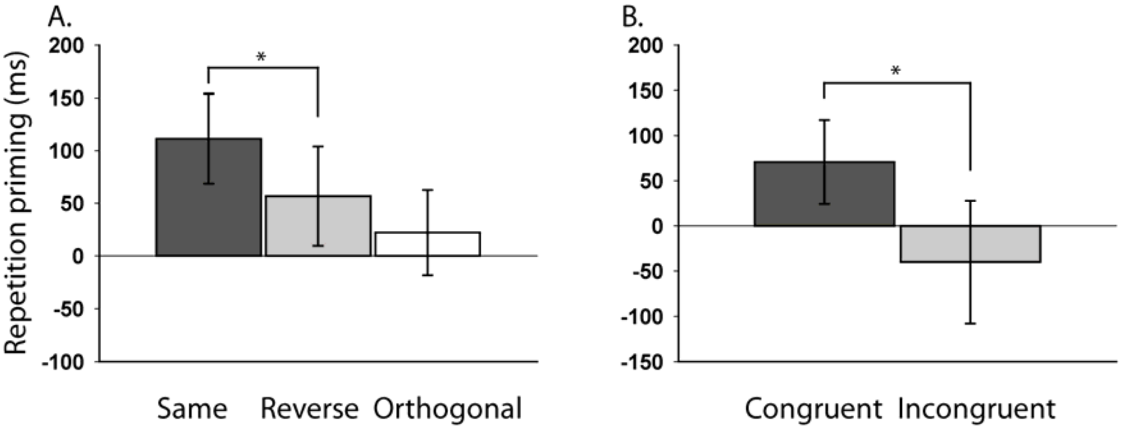

Figure 2.5. Mean repetition priming (Novel-Repeated) across (A) the Same, Reverse and Orthogonal conditions (collapsed across Prime-level) and (B) Congruent and Incongruent trials in the Orthogonal condition in Experiment 3. Error bars represent 95% two-tailed confidence intervals. * p<.05.

2.3.3 Discussion

Experiment 3 therefore replicates the results of Experiments 1 and 2. As in the first two experiments, most of the results appear explicable in terms of the retrieval of S-R bindings: (1) greater priming in the Same than Reverse condition and (2) greater priming for Congruent than Incongruent trials in the Orthogonal condition. These results suggest that S-R learning is a robust phenomenon that occurs regardless of overall differences in task difficulty at either Study (Experiment 3) or Test (Experiments 1 and 2). Once again, Experiment 3 failed to find reliable priming for Incongruent trials in the Orthogonal condition.

2.4 Inter-experimental analyses

The pattern of results across Experiments 1-3 was remarkably consistent despite changes in both Study and Test tasks between experiments. Figure 2.6 displays these main priming effects collapsed across Experiments 1-3. In order to formally compare such results, the data were subjected to a 3x2x2x3 (Task x Repetition x Prime-level x Experiment) mixed ANOVA with the between-subjects Experiment factor relating to Experiments 1-3. The only significant result involving the Experiment factor was a Task x Experiment interaction, *F*(3.7, 71.8) = 19.64, p<.001. This effect was driven by differences between the "bigger-than-shoebox" and "man-made" tasks used at Test in Experiments 1 and 2, with longer RTs in the "bigger-than-shoebox" task, *t*(29) = 4.24, p<.001 (collapsed across Experiments 1 and 2). Importantly, such task differences did not affect priming as the Experiment factor showed no significant interactions with the remaining factors, *F*'s<1.84, p's>.17. The present analysis also replicated the significant Task x Repetition interaction seen in each experiment separately, *F*(3.7, 71.8) = 19.64, p<.001 (as well as showing main effects of Task, *F*(1.8, 71.8) = 28.26, p<.001, and Repetition, *F*(1, 39) = 60.64, p<.001). Post-hoc tests revealed significantly greater priming in the Same than Reverse, *t*(41) = 5.29, p<.001 (see Figure 2.6-A), and Orthogonal, *t*(41) = 5.44, p<.001, conditions (Reverse vs. Orthogonal, *t*(41) = 1.54, p=.13). Interestingly, this analysis failed to reveal any effect of Prime-level on the pattern of priming across the Same and Reverse condition, although a numerical trend for greater priming in the Same condition for High-primed stimuli was seen. I will return to this issue in Chapter 3. Finally, I delay the issue of whether the task-order across participants affects the pattern of priming seen across conditions until the end of Chapter 3.

A further inter-experimental analysis was conducted on the congruency data from the Orthogonal condition of Experiments 1-3. A 2x2x3 (Congruency x Prime-level x Experiment) mixed ANOVA revealed a significant effect of Congruency, *F*(1, 39) = 39.53, p<.001, with greater priming for Congruent (+66ms) than Incongruent (-

20ms) trials (see Figure 2.6-B). As in the separate experimental analyses, priming was reliable for Congruent, *t*(41) = 4.49, p<.001, but not Incongruent, *t*(41) = 1.31, p=.20, trials. No further significant effects or interactions were present, *F*'s<2.51, p's>.10, though there was a numerical pattern for congruency effects across conditions to be exaggerated for High-primed vs. Low-primed stimuli.

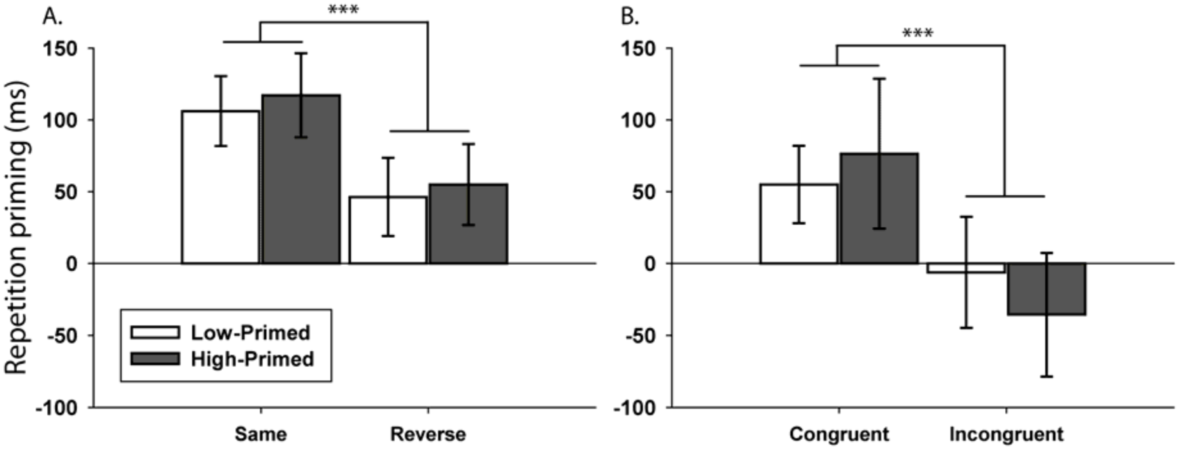

Figure 2.6. Main effects and interactions of interest averaged across Experiments 1-3. (A) Greater priming in the Same than Reverse condition (collapsed across Experiment and Prime-level). (B) Greater priming for Congruent than Incongruent stimuli in the Orthogonal condition (collapsed across Experiment and Prime-level). Errors bars represent 95% confidence intervals (two-tailed). *** p<.001.

2.5 General Discussion

In Experiments 1-3, I introduced a classification paradigm designed to assess S-R and CP contributions to long-lag repetition priming of visual objects. The results from Experiments 1-3 were clear, with much of the priming effects explicable in terms of S-R learning at the level of Actions (right/left finger-press) and/or Decisions (yes/no). Firstly, I saw greater priming for the Same than Reverse condition (see Figure 2.6-A). Secondly, I saw greater priming for Congruent than Incongruent trials in the Orthogonal condition (see Figure 2.6-B). Both effects are not readily explicable in terms of facilitation of component processes and would seem to rely upon repetition of responses between Study and Test. Indeed, once I controlled for S-R contributions (i.e., in the Orthogonal condition), little if any priming remained. These results suggest that, at least in the present paradigm, facilitation of component processes (e.g., perceptual facilitation) is not a necessary consequence of stimulus repetition.

Only one aspect of the data is difficult to explain in terms of bindings between stimuli and Action/Decision responses, namely the residual priming in the Reverse condition. Here the prior Action/Decision response given at Study should not result in facilitation at Test. Indeed, retrieval of an Action/Decision response might be expected to interfere with processing at Test, producing slower RTs compared to novel items. One possibility is that this residual priming reflects facilitation of conceptual processing, given that the same semantic information about the everyday size of an object is required in the Study and Test phases of the Reverse condition (but not the Orthogonal condition). I return to this possibility in the next chapter.

However, an alternative S-R account is that the “right/left” Action or "yes/no" Decision from the Study phase is retrieved rapidly at Test, but the participant develops a strategy of simply reversing this response, which may still take less time than re-computing a decision from semantic knowledge (as necessary for Novel stimuli). In other words, the Reverse condition may be susceptible to a conscious “retrieve and reverse” strategy, suggesting that the residual priming in this condition may not reflect the recruitment of processes thought to be automatic (e.g., CP facilitation; though see Chapter 3). A second alternative S-R account is that the positive priming in the Reverse condition reflects stimuli becoming bound with a more abstract response representation than the “right/left” Action or “yes/no” Decision that is reversed in this condition. For example, stimuli may be bound to a higher-level Classification (e.g., “bigger/smaller”) that would remain the same regardless of whether the size-judgement task is reversed (e.g., a lion is always "bigger" than a shoebox regardless of the direction of the question). Rapid retrieval of this Classification for a repeated stimulus would enable the generation of an overt response without the need to re-compute the typical size of the object. However, such an account would not explain the decrease in priming in the Reverse than Same condition. To explain such a result, S-R learning would need to occur at two levels of response representation (e.g., a particular "yes/no" Decision and a "bigger/smaller" Classification). I return to the possibility of different levels of response representation in Chapter 4.

Although significant priming was present in the Reverse condition, despite a switch in response between Study and Test, no priming was present for Incongruent Orthogonal trials. One possibility for this lack of priming is that there are no CP contributions present in the current long-lag classification paradigm. However, a second possibility is that response retrieval in the case of Incongruent trials led to interference, slowing overall RTs. Such an interference effect would act against any possible CP contributions, potentially cancelling each other out (i.e., resulting in no nett reliable priming). In order to confirm the presence of such interference effects one would need to demonstrate either significant slowing of RTs compared to novel items (i.e., negative priming) or significantly diminished priming for High- than Low-primed Incongruent trials. Although Experiments 1-3 presented a trend towards negative priming for Incongruent trials, as well as a trend for diminished priming for High- than Low-primed Incongruent trials, these effects were not significant, even in the inter-experimental analysis. Therefore, at present there is no definitive evidence for interference effects resulting from the retrieval of previous S-R bindings (though see Chapter 3).

2.5.1 Chapter Summary

In Chapter 2, I introduced an experimental paradigm designed to assess potential CP and S-R contributions to repetition priming. Presenting pictures of everyday visual objects in a long-lag classification paradigm, CP and S-R theories were assessed by means of task switches between Study and Test blocks. Three task manipulations were used: (1) the Same condition, where the same task was used at Study and Test, resulting in a response repetition, (2) the Reverse condition, where the opposite task was used at Test to that at Study, resulting in a response reversal and (3) the Orthogonal condition, where the task at Test was unrelated to that at Study and responses at Test were on average orthogonal to those at Study. Two possible markers of S-R learning were seen across three separate experiments: (1) greater priming in the Same than Reverse condition and (2) greater priming for Congruent than Incongruent items in the Orthogonal condition. These results confirm that the retrieval of S-R bindings can modulate priming in the present paradigm. Interestingly, once such S-R effects were appropriately controlled for, little if any priming effects remained. As such, the present results failed to provide unequivocal evidence for facilitation of particular perceptual and/or conceptual processes. The results of Chapter 2 therefore suggest that S-R effects dominate in the present paradigm. Given the prevalence of CP accounts of repetition priming, the next chapter attempts to increase potential perceptual and/or conceptual CP contributions to priming.

Chapter 3

In search of CP contributions to repetition priming

Chapter 2 provided clear evidence of S-R contributions to repetition priming, but no results that could only be explained in terms of the facilitation of other component processes (e.g., object identification or semantic access). Most notable was the failure to observe priming in the Orthogonal condition, which was intended to provide a baseline measure of priming with which to compare the Same and Reverse conditions. These results are striking given how widespread CP accounts of priming are within the literature. Given such unexpected results, Experiments 4-6 in Chapter 3 were designed to increase the contributions of facilitation of component processes, such as perceptual and/or conceptual processes. If Experiments 4-6 provide similar results to those of Experiments 1-3, with little evidence for facilitation of component processes, this would strengthen the argument that S-R contributions dominate in the present paradigm. As in Experiments 1-3, demonstrating significant positive priming for Incongruent trials in the Orthogonal condition would be particularly informative in this regard.

3.1 Experiment 4

In Experiment 4, I decided to use a new task for the Orthogonal condition that is likely to be closer matched to the “bigger-than-shoebox” task in terms of semantic processing. I opted for the “taller-than-it-is-wide” task previously used by Vriezen et al. (1995 - Experiment 6), reasoning that this categorisation at least requires access to similar “size semantics” about objects. Again, objects were selected so that half of those larger than a shoebox were generally taller than they were wide, as were half of those smaller than a shoebox, such that on average the response given at Test was not predicted by the response given at Study in the Orthogonal condition.

3.1.1 Method

The experimental design of Experiment 4 was identical to Experiment 1, with the following exceptions.

3.1.1.1 Participants

18 participants (11 male) gave informed consent to participate in the experiment. The mean age across participants was 21.7 years ($\sigma = 2.5$). All participants were right-handed (self-report).

3.1.1.2 Design

Experiment 4 used the same shoebox task as Experiment 1 in the Same and Reverse conditions, and in the Study phase of the Orthogonal condition; the only difference was in the Orthogonal Test phase, where participants were asked whether the object was “taller than it is wide” in real life (i.e., not based on the picture's on-screen dimensions). Again, correct responses for a given object were based on the modal response across participants.

3.1.2 Results

After excluding 0.9% of trials with outlying RTs, the percentage of errors are shown in Table 3.1 (the higher error rates in the Orthogonal task reflected greater individual differences in the "taller-than-wide" judgment; see Methods). Analyses of errors revealed no significant effects of Repetition (Appendix A-4). A further 4.9% of

Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

Table 3.1. *Mean percentage errors and error priming (plus standard deviations) across Task (questions denote Tasks carried out at Test), Prime-level, and Repetition for Experiments 4-6. LP = Low-primed; HP = High-primed; N = Novel; R = Repeated; P = Priming (Novel-Repeated). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Task /		**Same**		**Reverse**		**Orthogonal**	
Prime-level		**LP**	**HP**	**LP**	**HP**	**LP**	**HP**
% Errors							
		Bigger than shoebox?		**Smaller than shoebox?**		**Taller than wide?**	
Experiment 4	**N**	**7.8 (7.3)**	**8.9 (4.4)**	**11.9 (8.4)**	**11.1 (7.2)**	**20.0 (9.2)**	**19.7 (12.4)**
	R	**6.7 (4.5)**	**9.2 (7.7)**	**11.9 (8.1)**	**15.6 (8.4)**	**25.8 (13.1)**	**18.1 (11.1)**
	P	**1.1 (8.5)**	**-0.3 (7.2)**	**0.0 (9.1)**	**-4.4 (10.6)**	**-5.8 (13.9)**	**1.7 (12.7)**
		Bigger than shoebox?		**Smaller than shoebox?**		**Taller than wide?**	
Experiment 5	**N**	**11.9 (7.5)**	**12.8 (6.5)**	**16.4 (6.8)**	**10.6 (6.8)**	**23.6 (9.8)**	**21.4 (10.5)**
	R	**9.7 (4.4)**	**10.6 (7.5)**	**17.8 (8.1)**	**16.1 (9.9)**	**20.6 (11.5)**	**20.8 (10.7)**
	P	**2.2 (8.6)**	**2.2 (10.2)**	**-1.4 (9.0)**	**-5.6 (10.6)**	**3.1 (9.7)**	**0.6 (10.8)**
		Bigger than shoebox?		**Smaller than shoebox?**		**Taller than wide?**	
Experiment 6	**N**	**11.1 (5.8)**	**11.1 (7.8)**	**12.8 (6.5)**	**13.1 (8.9)**	**19.4 (10.3)**	**21.1 (13.1)**
	R	**10.8 (7.7)**	**10.3 (5.8)**	**11.4 (7.0)**	**10.0 (6.4)**	**22.2 (12.6)**	**19.7 (9.2)**
	P	**0.3 (8.8)**	**0.8 (9.9)**	**1.4 (9.2)**	**3.1 (10.0)**	**-2.8 (12.0)**	**1.4 (11.1)**

Table 3.2 displays mean RTs, together with measures of priming. A 3x2x2 ANOVA revealed a significant Task x Repetition interaction, *F*(1.4, 23.0) = 15.91, p<.001 (plus main effects of Task, *F*(1.7, 29.6) = 69.52, p<.001, and Repetition, *F*(1, 17) = 43.95, p<.001). Collapsing across Prime-level, subsequent tests revealed significantly greater priming in the Same relative to the Reverse, *t*(17) = 6.63, p<.001, and Same relative to Orthogonal, *t*(17) = 4.41, p<.001, conditions (Reverse vs. Orthogonal, *t*(17) = 1.44, p=.17). Furthermore, although priming was significantly greater than zero in the Same and Reverse conditions, *t*'s>2.86, p's<.05, it was not reliable in the Orthogonal condition, *t*(17) = 0.56, p=.58 (see Figure 3.1-A). RTs in

the "taller-than-wide" task were longer than in the "shoebox" task, but the proportional measure of priming showed the same pattern of results (Appendix A-4).

Table 3.2. *Mean reaction times (RT), RT priming and proportional priming (plus standard deviations) across Task (questions denote Tasks carried out at Test), Prime-level, and Repetition for Experiments 4-6. LP = Low-primed; HP = High-primed; N = Novel; R = Repeated; P = Priming (Novel-Repeated); PP = Proportional Priming ((Novel-Repeated)/Novel). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Task / Prime-level		**Same**		**Reverse**		**Orthogonal**	
		LP	**HP**	**LP**	**HP**	**LP**	**HP**
RT							
		Bigger than shoebox?		**Smaller than shoebox?**		**Taller than wide?**	
Experiment 4	**N**	**915 (124)**	**914 (140)**	**1028 (177)**	**986 (181)**	**1177 (232)**	**1220 (211)**
	R	**788 (115)**	**722 (90)**	**949 (154)**	**958 (182)**	**1196 (239)**	**1176 (183)**
	P	**128 (107)**	**192 (126)**	**79 (117)**	**28 (96)**	**-19 (154)**	**44 (112)**
	PP	**.13 (.11)**	**.20 (.11)**	**.07 (.12)**	**.02 (.10)**	**-.02 (.14)**	**.03 (.09)**
		Bigger than shoebox?		**Smaller than shoebox?**		**Taller than wide?**	
Experiment 5	**N**	**954 (141)**	**944 (151)**	**1035 (219)**	**1030 (200)**	**1373 (229)**	**1384 (200)**
	R	**827 (119)**	**769 (122)**	**1000 (199)**	**969 (187)**	**1305 (237)**	**1322 (201)**
	P	**127 (69)**	**175 (96)**	**36 (116)**	**61 (73)**	**68 (176)**	**63 (94)**
	PP	**.13 (.06)**	**.18 (.09)**	**.03 (.10)**	**.06 (.07)**	**.04 (.13)**	**.04 (.07)**
		Bigger than shoebox?		**Smaller than shoebox?**		**Taller than wide?**	
Experiment 6	**N**	**1169 (143)**	**1169 (148)**	**1332 (192)**	**1305 (235)**	**1497 (246)**	**1545 (220)**
	R	**987 (106)**	**910 (123)**	**1124 (171)**	**1146 (183)**	**1455 (309)**	**1434 (280)**
	P	**182 (95)**	**259 (82)**	**207 (106)**	**159 (148)**	**42 (134)**	**111 (139)**
	PP	**.15 (.07)**	**.22 (.06)**	**.15 (.07)**	**.11 (.10)**	**.03 (.09)**	**.07 (.10)**

Interestingly, there was a trend towards a Task x Prime-level x Repetition interaction, *F*(1.8, 30.4) = 2.83, p=.08. Given the predictions regarding possible facilitation and interference in the Same and Reverse condition respectively, a further 2x2x2 (Task x Prime-level x Repetition) ANOVA on the mean RT data from the Same and Reverse conditions only was conducted. This revealed a significant Task x Prime-level x Repetition interaction, *F*(1, 17) = 5.60, p<.05, reflecting numerically greater priming for High- than Low-primed stimuli in the Same condition (+64ms), and numerically less priming for High-primed stimuli in the Reverse condition (-51ms).

Priming in the Orthogonal condition was split according to Congruent and Incongruent responses and entered into a 2x2 ANOVA. Despite numerically greater priming for Congruent (+23ms) than Incongruent (-18ms) trials, as in Experiments 1-3, the main effect of congruency did not reach significance, *F*(1, 17) = 1.37, p=.26 (nor did any other effects) (see Figure 3.1-B). Priming was significant for High-primed Congruent trials (+86ms), *t*(17) = 2.49, p<.05, but not for the other trial-types, *t*'s<1.02, p's>.32.

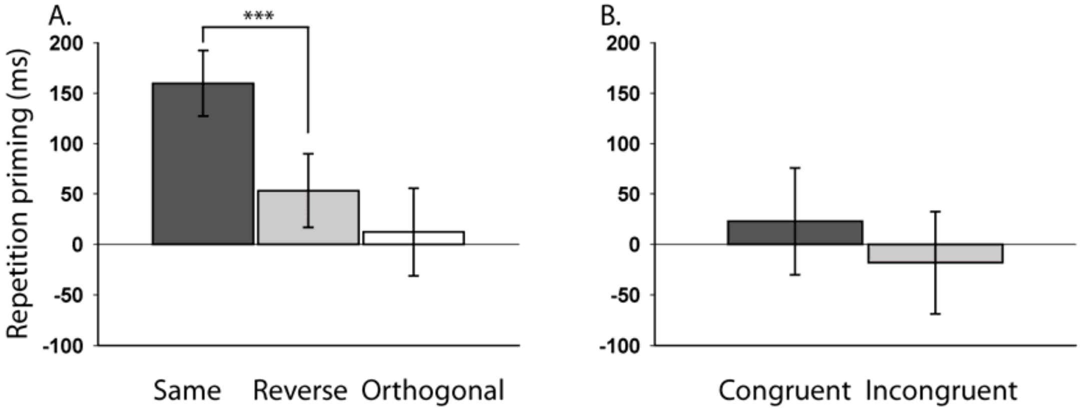

Figure 3.1. Mean repetition priming (Novel-Repeated) across (A) the Same, Reverse and Orthogonal conditions (collapsed across Prime-level) and (B) Congruent and Incongruent trials in the Orthogonal condition in Experiment 4. Error bars represent 95% two-tailed confidence intervals. *** p<.001.

3.1.3 Discussion

Experiment 4 replicated the results of Experiments 1-3; in particular, there was still no reliable nett priming in the Orthogonal condition, despite trying to maximise the overlap in semantic processing required by the Study and Test tasks. As in Experiments 1-3, most of the results are explicable in terms of S-R learning, namely (1) greater priming in the Same than Reverse condition, and (2) a trend for greater priming for Congruent than Incongruent trials in the Orthogonal condition.

Furthermore, Experiment 4 was the first to show a reliable interaction between Task and Prime-level, suggesting that increasing the number or strength of S-R bindings at Study can significantly increase the difference in priming across the Same and Reverse conditions. It is unclear however whether this effect is primarily driven by facilitation in the Same condition (i.e., greater priming for High- than Low-primed stimuli), interference in the Reverse condition (i.e., less priming for High- than Low-primed stimuli), or a combination of both. Indeed, a response facilitation effect for Congruent trials together with a response interference effect for Incongruent trials may explain the lack of nett priming in the Orthogonal conditions of Experiments 1-3. This point is revisited in the combined analysis across Experiments 4-6.

Regardless of whether this interaction is a result of facilitation or interference, it can be taken as evidence against one of the explanations put forward to explain the decrease in priming seen in the Reverse compared to Same condition in Chapter 2 (see General Discussion – Chapter 2). It was suggested that participants could adopt a conscious strategy to retrieve and rapidly reverse a previously encoded Action and/or Decision response. This process of reversal could slow RTs relative to the Same condition however still produce significant positive priming as it relies on the rapid retrieval of an S-R binding. If this were the case, one would expect to see greater priming for High- than Low-primed trials in both the Same and Reverse condition. In the terminology of Instance Theory, this is because increasing the number of repetitions at Study should increase the probability of response retrieval “winning the race”. Presuming the process of response reversal is unaffected by the speed of response retrieval, this should result in greater priming for High- than Low-primed trials in the Same and Reverse condition. This was not the case in the present experiment. Although I saw an increase for High-primed trials in the Same condition, no increase was seen in the Reverse condition. Such an interaction is difficult to explain in terms of a conscious "retrieve and reverse" strategy.

3.2 Experiment 5

Experiment 4 still failed to produce significant nett priming in the Orthogonal condition. These results were particularly surprising given that significant priming was seen in the Vriezen et al. study (1995 - Experiment 6) that used the same "bigger-than-shoebox" and "taller-than-wide" tasks. One important difference however is that Vriezen et al. used words rather than pictures. Experiment 5 was therefore a replication of Experiment 4, except that I replaced the pictures of objects with the object names.

3.2.1 Method

The experimental design of Experiment 5 was identical to Experiment 4, with the following exceptions.

3.2.1.1 Participants

18 participants (11 male) gave informed consent to participate in the experiment. The mean age across participants was 22.9 years ($\sigma = 3.7$). All participants were right-handed (self-report).

3.2.1.2 Materials

The same objects were used as in Experiment 4, except that the stimuli were the names of the objects rather than pictures of them (see General Methods – Chapter 1). Words were presented in black on a white background with the same pixel dimensions as the object picture stimuli.

3.2.2 Results

After excluding 1.3% of trials with outlying RTs, the percentage of errors are shown in Table 3.1. Analyses of errors revealed no main effect of Repetition, though there was a significant repetition effect in the Reverse condition reflecting greater errors for Repeated than Novel stimuli (Appendix A-5). Given the failure to find this effect in previous and subsequent experiments it will not be discussed further. A further 5.2% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

Table 3.2 displays mean RTs, together with the mean RT priming effect (Novel-Repeated) and proportional priming. A 3x2x2 ANOVA revealed a significant Task x Repetition interaction, $F(1.9, 32.2) = 8.86$, $p<.01$ (plus main effects of Task, $F(1.7, 28.3) = 94.88$, $p<.001$, and Repetition, $F(1, 17) = 42.49$, $p<.001$). Given no reliable effect involving Prime-level (F's<2.09, p's>.15), subsequent tests collapsed across this factor. These tests revealed significantly greater priming in the Same relative to the Reverse, $t(17) = 4.17$, $p<.01$, and Same relative to Orthogonal, $t(17) = 3.50$, $p<.01$, conditions (Reverse vs. Orthogonal, $t(17) = 0.58$, $p=.57$). As in Experiments 1-3, significant priming was present in the Same and Reverse conditions, *t*'s>2.40, p's<.05. Unlike Experiments 1-3, significant priming was also present in the Orthogonal condition, $t(17) = 2.53$, $p<.05$ (see Figure 3.2-A). The proportional measures of priming showed the same pattern of results (Appendix A-5).

A 2x2 ANOVA on the Orthogonal priming data revealed a main effect of Response Congruency, $F(1, 17) = 14.26$, $p<.01$, showing greater priming for Congruent (+103ms) than Incongruent (-29ms) stimuli (indeed, priming was reliable for Congruent trials, *t*(17) = 3.56, p<.01, but not Incongruent trials, *t*(17) = 1.09, p=.29; Figure 3.2-B). A main effect of Prime-level was also present, *F*(1, 17) = 5.26, p<.05, revealing greater priming for Low- than High-primed stimuli. This latter finding was unexpected, but given that it was not found in the other Experiments here, it is not considered further.

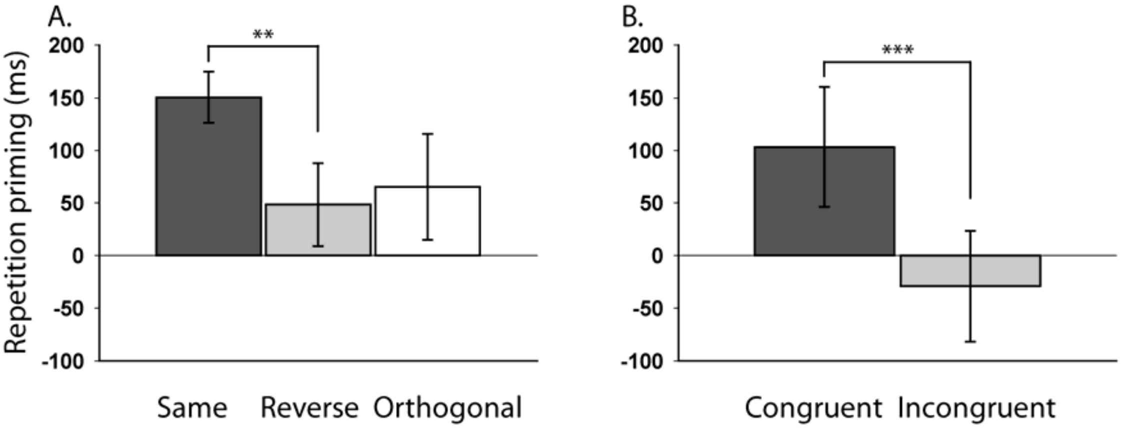

Figure 3.2. Mean repetition priming (Novel-Repeated) across (A) the Same, Reverse and Orthogonal conditions (collapsed across Prime-level) and (B) Congruent and Incongruent trials in the Orthogonal condition in Experiment 5. Error bars represent 95% two-tailed confidence intervals. *** p<.001; ** p<.01.

3.2.3 Discussion

The use of words (object names) rather than pictures in Experiment 5 produced, for the first time in the present series of experiments, significant nett priming in the Orthogonal condition. This "cross-task" priming in Experiment 5 replicates that found by Vriezen et al. (1995). One possibility is that significant priming can be induced even after controlling for S-R effects, by facilitation of one or more component processes. Why would this be the case for words, but not for the pictures in Experiments 1-3? One reason may be that performing the "shoebox" and "taller-than-wide" tasks with words requires the participant to imagine a specific (or prototypical) exemplar of the object, perhaps even forming a visual image. These processes of exemplar-selection and/or image-generation may be particularly prone to facilitation if they have been performed in the recent past - e.g., during the Study phase - producing a "savings" effect for Repeated stimuli. Because a picture of an object provides direct access to a specific exemplar, no such selection/image-generation processes would be necessary in Experiments 1-4. Indeed, previous research has shown priming during imagery tasks that require participants to form a mental image of an object (McDermott & Roediger, 1994). Another reason for priming in the Orthogonal condition for words but not for pictures may be facilitation of phonological access, given evidence that phonological representations are automatically accessed during word processing (Bowers & Turner, 2003), but not object processing (Damian & Bowers, 2003).

Nonetheless, priming in the Orthogonal condition was driven primarily by the Congruent trials, which could reflect retrieval of the previous response associated with a word repeated from the Study phase. Priming was not reliable for Incongruent trials. Indeed, this was also the case in Vriezen et al. (1995 – Experiment 6). In other words, the present results could still be explained by retrieval of S-R bindings, particularly if it is assumed that facilitation due to response repetition is greater than any interference due to response reversal. Thus the results from the present experiment cannot be taken as unequivocal evidence for the CP view of priming. These issues are revisited in Chapter 8. In the next experiment, I returned to pictures and tried another method to increase the potential for measurable facilitation of a more perceptual component process.

3.3 Experiment 6

In Experiment 6, I sought further evidence for the existence of CP contributions to priming. One reason for the failure to see evidence of perceptual facilitation in Experiments 1-4 may be that recognition of the objects depicted in the coloured pictures was already as efficient as possible (i.e., could not be facilitated appreciably by repetition). To tax object recognition processes to a greater extent, I visually degraded stimuli at Test in Experiment 6, anticipating more scope for perceptual facilitation owing to prior exposure of intact versions at Study.

3.3.1 Method

The experimental design of Experiment 6 was identical to Experiment 4, with the following exceptions.

3.3.1.1 Participants

18 participants (10 male) gave informed consent to participate in the experiment. The mean age across participants was 22.6 years ($\sigma = 4.4$). One participant was ambidextrous, all other participants were right-handed (self-report).

3.3.1.2 Procedure

Images were displayed in exactly the same manner as Experiment 4 during Study blocks, however at Test they were ‘degraded’ (see Figure 3.3). At stimulus onset the image was completely masked by setting 100% of pixels to gray. The amount of this noise was reduced gradually by randomly removing gray pixels from 100% at onset to 0% after 1000ms, over 25 steps. The unmasked stimulus then remained on screen for a further 1000ms. Participants performed the same Study and Test tasks as in Experiment 4, and were given exactly the same instructions (i.e., to respond as quickly and as accurately as possible).

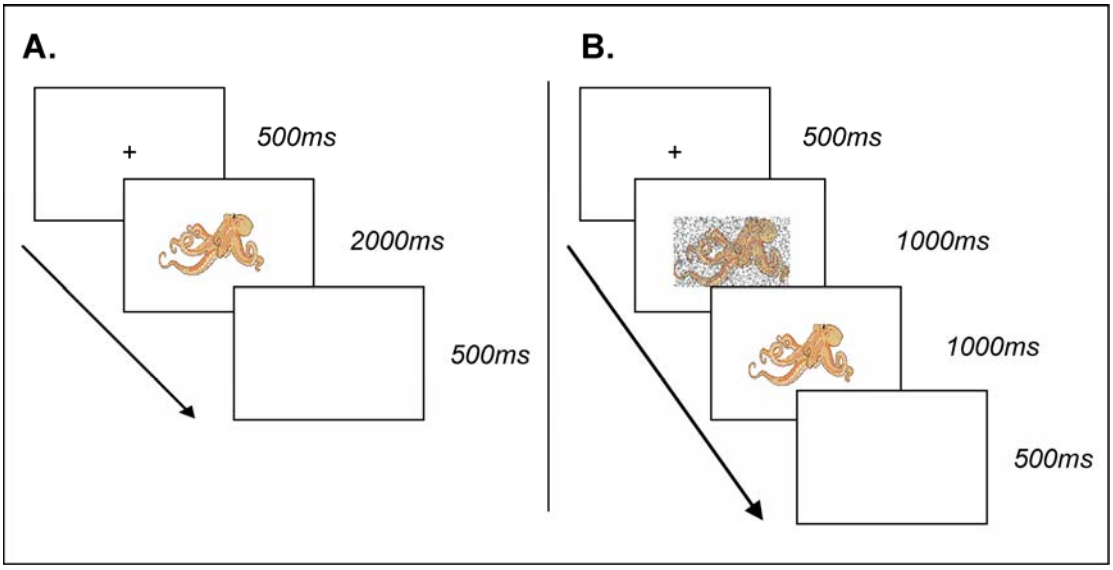

Figure 3.3. Trial sequence for (A) Study presentations and (B) Test presentations in Experiment 6. At Test stimuli were masked by visual noise at stimulus onset. The amount of this noise was gradually reduced over 1000ms followed by 1000ms of complete stimulus presentation.

3.3.2 Results

After excluding 0.8% of trials with outlying RTs, the percentage of errors are shown in Table 3.1. Analyses of errors revealed no significant effects of Repetition (Appendix A-6). A further 4.0% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

Table 3.2 displays mean RTs, together with measures of priming. Inspection of both additive priming and proportional priming scores suggests that priming was greater in Experiment 6 than previous Experiments. Tests confirmed that the mean additive priming, $t(17) = 4.48$, p<.001, and proportional priming, $t(17) = 3.26$, p<.01, was indeed greater in Experiment 6 than when using intact pictures in Experiment 4. A 3x2x2 ANOVA revealed a significant Task x Repetition interaction, $F(1.5, 26.3) = 16.28$, p<.001 (plus main effects of Task, $F(1.3, 22.8) = 45.27$, p<.001, and Repetition, $F(1, 17) = 156.85$, p<.001). Collapsing across Prime-level, subsequent tests revealed significantly greater priming in the Same, $t(17) = 6.23$, p<.001, and

Reverse, *t*(17) = 3.28, p<.01, conditions relative to the Orthogonal condition. Note that although the Same versus Reverse contrast did not reach significance, *t*(17) = 1.73, p=.10, analysis of the proportional measure of priming did reveal significantly greater priming in the Same condition, *t*(17) = 3.15, p<.01 (Appendix A-6). As in Experiments 1-5, significant priming was seen in the Same and Reverse conditions, *t*'s>9.82, p's<.001; and as in Experiment 5, there was also significant priming in the Orthogonal condition, *t*(17) = 3.25, p<.01 (see Figure 3.4-A).

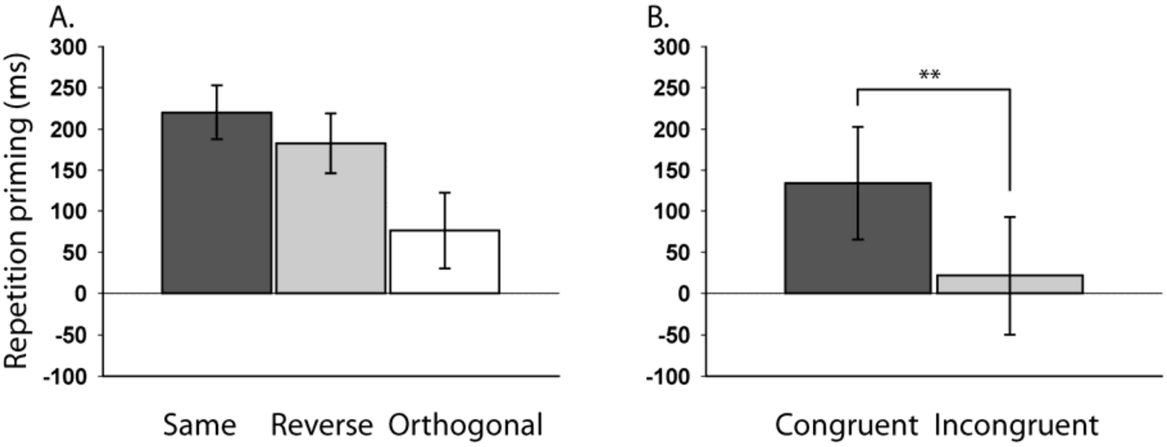

Figure 3.4. Mean repetition priming (Novel-Repeated) across (A) the Same, Reverse and Orthogonal conditions (collapsed across Prime-level) and (B) Congruent and Incongruent trials in the Orthogonal condition in Experiment 6. Error bars represent 95% two-tailed confidence intervals. ** p<.01.

As in Experiment 4, a trend towards a Task x Prime-level x Repetition interaction was present, *F*(1.5, 25.6) = 2.83, p=.09. A 2x2x2 ANOVA for the Same and Reverse conditions only revealed a significant Task x Prime-level x Repetition interaction, *F*(1, 17) = 5.19, p<.05 (as seen in Experiment 4). This interaction reflected greater priming for High- than Low-primed stimuli in the Same condition (+77ms), *t*(17) = 3.00, p<.01; a pattern that was not present in the Reverse condition (-49ms), *t*(17) = 1.01, p=.33.

A 2x2 ANOVA on the Orthogonal priming data revealed only a main effect of Congruency, *F*(1, 17) = 16.51, p<.001, with greater priming for Congruent (+134ms) than Incongruent (+21ms) stimuli, as in previous experiments (see Figure 3.4-B). As in Experiment 5, priming was reliable for Congruent trials, t(17) = 5.51, p<.001, but not for Incongruent trials, t(17) = 0.89, p=.39.

3.3.3 Discussion

Experiment 6 showed that a second type of experimental manipulation (in addition to the use of words rather than pictures in Experiment 5) - visual degradation of object pictures - can also reveal reliable nett priming in the Orthogonal condition. Indeed, this manipulation seemed to increase priming across all conditions relative to the non-degraded pictures in Experiment 4. One possible explanation is that, by "slowing down" object identification at Test via the gradual removal of visual noise, there was more scope for facilitation of this process by prior identification of objects at Study.

As in Experiment 4 however, priming in the Orthogonal condition was only reliable for Congruent trials. It is of course possible that there was a positive priming effect caused by perceptual facilitation for both Congruent and Incongruent trials, which was augmented by S-R contributions for Congruent trials, but counteracted by response interference for Incongruent trials. Such interference may have resulted in no nett priming for Incongruent trials. This would fit with the trend for positive priming for Incongruent trials seen in the present experiment compared to previous experiments that showed a trend towards negative priming. However, it is also possible that there was no contribution of perceptual facilitation at all, and retrieval of S-R bindings causes greater facilitation (for Congruent trials) than it does interference (for Incongruent trials), such that there was positive priming for Congruent trials but no negative priming for Incongruent trials. This is consistent with multiple study exposures (High-primed) increasing priming in the Same condition, but having little effect on priming in the Reverse condition. It is also consistent with the “instance” theory of Logan (1990), in which response retrieval can only cause facilitation (such that RTs for primed stimuli can never be slower than the “algorithmic” route required on initial presentation of a stimulus). The greater overall priming across all conditions when degrading stimuli (i.e., in Experiment 6 relative to Experiment 4) might simply be explained by the longer RTs allowing the retrieval of S-R bindings to have greater influence. Thus, to unequivocally rule out S-R learning as the explanation for “cross-task” priming, reliable positive priming needs to be demonstrated for Incongruent trials in the Orthogonal condition, and this was not found.

3.3.4 Inter-experimental analyses

Figure 3.5 displays the main priming effects seen across Experiments 4-6. In order to compare Experiments 4-6 formally, the results were entered into a 3x2x2x3 (Task x Repetition x Prime-level x Experiment) mixed ANOVA. Firstly, a significant Repetition x Experiment interaction was revealed, $F(2, 51) = 13.15$, $p<.001$, showing significantly greater priming in Experiment 6 than Experiment 4, $t(34) = 4.96$, $p<.001$, and Experiment 5, $t(34) = 3.86$, $p<.001$. This interaction however was modulated by Task (i.e., we found a significant Task x Repetition x Experiment interaction), $F(3.5, 88.7) = 3.12$, $p<.05$. Inspection of priming scores in Table 3.2 suggests that the increase in priming in Experiment 6 compared to Experiments 4 and 5 was greatest in the Reverse than the Same or Orthogonal condition. Comparing Experiments 4 and 6, post-hoc tests confirmed that the difference in priming between Experiments was greater in the Reverse than Same condition, $t(17) = 2.85$, $p<.05$, with a similar pattern of results when comparing Experiments 5 and 6, $t(17) = 2.44$, $p<.05$. Given this difference in priming across Task and Experiment did not affect the main priming effects of interest seen in Experiments 4-6 it is not discussed further.

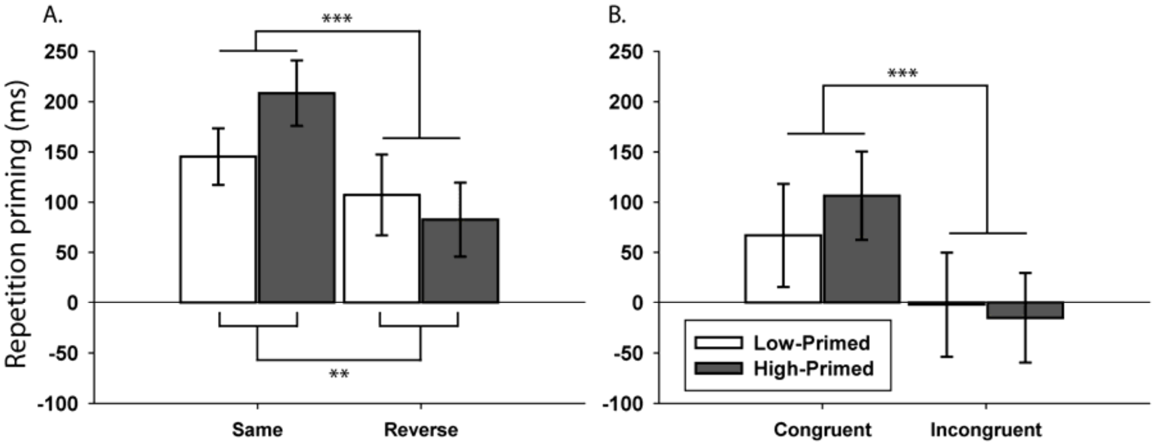

Figure 3.5. Main effects and interactions of interest across Experiments 4-6. (A) Greater priming in the Same than Reverse condition (collapsed across Experiment and Prime-level) and a Task x Prime-level interaction showing greater priming for High- than Low-primed items in the Same condition (collapsed across Experiment). (B) Greater priming for Congruent than Incongruent stimuli in the Orthogonal condition (collapsed across Experiment and Prime-level). Error bars represent 95% confidence intervals (two-tailed). *** p<.001; ** p<.01.

This analysis also revealed a significant Task x Repetition x Prime-level interaction, *F*(1.9, 95.6) = 4.64, p<.05. As Experiments 4 and 6 demonstrated a significant three-way interaction when analyses focussed specifically on the Same and Reverse condition, post-hoc tests were conducted comparing priming for High- vs. Low-primed items in the Same and Reverse conditions only. As in Experiments 4 and 6, these analyses revealed significantly greater priming for High- than Low-primed items in the Same condition, *t*(53) = 3.23, p<.01, and a non-significant trend for greater priming for Low- than High-primed items in the Reverse condition, *t*(53) = 1.17, p=.25 (see Figure 3.5-A). The main ANOVA also revealed a significant interaction between Task and Repetition, *F*(1.7, 88.7) = 35.00, p<.001, showing greater priming in the Same than Reverse condition (see Figure 3.5-A). Finally, a Task x Prime-level interaction was revealed, *F*(1.9, 95.5) = 5.55, p<.01 (and a marginal Repetition x Prime-level interaction, *F*(1, 51) = 3.91, p=.06), as well as main effects of Task, *F*(1.6, 79.3) = 192.66, p<.001, and Repetition, *F*(1, 51) = 220.18, p<.001.

A further inter-experimental analysis was conducted on the congruency data from the Orthogonal condition of Experiments 4-6. A 2x2x3 (Congruency x Prime-level x Experiment) mixed ANOVA revealed a significant effect of Congruency, *F*(1, 51) = 26.04, p<.001, with greater priming for Congruent (+86ms) than Incongruent (-8ms) trials (see Figure 3.5-B). As in the separate experimental analyses, priming was reliable for Congruent, *t*(53) = 5.25, p<.001, but not Incongruent, *t*(53) = .57, p=.57, trials. No further significant effects or interactions were present, *F*'s<2.73, p's>.08.

One final analysis was conducted in order to assess the effects of counterbalancing order on priming across our conditions of interest. This entailed a 3x2x2x6x6 (Task x Repetition x Prime-level x Experiment x Order) mixed ANOVA, where the between-subjects factor "Order" refers to the six counterbalancing orders of the three task conditions. The data from Experiments 1-6 were entered into this analysis so as to maximise the power to reveal any possible effect of Order. This resulted in a total of 16 participants per counterbalancing order, comparable in number to the individual experiments in Chapters 2 and 3. No main effect of Order was present, *F*(5, 60) = .76, p=.58, nor did this factor interact significantly with any other factor, *F*'s<1.62, p's>.17. Thus there was no evidence for any task order effects.

3.4 General Discussion

As in Chapter 2, the results of Experiments 4-6 from the present chapter were remarkably consistent. Again, across all three experiments greater priming was seen in the Same than Reverse condition as well as greater priming for Congruent than

Incongruent trials in the Orthogonal condition. As previously stated, these results are difficult to explain in terms of facilitation of component processes and serve to underline the dominance and consistency of S-R contributions within the present paradigm. Experiments 4 and 6 also revealed a further possible marker of S-R learning, with greater priming for High- than Low-primed items in the Same condition, and a trend in the opposite direction in the Reverse condition. This significant interaction was further confirmed in the inter-experimental analysis of Experiments 4-6, and is consistent with the notion that repeated co-occurrences of stimulus and response lead to greater facilitation when the same response is repeated at Test (i.e., in the Same condition).

Experiments 5 and 6 were the first in this thesis to demonstrate significant nett priming in the Orthogonal condition. Such a result is consistent with the notion of facilitation of component processes. In Experiment 5, I attempted to maximise the overlap in semantic processing between the Study and Test tasks in the Orthogonal condition, and presented word stimuli to increase possible exemplar generation and/or phonological processes. In Experiment 6, I visually degraded stimuli at Test thereby slowing down object identification. It was thought that such a manipulation would maximise the possibility of seeing facilitation of perceptual processes by taxing object recognition processes. Although facilitation of such processes is readily able to explain the nett priming in the Orthogonal condition, both experiments failed to demonstrate significant priming for Incongruent trials. As such, the priming seen in the Orthogonal conditions of these experiments may have been driven primarily by response repetition for Congruent trials. In short, these data cannot be taken as unequivocal evidence for facilitation of component processes.

3.4.1 Implications for S-R theories of priming

3.4.1.1 Extending Instance Theory?

Before progressing to the next chapter it is worth considering the results of Chapters 2 and 3 more carefully. In particular, it is worth examining whether existing S-R theories of priming can accommodate the present data. As previously discussed, one concrete example of an S-R theory of priming is the “Instance Theory” proposed by Logan (1990), as an extension of his theory of automaticity (Logan, 1988). This theory assumes that the response to the initial presentation of a stimulus is generated by an algorithmic processing route, but that this response also becomes stored together with a stimulus in a separate “instance” (i.e., an S-R binding). When the stimulus is repeated, there is a race between the algorithmic route and retrieval of any previous instances. When retrieval of a previous instance wins the race, the RT will be shorter, producing priming.

In situations in which participants realise that responses from previous tasks are likely to be inappropriate (i.e., in the present Reverse and Orthogonal conditions), Logan proposed that they revert to algorithmic processing, ignoring retrieval of previous instances. That is, the system should “run off the relevant algorithm and compute…a response” (Logan, 1988; p. 495). Because processing in the algorithmic route is assumed to be unaffected by repetition (unlike CP theories of priming), such situations should therefore not show any priming. However, the reliable priming in the present Reverse condition and for Congruent trials in the Orthogonal condition would suggest otherwise.

In order to accommodate the significant priming in the Reverse condition, Instance Theory could assume that S-R bindings are coded solely at the level of Classifications (e.g., “bigger/smaller”). That is, retrieval of an instance might provide a “bigger” Classification. Such a Classification would then be mapped to a “yes” Decision in the case of the Same condition, or a “no” Decision in the case of the Reverse condition. If S-R bindings were coded solely at the level of Classification, it is unclear why one should see a decrease in priming in the Reverse compared to the Same condition. If the only response information retrieved relates to the task-dependent Classification, equivalent priming should be seen across these conditions. Furthermore, it is unclear why High-primed trials (coded by three instances) would not produce greater priming than Low-primed trials in the Reverse as well as the Same condition. This is because increasing the number of repetitions at Study should increase the probability that retrieval of a Classification response “wins the race”, producing greater priming in both the Same and Reverse condition. Finally, one would not expect a congruency effect in the Orthogonal condition, where Decisions and Actions are repeated or reversed, but the Classification is quite different (e.g., “bigger” vs. “man-made” in Experiments 1-3). These data would seem to require either instances that encode multiple levels of response, or multiple separate instances for each level of response.

How would such an “extended” Instance Theory explain the congruency effect in the Orthogonal condition? In this condition (unlike the Reverse condition), Classifications from previous tasks are completely irrelevant. Furthermore, Actions and Decisions are not predictive of the correct response at Test given these responses are on average orthogonal to responses at Test. In such situations participants should revert to algorithmic processing, and no priming should occur for either Congruent or

Incongruent trials. Although this explanation fails to fit the RT data, it is consistent with the generally low error rates seen across Experiments 1-6 (i.e., <20% errors across all experiments and <3% in Experiment 1). In short, reverting to the algorithmic route should produce high accuracy rates but no nett priming.

Alternatively, one could assume that previous Action/Decision responses are retrieved and enacted, even if they are not predictive. This would explain the positive priming for Congruent trials. It could also explain the lack of reliable priming for Incongruent trials if one assumes that "Incongruent trials" represent situations in which the algorithm won the race (producing the opposite response to that made at Study). If this were the case however, one would expect to see much higher error rates as the algorithmic route is effectively ignored. Indeed, if response retrieval was consistently winning the race, errors should be as high as 50% as trials that should receive an Incongruent response are answered incorrectly. In other words, retrieved responses should be enacted without regard for accuracy (as the response retrieval route has no conception of whether the retrieved response is "correct"). This was not the case in the present experiments; in particular Experiment 1 had error rates of less than 3% in the Orthogonal condition.

In summary, the Orthogonal condition was able to show greater priming for Congruent than Incongruent trials whilst maintaining high accuracy levels. The only way to account for this pattern of results is to suggest that the response retrieval and algorithmic route interact prior to the generation of a response. During Congruent trials for example, there may be mutual reinforcement between the response retrieved from instances and the response currently favoured (even if not selected) by the algorithmic route, speeding up RTs. During Incongruent trials, there may be interference between the Action/Decision retrieved from instances and the response currently favoured by the algorithmic route. Such incongruency may lead to the algorithmic route running to completion, resulting in no nett priming. Alternatively, interference may in fact have slowed RTs, but this was counteracted by a small speeding of RTs from facilitation of perceptual processes. This latter possibility is not currently supported by the data as no significant interference effects have been seen in Chapters 2 and 3 (though see Chapter 4). Regardless, such interaction between the algorithmic and response retrieval routes would reflect a major departure from the original Instance Theory.

3.4.1.2 Extending Event-File Theory?

The proposal that responses are coded at multiple levels of response (Actions/Decisions and Classifications) would seem consistent with the Event-File theory proposed by Hommel (1998). This theory focuses more on interference effects of prior encounters, whereby discrepancies between the present circumstances and retrieved Event Files tend to slow RTs (Hommel, 2004). Although it does allow for the presence of multiple, separate Event Files (Waszak & Hommel, 2007), it is generally conceived that such bindings are temporary. As such, the theory has more often been applied to short-lag priming paradigms (though see Posse, Waszak & Hommel, 2006). Furthermore, it does not specify a mechanism (such as the race in Logan’s model) by which multiple records interact to generate a response (e.g., for High-primed stimuli).

More importantly, it is unclear how the theory predicts positive priming, given its focus on interference effects arising from prior experience. Waszak & Hommel (2007) have presented evidence of positive priming under certain experimental conditions. While they attribute the increase in priming to a disruption of S-R associations by an intervening task, it is unclear how such a reduction in interference can lead to significant *positive* priming without a separate mechanism (and indeed, Waszak and Hommel appeal to some form of additional facilitation of perceptual processing). As with Instance Theory, the present results would seem to require some form of interaction between "episodes" retrieved from previous trials and the component processes (algorithm) that compute the response in completely novel circumstances. This possible interaction between the response retrieval and algorithmic route is revisited in Chapter 8.

3.4.2 Chapter Summary

Chapter 3 presented three experiments designed to assess S-R and CP contributions to repetition priming. In Experiment 4, a new Orthogonal Test task was introduced (i.e., "taller than wide?") that was thought to increase the overlap in possible conceptual processing, requiring access to similar "size semantics" needed in the "bigger than shoebox" task. In Experiment 5, word rather than picture stimuli were presented to increase possible facilitation of exemplar generation/mental imagery and/or phonological processing. In Experiment 6, picture stimuli were degraded at Test to increase the scope to see possible facilitation of perceptual processes, by slowing overall RTs. Despite revealing significant nett priming in the Orthogonal condition of Experiments 5 and 6, no nett positive priming was seen for Incongruent trials. As such, Chapter 3 failed to provide unequivocal evidence for facilitation of particular component processes.

Chapter 3 revealed three possible markers of S-R learning: (1) greater priming in the Same than Reverse condition, (2) greater priming for Congruent than Incongruent trials in the Orthogonal condition and (3) greater priming for High- than

Low-primed trials in the Same condition, but no difference in the Reverse condition. These S-R effects were considered in relation to current S-R theories of repetition priming, specifically Instance Theory and Event-File Theory. Although both theories were capable of explaining certain portions of the data, they were unable to explain all the present results. Two critical issues were discussed: (1) the possibility that S-R bindings are coded at multiple levels of response representation and (2) the necessary interaction between response retrieval and algorithmic routes prior to response generation. The issue of interaction between these two routes will be addressed in Chapter 8. The next chapter focuses on the issue of multiple levels of response (and stimulus) representation. Although such multiple response representations were needed in order to explain the full set of results in Chapters 2 and 3 (without requiring additional CP contributions), no direct evidence has been provided for the existence of such representations. The experiments presented in the next chapter therefore directly assess this assumption of multiple response representations.

Chapter 4

S-R bindings at multiple levels of stimulus and response

Chapters 2 and 3 suggested that S-R contributions dominate in the present long-lag classification paradigm. Interestingly, I found little, if any, evidence for significant CP contributions to priming. These results question the commonly held assumption that priming reflects the facilitation of particular perceptual and/or conceptual processes. Having provided evidence for this dominance, the present chapter focuses on the S-R bindings that produce these S-R learning effects. Specifically, I asked: at what level of abstraction are both the response and stimulus represented within such S-R bindings? Whereas Experiments 7 and 8 concentrate on the level of response representation, Experiment 9 focuses on the level of stimulus representation.

As discussed in Chapters 2 and 3, the pattern of priming across the Same, Reverse and Orthogonal conditions of Experiments 1-6 can be explained fully by S-R learning. One effect that would seem difficult to explain is the significant priming found in the Reverse condition. In Chapter 3, I discussed the concept that S-R learning may occur at differing levels of response representation. Specifically, in order to explain the significant priming found in the Reverse condition, I suggested that responses may form at the abstract level of a “Classification” (e.g., “bigger/smaller” in the case of the shoebox task). Such abstract response coding however would not appear sufficient to explain the reliable congruency effects seen in the Orthogonal condition, where a previously learnt Classification (e.g., “bigger”) is irrelevant to the Test task (e.g., “is the object man-made?”). As such, S-R learning would also need to be occurring at the more specific level of a Decision (e.g., “yes/no”) or perhaps even an Action (e.g., right/left hand finger-press). Thus I can distinguish between at least three potential levels of response representation, an

Action (right/left finger-press), a Decision (yes/no) and a Classification (bigger/smaller).

The conditions in Experiments 1-6 could not distinguish S-R binding at the level of Decisions from the level of Actions, given that the assignment of “yes/no” to keys was fixed for a given participant. Furthermore, they could not provide direct evidence for S-R binding at the level of Classifications given the significant priming seen in the Reverse condition could have resulted from facilitation of conceptual processes (e.g., retrieval of semantic information relating to an object’s size in real life in the case of the “bigger than a shoebox” task – see predictions in Chapter 2). These response manipulations are illustrated in Table 4.1. The aim of Experiments 7 and 8 was to distinguish these, and provide more direct evidence that stimuli become bound simultaneously to each of these three levels of response representation. In Experiment 7 I manipulated responses at the level of Action and Decision, whereas in Experiment 8 I manipulated responses at the level of Decision and Classification. In order to address the issue of Classification responses in Experiment 8, I introduced a new response-congruency manipulation whereby I changed the referent in the “bigger than shoebox” task between Study and Test (e.g., to “bigger than a wheelie bin”). Changing the referent size has the effect of changing Classification responses between Study and Test for particular stimuli (i.e., stimuli that are “bigger” than a shoebox but “smaller” than a wheelie bin).

This new manipulation was then used in Experiment 9 to explore the related question about the level of stimulus abstraction within S-R bindings. Specifically, I asked: can S-R effects be seen despite switching from the name of an object (e.g., the word “lion”) to a picture of an object (e.g., a picture of a lion)? Given previous research has primarily focussed on Action and Decision response representations within S-R bindings (e.g., Dobbins et al., 2004; Logan, 1990; Schnyer et al., 2007), I first turned to distinguishing between these two responses.

Table 4.1. *Schematic of all conditions across Experiments 1-8 in terms of three different levels of response representation (Classification, Decision and Action). S = Same response; R = Reverse response; D = Different response. * indicates the critical differences in Contrast 1 of the inter-experimental analysis of Experiments 7 and 8, related to changes in Action (see text); + indicates the critical differences in Contrast 2 of the inter-experimental analysis of Experiments 7 and 8, related to changes in Classification (see text).*

	Classification	**Decision**	**Action**
Experiments 1-6			
Same	S	S	S
Reverse	S	R	R
Orthogonal			
Congruent	D	S	S
Incongruent	D	R	R
Experiment 7			
Same-Action Same-Decision	S	S	S*
Different-Action Same-Decision	S+	S	D*
Different-Action Different-Decision	D+	D	D
Experiment 8			
Classification-Congruent Decision-Congruent	S	S	S*
Classification-Congruent Decision-Incongruent	S+	R	R*
Classification-Incongruent Decision-Congruent	R	S	S
Classification-Incongruent Decision-Incongruent	R+	R	R

4.1 Experiment 7

In Experiment 7, participants always performed the “shoebox” task at Test. There were three different conditions at Study. In two conditions, the “shoebox” task was also performed, but participants either responded with key-presses (same Action and same Decision as at Test) or with vocal “yes/no” responses (different Action but same Decision from Test); in the third Study condition, participants were required to vocalise the object’s name (different Action and different Decision from Test). This design therefore separated learning of an Action (finger-press vs. vocal response) from learning of a Decision (yes/no vs. object-naming), as illustrated in Table 4.1.

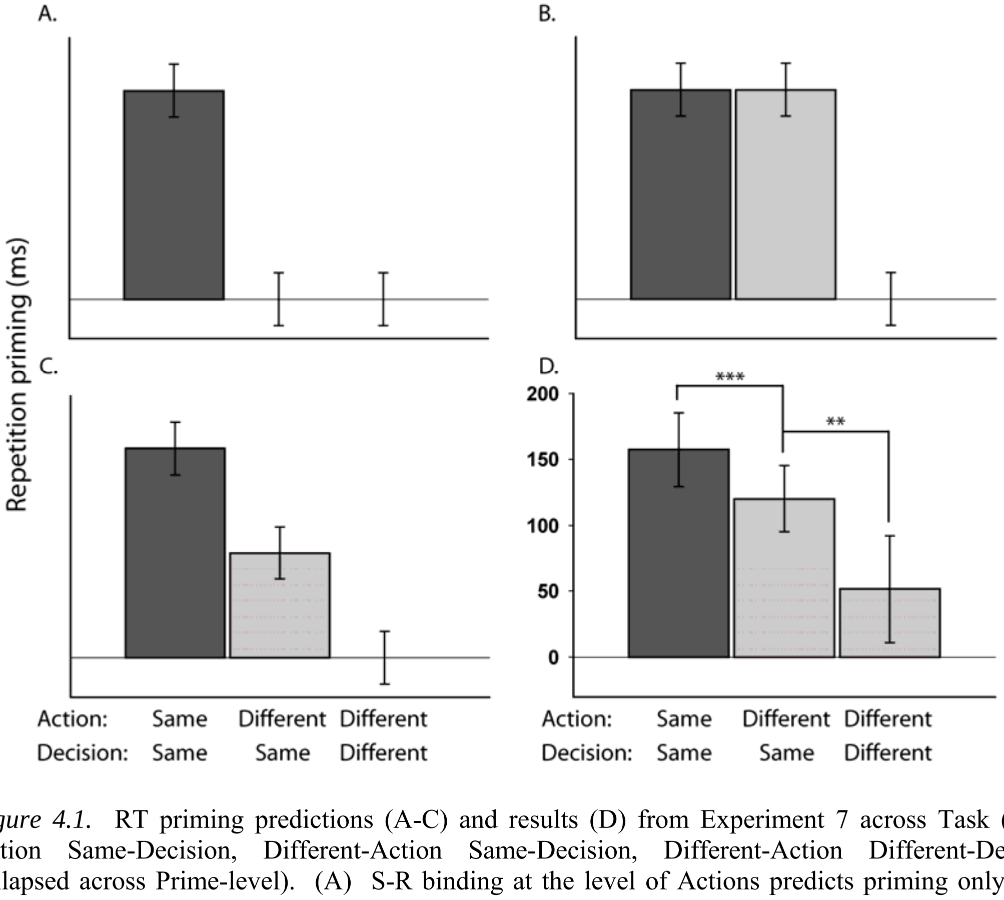

Figure 4.1. RT priming predictions (A-C) and results (D) from Experiment 7 across Task (Same-Action Same-Decision, Different-Action Same-Decision, Different-Action Different-Decision; collapsed across Prime-level). (A) S-R binding at the level of Actions predicts priming only in the Same-Action Same-Decision condition; (B) S-R binding at the level of Decisions predicts equivalent priming in the Same-Action Same-Decision and Different-Action Same-Decision condition; (C) S-R binding at the level of Actions and Decision predicts reduced though significant priming in the Different-Action Same-Decision condition. (D) Mean RT priming across Task collapsed across Prime-level. Error bars represent 95% confidence intervals (two-tailed). *** p<.001; ** p<.01.

Figure 4.1 presents the patterns of priming expected if S-R bindings are coded at the level of Actions, Decisions or Actions and Decisions. If responses are only coded at the level of Actions, significant priming should only be present in the Same-Action Same-Decision condition, with no nett priming in the other two conditions (Figure 4.1-A). This is because the response manipulation in Experiment 7 changed rather than reversed particular responses (e.g., the Action response changed from a finger-press to a vocal response instead of switching from a right to a left finger-press), decreasing the possibility of interference effects. If responses are coded at the level Decisions, equal priming should be present in the Same-Action Same-Decision and Different-Action Same-Decision conditions, with no priming in the Different-Action Different-Decision condition (Figure 4.1-B). However, if responses are coded at the level of Actions and Decisions priming should be present in both the Same-Action Same-Decision and Different-Action Same-Decision condition, however I should see significantly reduced priming in the latter condition (Figure 4.1-C). Again, no priming should be present in the Different-Action Different-Decision condition as no S-R bindings were repeated in this condition. Indeed, if priming was present in this condition this could be taken as evidence for the facilitation of particular component processes.

4.1.1 Method

The experimental design of Experiment 7 was identical to Experiment 1, with the following exceptions.

4.1.1.1 Participants

18 participants (7 male) gave informed consent to participate in the experiment. The mean age across participants was 24.7 years (σ = 6.0). 4 participants were left-handed, the remaining 14 participants were right-handed (self-report).

4.1.1.2 Design

Experiment 7 involved three study-test cycles. At Test, participants always performed the “bigger-than-shoebox” task, using key-press responses. At Study, participants completed one of three tasks: (1) the “bigger-than-shoebox” task with a key-press response (Same-Action Same-Decision), (2) the “bigger-than-shoebox” task verbally stating “yes” or “no” (Different-Action Same-Decision), or (3) a verbal naming task (Different-Action Different-Decision).

4.1.2 Results

After excluding 0.3% of trials with outlying RTs, the percentage of errors, together with mean RTs, mean RT priming and proportional priming, are shown in Table 4.2. Analyses of errors revealed no significant effects of Repetition (Appendix A-7). A further 2.1% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

A 3x2x2 (Task x Repetition x Prime-level) ANOVA revealed significant Task x Repetition, $F(1.6, 27.2) = 17.04$, $p<.001$, and Prime-level x Repetition, $F(1, 17) = 6.95$, $p<.05$, interactions (plus main effects of Task, $F(1.8, 30.3) = 10.15$, $p<.001$, Prime-level, $F(1, 17) = 6.09$, $p<.05$, and Repetition, $F(1, 17) = 79.31$, $p<.001$). The Prime-level x Repetition interaction reflected greater priming for High- than Low-primed stimuli irrespective of Task. To further investigate the Task x Repetition interaction, subsequent pairwise comparisons across Tasks were collapsed across Prime-level. These revealed significantly greater priming in the Same-Action Same-Decision than Different-Action Same-Decision condition, *t*(17) = 2.85, p<.05, and significantly greater priming in the Different-Action Same-Decision than Different-Action Different-Decision condition, *t*(17) = 3.28, p<.01 (see Figure 4.1-D). Note that there were no reliable task differences in RTs for Novel stimuli across Task (as expected since the Test task was the same across conditions); as a result, the proportional priming data showed a similar pattern to those of the main analysis (Table 4.2 and Appendix A-7). Therefore, changes (not reversals) in both Action and Decision caused a significant decrease in priming.

Table 4.2. *Mean percentage errors, error priming, reaction time (RT), RT priming and proportional priming (Prop. Priming) (plus standard deviations) across Task, Prime-level and Repetition for Experiment 7. LP = Low-primed; HP = High-primed; PP = Proportional Priming ((Novel-Repeated)/Novel). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Task / Prime-level		**Same-Action Same-Decision**		**Different-Action Same-Decision**		**Different-Action Different-Decision**	
		LP	**HP**	**LP**	**HP**	**LP**	**HP**
Errors	Novel	11.1 (5.0)	12.2 (8.3)	12.5 (6.9)	11.1 (7.6)	10.3 (6.7)	12.2 (7.5)
	Repeated	9.7 (6.3)	9.4 (5.4)	12.2 (10.2)	11.9 (7.3)	10.8 (6.2)	13.3 (7.5)
	Priming	1.4 (7.2)	2.8 (10.9)	0.3 (10.4)	-0.8 (6.5)	-0.6 (6.8)	-1.1 (10.2)
RTs	Novel	857 (131)	832 (133)	813 (126)	834 (119)	862 (174)	885 (176)
	Repeated	708 (101)	667 (99)	734 (127)	674 (102)	832 (141)	812 (151)
	Priming	150 (77)	165 (87)	80 (59)	161 (73)	30 (105)	73 (100)
	PP	.17 (.08)	.19 (.09)	.10 (.07)	.19 (.08)	.02 (.11)	.08 (.10)

Interestingly, priming was still significant in the Different-Action Different-Decision condition, *t*(17) = 2.48, p<.05. Indeed, this priming effect was significant even for participants who performed the Different-Action Different-Decision condition first, *t*(5) = 2.65, p<.05, suggesting that it was not simply because participants who performed the Different-Action Different-Decision condition last continued to (covertly) categorise objects as bigger/smaller at Study.

4.1.3 Discussion

Experiment 7 therefore produced two important findings for S-R learning: (1) significantly greater priming when an Action is repeated than when it is not (from contrasting key presses with yes/no vocalisations at Study) and (2) significantly greater priming when a Decision is repeated than when it is not (from contrasting yes/no vocalisation with object name vocalisation at Study). These results suggest that responses are coded at both the level of the Action and the Decision, possibly explaining some of the discrepancies in this regard across previous studies (Dobbins et al., 2004; Koch & Allport, 2006; Logan, 1990; Rothermund et al., 2005; Schnyer et al., 2007; Waszak & Hommel, 2007). Note also that the Different-Action Same-Decision and Different-Action Different-Decision conditions did not entail any response reversal, unlike the Reverse condition or the Incongruent trials in the Orthogonal condition of Experiments 1-6. Therefore there was no opportunity for a decrease in RTs owing to response interference, consistent with the greater overall priming for High- than Low-primed stimuli in Experiment 7, but no interaction of this effect with Task condition.

A third finding was reliable residual priming even when neither the finger press nor yes/no decision was repeated (i.e., in the Different-Action Different-Decision condition, when objects are only named at Study). This finding cannot be explained by responses at the level of Classification either, since naming an object has nothing to do with its subsequent “bigger” or “smaller” classification; nor did it appear to reflect covert performance of the “shoebox” task at Study, given that it was reliable even for participants who performed this condition first (though covert classification might have been encouraged by the practice phase). Repeating this condition on a group of participants who are never informed about the subsequent shoebox task would be informative in this regard. If reliable priming remains, this would be strong support for some form of facilitated perceptual processing (e.g., object identification). Note this is the first time in the present thesis that an identification, as opposed to a classification, task has been used. These results therefore underline the distinction drawn between identification and classification tasks in Chapter 1, with the former demonstrating CP contributions to repetition priming. Nonetheless, the main focus of Experiment 7 was on S-R bindings, for which Experiments 1-7 taken together suggest simultaneous coding of at least three levels of responses: Actions, Decisions and Classifications. This proposal was tested further in Experiment 8.

4.2 Experiment 8

Given the evidence from Experiment 7 that stimuli become bound with both overt Actions and covert Decisions, I wanted to find analogous evidence that stimuli can become bound with both yes/no Decisions and task-specific Classifications. While I appealed to the distinction between Actions/Decisions and Classifications to explain the results of Experiments 1-6, this was rather post hoc and indirect. Furthermore, I wanted to distinguish S-R learning of Classifications from facilitation of conceptual processes, given that the implication of Classification response codes in Experiments 1-6 was based partly on comparing the Reverse condition with the Orthogonal condition. Because this comparison entailed a change in task, it was difficult to guarantee that the same degree of overlap in conceptual processing occurred in the

Orthogonal condition as in the Reverse condition (even when using the “taller-wider” task in Experiments 4-6 to be as similar as possible to the “shoebox” task). Experiment 8 was therefore designed to contrast the use of Classification and Decision codes within the context of a constant task.

I achieved this by first introducing a referent change manipulation between Study and Test (e.g., “bigger than X” to “bigger than Y”). This requires a response change for stimuli whose size falls in between the two referent sizes. For example, whereas a picture of a monkey would be classified as “bigger” than a shoebox it would be “smaller” than a wheelie bin. This ensures a reversal in response at all three possible levels of response representation (i.e., Actions, Decisions and Classifications) and is therefore a more thorough manipulation of response congruency than the Same vs. Reverse manipulation utilised in Experiments 1-6 (that only required a reversal of response at the levels of Action and Decision). Note that this manipulation is also a within-block manipulation of response congruency in that some stimuli will receive a congruent response between Study and Test (i.e., if the object is bigger than a shoebox and wheelie bin), whilst others will receive an incongruent response (i.e., if the object is bigger than a shoebox but smaller than a wheelie bin). As such, participants will have no *a priori* knowledge concerning whether a response should be repeated or reversed between presentations (analogous to the Orthogonal condition of Experiments 1-6).

In order to contrast Decisions with Classifications, I combined this change in referent manipulation (e.g., “bigger than X” to “bigger than Y”) with task reversals (e.g., “bigger than X” to “smaller than X”), resulting in a factorial manipulation of Decision-congruency versus Classification-congruency (see Figure 4.2). For instance, when asked whether a monkey is bigger than a shoebox at Study, the participant is likely to classify it as “bigger” (the Classification) and therefore answer “yes” (the Decision). When asked at Test whether a monkey is bigger than a wheelie bin, the Classification will now be reversed (from “bigger” to “smaller”), as will the Decision (from “yes” to “no”). This would correspond to a Classification-Incongruent, Decision-Incongruent trial because both responses were reversed. However, when asked at Test whether a monkey is smaller than a wheelie bin, the correct Decision would now be “yes” as the monkey is smaller. This would correspond to a trial that is Decision-Congruent (because the participant answers “yes” at both Study and Test) but Classification-Incongruent (because the participant classifies the monkey as “bigger” at Study but “smaller” at Test).

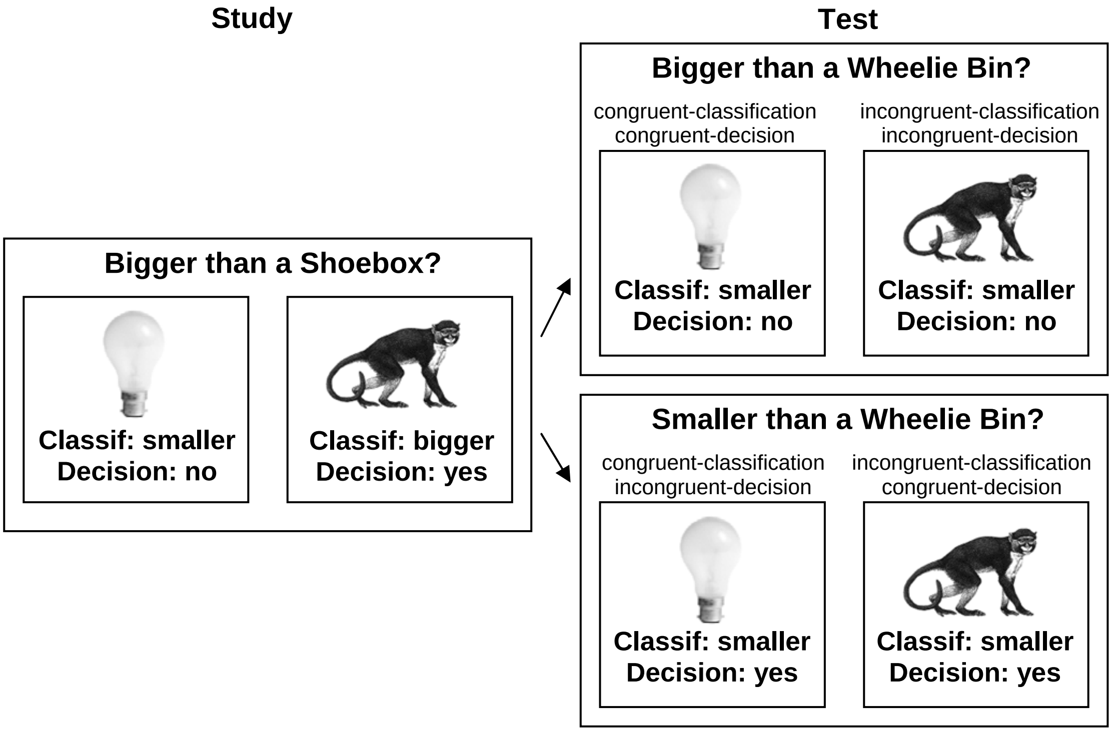

Figure 4.2. Schematic of experimental design for Experiment 8. Reversals in task (Bigger/Smaller) coupled with changes in size-referent (Shoebox to Wheelie Bin/Pencil Case) resulted in a 2x2 (Classification-congruency x Decision-congruency) factorial design. Note a referent change was also made to a smaller referent (a Pencil Case) as well as the larger Wheelie Bin referent change shown here. Classif. = Classification.

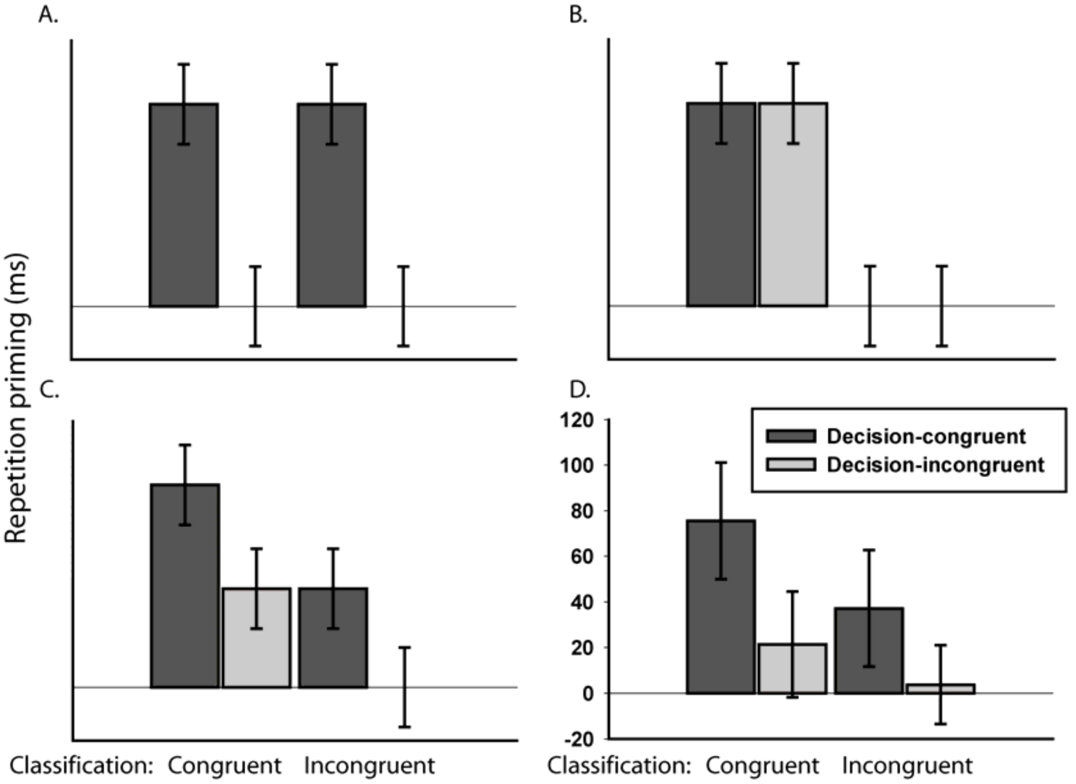

Figure 4.3. RT priming predictions (A-C) and results (D) from Experiment 8 across Classification-congruency and Decision-congruency (collapsed across Prime-level). (A) S-R binding at the level of Decisions predicts priming only for Decision-congruent trials, irrespective of Classification-congruency; (B) S-R bindings at the level of Classifications predicts priming only for Classification-congruent trials, irrespective of Decision-congruency; (C) S-R binding at the level of Decisions and Classifications predicts maximal priming for Classification-congruent Decision-congruent trials and reduced priming for Classification-incongruent Decision-congruent and Classification-congruent Decision-incongruent trials. (D) Mean RT priming across Classification-congruency and Decision-congruency collapsed across Prime-level. Error bars represent 95% confidence intervals (two-tailed).

What predictions do S-R theories make if bindings form at the level of Decisions, Classifications or both? If S-R bindings form at the level of Decisions, I should see greater priming for Congruent than Incongruent Decisions, irrespective of Classification-congruency (Figure 4.3-A). If, however, S-R bindings form at the level of Classifications, I should see greater priming for Congruent than Incongruent Classifications, irrespective of Decision-congruency (Figure 4.3-B). Finally, if bindings form at the level of Decisions and Classifications, maximal priming should be seen for Decision-congruent Classification-congruent trials (Figure 4.3-C). Reduced priming should be seen for Decision-congruent Classification-incongruent and Decision-incongruent Classification-congruent trials with a further reduction for Decision-incongruent Classification-incongruent trials. Indeed, if CP contributions are not present in Experiment 8, no nett priming should be seen in this latter condition given that it controls for S-R learning at all three possible levels of response representation. Note that the above predictions are based on the retrieval of S-R bindings causing facilitation when responses are congruent, but not interference when responses are incongruent. This is in line with the results of Chapters 2 and 3 that failed to find evidence for significant interference effects (though see below).

4.2.1 Method

Experiment 8 utilised a similar study-test design to previous experiments, however there were several key differences.

4.2.1.1 Participants

24 Participants (7 male) gave informed consent to participate in the experiment. The mean age across participants was 21.7 years ($\sigma = 3.7$). Four participants were left-handed, the remaining 20 participants were right-handed (self-report).

4.2.1.2 Design

Participants performed four study-test cycles. At Study, participants always performed the "bigger-than-shoebox" task. At Test, the referent was changed from a "shoebox" to either a "wheelie bin" or a "pencil case". Importantly, half the stimuli seen at Study that were bigger than a shoebox were smaller than a wheelie bin (for the wheelie bin referent change); equally, half the stimuli that were smaller than a shoebox were bigger than a pencil case (for the pencil case referent change). The other half of stimuli were split so that 50% were bigger than a shoebox and bigger than a wheelie bin, and 50% were smaller than a shoebox and smaller than a wheelie bin. The same was true for the pencil case referent change condition. This design meant that, for 50% of Repeated stimuli, a congruent Classification was given between Study and Test (e.g., “bigger” – “bigger”), and for the remaining 50% an incongruent Classification was given (e.g., “bigger” – “smaller”).

Crucially, participants were asked whether the object was either “bigger” or “smaller” than a wheelie bin or a pencil case at Test. In other words, four possible questions were posed at Test: (1) “bigger-than-wheeliebin?”, (2) “smaller-than-wheeliebin?”, (3) “bigger-than-pencilcase?”, and (4) “smaller-than-pencilcase?”. These manipulations factorise the Decision (yes/no) and Classification (bigger/smaller). For example, an object that is smaller than a shoebox and smaller than a pencil case will have a congruent Classification and congruent Decision in both “bigger than” tasks at Test (i.e., "smaller-smaller" and "no-no" respectively). For the "smaller than" tasks at Test on the other hand, that object will have a congruent Classification but incongruent Decision (i.e., "smaller-smaller" and "no-yes" respectively). However, an object that is smaller than a shoebox but bigger than a pencil case will have an incongruent Classification but congruent Decision for the “smaller-than-pencilcase” task at Test (i.e., "smaller-bigger" and "no-no" respectively). For the "bigger-than-pencilcase" task at Test on the other hand, that object will have both an incongruent Classification and incongruent Decision (i.e., "smaller-bigger" and "no-yes" respectively) (see Figure 4.2).

This results in a 2x2x2 factorial design of Classification-congruency (Congruent/Incongruent), Decision-congruency (Congruent/Incongruent), and Test-referent (Wheeliebin/Pencilcase). Two further factorial manipulations were also added: (1) Repetition (Novel, Repeated), and (2) Prime-level (Low-primed, High-primed). Following the logic of previous experiments, the Novel stimuli were arbitrarily split into groups equal in size to the Repeated conditions. Order of Test tasks was counterbalanced across participants.

4.2.1.3 Materials

384 stimuli from the main stimulus were split between the two Test referents (wheelie bin/pencil case) so that, of the 192 stimuli per referent, 48 were bigger than a shoebox and bigger than a wheelie bin (or pencil case), 96 were bigger than a shoebox and smaller than a wheelie bin (or smaller than a shoebox and bigger than a pencil case), and 48 were smaller than a shoebox and smaller than a wheelie bin (or pencil case). Therefore 96 stimuli were Classification-congruent, and 96 were Classification-incongruent. These 96 stimuli were then randomly assigned to one of 8 groups relating to the remaining 8 experimental conditions (2x2x2 – Decision-congruency x Prime-level x Repetition), resulting in 12 stimuli per group. The assignment of groups to experimental conditions was rotated across participants.

4.2.2 Results

After excluding 6.2% of trials with outlying RTs, the percentage of errors, together with mean RTs, mean RT priming and proportional priming, are shown in Table 4.3. Analyses of errors revealed no significant main effect of Repetition, however a Repetition x Prime-level interaction was present reflecting fewer errors for Repeated Low-primed than High-primed stimuli (Appendix A-8). A further 7.7% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

Given that there was no significant difference in RTs across the two Test-referents (wheelie bin/pencil case), *t*(23) = 1.12, p=.28, and the lack of theoretical interest in this manipulation, the RT data were collapsed across Test-referent for all further analyses. The resulting RT data were entered into a 2x2x2x2 (Classification-congruency x Decision-congruency x Prime-level x Repetition) ANOVA, which revealed several significant interactions and main effects. A similar pattern of results were seen for the proportional measure of priming (Appendix A-8).

Table 4.3. *Mean percentage errors, error priming, reaction time (RT), RT priming and proportional priming (plus standard deviations) across Classification-congruency, Decision-congruency, Prime-level, and Repetition for Experiment 8. LP = Low-primed; HP = High-primed; N = Novel; R = Repeated; P = Priming (Novel – Repeated); PP = Proportional Priming ((Novel-Repeated)/Novel). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Classification:		**Congruent**				**Incongruent**			
Decision:		**Congruent**		**Incongruent**		**Congruent**		**Incongruent**	
		LP	**HP**	**LP**	**HP**	**LP**	**HP**	**LP**	**HP**
Errors	**N**	3.5 (4.0)	3.6 (3.5)	4.2 (3.7)	4.0 (4.7)	4.9 (4.0)	3.0 (3.6)	5.6 (5.3)	3.0 (4.2)
	R	2.4 (3.2)	3.5 (3.2)	3.0 (2.9)	4.0 (4.2)	2.8 (3.2)	3.0 (3.6)	4.0 (3.6)	3.6 (3.7)
	P	1.0 (4.6)	0.2 (4.5)	1.2 (4.7)	0.0 (6.5)	2.1 (5.5)	0.0 (5.4)	1.6 (6.6)	-0.7 (5.4)
RT	**N**	838 (132)	845 (139)	887 (106)	849 (92)	939 (118)	918 (114)	910 (144)	926 (136)
	R	775 (120)	755 (96)	835 (104)	849 (94)	886 (115)	900 (115)	893 (134)	932 (153)
	P	60 (87)	91 (67)	47 (75)	-4 (67)	57 (88)	18 (59)	20 (69)	-12 (76)
	PP	.07 (.04)	.10 (.02)	.05 (.03)	-.01 (.03)	.06 (.04)	.02 (.02)	.02 (.03)	-.01 (.03)

The highest-order interaction was a Decision-congruency x Prime-level x Repetition interaction, *F*(1, 23) = 5.63, p<.05. Further tests revealed a significant decrease in priming for High-primed Decision-Incongruent than Low-primed Decision-Incongruent trials, *t*(23) = 3.64, p<.01, which was not present for the Decision-Congruent trials, *t*(23) = 0.37, p=.72. Therefore, increasing the number of repetitions at Study resulted in greater interference when the Decision was incongruent at Test. Although the Classification-congruency x Prime-level x Repetition interaction did not reach significance, *F*(1, 23) = 2.38, p=.14, there was a trend in the same direction as above, with significantly decreased priming for High-primed Classification-Incongruent than Low-primed Classification-Incongruent trials, *t*(23) = 2.91, p<.01, which was not present for Classification-Congruent trials, *t*(23) = 0.98, p=.34.

The main ANOVA also revealed a significant Decision-congruency x Repetition interaction, *F*(1, 23) = 19.19, p<.001, as well as a trend towards an Classification-congruency x Repetition interaction, *F*(1, 23) = 3.66, p=.07 (and no evidence for a three-way interaction between Decision-congruency, Classification-congruency and Repetition, *F*(1, 23) = .83, p=.37). Given I predicted greater priming for Congruent than Incongruent stimuli, one-tailed t-tests revealed significantly greater priming for Decision-Congruent than Decision-Incongruent trials, *t*(23) = 4.38, p<.001, and for Classification-Congruent than Classification-Incongruent trials, *t*(23) = 1.91, p<.05 (collapsed across Prime-level, Classification-congruency and Decision-congruency respectively). Thus, congruency of both the Decision and the Classification significantly affected priming (see Figure 4.3-D). There were also significant two-way interactions between Prime-level and Repetition, *F*(1, 23) = 8.32, p<.01, and Classification-congruency and Prime-level, *F*(1, 23) = 4.92, p<.05, as well as main effects of Classification-congruency, *F*(1, 23) = 77.04, p<.001, Decision-congruency, *F*(1, 23) = 21.38, p<.001, and Repetition, *F*(1, 23) = 41.59, p<.001, but no further interactions involving Repetition. Finally, priming in the Incongruent-Classification Incongruent-Decision condition was not reliable (+4ms), *t*(23) = .42, p=.68, suggesting that once S-R learning is controlled at all three levels of response representation, no additional contributions to priming (i.e., facilitation of component processes) remained (see Figure 4.3-D).

4.2.3 Discussion

The two main findings of Experiment 8 were (1) significantly greater priming for Decision-Congruent than Decision-Incongruent trials, and (2) significantly greater priming for Classification-Congruent than Classification-Incongruent trials, with no reliable interaction between these two effects. These findings support the prior hypothesis that responses are coded at the level of the Classification separately and simultaneously from the levels of Decision and/or Action. Importantly, these findings were in the context of conditions that appeared to be matched in their semantic requirements (i.e., differing only in the direction of the comparison - “bigger-than-X” vs. “smaller-than-X” - and in the referent, X). This makes the congruency effects unlikely to reflect differential levels of conceptual processing (as may have been the case when comparing the Reverse and Orthogonal conditions of Experiments 1-6).

When both Classifications and Decisions were incongruent, there was no reliable priming, consistent with the lack of any contribution from facilitation of conceptual processes. This is unlike Experiment 7, where there was evidence of priming despite no overlap in the Classification, Decision or Action (in the Different-Decision Different-Action condition). However, the third notable finding of Experiment 8 was a significant reduction in priming for High- relative to Low-Primed stimuli given an incongruent response at Test. This would suggest greater amounts of response interference when an S-R pairing has occurred three times at Study. This is the first appreciable evidence in the present thesis for the presence of interference in S-R learning. This point will be revisited in Chapter 8.

4.2.4 Inter-experimental analyses of experiments 7 and 8

The results of Experiments 7 and 8 suggest that S-R bindings can form at the level of Actions, Decisions, and Classifications. In Experiment 7, I manipulated Actions and Decisions. Note however that the change in Decision also entailed a change in Classification (e.g., from “monkey” to "bigger” in the Different-Decision Different-Action condition). The decrease in priming associated with this change may therefore reflect the change in Classification rather than Decision. In Experiment 8, on the other hand, I manipulated Decisions and Classifications. Here however the change in Decision also entailed a change in Action (e.g., a switch from “yes” to “no” also entailed a switch from “right” to “left”). As such, the decrease in priming associated with this change may have been due to a change in Actions rather than Decisions. It might therefore be possible to explain the results of Experiments 7 and 8 by proposing just two levels of response representation, namely Actions and Classifications.

In order to address this concern, I calculated the difference in proportional priming (to control for baseline RT differences across experiments) between certain conditions from Experiments 7 and 8 (collapsing across Prime-level). For each experiment, two difference scores were calculated across pairs of conditions. For Experiment 7, these were: (1) the difference between the Same-Action Same-Decision condition and the Different-Action Same-Decision condition, and (2) the difference between the Different-Action Same-Decision condition and the Different-Action Different-Decision condition. For Experiment 8, these were: (1) the difference between the Classification-Congruent Decision-Congruent condition and the Classification-Congruent Decision-Incongruent condition, and (2) the difference between the Classification-Congruent Decision-Incongruent condition and the

Classification-Incongruent Decision-Incongruent condition. For both experiments, as can be seen from Table 4.1, Contrast (1) is a measure of Action change, whereas contrast (2) is a measure of Classification change. Importantly however, Contrast (1) is a pure measure of Action change in Experiment 7, but a measure of both Action and Decision change in Experiment 8. Similarly, Contrast (2) is a pure measure of Classification change in Experiment 8, but a measure of both Classification and Decision change in Experiment 7.

Thus in order to test for an effect of Decision change, a 2x2 (Action vs. Classification x Experiment 7 vs. Experiment 8) ANOVA was conducted. If responses form at the level of the Decision, Contrast (1) should be greater in Experiment 7 than in Experiment 8, but Contrast (2) should be greater in Experiment 8 than Experiment 7 (i.e., there should be a significant Response-level x Experiment interaction). Such an interaction was indeed significant, $F(1, 40) = 6.05$, $p<.05$. This reflected a larger change in priming for Contrast (2) in Experiment 7 than in Experiment 8, $t(40) = 2.75$, $p<.01$, and a numerical trend for a larger change in priming for Contrast (1) in Experiment 8 than in Experiment 7, $t(40) = 1.20$, $p=.24$. This result is therefore consistent with all three levels of response representation having an effect on priming.

4.3 Experiment 9

Experiments 7 and 8 provided evidence for S-R effects at three distinct levels of response representation, the Action (e.g., right/left key-press), the Decision (e.g., “yes/no”) and the Classification (e.g., “bigger/smaller”). In Experiment 9 I changed my focus to the level of stimulus representation. Specifically, I asked: can S-R learning abstract away from the specific visual format of the stimulus presented at

Study? As with the level of response representation, previous research has presented conflicting evidence for either highly specific (Schnyer et al., 2007) or more abstract (Denkinger & Koutstaal, 2009) levels of stimulus representation, with the latter study demonstrating S-R learning effects despite a change in exemplar (e.g., between two differing pictures of a lion) between presentations. Given this more recent evidence for abstract stimulus representations I decided to go one step further and ask: can I see S-R learning effects despite switching from the name of an object (e.g., the word “lion”) to a picture of an object (e.g., a picture of a lion)? This manipulation was particularly important given recent evidence suggesting that across-exemplar repetition effects can in fact be driven by visual similarity between exemplars (e.g., two pictures of a lion are likely to share visual information not shared by two pictures of unrelated objects) (Chouinard, Morrissey, Köhler & Goodale, 2008). I reasoned that switching from visual word stimuli at Study to visual pictures at Test was unlikely to suffer from the same issues of visual similarity. As such, if S-R learning effects are still present despite such a switch, this would provide compelling evidence for S-R learning at an abstract level of stimulus representation (e.g., at the lexical/semantic level).

Experiment 9 utilised the same Response-congruency manipulation introduced in Experiment 8, changing the size of the referent between Study and Test. At Test the referent was changed to either a smaller (pencil case) or larger (wheelie bin) object, however the direction of the question remained constant (i.e. “bigger than X”). As a result of the referent change, half of the stimuli seen during Study will have required the same (i.e., Congruent) response at Test whereas half will have required the reverse response (i.e., Incongruent). Note that this manipulation of congruency requires a reversal of response at all three levels of response representation (see

Introduction of Experiment 8). This “optimal” experimental design is therefore used in the present experiment as well as Chapters 5 and 6. Importantly, I now added a stimulus manipulation whereby items were either presented as pictures, or as printed names, during the Study phase. At Test all items were presented as pictures. Therefore, half the picture stimuli were primed with a visually identical stimulus (the Picture-Picture condition) and half were primed with their named equivalent (the Word-Picture condition). I also included two further factorial manipulations of Prime-level (Low-primed, High-primed) and Repetition (Novel, Repeated). This resulted in a 2x2x2x2x2 factorial design with factors Referent (Pencilcase, Wheeliebin), Response-congruency (Congruent, Incongruent), Stimulus (Words, Pictures), Prime-level (Low-primed, High-primed), and Repetition (Novel, Repeated).

Before presenting the results of Experiment 9 it is worth considering the different predictions made if stimuli within S-R bindings were coded at a level that is specific to the visual format of the stimulus or at a more abstract level of representation. Firstly, if S-R bindings were specific to the visual format of the stimulus presented at Study, I would expect to see a Response-congruency effect in the Picture-Picture condition alone. If no interference is present, this should result in significant priming in the Picture-Picture Congruent condition and no priming in the Picture-Picture Incongruent condition (see Figure 4.4-A). However, if stimuli are coded at a level that abstracts away from the specific visual format of the stimulus presented at Study (e.g., at the semantic/lexical level), I should see equivalent Response-congruency effects in the Picture-Picture and Word-Picture condition (see Figure 4.4-B). Finally, if stimuli are coded at multiple levels of representation, one that is specific to the visual format of the stimulus and one that abstracts away from the visual format, I should see a Response-congruency effect in both the Picture-

Picture and Word-Picture condition. Critically, the Response-congruency effect should be greater in the Picture-Picture than Word-Picture condition (i.e., I should see a Response-congruency x Stimulus-type interaction; see Figure 4.4-C). This is because the Picture-Picture condition should benefit from the retrieval of S-R bindings at both levels of stimulus representation, whereas only S-R bindings that code "abstract" stimulus representations will be retrieved in the Word-Picture condition (as no visual similarity is present between object names and picture).

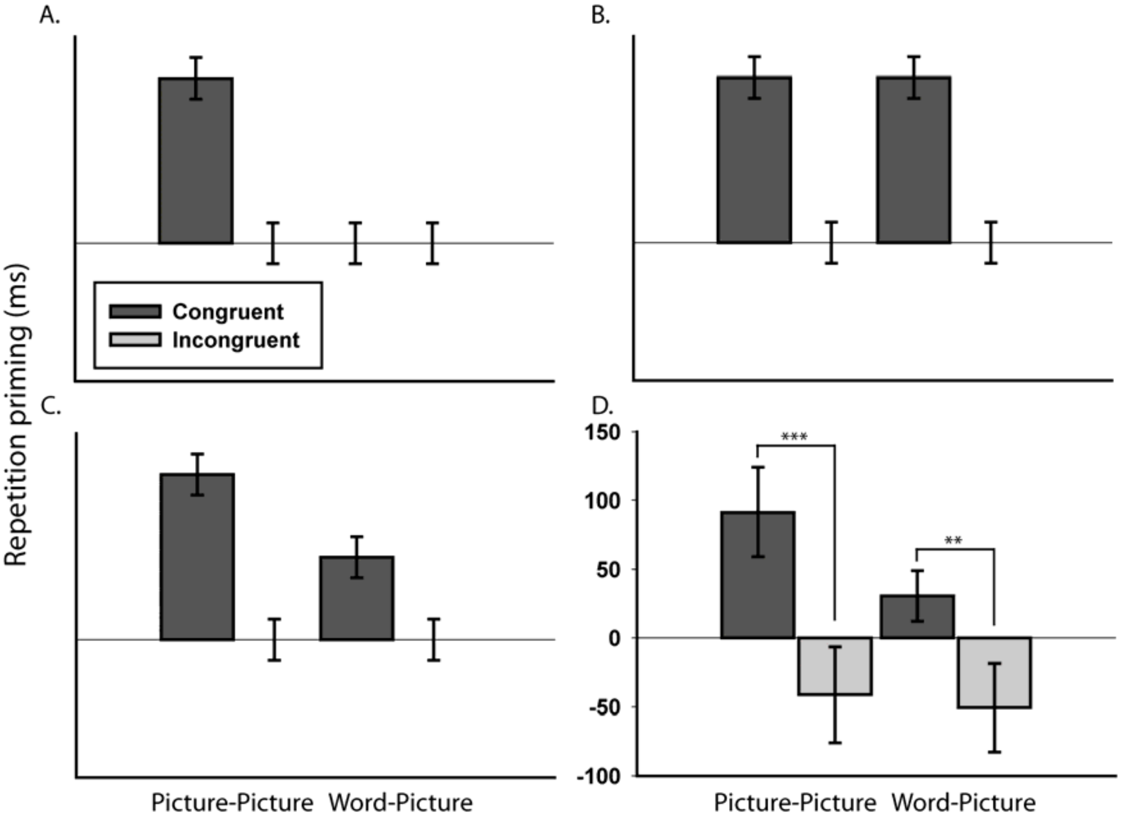

Figure 4.4. RT priming predictions (A-C) and results (D) from Experiment 9 across Response-congruency and Stimulus-type (collapsed across Prime-level). (A) S-R binding at a stimulus level that is specific to the visual format of the stimulus; (B) S-R binding at a stimulus level that abstracts away from the visual format of the stimulus; (C) S-R binding at a specific and abstract stimulus level. (D) Mean RT priming across Response-congruency and Stimulus-type collapsed across Prime-level. Error bars represent 95% confidence intervals (two-tailed).

4.3.1 Method

The experimental design of Experiment 9 was identical to Experiment 8 with the following exceptions.

4.3.1.1 Participants

16 participants (5 male) gave informed consent to participate in the experiment. The mean age across participants was 24.2 years ($\sigma = 4.1$). By self-report, two participants were left-handed; the remainder were right-handed.

4.3.1.2 Materials

Stimuli were the same as those used in Experiment 8. As in Experiment 8, 96 stimuli would receive a Congruent response between Study and Test and 96 stimuli would receive an Incongruent response (split across referent). Each group of 96 stimuli were then randomly assigned to one of 8 groups relating to the 8 remaining experimental conditions (Stimulus-type x Prime-level x Repetition), resulting in 12 stimuli per group (24 collapsed across referent). The assignment of groups to experimental conditions was rotated across participants.

4.3.1.3 Procedure

During each Study phase, 48 stimuli were shown; 12 were words presented once (Word-Picture – Low-primed), 12 were words presented three times (Word-Picture – High-primed), 12 were pictures presented once (Picture-Picture – Low-primed) and 12 were pictures presented three times (Picture-Picture – High-primed), resulting in 96 trials. Importantly, for each set of 12 stimuli, half received a Congruent and half received an Incongruent response at Test. During each Test phase, the 48 stimuli from the Study phase (Repeated) were randomly intermixed with 48 novel stimuli. All the stimuli presented at Test were pictures (i.e. for items primed with words at Study, their picture equivalent was presented at Test). Words were presented in black on a white background with the same pixel dimensions as the object picture stimuli.

4.3.2 Results

After excluding 0.4% of trials with outlying RTs, the percentage of errors, together with mean RTs and proportional priming, are shown in Table 4.4 (collapsed across Referent). Analysis of errors is reported in Appendix A-9. A further 7% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study.

Table 4.4. *Mean percentage errors, error priming, reaction time (RT), RT priming and proportional priming (plus standard deviations) across Stimulus-type, Response-congruency, Prime-level, and Repetition for Experiment 9. LP = Low-primed; HP = High-primed; N = Novel; R = Repeated; P = Priming (Novel – Repeated); PP = Proportional Priming ((Novel-Repeated)/Novel). Note that the division of Novel stimuli into High- and Low-primed is based on an arbitrary, equal split.*

Stimulus-type:		**Picture-Picture**				**Word-Picture**			
Congruency:		**Congruent**		**Incongruent**		**Congruent**		**Incongruent**	
		LP	**HP**	**LP**	**HP**	**LP**	**HP**	**LP**	**HP**
Errors	**N**	5.0 (4.6)	3.9 (3.6)	17.7 (9.1)	16.2 (8.0)	6.0 (3.7)	5.7 (4.0)	17.2 (5.7)	14.8 (5.3)
	R	5.7 (4.8)	4.2 (5.0)	20.1 (9.5)	19.3 (11.3)	3.6 (3.0)	2.9 (3.3)	18.2 (9.2)	17.4 (5.9)
	P	-0.8 (6.1)	-0.3 (6.9)	-2.3 (11.2)	-3.1 (12.4)	2.3 (4.3)	2.9 (4.5)	-1.0 (8.7)	-2.6 (7.9)
RT	**N**	794 (134)	827 (134)	837 (119)	896 (166)	800 (138)	805 (146)	889 (139)	908 (169)
	R	729 (150)	709 (121)	873 (163)	942 (159)	788 (149)	755 (114)	942 (182)	955 (166)
	P	65 (95)	118 (61)	-37 (94)	-46 (106)	12 (71)	50 (72)	-54 (129)	-47 (90)
	PP	.08 (.11)	.14 (.06)	-.04 (.11)	-.06 (.12)	.01 (.09)	.05 (.08)	-.06 (.14)	-.06 (.10)

Given the Referent manipulation did not significantly interact with any other factor (*F*'s<.60, p's>.45), and the lack of theoretical interest in this factor, subsequent analyses were collapsed across Referent (note however that a main effect of Referent was present, *F*(1, 15) = 9.07, p<.01, showing greater RTs when the referent was a pencilcase than a wheeliebin). Inspection of Figure 4.4-D shows that positive priming was seen for both Picture-Picture and Word-Picture Congruent trials, in line with facilitation due to response repetition. Interestingly, both Picture-Picture and Word-Picture Response-incongruent trials show significant negative priming (i.e., a slowing of RTs relative to Novel trials). This suggests that the retrieval of previously learnt responses can interfere with the process of response selection at Test. These S-R learning effects seem to be present in both the Picture-Picture and Word-Picture condition, suggesting that stimuli within S-R bindings can form at "abstract" levels of representation.

To confirm these results, I conducted a 2x2x2x2 (Response-congruency x Stimulus-type x Prime-level x Repetition) ANOVA on RTs. This analysis revealed a trend towards a Response-Congruency x Stimulus-type x Repetition interaction, *F*(1, 15) = 3.75, p=.07 (this effect was reliable in the proportional priming analysis – Appendix A-9). To unpack this interaction I conducted two separate 2x2x2 (Response-Congruency x Prime-level x Repetition) ANOVAs on the Picture-Picture and Word-Picture conditions separately. The Picture-Picture analysis revealed a significant Response-congruency x Repetition interaction, *F*(1, 15) = 45.76, p<.001, showing greater priming for response congruent than incongruent trials, *t*(15) = 6.74, p<.001 (no further interactions with Repetition were present, *F*'s<2.23, p=.16). Therefore stimuli that required a switch in response between Study and Test decreased priming compared to stimuli that required a response repetition (see Figure 4.4-D).

The Word-Picture analysis also revealed a significant Response-Congruency x Repetition interaction, *F*(1, 15) = 15.47, p<.001, again showing greater priming for response congruent than incongruent trials, *t*(15) = 3.98, p<.001 (no further interactions with Repetition were present, *F*'s<1.27, p's>.28). Thus the S-R learning effect seen in the Picture-Picture condition was replicated in the Word-Picture condition. In other words, I have provided evidence that stimuli in S-R bindings can form at a representational level that abstracts away from the specific visual characteristics of a stimulus presented at Study. Interestingly, this S-R learning effect was numerically smaller in the Word-Picture than Picture-Picture analysis. This numerical trend towards a greater Response-congruency effect on RT priming in the Picture-Picture condition (i.e., a trend towards a full Response-congruency x Stimulus-type x Repetition interaction) reached significance in the proportional analysis (see Appendix A-9).

The main 2x2x2x2 ANOVA also revealed a significant Stimulus-type x Repetition interaction, *F*(1, 15) = 5.48, p<.05, showing greater priming for items presented as pictures at Study compared to items presented as words, *t*(15) = 2.37, p<.05 (collapsed across Response-congruency and Prime-level). Therefore, presenting the same picture stimulus at Study and Test resulted in greater priming than presenting a word at Study and a picture at Test (irrespective of Response-congruency). Further interactions were seen between Response-congruency and Prime-level, *F*(1, 15) = 11.91, p<.01, and Stimulus-type and Prime-level, *F*(1, 15) = 6.25, p<.05, as well as main effects of Response-congruency, *F*(1, 15) = 136.47, p<.001, Stimulus-type, *F*(1, 15) = 20.38, p<.001 and Prime-level, *F*(1, 15) = 7.07, p<.05, however no main effect of Repetition was present, *F*(1, 15) = .76, p=.40. Given that these effects did not interact with Repetition they are of little theoretical interest and are therefore not discussed further.

4.3.3 Discussion

Experiment 9 therefore provided evidence for S-R learning at an abstract level of stimulus representation, with a significant response congruency effect despite switching from word stimuli at study to picture stimuli at Test. These results go beyond those of Denkinger et al. (2009) who demonstrated significant S-R learning effects despite a change in object exemplar between repetitions. Although the previous results may have been driven by the degree of visual similarity between object exemplars, the present word-to-picture manipulation does not suffer from the same concern. As such, I can state that the stimulus within S-R bindings can be encoded at a representational level that abstracts away from the specific visual format of the initially presented stimulus.

I also saw evidence for a greater S-R learning effect in the Picture-Picture than Word-Picture condition (a trend in the "additive" analysis of priming, but reliable in the "proportional" analyses), suggesting that S-R learning effects are maximal when the stimulus presented at Test is the same as that presented at Study. This is consistent with the idea that S-R learning can occur at multiple levels of stimulus representation (akin to the multiple levels of response representation seen in Experiments 7 & 8), one that is tied to the specific visual form of the object and a second that forms at a level of abstraction that allows for S-R learning to transfer from a word to a picture stimulus. Priming would therefore be greater in the Picture-Picture Congruent condition than the Word-Picture Congruent condition because there are contributions from responses bound to both "visual" and "abstract" stimulus representations in the Picture-Picture condition, but only responses bound to "abstract" stimulus representations in the Word-Picture condition.

Note that this interaction between stimulus condition and response congruency could be a result of stimulus differences, with word stimuli in general demonstrating diminished congruency effects compared to picture stimuli (i.e., the cross-stimulus manipulation was always primed with words and this may have resulted in weaker S-R bindings compared to when an item was primed with an object). This explanation is unlikely however, given that I saw similar S-R learning effects in Experiment 5, where I presented words at both Study and Test, compared to Experiments 1-4, where I presented object pictures at both Study and Test. As such, the difference in response congruency seen in the present experiment is likely to have resulted from the fact that I switched from a word to a picture, rather than because I simply primed these items with a word.

Finally, Experiment 9 provided evidence for interference effects resulting from the retrieval of previously learnt S-R bindings. Specifically, when a response given at Test was incongruent to that previously given at Study, I saw slower RTs compared to experimentally novel items. These results suggest that previously learnt S-R bindings are automatically retrieved when an item is repeated, and that this retrieval can actively facilitate or interfere with the generation of a new response, dependent on the congruency of response between repetitions.

4.4 General Discussion

The present chapter has focussed on the level of both stimulus and response representation within S-R bindings. In Experiments 7 and 8 I manipulated the level of response between Study and Test, providing evidence for S-R learning at three distinct levels of response representation, the Action (right/left finger-press), the Decision (“yes/no”) and the task-dependent Classification (e.g., “bigger/smaller”). In

Experiment 9 I manipulated the level of stimulus between Study and Test, providing evidence for S-R learning at an abstract level of stimulus representation that does not require the repetition of the same visual format (e.g., between word and picture stimuli). Furthermore, the results were consistent with the idea that S-R bindings can form at two possible levels of stimulus representation, at the level of the specific visual format of the stimulus, and at a more abstract “identity” level of representation. This conclusion is supported by the interaction between priming, response-congruency and stimulus-type seen in Experiment 9 (i.e., the response-congruency effect was greater in the Picture-Picture than Word-Picture condition). As such, the present results suggest that S-R learning is a highly flexible process, with S-R bindings forming at multiple levels of both stimulus and response representation.

Experiments 8 and 9 were the first in the present thesis to demonstrate significant interference when a retrieved response was incongruent with the response needed at Test. These results concur with studies that focus on RT changes following task switches (e.g., Waszak et al., 2003). These studies typically show slower RTs for stimuli that were previously paired with a different task and/or response, suggesting that retrieval of information relating to a particular task-set or response can actively interfere with current processing. This interference was reflected in a reduction for High- compared to Low-primed items in Experiment 8, when either Decisions or Classifications were incongruent. These results suggest that increasing the number of repetitions at Study increases the amount of interference when the retrieved response is incongruent. This compliments the finding of greater priming for High- than Low-primed items seen in the Same condition in Chapter 3. In other words, increasing the number of repetitions at Study can increase priming when the retrieved response is congruent and decrease priming when the retrieved response is incongruent. In

Experiment 9 interference was reflected by a slowing of RTs for incongruent trials in both the Picture-Picture and Word-Picture condition. Thus, retrieving an incongruent response can actively interfere with processing, resulting in a slowing of RTs compared to novel stimuli.

As in the previous chapter it is necessary to explore whether Instance Theory (Logan, 1990) can explain these results. Firstly, the proposal that S-R bindings can form at multiple levels of stimulus and response is not currently predicted by Instance Theory. As discussed in Chapter 3 however, Instance Theory could be extended to include the possibility that a single instance encodes information relating to each level of stimulus and response, or that separate instances form between each level of stimulus and response. The finding of interference, in particular the slowing of RTs for incongruent items in Experiment 9, is more difficult to explain in terms of Instance Theory. At present, Instance Theory predicts that negative priming should not be seen. Either the response retrieval route wins the race, resulting in a speeding of RTs, or the system reverts to algorithmic processing, resulting in no change in RTs. The finding of interference therefore underlines the necessary interaction between the response retrieval and algorithmic route. The present results suggest that this interaction can either facilitate or interfere with processing dependent on the congruency of response generated by the two routes.

Finally, the finding of multiple levels of stimulus and response representation as well as interference effects is readily explicable in terms of Event File Theory (Hommel, 1998). In particular, this theory focuses on interference effects that result from incongruency between the present circumstances and the retrieved Event File. As previously discussed however, it is unclear how this theory could explain the facilitation seen across Chapters 2-4 whereby congruency between the current circumstances and the retrieved Event File (i.e., S-R binding) speeds up RTs. This facilitation would seem to require some mechanism that allows for facilitation. Although the "race" in Instance Theory is able to explain this facilitation, the currently proposed interaction between response retrieval and algorithmic processing would seem a more appropriate mechanism to explain these facilitatory effects. Such an interaction between routes would readily lend itself to explaining both facilitation and interference effects that result from the retrieval of S-R bindings. This possible interaction is discussed in depth in Chapter 8.

4.4.1 Summary of chapters 2-4

In summary, the results of Experiments 1-9 have shown that S-R learning dominates in long-lag classification paradigms. These S-R learning effects can be shown across a range of classification tasks regardless of whether the task is varied at either Study or Test (Experiments 1-3). The dominance of these effects was most apparent in my inability to show significant positive priming for Incongruent items in the Orthogonal condition. This was the case despite an attempt to equate the type of semantic information accessed between Study and Test (Experiment 4), to increase the likelihood of facilitation of phonological and/or exemplar generation processes through the presentation of word stimuli (Experiment 5) and to increase the likelihood of facilitation of perceptual processes through stimulus degradation at Test (Experiment 6).

Although the pattern of priming effects in Experiments 1-6 was consistent with the proposal that S-R learning can occur at multiple levels of response representation, these experiments failed to provide direct evidence for this. As such, I directly manipulated response (and stimulus) representation in Experiments 7-9, presenting evidence for S-R learning at multiple levels of stimulus and response. Finally, I have shown the retrieval of S-R bindings can both facilitate (i.e., for High-primed items in the Same condition of Experiments 4-6) and interfere (i.e., for Incongruent items in Experiment 9) with processing at Test, both speeding and slowing RTs relative to experimentally novel items, dependent on the congruency of response between Study and Test. These results were discussed in relation to Instance Theory and Event File theory. Both theories were unable to explain the complete picture of results across Chapters 2-4. In particular, the results highlighted the need for a form of interaction between response retrieval and algorithmic processing. These issues are discussed in depth in Chapter 8. In the next chapter I turn my attention to the repetition-related decreases in neural activity (i.e., repetition suppression) that have recently been associated with S-R theories of repetition priming (Dobbins et al., 2004).

Chapter 5

S-R learning and repetition suppression: an fMRI study

As discussed in Chapter 1, S-R accounts have recently been used to explain the repetition-related decreases in neural activity – as measured by functional magnetic resonance imaging (fMRI) – known as repetition suppression (RS). Here the reductions in neural activity seen within distinct cortical regions are thought a result of an effective by-passing (or curtailing) of activation within such regions, due to the retrieval of an appropriate S-R binding. In support of this idea, Dobbins et al. (2004) provided evidence for robust RS within occipital/temporal as well as inferior prefrontal regions when a response was repeated between stimulus presentations. When a response was reversed, they saw a significant reduction in RS within these regions. Most strikingly, they no longer saw reliable RS in higher-order regions of the ventral visual stream (i.e., fusiform cortex) where such effects are usually assumed to reflect facilitation of perceptual processes. As such, they suggested that RS reflects the by-passing of such regions when responses are repeated (i.e., S-R learning), rather than the facilitation of processes localised within such regions (i.e., facilitation of component processes).

One puzzling aspect of these data is that other fMRI studies have found robust RS in fusiform regions under conditions deliberately chosen to limit the occurrence of S-R learning. For example, reliable RS has been shown when using tasks with no explicit response requirements for the critical stimuli (e.g., Henson et al., 2000), when using task switches such that the response on repetition of a stimulus is (on average) orthogonal to its previous response (i.e., the Orthogonal condition of Experiments 1-6) (Henson et al., 2003; Horner & Henson, 2008), and when using changes in both the stimulus and response, with no obvious S-R pairing, such as in word-stem completion paradigms that involve different tasks at study and test (Schacter Alpert, 1996; Schott et al., 2005). Thus, S-R bindings would not appear sufficient to explain RS in all brain regions, particularly parts of the ventral visual processing stream.

Indeed, recent research has suggested a possible dissociation between occipital/temporal ventral visual and inferior prefrontal regions. Whereas RS was shown to be robust to switches in task and/or response between presentations in occipital/temporal regions, RS was sensitive to such switches in inferior PFC regions (Horner & Henson, 2008; Race et al., 2009). Horner & Henson (2008) assessed RS across the Same, Reverse and Orthogonal conditions introduced in Experiments 1-6 of the present thesis. In a region in the left fusiform gyrus, similar to that seen in the Dobbins et al. (2004) study, equivalent RS was seen across all three conditions. The authors therefore suggested that response retrieval does not result in the by-passing of all component processes, and that such RS was plausibly related to the facilitation of particular perceptual and/or conceptual processes. RS in inferior prefrontal regions, specifically *pars orbitalis* and *pars opercularis* was shown to vary as a function of Task, with maximal RS in the Same condition (i.e., when the task and response was repeated). RS in such regions, in line with Dobbins et al. (2004), was therefore thought to result from the repetition of responses between presentations.

One issue with this latter conclusion however was that it was primarily based on finding significantly decreased RS in the Orthogonal compared to the Same condition (although a numerical trend for decreased RS in the Reverse compared to the Same condition was seen). As discussed in Chapters 2-3, the Orthogonal condition requires a change in task between presentations, as well as possibly requiring the retrieval of differing semantic information (e.g., by switching from the “bigger than a shoebox?” to “man-made?” task). Thus the RS effect in PFC regions may have reflected: (1) the retrieval of bindings between stimulus and task (e.g., Waszak & Hommel, 2007; Waszak et al., 2003) or (2) the facilitation of processes involved in the controlled retrieval of task-specific semantic information (e.g., Wagner, Pare-Blagoev, Clark & Poldrack, 2001). A recent study by Race et al. (2009), that utilised a similar across-task design, could also be interpreted in a similar manner. Thus, research suggesting RS in PFC regions is primarily driven by the retrieval of S-R bindings has not effectively separated such effects from retrieval of S-task bindings or the controlled retrieval of semantic information.

Given these data, Experiment 10 was designed to assess S-R vs. CP contributions to RS. I used the same referent change manipulation used in Experiments 8 and 9 to control for S-R learning at all three levels of response representation (i.e., Actions, Decisions and Classifications). Thus, I could assess RS following response repetition (Congruent) vs. response reversal (Incongruent). Note that this Response-congruency manipulation is not confounded with switches in task between presentations as a task switch occurs for both Congruent and Incongruent trials (i.e., the task is switched from “Bigger than X” to “Bigger than Y”). Furthermore, all tasks require the retrieval of information relating to object size thus equating conceptual processing across conditions. As such, the present experiment does not suffer from the same issues as the Horner & Henson (2008) and Race et al. (2009) studies described above.

Given the evidence for abstract stimulus representations within S-R bindings I also included the word-to-picture manipulation introduced in Experiment 9. Whereas at Study I presented both word and picture stimuli, at Test I only presented pictures. Stimuli at test were therefore either previously presented as pictures (Picture-Picture condition), previously presented as words (Word-Picture condition) or experimentally novel (Novel condition). Note that the Novel condition is included in the Stimulus-type factor and there is therefore no factorial manipulation of Repetition (as in Experiment 9). This resulted in a 3x2 design with factors Stimulus-type (Picture-Picture, Word-Picture, Novel) and Congruency (Congruent, Incongruent). I used this same design in Experiment 11 (Chapter 6).

Given the behavioural evidence for a greater response-congruency effect in the Picture-Picture than Word-Picture condition in Experiment 9, I analysed both the behavioural and neuroimaging data (Chapters 5 and 6) in the following manner. Firstly, I conducted separate ANOVAs for the Picture-Picture and Word-Picture conditions (comparing each condition to the same Novel baseline condition in a 2x2 – Repetition x Stimulus-type – ANOVA). This allowed for a separate assessment of repetition-related behavioural and neural changes as a function of response-congruency for both the Picture-Picture and Word-Picture condition. Following these separate assessments, I compared the effects seen in each analysis (e.g., the response-congruency effect in the Picture-Picture and Word-Picture condition). Note that I have specific behavioural predictions based on each planned analysis: (1) the Picture-Picture analysis should demonstrate a Repetition x Response-congruency interaction, (2) the Word-Picture analysis should demonstrate a Repetition x Response-congruency interaction and (3) the Repetition x Response-congruency effect should be greater in the Picture-Picture than Word-Picture condition.

In relation to RS, I asked the following questions. Firstly, with regard to S-R learning: (1) is RS in higher-order ventral visual as well as inferior prefrontal regions primarily driven by response repetition as predicted by S-R theories and (2) if such S-R learning contributions are present, are they seen in both the Picture-Picture and Word-Picture analysis – mirroring the behavioural data from Experiment 9?

Secondly, in relation to facilitation of component processes: (3) can I see RS in higher-order ventral visual regions despite a reversal in response between presentations and (4) if such an effect is present, is it specific to the repetition of the same visual stimulus (i.e., the Picture-Picture condition) or can I see evidence for facilitation of component processes in both the Picture-Picture and Word-Picture condition? With regards to the latter question, a RS effect (that is unaffected by Response-congruency) that is specific to the Picture-Picture condition could be taken as evidence for facilitation of perceptual processes, whereas a RS effect that is present regardless of Stimulus-type could be taken as evidence for facilitation of semantic/lexical processes (i.e., that are not specific to repetition of the same visual stimulus).

5.1 Experiment 10

5.1.1 Method

Apart from the following exceptions, Experiment 10 was identical to Experiment 9.

5.1.1.1 Participants

Eighteen participants (10 male) gave informed consent to participate in the experiment. The mean age across participants was 25.9 years ($\sigma = 4.3$). By self-report, all participants were right-handed.

5.1.1.2 Materials

The 384 stimuli, split between the wheelie bin and pencil case referent change and size classifications, were randomly assigned to one of three groups relating to whether they were presented as a picture at Study (Picture-Picture), a word at Study (Word-

Picture) or were experimentally novel (Novel). This resulted in 64 stimuli per condition collapsing across the two referent changes. This resulted in a 3x2 design with factors Stimulus-type (Picture-Picture, Word-Picture, Novel) and Congruency (Congruent, Incongruent). The assignment of stimuli to the three Stimulus-type factors was rotated across participants.

5.1.1.3 Procedure

The experiment consisted of four Study-Test blocks (two relating to the wheelie bin referent change and two relating to the pencil case referent change). During each Study phase, 64 stimuli were shown three times each resulting in 192 trials (i.e., all stimuli were “high-primed”). 32 stimuli were presented as pictures (Picture-Picture) and 32 were presented as words (Word-Picture). Each set of 32 stimuli consisted of equal numbers of Congruent and Incongruent items. During each Test phase, the 64 stimuli from the Study phase (Picture-Picture and Word-Picture) were randomly intermixed with 32 novel stimuli (Novel). All items at Test were presented as pictures.

5.1.1.4 fMRI Acquisition

Thirty-two T2*-weighted transverse slices (64x64 3mmx3mm pixels, TE = 30ms, flip-angle = 78^o) per volume were taken using Echo-Planar Imaging (EPI) on a 3T TIM Trio system (Siemens, Erlangen, Germany). Slices were 3-mm thick with a 0.75mm gap, tilted approximately 30^o at the front to minimise eye-ghosting, and acquired in descending order. Eight sessions were acquired, equating to the four study-test cycles. 298 volumes were acquired during each Study phase, 154 were acquired during each Test phase, with a repetition time (TR) of 2000ms. The first five volumes of each session were discarded to allow for equilibrium effects. A T1-

weighted structural volume was also acquired for each participant with 1mmx1mmx1mm voxels using MPRAGE and GRAPPA parallel imaging (flip-angle = 9^{o}; TE = 2.00s; acceleration factor = 2).

5.1.1.5 fMRI Analysis

Data were analysed using Statistical Parametric Mapping (SPM5, http://www.fil.ion.ucl.ac.uk/spm5.html). Preprocessing of image volumes included spatial realignment to correct for movement, followed by slice-timing correction. Each image was then spatially normalised to Talairach space, using the linear and non-linear normalisation parameters estimated from warping each participant's segmented structural image to a T1-weighted average template image from the Montreal Neurological Institute (MNI). These re-sampled images (voxel size 3x3x3 mm) were smoothed spatially by an 8mm FWHM Gaussian kernel (final smoothness approximately 11x11x11 mm).

Statistical analysis was performed in a two-stage approximation to a Mixed Effects model. In the first stage, neural activity was modelled by a delta function at stimulus onset. The BOLD response was modelled by a convolution of these delta functions by a canonical Haemodynamic Response Function (HRF). The resulting time-courses were down-sampled at the midpoint of each scan to form regressors in a General Linear Model.

For each Test session, 7 regressors were modelled – the 6 experimental conditions (3x2; Stimulus-type x Congruency) plus an additional regressor for discarded trials (using the standard behavioural exclusion criteria). To account for (linear) residual artefacts after realignment, the model also included six further regressors representing the movement parameters estimated during realignment. Voxel-wise parameter estimates for these regressors were obtained by Restricted

Maximum-Likelihood (ReML) estimation, using a temporal high-pass filter (cut-off 128secs) to remove low-frequency drifts, and modelling temporal autocorrelation across scans with an AR(1) process.

Images of contrasts of the resulting parameter estimates (collapsed across the four Test phases) comprised the data for a second-stage model, which treated participants as a random effect. In addition to the 18 subject effects, this model had 6 condition effects, corresponding to a 3x2 (Stimulus-type x Congruency) repeated-measures ANOVA. Within this model, Statistical Parametric Maps (SPMs) were created of the *T* or *F*-statistic for the various ANOVA effects of interest, using a single pooled error estimate for all contrasts, whose nonsphericity was estimated using ReML as described in Friston et al. (2002).

Unless otherwise stated, all SPMs were thresholded at p<.05, corrected for multiple comparisons using Random Field Theory, either across the whole-brain or within regions of interest (ROIs) defined by contrasts from independent data. Stereotactic coordinates of the maxima within the thresholded SPMs correspond to the MNI template.

5.1.2 Results

5.1.2.1 Behavioural results

After excluding 5% of trials with outlying RTs, the percentages of errors are shown in Table 5.1. Analyses of errors are detailed in Appendix A-10. A further 11% of trials were excluded from RT analyses due to incorrect responses given at Study. Table 5.1 displays mean RTs, while Figure 5.1-C shows priming (Novel-Repeated) of RTs across all conditions.

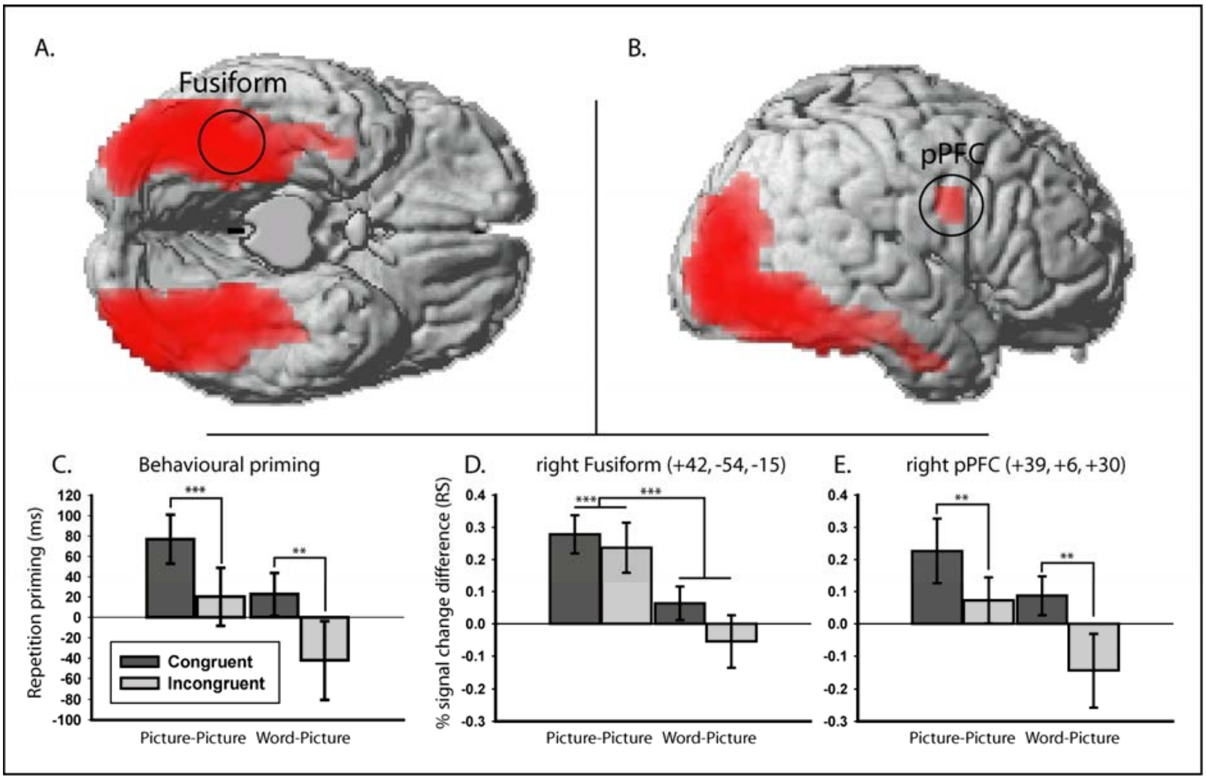

Figure 5.1. (A-B) Picture-Picture RS effect, small-volume corrected p<.05 FWE (see main analysis); (A) View of ventral surface of temporal and frontal lobes highlighting the right fusiform ROI; (B) View of lateral surface of right hemisphere highlighting the right pPFC ROI. (C) Mean repetition priming across Stimulus-type (Picture-Picture, Word-Picture) and Congruency (Congruent, Incongruent); (D) Mean RS effect in right fusiform ROI; (E) Mean RS effect in right pPFC ROI. Error bars represent 95% confidence intervals (two-tailed). *** p<.001; ** p<.01.

Inspection of Figure 5.1-C reveals a similar pattern of results to those of Experiment 9. The only positive priming effect was seen in the Picture-Picture Congruent condition, though there was a trend in the Word-Picture Congruent condition. Interestingly, the Word-Picture Incongruent condition showed a significant slowing of RTs relative to novel items (i.e., negative priming). A 3x2 (Stimulus-type x Congruency) ANOVA revealed a significant Stimulus-type x Congruency interaction, $F(1.7, 28.3) = 11.25$, $p<.01$ (as well as main effects of Stimulus-type, $F(1.5, 25.0) = 30.94$, $p<.001$, and Congruency, $F(1, 17) = 68.29$, $p<.001$).

As outlined in the introduction, I broke this Stimulus-type x Congruency interaction down into two separate 2x2 (Repetition x Congruency) ANOVAs comparing (1) the Picture-Picture condition with the novel condition and (2) the

Word-Picture condition with the novel condition. This allowed me to assess priming for each Stimulus-type separately across Congruency. The Picture-Picture analysis revealed a significant Repetition x Congruency interaction, *F*(1, 17) = 23.28, p<.001, reflecting greater priming for Congruent than Incongruent stimuli, *t*(17) = 4.84, p<.001. A main effect of Repetition was also present, *F*(1, 17) = 26.08, p<.001, revealing significant positive priming when collapsing across Congruency (as well as a main effect of Congruency, *F*(1, 17) = 84.62, p<.001).

Table 5.1. *Mean percentage errors, error priming, reaction times (RTs), RT priming and proportional priming (Prop. Priming) (plus standard deviations) across Stimulus-type (Picture-Picture, Word-Picture, Novel) and Congruency (Congruent, Incongruent) for Experiment 10.*

Stimulus-type /	Picture-Picture		Word-Picture		Novel	
Congruency	Con	Incon	Con	Incon	Con	Incon
% Errors	5.4 (4.1)	11.0 (8.4)	5.1 (3.4)	11.6 (9.4)	5.1 (3.8)	11.0 (6.8)
Error Priming	0.3 (3.6)	0.0 (3.8)	0.0 (3.7)	0.6 (6.6)		
RTs	685 (85)	800 (104)	739 (94)	853 (139)	752 (100)	810 (117)
RT Priming	67 (46)	9 (34)	14 (30)	-44 (49)		
RT Prop. Priming	.09 (.05)	.01 (.04)	.02 (.04)	-.05 (.06)		

The Word-Picture analysis also revealed a significant Repetition x Congruency interaction, *F*(1, 17) = 11.63, p<.01, again reflecting greater priming for Congruent than Incongruent stimuli, *t*(17) = 3.41, p<.01. As in the Picture-Picture analysis, a main effect of Repetition was present, *F*(1, 17) = 10.99, p<.01, in this instance reflecting significant negative priming (i.e., a slowing of RTs compared to baseline) (as well as a main effect of Congruency, *F*(1, 17) = 49.57, p<.001). Interestingly, the difference in priming between Congruent and Incongruent stimuli did not significantly differ between the Picture-Picture and Word-Picture condition, *t*(17) = .03, p=.98. In other words, the S-R effects in the Picture-Picture and Word-Picture condition were statistically equivalent (though see later inter-experimental analysis in Chapter 6 focussing on this issue). These results therefore replicate the main finding of Experiment 9, suggesting that S-R learning effects can be seen despite switching from a visual word at Study to an object picture (of the same object identity) at Test.

For the subsequent fMRI results, I adopted the same approach used in the behavioural analyses, searching for "main effects" of Repetition (i.e., repetition suppression) and interactions between Repetition and Congruency separately for each Stimulus-type. Thus, each Stimulus-type (Picture-Picture and Word-Picture) is compared separately with the same Novel baseline condition. This approach was also applied to the EEG results in Chapter 6.

5.1.2.2 fMRI Results

5.1.2.2.1 Whole-brain analyses

Given I was interested in regions previously shown to demonstrate RS, in particular prefrontal regions that have been shown to be sensitive to changes in response between presentations (e.g., Dobbins et al., 2004; Horner & Henson, 2008; Race et al., 2009), I constrained my search by using a whole-brain corrected t-contrast map from Horner & Henson (2008). This independently acquired t-contrast is the equivalent of the "main effect" of RS in the Picture-Picture condition of the present study and includes bilateral regions of the occipital and temporal lobes including lateral occipital and inferior temporal regions (i.e., the ventral visual stream). This map also included two bilateral clusters in the inferior prefrontal gyrus; the first a more anterior region, *pars triangularis* (BA 45), and the second a more posterior region, *pars opercularis* (BA 44).

I first searched for regions that demonstrated a significant effect of RS in the Picture-Picture condition, using Random Field Theory to correct for multiple comparisons within this constrained search space. This revealed large bilateral clusters in the occipital/temporal lobes, including lateral occipital and inferior temporal regions (see Figure 5.1-A & 5.1-B). This effect peaked in the fusiform gyrus in the right hemisphere (+42, -54, -15) and the inferior occipital gyrus in the left hemisphere (-36, -78, -9). A further region in the right inferior prefrontal gyrus (+39, +6, +30) – *pars opercularis* – henceforth referred to as posterior prefrontal cortex (pPFC), was also revealed (see Table 5.2 for peak voxels within these clusters). I next searched for regions that showed a significant Repetition x Congruency interaction in the Picture-Picture analysis. This revealed a significant cluster in the right inferior prefrontal gyrus (+42, +30, +12) – *pars triangularis* – that showed greater RS for Congruent than Incongruent stimuli. Importantly, this Repetition-by-Congruency contrast failed to reveal any significant clusters within occipital/temporal regions. Thus these analyses demonstrate that significant RS was present in occipital/temporal as well as inferior prefrontal regions however it is only the inferior prefrontal regions where RS showed a sensitivity to switches in response between presentations.

Turning to the Word-Picture analysis, the "main effect" of Repetition contrast failed to reveal any significant clusters in the small-volume correction (SVC). Interestingly, in the Repetition-by-Congruency contrast for the Word-Picture condition, a cluster in the right inferior prefrontal gyrus was revealed with identical co-ordinates to that revealed in the Picture-Picture Repetition-by-Congruency analysis (+42, +30, +12). These results therefore mirror the behavioural priming results in that the RS effect in inferior prefrontal regions was sensitive to switches in response despite switching from a visual word at Study to an object picture at Test.

Table 5.2. *Peak voxels (and local maxima) showing an effect of repetition suppression in the Picture-Picture condition (Novel > Picture-Picture) and a Repetition-by-Congruency interaction in the Picture-Picture condition, p<.05 FWE small-volume corrected. Voxel numbers reported are for entire cluster, so are not available for local maxima. IFG = Inferior Frontal Gyrus.*

Region	Voxels	MNI co-ordinates			Z-score
Picture-Picture Repetition					
Right Fusiform Gyrus	913	+42	-54	-15	7.84
Inferior Occipital Gyrus		+42	-72	-9	7.25
Fusiform Gyrus		+36	-39	-21	7.14
Middle Occipital Gyrus		+33	-87	+3	6.39
Left Inferior Occipital Gyrus	852	-36	-78	-9	6.90
Fusiform Gyrus		-33	-42	-18	6.40
Middle Occipital Gyrus		-36	-87	-3	6.10
Fusiform Gyrus		-42	-60	-12	5.96
Fusiform Gyrus		-33	-57	-12	5.95
Superior Occipital Gyrus		-30	-84	+21	5.25
Right Posterior IFG	38	+39	+6	+30	4.33
Repetition x Congruency					
Right Anterior IFG	55	+42	+30	+12	3.72

In summary, these analyses revealed two main effects: (1) a RS effect in the inferior prefrontal gyrus that differed as a function of Congruency that was seen in both the Picture-Picture and Word-Picture analyses and (2) a RS effect that was specific to the Picture-Picture condition (i.e., that was reliant upon visual similarity between Study and Test presentations) within bilateral occipital/temporal regions that did not differ as a function of Congruency. Before discussing these findings further, I conducted a series of region-of-interest (ROI) analyses based on the above results.

5.1.2.2.2 ROI analyses

To further interrogate the fMRI data, I extracted data from two regions that were identified in the SVC Picture-Picture RS t-contrast: (1) a region in the right fusiform gyrus (+42, -54, -15) and (2) a region in the posterior portion of the right inferior prefrontal gyrus – *pars opercularis* – (+39, +6, +30; pPFC). The mean percentage signal change and RS effect for these regions are presented in Table 5.3. These ROI data reflect a weighted average of nearby voxel values by virtue of the Gaussian smoothing of the fMRI images. Note that these regions were defined by the "main effect" of RS in the Picture-Picture condition and therefore do not bias any further analyses concerned with significant Repetition-by-Congruency interactions (i.e., an orthogonal contrast). The data from each region were subjected to separate 2x2 (Repetition x Congruency) repeated-measures ANOVAs for the Picture-Picture and Word-Picture condition separately (mirroring the behavioural analyses).

Table 5.3. *Mean percentage signal change and repetition suppression (RS) (and standard deviations) in right fusiform (+42, -54, -15), right posterior PFC (+39, +6, +30; pPFC), left fusiform (-24, -57, -15) and left inferior PFC (-36, +33, -12; iPFC) ROIs across Stimulus-type (Picture-Picture, Word-Picture, Novel) and Congruency (Congruent, Incongruent). Percent signal change refers to the peak of the fitted BOLD impulse response, and is relative to the grand mean over all voxels and scans. Note that the baseline level of 0 was not estimated reliably in this design so only patterns across conditions are meaningful.*

Stimulus-type /	Picture-Picture		Word-Picture		Novel	
Congruency	Con	Incon	Con	Incon	Con	Incon
Right Fusiform						
% signal change	.23 (.32)	.22 (.32)	.45 (.32)	.51 (.32)	.51 (.32)	.46 (.29)
RS	.28 (.13)	.24 (.17)	.06 (.11)	-.05 (.18)		
Right pPFC						
% signal change	-.18 (.30)	-.15 (.33)	-.04 (.32)	.07 (.30)	.04 (.33)	-.07 (.35)
RS	.23 (.22)	.07 (.16)	.09 (.13)	-.14 (.25)		
Left Fusiform						
% signal change	.13 (.36)	.13 (.47)	.18 (.43)	.27 (.38)	.30 (.40)	.24 (.39)
RS	.17 (.16)	.11 (.19)	.12 (.21)	-.03 (.19)		
Left iPFC						
% signal change	.14 (.19)	.14 (.20)	.16 (.17)	.23 (.23)	.24 (.19)	.18 (.20)
RS	.10 (.12)	.03 (.14)	.08 (.10)	-.06 (.15)		

Focussing on the right fusiform region (see figure 5.1-D), the main effect of Repetition in the Picture-Picture analysis that defined the region did not significantly interact with Congruency, *F*(1, 17) = 1.26, p=.28. The Word-Picture analysis failed to reveal any significant effects or interactions (F's<.11, p's>.75), though I note a trend towards a Repetition-by-Congruency interaction was present, *F*(1, 17) = 4.16, p=.06. Thus the right fusiform region only showed significant RS in the Picture-Picture analysis, an effect that was robust to the Congruency manipulation.

Turning to the right pPFC region (see Figure 5.1-E), the Picture-Picture analysis revealed a significant Repetition-by-Congruency interaction, *F*(1, 17) = 12.05, p<.01, reflecting greater RS for Congruent than Incongruent trials. The Word-Picture analysis also revealed a significant Repetition-by-Congruency interaction, *F*(1, 17) = 11.05, p<.01, again reflecting greater RS for Congruent than Incongruent trials (no main effects were present in this analysis, *F*'s<.86, p's>.37). Indeed, a significant repetition enhancement (RE) effect was seen for Incongruent trials in the Word-Picture analysis (see Figure 5.1-E). In other words, when a retrieved S-R binding was incongruent, pPFC showed greater activation compared to Novel trials. This suggests that retrieval of an incongruent S-R binding can result in interference within the inferior prefrontal gyrus. Finally, no significant difference was seen when comparing the Repetition-by-Congruency effects in the Picture-Picture and Word-Picture analyses, *t*(17) = 1.29, p=.22. In other words, the effect of Congruency on RS in this region was equivalent across the Picture-Picture and Word-Picture condition. The right pPFC region therefore showed a significant sensitivity to switches in response between Study and Test in both the Picture-Picture and Word-Picture condition, mirroring the results from the behavioural analyses. Critically, S-R retrieval resulted in neural decreases when the response was congruent (in both the

Picture-Picture and Word-Picture conditions) and neural increases when the response was incongruent (in the Word-Picture condition) compared to Novel trials.

These ROI analyses suggest a possible dissociation between the right fusiform, in which RS is insensitive to switches in response between Study and Test, and right pPFC, in which RS is sensitive to such changes. To formally assess this I conducted separate 2x2x2 (Region x Repetition x Congruency) ANOVAs for the Picture-Picture and Word-Picture conditions separately. Specifically, if a dissociation is present between the RS effect within these two regions in terms of their sensitivity to switches in response I should see significant three-way interactions between Region, Repetition and Congruency. Both the Picture-Picture, *F*(1, 17) = 7.47, p<.05, and Word-Picture, *F*(1, 17) = 7.07, p<.05, analyses revealed significant three-way interactions. As such, the sensitivity of the RS effect to switches in response in the pPFC region was significantly greater than in the fusiform region.

5.1.2.2.3 Further ROI analyses

The present data are at odds with the results of Dobbins et al. (2004) in that I saw equivalent RS in a right fusiform region across Congruent and Incongruent trials. These results therefore support those of Horner & Henson (2008) and Race et al. (2009), suggesting that RS in occipital/temporal regions may reflect the facilitation of particular perceptual and/or conceptual processes that are present irrespective of response-congruency. One possibility is that a functional dissociation is present between the fusiform regions described in Dobbins et al. (2004) and the present experiment. Indeed, the Dobbins et al. fusiform region was in the left hemisphere and was more medial than the right hemisphere region in the present experiment. As such, it is possible that some regions in occipital/temporal cortex may show sensitivity to response switches whereas others may be robust to such switches. To address this concern, I extracted data using the co-ordinates of the left fusiform region (-24, -57, -15) presented in Dobbins et al. (2004) (see Table 5.3). The Picture-Picture analysis from this ROI revealed a significant effect of Repetition, *F*(1, 17) = 15.01, p<.001, that did not significantly interact with Congruency, *F*(1, 17) = 1.83, p=.19. A trend was present in the Word-Picture analysis for an effect of Repetition, *F*(1, 17) = 4.27, p=.06, however no interaction was seen with Congruency, *F*(1, 17) = 2.97, p=.10. Thus I could find no evidence that RS in occipital/temporal regions was sensitive to switches in response between presentations, even when focussing on the Dobbins et al. fusiform region.

A final analysis was conducted on a region in the inferior prefrontal gyrus – *pars orbitalis* – that has been previously implicated in S-R learning (Horner & Henson, 2008). Whereas Horner & Henson (2008) showed that RS in this region was sensitive to switches in task/response between presentations, the results of Race et al. (2009) suggested that RS in this region was resilient to such changes. The latter study concluded that RS in this inferior PFC region reflected the facilitation of processes involved in the controlled retrieval of semantic information, in line with the two-process theory of inferior prefrontal function (Badre & Wagner, 2007). Critically, this facilitation was believed to occur regardless of S-R retrieval and as such would represent evidence of facilitation of component processes in inferior PFC.

To address this discrepancy between previous studies, I extracted the data from an inferior PFC region – *pars orbitalis* – (-36, +33, -15) using the co-ordinates from Horner & Henson (a similar pattern of results was also present when using the co-ordinates of Race et al.) (see Table 5.3). The Picture-Picture analysis from this ROI revealed a significant effect of Repetition, *F*(1, 17) = 7.65, p<.05, and a trend towards a Repetition x Congruency interaction, *F*(1, 17) = 3.50, p=.08. The Word-Picture analysis revealed a significant Repetition x Congruency interaction, *F*(1, 17) = 12.67, p<.01 only. The numerical trend in the Picture-Picture analysis and the significant interaction in the Word-Picture analysis reflected greater RS for Congruent than Incongruent trials, as seen in the pPFC region described in the main ROI analyses. As the Repetition x Congruency effects in the Picture-Picture and Word-Picture analysis showed no evidence of a statistical difference, *t*(17) = 1.73, p=.10, a t-contrast collapsing across the Picture-Picture and Word-Picture conditions revealed significantly greater RS for Congruent than Incongruent trials, *t*(17) = 3.19, p<.01. Indeed, RS for Incongruent trials was not reliably greater than zero in either the Picture-Picture, *t*(17) = .93, p=.37, or Word-Picture, *t*(17) = 1.71, p=.11, conditions. Thus, RS in this region was sensitive to switches in response between presentations, in line with the results of Horner & Henson (2008). The consequences of these results for current theories of inferior prefrontal function and cognitive control are discussed below.

5.2 General Discussion

The present experiment revealed several important findings. Firstly, I saw significant RS in bilateral occipital/temporal regions as well as distinct clusters in the inferior prefrontal cortex. Whereas the RS effect in occipital/temporal regions was robust to switches in response between presentations, the RS effect in inferior prefrontal regions was sensitive to such changes. Though previous research has shown such sensitivity in inferior PFC regions, these effects were not unequivocally a result of switches in response and may have resulted from switches in task or changes in the type of semantic information retrieved between presentations (Horner & Henson, 2008; Race et al., 2009). The present results therefore suggest that RS in occipital/temporal regions is specific to the repetition of a visual stimulus, but occurs irrespective of whether a response is repeated or reversed. On the other hand, RS in inferior PFC regions is sensitive to the repetition or reversal of a response.

5.2.1 Retrieval of S-R bindings

When incongruent S-R bindings were retrieved in the present study, RS decreased in inferior PFC regions. Importantly, this decrease in RS was present in both the Picture-Picture and Word-Picture analyses. These results therefore suggest that stimuli within S-R bindings can form at a level of representation that abstracts away from the specific visual characteristics of the stimulus presented at Study, in line with the behavioural repetition priming results. This is the first evidence that retrieval of abstract S-R bindings affects RS in inferior prefrontal regions.

When responses were reversed between presentations, a significant repetition effect was still present in inferior PFC (at least in the Word-Picture condition). This effect however was characterised by an increase in activation relative to Novel baseline – repetition enhancement (RE) – as opposed to a decrease in activation. Thus, when responses were repeated I saw RS and when responses were reversed I saw RE. These findings mirror the behavioural repetition priming results in that I saw positive priming when responses were repeated and negative priming when responses were reversed. These results suggest that retrieval of an incongruent S-R binding can interfere with the processes carried out in inferior PFC. Such interference would serve to increase processing demands in inferior PFC regions, possibly slowing such processing, resulting in slower RTs. Although previous research has suggested that repetition-related changes in neural activity within inferior PFC are primarily driven by response repetition/reversal (Dobbins et al., 2004; Horner & Henson, 2008; Race et al., 2009), such effects have largely been interpreted in terms of facilitation. In other words, the retrieval of S-R bindings was considered to decrease processing demands in inferior PFC. This is the first study to demonstrate significant facilitation *and* interference in the same inferior PFC regions.

This evidence for facilitation and interference has clear implications for S-R theories of repetition priming (Logan, 1990) and RS (Dobbins et al., 2004). Here RS is thought to result from the by-passing of previously engaged component processes (i.e., the algorithmic route). When a response is incongruent with the current situation, this by-passing should no longer occur and the system should revert to algorithmic processing. If RS in inferior PFC is a result of the by-passing of the processes performed in this region, the retrieval of an incongruent response should result in the re-engagement of such processes. In other words, I should see similar levels of activation for incongruent and novel trials. This was not the case; I saw greater activation for incongruent than novel trials. In the General Discussion of Chapter 3, I discussed how the pattern of priming (and accuracy) across tasks could only be explained by an interaction between the algorithmic and response retrieval route prior to response generation. The present results strengthen this claim, and implicate the inferior prefrontal gyrus as the site for such interaction.

5.2.1.1 Theories of inferior PFC function and cognitive control

One remaining issue is how such results fit with existing theories of inferior PFC function and cognitive control. The two-process theory of inferior prefrontal cortex suggests that this region plays a critical role in the retrieval and selection of task-specific semantic information (e.g., Badre & Wagner, 2007; Wagner et al., 2001).

Specifically, whereas the most anterior portion of the inferior prefrontal gyrus – *pars orbitalis* – is thought to control the retrieval of semantic information, a more posterior portion – *pars triangularis* – is thought to mediate selection between competing active representations in the service of goal-directed action.

With regard to this latter selection process, it is possible to incorporate the present data within this framework. Specifically, this competitor selection process would need to be broadened to include selection between particular response competitors (e.g., Actions, Decision or Classifications) generated by algorithmic and response retrieval routes. In situations where the two routes generate a congruent response, processing demands may be decreased in *pars triangularis* due to a lack of response competition. This in turn could result in a decrease in neural activity, i.e., RS. In situations where the two routes generate an incongruent response, processing demands may be increased due to response competition, resulting in an increase in neural activity. Such an explanation for the present inferior PFC results could readily be applied to the more anterior portion *pars orbitalis*. In this region I again saw greater RS for Congruent than Incongruent trials (although I did not see significant RE in this region for Incongruent trials). This idea however is at odds with the conception that this region controls the retrieval of semantic information. This is because Congruent and Incongruent trials required the retrieval of information relating to object size at both Study and Test (although the comparator "referent" changed, this too was constant across Congruency).

Although the present results pose questions for the two-process theory of inferior PFC function, they are broadly consistent with hierarchical models of cognitive control (e.g., Badre & D'Esposito, 2007, 2009; Fuster, 2001). Here executive functions are thought to be organised on a posterior-anterior axis, with regions more proximal to motor regions selecting actions closest to response output and progressively more anterior regions coding higher-level conceptual representations. In the present circumstances, such higher-level "conceptual" representations coded in anterior regions might relate to the more abstract response representations seen in Chapter 4 (i.e., Classifications). In turn, Decisions and Actions would be coded in more posterior regions of the inferior PFC en route to generation of an overt response. Consistent with this perspective, Race et al. (2009) presented evidence that RS in a more posterior PFC region showed sensitivity to switches in Actions/Decisions, whereas RS in a more anterior PFC region showed sensitivity only to switches in Classification and/or Task. The present results therefore suggest that inferior PFC is involved in the selection of task-appropriate responses, plausibly at multiple levels of abstraction. The amount of neural activity is therefore a reflection of the degree of facilitation or interference due to the generation of congruent or incongruent responses from algorithmic and response retrieval routes.

5.2.2 Facilitation of component processes

The RS effect seen in occipital/temporal cortex was seemingly robust to switches in response between presentations. These results support recent research suggesting that the RS effect in higher-order ventral visual regions is unaffected by response switches/reversals between presentations (Horner & Henson, 2008; Race et al., 2009; Wig et al., 2009). Importantly, in the present study I controlled for S-R learning contributions at all three levels of response representation revealed in Chapter 4 (i.e., Actions, Decision and Classifications). As the manipulations used in these previous studies did not result in the reversal of responses at all three levels of response representation simultaneously, the present results strengthen the claim that RS in occipital/temporal regions is unaffected by the repetition and/or reversal of responses between stimulus repetitions. Interestingly, this occipital/temporal RS effect was only seen in the Picture-Picture condition, suggesting it was specific to the repetition of the same visual stimulus. These results suggest that the RS in occipital/temporal regions reflects the repetition of processes specific to the visual form of a stimulus (i.e., perceptual processes).

Indeed, I saw no evidence for a significant Word-Picture RS effect that was unaffected by the Response-congruency manipulation and as such have no evidence for semantic and/or lexical CP contributions to RS, either in occipital/temporal or inferior prefrontal regions. These results are at odds with previous research suggesting that RS in inferior prefrontal regions (Poldrack et al., 1999; Wagner et al., 1997; Wagner et al., 2000), as well as specific lateral occipital (Horner & Henson, submitted) and/or fusiform (Koutstaal et al., 2001; Simons, Koutstaal, Prince, Wagner & Schacter, 2003) regions in the left hemisphere, reflects the facilitation of processes that are not specific to repetition of the same visual stimulus (i.e., perceptual facilitation) or repetition of the same response (i.e., S-R learning). In other words, such RS was previously attributed to facilitation of semantic and/or lexical/phonological processes. The present results suggest that once one controls for S-R learning at all three levels of response representation, one no longer sees evidence for the facilitation of such processes.

5.2.3 Outstanding issues

The results from the present fMRI study therefore present evidence for both S-R and CP (i.e., perceptual facilitation) contributions to RS. These results are somewhat at odds with the behavioural priming studies presented in Chapters 2-4. Behaviourally, I have thus far failed to provide convincing evidence for significant CP contributions to priming. In short, priming has been dominated by S-R contributions. One possibility is that CP contributions have been present in the behavioural studies of Chapters 2-4 however they have been effectively cancelled out by interference effects owing to response reversal (as evidenced in the present behavioural and fMRI results). Another possibility is the RS effect seen in occipital/temporal regions in the present study is unrelated to the behavioural priming effect. This possibility is particularly pertinent given the poor temporal resolution of fMRI, a result of the sluggish nature of the BOLD response. It is even possible that the RS effect seen in the present study reflects reduced attention to a visual stimulus once a decision or response has been made. This would be consistent with an fMRI study that artificially slowed down object recognition, so that the BOLD response pre- and post-recognition could be separated (Eger, Henson, Driver & Dolan, 2007): this study found that RS (associated with priming object identification with an object name) in fusiform cortex occurred after the recognition point, not before. This questions the causal role of fMRI RS in object recognition/classification. EEG does not suffer from such issues, due to its high temporal resolution. As such, EEG allows one to search for event-related potential (ERP) repetition effects that occur between stimulus presentation and response onset. EEG also allows for the possibility of searching for effects that are time-locked to either stimulus presentation or response onset. Thus EEG does not suffer from the same temporal limitations as the present fMRI study. In the next chapter, I therefore present the results of an EEG study using the same experimental design as in the present chapter.

5.2.4 Chapter Summary

The present chapter assessed both S-R and CP contributions to repetition suppression (RS). Using an “optimal” design that controlled for S-R learning at all three level of response representation, I used fMRI to assess RS in distinct occipital/temporal and inferior PFC regions. This design also included the Picture-Picture and Word-Picture manipulations introduced in Chapter 4 as a means of assessing whether bindings form between responses and “abstract” stimulus representations. RS was seen in bilateral occipital/temporal regions as well as distinct clusters in inferior PFC. Although RS in occipital/temporal regions was robust to switches in response between presentations, RS in inferior PFC was sensitive to such switches. The RS seen in occipital/temporal regions was only present in the Picture-Picture condition (i.e., was only present when there was complete visual overlap between presentations), and thus plausibly reflects the facilitation of perceptual processes. In inferior PFC I saw a significant decrease in RS for Incongruent compared to Congruent trials. Indeed, I even saw evidence for significant repetition enhancement (RE) for Incongruent trials in inferior PFC suggesting possible interference. These S-R effects were shown in both the Picture-Picture and Word-Picture condition, confirming that S-R bindings can form between responses and “abstract” stimulus representations.

These results were considered in relation to S-R theories of repetition priming and RS, as well as theories of inferior PFC function and cognitive control. Although the data presented certain specific problems for some theories, they were broadly consistent with hierarchical views of PFC function. It was suggested that activity in inferior PFC may reflect the resolution of competition between particular task-relevant response representations at varying levels of abstraction along a posterior-to-anterior axis. Although revealing, the present fMRI results suffer from the lack of temporal resolution inherent in this methodology – a product of the sluggish nature of the BOLD response. It was suggested that the temporal resolution of EEG would help to circumvent these issues, ensuring any repetition effects were occurring prior to response onset. In the next Chapter I therefore present the results of an EEG experiment using the same design as the present chapter.

Chapter 6

S-R learning, repetition and event-related potentials: an EEG study

In chapter 5 I presented an fMRI study designed to assess repetition-related decreases – repetition suppression (RS) – within occipital/temporal and prefrontal regions. I saw a dissociation between occipital/temporal regions, in which RS was robust to switches in response between presentations, and inferior prefrontal regions, in which RS was sensitive to such switches. Critically, the RS effect in occipital/temporal regions was specific to the Picture-Picture condition, and was therefore suggested to be a marker of perceptual facilitation owing to the repetition of the same visual stimulus at Study and Test. Thus I plausibly have evidence for two distinct RS effects: (1) perceptual facilitation within occipital/temporal regions and (2) S-R learning within inferior prefrontal regions. Interestingly, this latter prefrontal RS effect was seen in both the Picture-Picture and Word-Picture condition, suggesting that stimuli within S-R bindings can form at a representational level that abstracts away from the specific visual format of a stimulus.

One issue with these data however, which I discussed in the former chapter, concerns the temporal sequence of such effects. Although it is plausible that the "perceptual" effect seen within occipital/temporal regions occurs earlier than the "S-R learning" effect seen within inferior prefrontal regions, the sluggish nature of the BOLD response does not allow for the temporal separation of such effects. For example, the RS in occipital/temporal regions could reflect reduced attention to a stimulus after a response has been made. Indeed, it is possible that the RS effect seen in the fMRI study of Chapter 5 was a result of neural decreases subsequent to object identification/classification and therefore may not play a causal role in behavioural priming. EEG does not suffer from these issues, having a temporal resolution in the order of milliseconds. This improved resolution not only allows the temporal separation of effects within an epoch, but also allows one to separate processes that are "locked" to either stimulus- or response-onset. For example, it is likely that the "perceptual" effect seen in the fMRI data occurs at a consistent time after stimulus-onset, whereas the "S-R learning" effect may vary in time in relation to stimulus-onset, but occur at a consistent time prior to response-onset. Such response-locked analyses are also appropriate as they control for RT differences (i.e., priming) across conditions that may affect stimulus-locked analyses. For example, an event-related potential (ERP) component relating to response preparation and/or execution would occur earlier for trials with shorter RTs. As such, ERP "repetition" effects in stimulus-locked analyses may reflect the earlier onset of such response processes, rather than a change in magnitude of the same ERP component.

In the present chapter I present the results of an EEG experiment using the same design used in the fMRI study of Chapter 5. Specifically, I asked (1) can I see differential "perceptual" and "S-R learning" effects as in the fMRI data, (2) are these effects temporally dissociated (either in terms of latency relative to stimulus onset, or in terms of being stimulus-locked versus response-locked) and (3) are the topographic distributions of these effects qualitatively different (i.e., suggesting that their underlying neural generators are distinct)?

Previous EEG research has shown repetition-related changes to ERPs in visual object classification experiments similar to the present paradigm (e.g., Guillaume et al., 2009; Henson et al., 2004; Schendan & Kutas, 2003). For example, Henson et al. (2004) produced evidence for ERP long-lag repetition effects between 200-300ms and 400-600ms post-stimulus onset (albeit using shorter lags than the present paradigm).

This latter time-window in particular was characterised by increased positivity (relative to a mastoid reference) for repeated stimuli that was maximal over central electrodes. Repetition-related changes in induced responses have also been shown, with repetition resulting in a decrease in power in the gamma frequency band (i.e., >20Hz) between 200 and 400ms (e.g., Gruber & Muller, 2002, 2006). The authors suggested that these changes in induced gamma were a potential correlate of the same neural mechanism that produces the BOLD RS effect, as measured by fMRI. Finally, a recent MEG study has suggested that stimulus repetition can lead to changes in synchrony between frontal and temporal sources (Ghuman, Bar, Dobbins & Schnyer, 2008). These authors saw an increase in phase synchrony in the beta frequency band (i.e., 10-30Hz) between frontal and temporal sources occurring between 200 and 250ms, as well as a decrease in neural activity within these sources between 300 and 400ms.

Although these studies have presented evidence for changes in ERPs, induced gamma responses and phase synchrony following repetition of visual object stimuli, such effects have been primarily attributed to the facilitation of particular perceptual and/or conceptual component processes. Indeed, some of these studies failed to suitably control for S-R contributions, and as such any effects seen may have been driven by the repetition of particular S-R bindings (e.g., Ghuman et al., 2008). Using the present experimental design, I was able to assess directly whether the repetition-related (ERP) changes seen in previous studies were a result of the facilitation of specific component processes, in which case they should be robust to changes in response between presentations, or were a result of the retrieval and repetition of an S-R binding, in which case they should be sensitive to changes in response between presentations.

6.1 Experiment 11

6.1.1 Method

Apart from the following exceptions, Experiment 11 was identical to Experiment 10 in Chapter 5.

6.1.1.1 Participants

Eighteen participants (8 male) gave informed consent to participate in the experiment. The mean age across participants was 23.5 years ($\sigma = 4.0$). By self-report, all participants were right-handed.

6.1.1.2 Procedure

The trial sequence was as follows. A central fixation cross was presented for 500ms, followed by a stimulus for 1000ms, followed by another fixation cross for 500ms. At the end of each trial a circle was presented centrally for a varied time between 750ms and 1250ms, with a mean of 1000ms. Participants were instructed to keep blinks to a minimum, however if a blink was necessary to wait till the presentation of the central circle (i.e., the end of the trial). The mean time per trial was 3000ms.

6.1.1.3 EEG acquisition

EEG was recorded in a magnetically shielded room from 70 electrodes placed within an elastic cap (EASYCAP GmbH, Herrching-Breitbrunn, Germany) according to the extended 10-10 system, using a nose electrode as the recording reference and also bipolar electrodes to measure the vertical and horizontal electro-oculogram (EOG). All data were sampled at 1kHz with a band-pass filter from 0.03-330Hz. Although simultaneous magnetoencephalographic data was recorded with a VectorView system (Elekta-Neuromag, Helsinki, Finland), these data are not reported in the present chapter.

6.1.1.4 ERP analysis

Analyses were conducted using SPM5 (http://www.fil.ion.ucl.ac.uk/spm) as well as using custom-made scripts within MATLAB (The Mathworks Inc., MA, USA). The continuous EEG data from each Test session were downsampled to 100Hz and band-pass filtered between 1 and 40Hz in both forward and backward directions using a 5th-order Butterworth digital filter. These data were epoched in two ways: (1) from -100ms to 800ms relative to stimulus onset (and baseline-corrected from -100ms to 0ms), and (2) from -300 to 200ms relative to response onset (and baseline-corrected from -300ms to -200ms). Epochs in which the signal from any channel, including EOG, exceeded 150μV were removed (median number of trials = 8; range = 0-84). Channels were removed if the proportion of rejected trials within a channel exceeded 20% of the total number of trials (median number of channels removed = 1; range = 0-3). The data were then averaged across trials within each condition, and re-referenced to the average across all remaining channels. For purposes of later statistics, 57 EEG channels remained that were not bad in any subject.

6.1.1.5 Space x Time SPM analysis

Given I had few a priori predictions regarding when (within an epoch) and where (over sensors) repetition effects would be present, particularly for the response congruency manipulation, I adopted a mass univariate approach in which F-tests were performed at every point in a 3D image of channel space and time. The 2D channel space was created by a spherical projection of the standardised Easycap channel locations onto a plane, followed by a linear interpolation to a 32x32 pixel grid. The time dimension consisted of the 91 (stimulus-locked analysis) or 51 (response-locked analysis) 10ms samples in each epoch. In line with the analyses of Experiments 9 and 10, four specific contrasts were tested: (1) Picture-Picture repetition effects (Picture-Picture minus Novel), (2) Word-Picture repetition effects (Word-Picture minus Novel), (3) Picture-Picture repetition effects that interact with response congruency ((Picture-Picture Congruent – Novel Congruent) – (Picture-Picture Incongruent – Novel Incongruent)) and (4) Word-Picture repetition effects that interact with response congruency ((Word-Picture Congruent – Novel Congruent) – (Word-Picture Incongruent – Novel Incongruent)). Each contrast was performed within a general linear model (GLM) using a pooled error over the 6 conditions, with nonsphericity across conditions estimated using Restricted Maximal Likelihood. The resulting statistical parametric maps (SPMs) were corrected for multiple comparisons using Random Field Theory. Effects were first height thresholded at p<.001 uncorrected and are reported if they survived subsequent correction at either the voxel or cluster level with alpha set at .05.

6.1.1.6 Time window analysis

I next identified specific time-windows of interest based on the above SPM analyses. For the stimulus-locked analysis I identified two time-windows: (1) between 400-500ms and (2) between 500-600ms. For the response-locked analyses I identified one time-window, between -200 and -100ms (i.e., from 200-100ms prior to response onset). For each time-window I performed ANOVAs on the mean amplitude, compared to the mean pre-stimulus baseline, with the factors of Stimulus-type and Congruency as well as a further factor of Channel.

6.1.2 Results

6.1.2.1 Behavioural results

After excluding 6% of trials with outlying RTs, the percentages of errors are shown in Table 6.1. Analyses of errors revealed a significant increase in errors for repeated than novel items (in the Picture-Picture and Word-Picture conditions) for Incongruent trials only (see Appendix A-11). Thus the retrieval of an incongruent S-R binding resulted in participants producing more errors, irrespective of whether the item was previously seen as a picture or a word.

Table 6.1. *Mean percentage errors, error priming, reaction times (RTs), RT priming and proportional priming (Prop. Priming) (plus standard deviations) across Stimulus-type (Picture-Picture, Word-Picture, Novel) and Congruency (Congruent, Incongruent) for Experiment 11.*

Stimulus-type /	Picture-Picture		Word-Picture		Novel	
Congruency	Con	Incon	Con	Incon	Con	Incon
% Errors	5.4 (3.8)	17.6 (7.2)	5.4 (3.7)	14.1 (6.2)	6.3 (5.7)	9.8 (7.8)
Error Priming	1.0 (6.0)	-7.8 (9.8)	1.0 (4.3)	-4.3 (8.7)		
RTs	678 (65)	811 (90)	734 (82)	826 (97)	749 (81)	802 (101)
RT Priming	70 (41)	-8 (36)	15 (42)	-24 (37)		
RT Prop. Priming	.09 (.05)	-.01 (.04)	.02 (.05)	-.03 (.04)		

A further 12% of repeated trials were excluded from RT analysis due to incorrect responses given at Study. Table 6.1 displays mean RTs, while Figure 6.1 shows priming (Novel-Repeated) of RTs across all conditions. Inspection of Figure 6.1 shows the only positive priming effect was seen in the Picture-Picture Congruent condition, though there was a trend in the Word-Picture Congruent condition. Interestingly, the Word-Picture Incongruent condition shows a significant slowing of RTs relative to novel items (i.e., negative priming), with a trend in the Picture-Picture

Incongruent condition. A 3x2 (Stimulus-type x Congruency) ANOVA revealed a significant Stimulus-type x Congruency interaction, *F*(2.0, 33.3) = 16.75, p<.001 (as well as main effects of Stimulus-type, *F*(1.9, 31.5) = 23.04, p<.001, and Congruency, *F*(1, 17) = 146.74, p<.001).

As in Experiments 9 and 10, I broke this Stimulus-type x Congruency interaction down into two separate 2x2 (Repetition x Congruency) ANOVAs comparing (1) the Picture-Picture condition with the Novel condition and (2) the Word-Picture condition with the Novel condition. This allowed me to assess priming for each Stimulus-type separately across Congruency. The Picture-Picture analysis revealed a significant Repetition x Congruency interaction, *F*(1, 17) = 34.08, p<.001. As can be seen in Figure 6.1, this interaction reflected reliable positive priming in the Congruent Picture-Picture condition, coupled with a trend for negative priming in the Incongruent Picture-Picture condition.

The Word-Picture analysis also revealed a significant Repetition x Congruency interaction, *F*(1, 17) = 6.94, p<.05. As can be seen in Figure 6.1, this interaction reflected a trend for positive priming in the Congruent Word-Picture condition, coupled with significant negative priming in the Incongruent Word-Picture condition. These results therefore mirror those of Experiments 9 and 10, in that I saw a decrease in priming for Incongruent than Congruent trials in both the Picture-Picture and Word-Picture analyses. A t-test comparing the difference in priming between Congruent and Incongruent trials across the Picture-Picture and Word-Picture conditions revealed that this congruency effect was greater in the Picture-Picture condition, *t*(17) = 3.19, p<.01. Thus the retrieval of S-R bindings led to a greater difference in priming between Congruent and Incongruent trials in the Picture-Picture than Word-Picture condition. These results mirror those of Experiment 9, suggesting that S-R bindings can form at two distinct levels of stimulus representation.

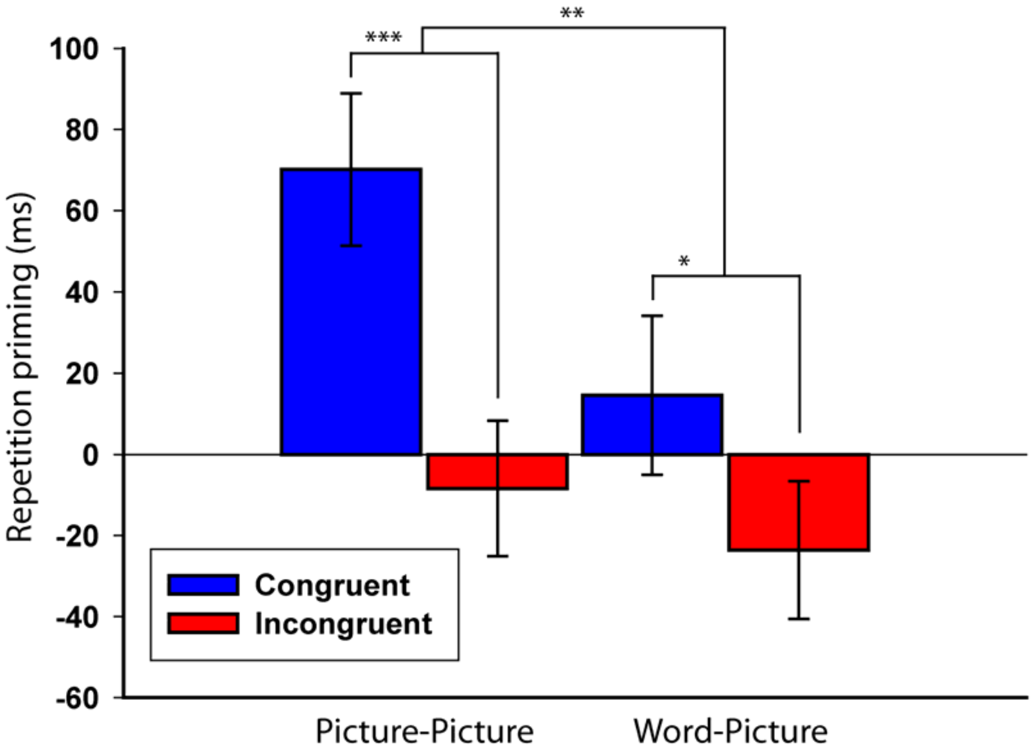

Figure 6.1. Mean repetition priming (Novel-Repeated) across Stimulus-type (Picture-Picture and Word-Picture) and Congruency (Congruent and Incongruent) in Experiment 11. Error bars represent 95% two-tailed confidence intervals of priming effect. *** p<.001; ** p<.01; * p<.05.

6.1.2.2 Analysis across Experiments 9-11

Note that the behavioural results of Experiments 9, 10 and 11 do not appear entirely consistent. I saw a difference in the magnitude of the Repetition x Congruency effect between the Picture-Picture and Word-Picture conditions in Experiment 9 and the present experiment. On the other hand, Experiment 10 failed to reveal any difference in the magnitude of this effect. In other words, the S-R learning effect in Experiment 10 was equivalent across the Picture-Picture and Word-Picture conditions. To address this inconsistency, I entered the results of Experiments 9, 10 and 11 into a 2x3

(Picture-Picture S-R effect, Word-Picture S-R effect x Experiment) mixed ANOVA (collapsing the results of Experiment 9 across Prime-level). If a consistent difference is present between the Picture-Picture and Word-Picture S-R effect, I should see a significant main effect of this factor that does not interact with experiment. This analysis revealed a main effect of Picture-Picture vs. Word-Picture S-R effect, $F(1, 49) = 8.82$, $p<.01$, that did not significantly interact with the between-subjects Experiment factor, $F(2, 49) = 2.26$, $p=.15$. Thus, across Experiments 9, 10 and 11, the S-R effect (i.e., greater priming for Congruent than Incongruent trials) in the Picture-Picture condition was greater than in the Word-Picture condition. This analysis therefore supports the conclusion drawn in Chapter 4, that S-R bindings can form at multiple levels of stimulus representations.

6.1.2.3 EEG results

For the subsequent EEG results, I adopted the same approach used in the behavioural analyses (as introduced in Experiments 9 and 10). For each Stimulus-type (i.e., Picture-Picture and Word-Picture), I searched for effects of Repetition, collapsed across Congruency, followed by a search for Repetition x Congruency effects. Thus, each Stimulus-type is compared separately to the same Novel baseline condition. This approach of analysing the Picture-Picture and Word-Picture conditions separately was supported by the above inter-experimental analysis, suggesting that S-R effects in the Picture-Picture condition are greater than in the Word-Picture condition.

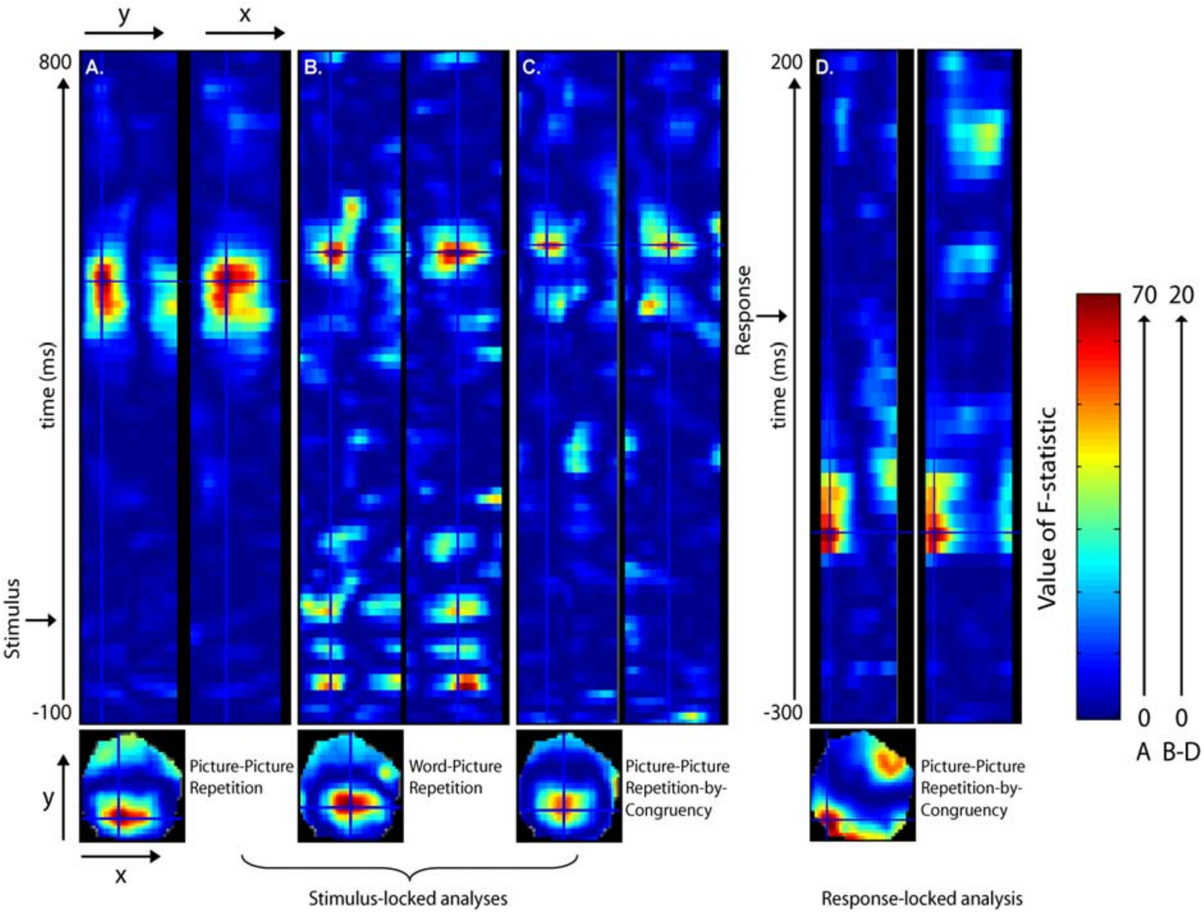

Figure 6.2. Unthresholded space-time Statistical Parametric Map (SPM) F-tests for (A) the main effect of Repetition in the Picture-Picture stimulus-locked analysis, with the crosshair located on the parietal maximum at 500ms, (B) the main effect of Repetition in the Word-Picture stimulus-locked analysis, with the crosshair located on the centroparietal maximum at 540ms, (C) the Repetition x Congruency interaction in the Picture-Picture stimulus-locked analysis, with the crosshair located on the parietal maximum at 550ms and (D) the Repetition x Congruency interaction in the Picture-Picture response-locked analysis, with the crosshair located on the left posterior maximum at 150ms prior to response onset. The three images in each panel represent the orthogonal planes (y-t, x-t, x-y) through the 3D image at the location of the crosshair. Colour-maps show F-values from (A) 0-70 and (B-D) 0-20.

6.1.2.3.1 Space x Time SPMs

6.1.2.3.1.1 Stimulus-locked analyses

I first looked for a significant Picture-Picture repetition effect (Picture-Picture minus Novel, collapsed across Congruency) in the EEG data. This revealed a significant effect extending from approximately 400-600ms, with two clusters over frontal and parietal electrodes respectively (Figure 6.2-A). These clusters are likely to be reflections of the same effect, but simply of opposite polarity relative to the average reference (see ahead to Figure 6.3). The Word-Picture condition revealed a repetition effect over similar centroparietal electrodes, onsetting somewhat later, and extending from approximately 520-560ms (Figure 6.2-B). I next looked for a significant interaction between repetition, in both the Picture-Picture and Word-Picture condition, and Congruency. The only effect to survive correction was for the Picture-Picture condition, extending from 540-560ms over parietal electrodes (Figure 6.2-C). The stimulus-locked analyses therefore revealed three effects: (1) a Picture-Picture repetition effect onsetting around 400ms, (2) a Word-Picture repetition effect onsetting around 520ms and (3) a Picture-Picture Repetition x Congruency effect onsetting around 540ms.

6.1.2.3.1.2 Response-locked analyses

I next performed the same four contrasts on the response-locked epochs. Note that this analysis is only concerned with the 200ms prior to response onset (i.e., from -200 to 0ms). This analysis controls for differences between RTs across conditions (e.g., relating to priming), revealing possible effects that are time-locked to response-onset as opposed to stimulus-onset. Firstly, the EEG data revealed a significant deflection in the Picture-Picture relative to Novel condition over left posterior sensors extending from -160 to -105ms. This effect however looked to be driven primarily by the Picture-Picture Congruent condition, as shown by a significant interaction between Picture-Picture repetition and Congruency over similar sensors extending from -170 to -110ms (Figure 6.2-D). The Word-Picture analysis failed to reveal any significant effects that survived correction for multiple comparisons. The response-locked analyses therefore revealed a significant Repetition x Congruency interaction in the Picture-Picture analysis, onsetting approximately 170ms prior to the key press.

6.1.2.3.2 Time-window analyses

Whereas the mass univariate SPM analysis is appropriate for localising effects in space and time, the multiple comparisons problem means that it may not be as sensitive to effects that are widely distributed over space and time. Therefore I performed additional analyses that averaged over time, within windows informed by the SPM results (that are corrected for multiple comparisons over time). In these time-window analyses, channels were also included as a factor in an ANOVA (rather than tested separately). Note that main effects of channel in these ANOVAs are not of interest; nor are main effects of condition (because their referencing to the average channel means that the mean over channels for each condition and time-point is zero); the main interest is in interactions between conditions and channels.

6.1.2.3.2.1 Stimulus-locked analyses

The space x time SPM analyses revealed several effects between 400 and 600ms: (1) a Picture-Picture repetition effect onsetting around 400ms, (2) a Word-Picture repetition effect onsetting around 520ms and (3) a Picture-Picture repetition x Congruency interaction onsetting around 540ms. In light of these possible latency differences, I extracted two time-windows for further analyses: (1) between 400-500ms and (2) between 500-600ms. Averaging across samples within these time-windows, I conducted 2 x 2 x 57 (Repetition x Congruency x Channel) ANOVAs (with Greenhouse-Geisser correction for nonsphericity), where 57 relates to the total number of remaining EEG channels (see Methods). Separate ANOVAs were conducted for both the Picture-Picture and Word-Picture condition (against the Novel condition) for each sensor type.

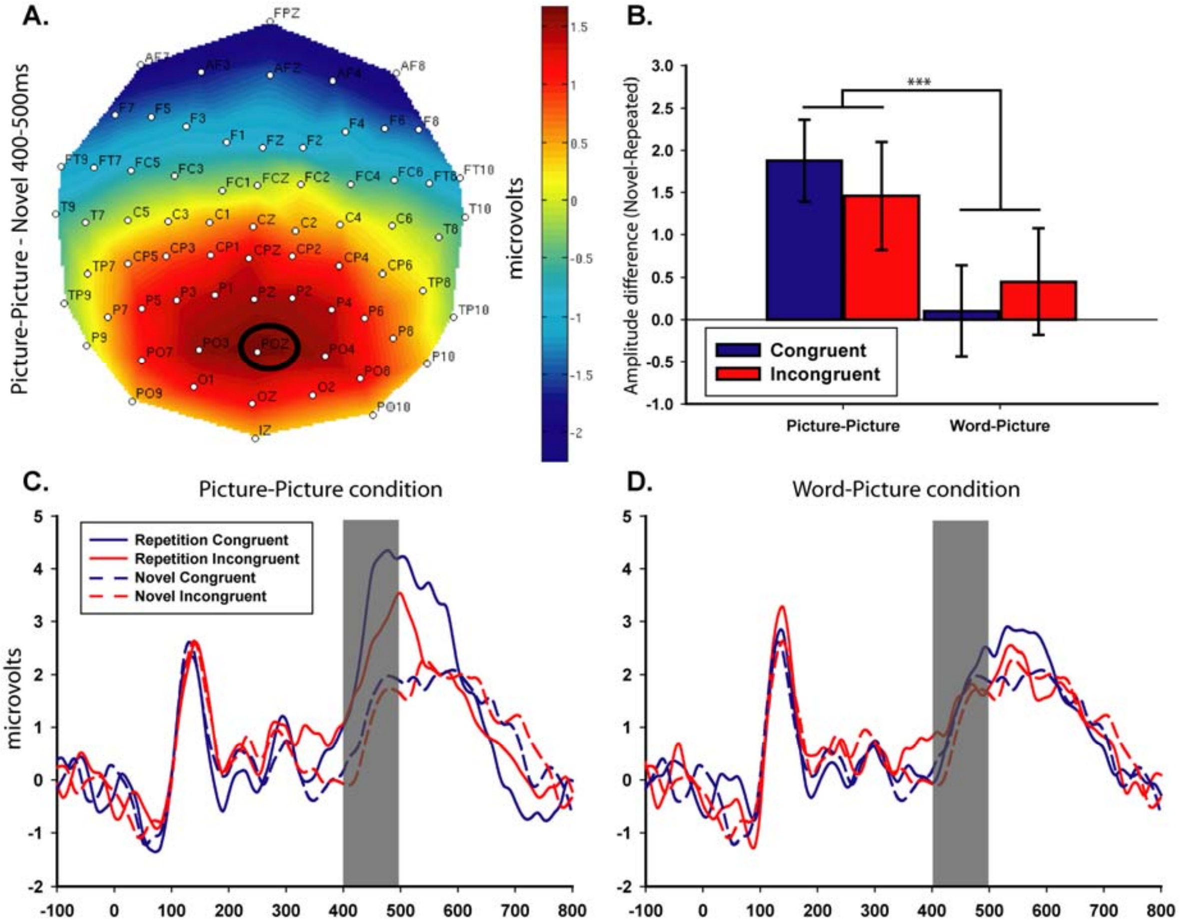

Figure 6.3. Picture-Picture stimulus-locked repetition effect. (A) Scalp topography of the global repetition effect from 400-500ms with peak channel (POZ) circled; (B) Amplitude difference between Repeated and Novel trials across Stimulus-type (Picture-Picture, Word-Picture) and Congruency (Congruent, Incongruent) for peak channel; (C) ERPs for Picture-Picture Repeated vs. Novel across Congruency for peak channel with 400-500ms time-window shaded in gray; (D) ERPs for Word-Picture Repeated vs. Novel across Congruency for peak channel with 400-500ms time-window shaded in gray. Error bars in (B) represent 95% confidence intervals (two-tailed); *** p<.001.

Firstly, in the 400-500ms time-window, the Picture-Picture analysis revealed a significant Repetition x Channel interaction, *F*(3.8, 64.8) = 24.34, p<.001, with no other interaction with Channel approaching significance, *F*'s<2.0, p's>.11. The Word-Picture analysis in this time-window failed to show a reliable Repetition x

Channel interaction, *F*(3.2, 55.1) = 2.21, p=.09. Indeed, when comparing the repetition effects across Stimulus-type in a 2 x 57 (Picture-Picture repetition effects vs. Word-Picture repetition effects x Channel) ANOVA, a significant main effect of P-P vs. W-P repetition effect was present, *F*(1, 17) = 33.77, p<.001. Therefore the magnitude of the repetition effect in the Picture-Picture condition was greater than in the Word-Picture condition. Inspection of Figure 6.3 reveals this effect reflects a positivity over parietal electrodes, in line with the SPM analysis that defined this time-window. The peak channel (POZ) shows a positive deflection for Picture-Picture vs. Novel trials irrespective of Congruency, an effect that is not present in the Word-Picture condition. Thus, this repetition effect is specific to the repetition of the same visual stimulus between presentations and is robust to switches in response between presentations.

In the 500-600ms time-window the Picture-Picture analysis revealed a significant Repetition x Congruency x Channel interaction, *F*(3.6, 61.2) = 3.71, p<.05 (as well as Repetition x Channel, *F*(3.8, 65.0) = 14.10, p<.001, and Congruency x Channel, *F*(3.4, 58.0) = 5.55, p<.001, interactions). The Word-Picture analysis revealed a significant Repetition x Channel interaction, *F*(2.9, 48.5) = 5.08, p<.01, in this same time-window. Thus, repetition effects were present in the 500-600ms time-window for both the Picture-Picture and Word-Picture condition. Inspection of Figure 6.4 reveals the Word-Picture repetition effect reflects a positivity over central electrodes. The peak channel (CPZ) shows a positive deflection for Picture-Picture and Word-Picture vs. Novel trials. Although the Word-Picture repetition effect is not modulated by Congruency, the Picture-Picture condition shows a greater repetition effect for Congruent than Incongruent trials. The 500-600ms time-window may therefore be showing two separate effects: (1) a Word-Picture repetition effect and (2) a Picture-Picture repetition x congruency effect. Regardless of whether these effects have differing topographies, the 500-600ms time-window suggests that ERP repetition effects can be seen when switching from a word to a picture between presentations.

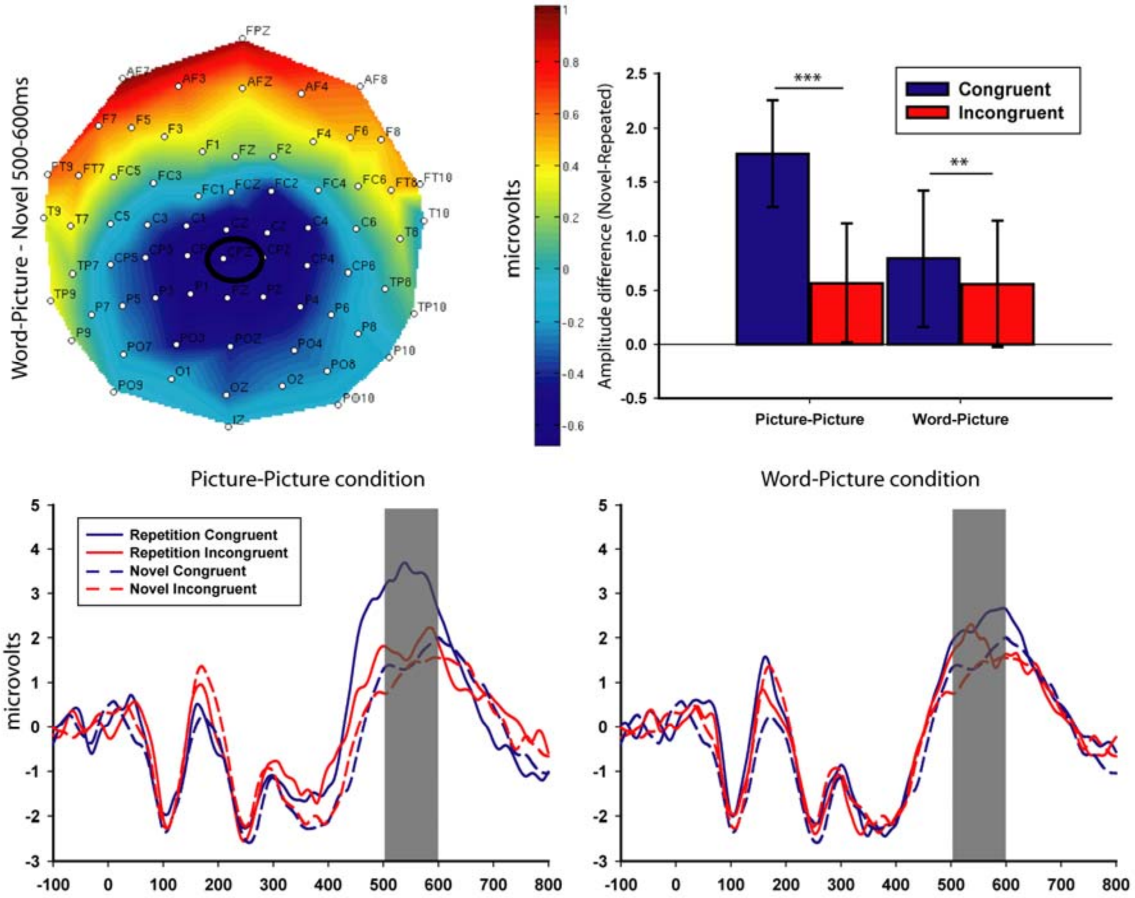

Figure 6.4. Word-Picture stimulus-locked repetition effect. (A) Scalp topography of the global repetition effect from 500-600ms with peak channel (CPZ) circled; (B) Amplitude difference between Repeated and Novel trials across Stimulus-type (Picture-Picture, Word-Picture) and Congruency (Congruent, Incongruent) for peak channel; (C) ERPs for Picture-Picture Repeated vs. Novel across Congruency for peak channel with 500-600ms time-window shaded in gray; (D) ERPs for Word-Picture Repeated vs. Novel across Congruency for peak channel with 500-600ms time-window shaded in gray. Error bars in (B) represent 95% confidence intervals (two-tailed); *** p<.001; ** p<.01.

The stimulus-locked analyses therefore revealed three possibly distinct effects: (1) a Picture-Picture repetition effect in the earlier 400-500ms time-window (that did not interact with Congruency), (2) a Word-Picture repetition effect in the later 500-600ms time-window (that did not interact with Congruency) and (3) a Picture-Picture repetition x congruency interaction in the later 500-600ms time-window. The issue of whether these effects have qualitatively distinct topographies, and thus have plausibly differing underlying neural generators, is addressed later.

6.1.2.3.2.2 Response-locked analyses

The space x time SPM analyses revealed a significant Picture-Picture repetition x Congruency effect between 200-100ms prior to response onset. Taking this time-window, I conducted the same ANOVAs as in the stimulus-locked analyses for the Picture-Picture and Word-Picture conditions separately. Firstly, the Picture-Picture analysis revealed a significant Repetition x Congruency x Channel interaction, *F*(3.2, 54.4) = 3.95, p<.05 (as well as significant Repetition x Channel, *F*(3.5, 58.6) = 2.71, p<.05, and Congruency x Channel, *F*(4.2, 71.6) = 6.02, p<.001, interactions). Although the Word-Picture condition revealed a significant Congruency x Channel interaction, *F*(3.8, 63.7) = 4.05, p<.01, the Repetition x Congruency x Channel interaction failed to reached significance, *F*(4.2, 70.9) = .84, p=.51. Inspection of Figure 6.5 reveals the Picture-Picture Repetition x Congruency effect reflects a posterior negativity (and frontal positivity) that is maximal over left posterior channels (PO7). The pattern on this channel seems to reflect a negative repetition effect for Picture-Picture Incongruent trials that is not present for Congruent trials. Interestingly, this negative repetition effect for Incongruent trials was also present in the Word-Picture condition, despite failing to reveal a significant Repetition x

Congruency x Channel interaction in the Word-Picture analysis. Thus, analysis of the peak sensor (as defined by the Picture-Picture repetition x congruency interaction) suggests that this congruency effect can also be seen (albeit reduced) in the Word-Picture condition.

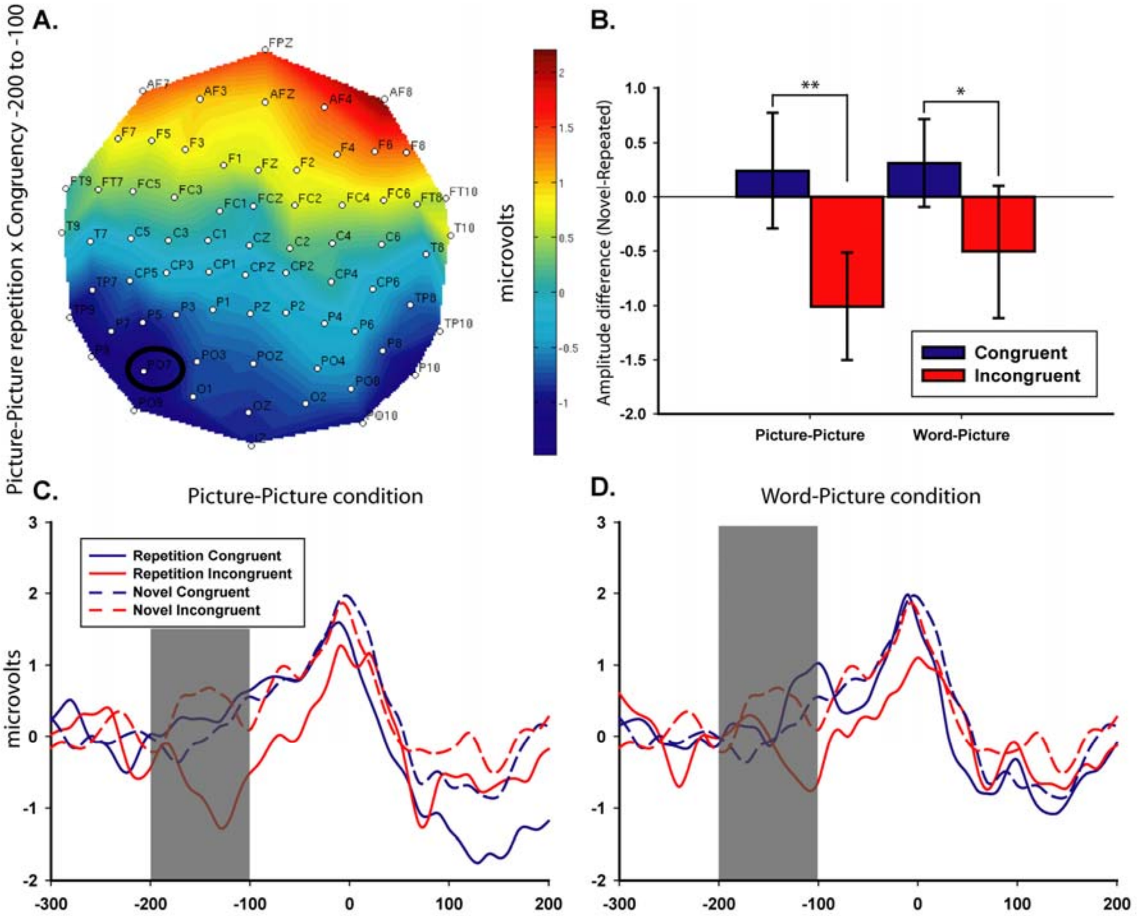

Figure 6.5. Picture-Picture Repetition x Congruency response-locked effect. (A) Scalp topography of the global repetition x Congruency effect from 200-100ms prior to response-onset with peak channel (PO7) circled; (B) Amplitude difference between Repeated and Novel trials across Stimulus-type (Picture-Picture, Word-Picture) and Congruency (Congruent, Incongruent) for peak channel; (C) ERPs for Picture-Picture Repeated vs. Novel across Congruency for peak channel with 200-100ms time-window shaded in gray; (D) ERPs for Word-Picture Repeated vs. Novel across Congruency for peak channel with 200-100ms time-window shaded in gray. Time-point zero = response-onset. Error bars in (B) represent 95% confidence intervals (two-tailed); ** p<.01; * p<.05.

6.1.2.3.3 EOG analyses

Finally, analyses were conducted on the vertical and hortizontal EOG channels to rule out eye-movements as a cause for the above ERP effects. Separate 2 x 2 (Repetition x Congruency) ANOVAs were conducted separately for the Picture-Picture and Word-Picture conditions for VEOG and HEOG in each time-window. The only effect to reach significance in these analysis was a main effect of Congruency in the 400-500ms time-window for the VEOG Picture-Picture analysis, *F*(1, 17) = 10.64, p<.01. Given no effect of Congruency was present in this time-window in the ERP analyses, this is unlikely to have affected the present results. No further main effects or interactions were seen across the Picture-Picture and Word-Picture analyses in VEOG and HEOG across the three main time-windows of interest, *F*’s<4.2, p’s>.06. Thus, eye-movement artefacts are unlikely to have contributed to the above ERP effects.

6.1.2.3.4 Effect x Channel analyses

The ANOVA analyses revealed several interesting effects. In the stimulus-locked analyses I saw: (1) a Picture-Picture repetition effect in the 400-500ms time-window, (2) a Word-Picture repetition effect in the 500-600ms time-window and (3) a Picture-Picture repetition x Congruency interaction in the 500-600ms time-window. I also saw a Picture-Picture repetition x Congruency interaction in the response-locked time-window from 200-100ms prior to response onset. To see whether there was evidence for different underlying generators in the brain, I tested for differences in scalp topographies using separate ANOVAs comparing 2 “effects” x 57 channels, after normalizing amplitude differences across effects to the mean min-max range over sites and participants (McCarthy & Wood, 1985; note that this scaling does not suffer the problems of RMS scaling that are discussed by Urbach & Kutas, 2002). I used the response-locked rather than stimulus locked congruency x condition interaction, given that it was more reliable and less contaminated by motor differences relating to different RTs (see Introduction).

I therefore conducted three separate ANOVAs comparing: (1) the Picture-Picture repetition effect in the 400-500ms time-window from the stimulus-locked analysis with the Word-Picture repetition effect in the 500-600ms time-window for the stimulus-locked analysis, (2) the same Picture-Picture repetition effect with the Picture-Picture repetition x Congruency effect in the -200 to -100ms time-window from the response-locked analysis and (3) the same Word-Picture repetition effect with the response-locked Picture-Picture repetition x Congruency effect[1]. Significant Effect x Channel interactions were seen for the Picture-Picture vs. Word-Picture repetition effect analysis, $F(4.1, 69.5) = 8.26$, p<.001, the Picture-Picture repetition effect vs. Picture-Picture repetition x Congruency effect analysis, $F(4.0, 68.7) = 22.46$, p<.001, and the Word-Picture repetition effect x Picture-Picture repetition x Congruency effect analysis, $F(3.6, 60.5) = 7.21$, p<.001. As can be seen from Figures 6.2-6.4, the Picture-Picture 400-500ms repetition effect was maximal over parietal and frontal electrodes, the Word-Picture 500-600ms repetition effect was maximal over central and frontal electrodes and the Picture-Picture -200 to -100 repetition x congruency effect was maximal over left posterior and right frontal electrodes. These

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[1] Analyses with the Picture-Picture repetition x Congruency effect in the 500-600ms time-window for the stimulus-locked analysis revealed similar dissociations with the stimulus-locked Picture-Picture and Word-Picture repetition effect. All three effects were also topographically distinct if a standard 400-600ms time-window for the stimulus-locked analysis was used (i.e., using the same time-window for all three effects). Finally, the 400-500ms stimulus-locked Picture-Picture repetition effect, $F(3.4, 57.6) = 4.81$, p<.01, and 500-600ms stimulus-locked Word-Picture repetition effect, $F(3.4, 58.3) = 5.13$, p<.01, showed distinct topographies from the -200 to -100ms response-locked Picture-Picture Incongruent repetition effect (i.e., when comparing across repetition effects as opposed to comparing a repetition effect with a repetition x congruency interaction).

analyses revealed that these topographies are qualitatively distinct, suggesting (though not conclusively; Urbach & Kutas, 2002) that the above ERP effects have distinct underlying neural generators (in line with the fMRI results from Chapter 5).

6.2 General Discussion

The EEG data revealed several temporally and spatially distinct effects. Specifically, I saw (1) a Picture-Picture repetition effect onsetting around 400ms, (2) a Word-Picture repetition effect onsetting around 520ms and (3) a Picture-Picture repetition x Congruency effect onsetting around 540ms in the stimulus-locked analysis and onsetting around -170ms in the response-locked analysis. As well as demonstrating possibly distinct temporal profiles, the three effects were shown to have significantly distinct topographies suggesting that each effect has distinct neural generators. Thus, the EEG data confirmed the results of the fMRI data in Chapter 5. Although S-R contributions were present, effects plausibly relating to the facilitation of component processes were also present. Moreover, these effects were present prior to response-onset and are not therefore attributable to post-decision processes such as a reduction in attention to a visual stimulus after a decision has been made (see Discussion – Chapter 5).

6.2.1 Stimulus-locked effects

The repetition effects seen in the stimulus-locked analyses between 400-600ms over centroparietal and frontal electrodes have been seen in previous studies (e.g., Guillaume et al., 2009; Henson et al., 2004; Schendan & Kutas, 2003). Although the repetition effects in these studies may not have been contaminated by S-R contributions, they did not directly manipulate response congruency between presentations. In the present experiment, the Picture-Picture repetition effect between 400-500ms and the Word-Picture repetition effect between 500-600ms were not significantly modulated by response congruency. Thus, these effects are not readily attributable to the retrieval of S-R bindings.

It is noteworthy that the fMRI experiment presented in Chapter 5 failed to find a Word-Picture repetition effect. This is at odds with the present experiment that found a significant Word-Picture repetition effect in the stimulus-locked analyses. Although I found no evidence for a RS effect when switching from words to pictures in the fMRI experiment, previous research has suggested that RS effects in prefrontal and occipital/temporal regions can be seen when switching between object exemplars (Koutstaal et al., 2001; Simons et al., 2003; Vuilleumier et al., 2002) or even between words and pictures (Horner & Henson, submitted). Thus, the failure to find a significant Word-Picture repetition effect in the fMRI data of Chapter 5 may simply have been a Type II error. Another possibility is that these previous fMRI studies failed to suitably control of S-R learning contributions, however it is unclear how this argument relates to the RS previously seen in occipital/temporal regions given such effects have been shown to be robust to switches in response/task between presentations (Experiment 10 in Chapter 5; Horner & Henson, 2008; Race et al., 2009).

6.2.1.1 Facilitation of component processes?

One possibility is that these stimulus-locked repetition effects reflect the facilitation of particular component processes that are engaged at both Study and Test. As the 400-500ms effect was present only in the Picture-Picture analysis, this effect would seem to be specific to the repetition of the same visual stimulus. As such, this effect is likely to reflect the facilitation of specific perceptual (e.g., object recognition) processes. The 500-600ms effect was present when stimuli at Test were previously seen as words. Thus, this effect would seem to occur regardless of visual similarity between presentations and plausibly reflects the facilitation of conceptual processes relating to the retrieval of task-relevant semantic and/or phonological/lexical information. Note that the different topographies of the Picture-Picture and Word-Picture repetition effects suggests that they do not simply reflect facilitation of the same component process (e.g., access to conceptual information) that simply occurs earlier when Pictures are repeated at Test. Such an explanation would fit with the notion that component processes are engaged in a serial feed-forward manner, with the engagement of perceptual processes involved in stimulus identification occurring prior to the engagement of conceptual processes involved in the extraction of task-relevant semantic information.

One issue with this proposal is the latency of the current repetition effects. The present experiment failed to provide evidence for repetition effects occurring within 400ms of stimulus-onset. In particular, no effects were seen for the so-called N170 component, a posterior negativity that is typically seen between 150 and 200ms post stimulus-onset. While the present results accord with the long-lag results of Henson et al. (2004), repetition has recently been shown to modulate these earlier components even within a long-lag Study-Test paradigm (Guillaume et al., 2009). It is this early pre-200ms effect that has been proposed as a marker of perceptual processes involved in both object (Guillaume et al., 2009) and face (e.g., Bentin, Allison, Puce, Perez & McCarthy, 1996; Eimer & Holmes, 2007) identification. Given these data, it is unclear why I should see “perceptual” repetition effects relatively late in the epoch. One possibility is that these late effects are the result of feedback from cortical regions further along the processing stream. This conception accords with recent evidence suggesting that repetition effects in occipital/temporal ventral visual regions result from feedback projections from regions in the prefrontal cortex (Ghuman et al., 2008). Indeed, when inferior prefrontal regions were targeted using TMS during the Study phase of a visual object priming experiment, repetition effects (i.e., RS as measured by fMRI) at Test were reduced in both prefrontal and occipital/temporal regions (Wig, Grafton, Demos & Kelley, 2005). Thus, repetition effects plausibly relating to the facilitation of particular perceptual and/or conceptual processes would seem to result from feed-back from frontal to occipital/temporal regions. Although the present sensor-level analysis cannot confirm the cortical regions that underlie the present repetition effects, the relatively longer latencies of such effects fit with this conception.

6.2.1.2 Explicit memory retrieval?

Although the above account is plausible, it does not explain why no perceptual and/or conceptual effects were seen in the RT priming data. Here the data were fully explicable in terms of the retrieval of S-R bindings, with no effects that were unequivocally a result of CP facilitation. The present stimulus-locked repetition effects may therefore be incidental to behavioural priming, possibly reflecting the conscious recollection of a previous stimulus encounter. In other words, these effects may not be driving the RT differences seen between conditions. With this in mind, it is noteworthy that repetition effects have been shown at similar latencies and electrodes in the context of direct “explicit” memory tasks (see Rugg & Curran, 2007 for a review). Furthermore, regions associated with explicit memory retrieval (e.g., precuneus) showed repetition-related increases during the Test phase of fMRI studies similar to the present experiment (e.g., Horner & Henson, 2008). Given participants were often aware of stimulus repetition throughout the experiment, such conscious recollection was indeed likely.

This proposal however does not readily explain the two distinct repetition effects seen in the stimulus-locked analyses – for the Picture-Picture condition between 400-500ms and the Word-Picture condition between 500-600ms. If such effects were simply a result of incidental memory retrieval it is unclear why two temporally and spatially distinct effects should be present. One could of course propose that the earlier effect reflected incidental retrieval of information relating to the perceptual characteristics of the stimulus, whereas the later effect reflected retrieval of semantic information. If one were to pursue such an argument however it is unclear why this account is a more parsimonious explanation than the component process view. One way to address this issue would be to source localise the stimulus-locked repetition effects. If such localisation were to fit with the results from the fMRI experiment in Chapter 5, for instance localising these effects within occipital/temporal regions, this could be taken as evidence against the proposed incidental explicit retrieval account.

6.2.2 Response-locked effect

In the response-locked analyses I saw a significant interaction between repetition and congruency in the Picture-Picture condition. This effect was characterised by a posterior negativity (and a frontal positivity) for Repeated Incongruent trials occurring between 200-100ms prior to response-onset and was maximal over left posterior sensors. Importantly, this response-locked effect cannot be attributable to RT differences between conditions (i.e., priming), a statement that cannot be made in relation to the stimulus-locked repetition x congruency effect.

Interestingly, the peak sensor identified in the Picture-Picture analysis showed a similar (albeit reduced) negative deflection for Incongruent trials in the Word-Picture condition (although I note this effect was not significant in the main SPM and ANOVA analyses). This suggests that the S-R effect in this response-locked analysis was not specific to the repetition of the same visual stimulus between presentations, a finding that fits with the behavioural results of the present experiment. Thus, this effect is most readily attributable to the retrieval of a previously encoded S-R binding. Interestingly, this effect was primarily driven by Repeated Incongruent trials. This is at odds with the behavioural and fMRI data that principally showed differences between Repeated Congruent vs. Novel trials. Differences were seen between Repeated Incongruent vs. Novel trials in the Word-Picture condition however, suggesting that retrieval of an incongruent response can lead to interference. The present response-locked ERP effect is therefore likely to reflect such interference, given it was specific to Repeated Incongruent trials. It remains to be seen whether the present response-locked effect localises to the prefrontal regions highlighted in the fMRI study in Chapter 5.

6.2.3 Chapter Summary

The present chapter assessed both S-R and CP contributions to repetition-related changes in ERPs. I have presented the results of an EEG experiment that utilised the same design as the fMRI experiment in Chapter 5. Importantly, the use of EEG allowed me to identify repetition effects that occurred prior to response-onset. This was not possible in the fMRI experiment given the sluggish nature of the BOLD response. I indentified three separate ERP effects: (1) a Picture-Picture repetition effect between 400-500ms over centroparietal electrodes in the stimulus-locked analyses that did not vary as a function of response congruency, (2) a Word-Picture repetition effect between 500-600ms over central electrodes in the stimulus-locked analyses that did not vary as a function of response congruency and (3) a Picture-Picture repetition x congruency interaction between -200 to -100ms in the response-locked analyses. Importantly, all three effects were shown to have distinct topographies, suggesting that they were produced by differing underlying neural generators. These effects were suggested as possible markers of (1) perceptual facilitation, (2) conceptual facilitation and (3) retrieval of S-R bindings respectively (although alternative explanations were discussed). Thus, the EEG data presented evidence for both S-R and CP contributions to repetition-related ERP changes. In summary, Chapters 5 and 6 have presented evidence for S-R and CP contributions to repetition-related changes in neural activity that are temporally and spatially distinct. Future research will need to address whether the present ERP effects are a correlate of the same neural mechanisms that underpin the RS effects seen in Chapter 5. In the final experimental chapter I turn my attention back to behavioural repetition priming and address the final question posed in Chapter 1: is attention necessary for both the encoding and retrieval of S-R bindings?

Chapter 7

Is attention necessary for the both the encoding and retrieval of S-R bindings?

The role of attention has been studied extensively in relation to repetition priming (e.g., Allport, Tipper & Chmiel, 1985; Chiappe & MacLeod, 1995; Fox, 1995; Joordens, Betancourt & Spalek, 2006; Lavie & Fox, 2000; MacDonald & Joordens, 2000; MacDonald, Joordens & Seergobin, 1999; Mackintosh, Mathews & Holden, 2002; May, Kane & Hasher, 1995; Simone, Ahrens, Foerde & Spinetta, 2006; Tipper & Driver, 1988). The phenomenon of negative priming (Tipper, 1985), in particular, has received much attention and has been the cause of much debate (see Fox, 1995; May et al., 1995; Tipper, 2001 for reviews). Here the repetition of a previously unattended stimulus can lead to the slowing of RTs compared to an experimentally novel stimulus. The negative priming effect is often thought to reflect the inhibition of unattended stimulus representations (Tipper, 1985). Such inhibition is thought to produce carry-over effects from initial to subsequent presentations, resulting in a slowing of RTs. Alternatively, unattended stimuli are tagged with a “do-not-respond” code that interferes with response generation on subsequent presentation (Neill, 1997).

Again however, a third type of explanation for negative priming has appealed to S-R learning (Frings et al., 2007; Rothermund et al., 2005). According to such accounts, the response given to an attended stimulus becomes bound to the critical unattended stimulus. In other words, a response becomes bound to any co-occurring stimulus, regardless of attention. When the unattended stimulus is repeated (and attended) negative priming can manifest if the response previously bound to the stimulus is incongruent to the newly generated response. Note that this makes a clear prediction in relation to other theories of negative priming – I should only see a slowing of RTs if the response between initial and subsequent presentation is incongruent. Both the inhibition and "tagging" theory of negative priming do not predict such specificity (i.e., negative priming should occur regardless of response congruency). In favour of such an account, Rothermund et al. (2005) presented adjectives and nouns in either red or green font as primes and participants were required to respond to the colour of the word presented (and ignore the meaning of the word). At probe, participants categorised repeated or novel words as either an adjective or noun. Critically, the colour of the prime words was manipulated such that repeated words received a congruent or incongruent response between presentations. Although significant positive priming was seen when a stimulus and response was repeated, significant negative priming (i.e., a slowing of RTs) was seen when a stimulus was repeated but the response was reversed. The authors attributed such negative priming to the retrieval of an S-R binding between the unattended stimulus (the word meaning) and the previously generated response.

These immediate "prime-probe" repetition studies complement the results of Hommel (2005), who presented evidence to suggest that Event Files can form in the absence of attention, even when a particular stimulus is task-irrelevant. Here participants were required to prepare a right or left key-press response at the beginning of each trial, cued by a right or left facing arrow. This response was enacted when a visual stimulus, such as an "X" in the upper half of the screen (S1), was presented. Following a brief delay the same stimulus was repeated (S2) and participants were required to respond with a right or left key-press according to the stimulus location (e.g., upper or lower half of the screen). Typically, responses are slower when a stimulus is repeated and a response is reversed between presentations (Hommel, 1998). Importantly, such interference effects were seen despite the response at S1 being cued by an auditory tone. In other words, although a visual stimulus is still present at S1, it is no longer task-relevant. These results again suggest that responses can become bound to task-irrelevant unattended stimuli.

Although negative priming effects have been recently shown across lags similar to the experiments in the present thesis (Grison et al., 2005), the issue of whether such effects are due to the binding of a response to an unattended stimulus have not presently been explored. Given these results, I sought evidence for S-R effects for unattended stimuli in a long-lag paradigm using semantic classification of visual objects. Given the large S-R effects seen in Experiments 1-11, such a paradigm would seem ideal for studying attentional effects on S-R learning. Using a long-lag paradigm is also informative for negative priming in general, as such effects are usually examined using immediate repetition (though see Grison et al., 2005). In the present chapter I therefore assessed whether bindings can form between responses (to task-relevant attended stimuli) and co-occurring though unattended (task-irrelevant) stimuli. Furthermore, I asked whether previously encoded S-R bindings are automatically retrieved when a repeated stimulus is unattended (and task-irrelevant). In other words, I tested whether spatial attention is necessary for the encoding and/or retrieval of S-R bindings.

The designs of Experiments 12-15 are presented in Figure 7.1. In Experiment 12, I presented two spatially non-overlapping stimuli at Study and directed participants' attention to a stimulus using an attentional pre-cue. At Test, a single stimulus was presented that was either previously attended, previously unattended or novel. By pairing stimuli at Study with either the same or a different size-classification (i.e., bigger/smaller than a shoebox), previously unattended stimuli either received a congruent or incongruent response to that made at Study. In Experiment 13, I presented two spatially non-overlapping stimuli at Study and Test in order to increase possible stimulus competition at Test, again manipulating response congruency for previously unattended stimuli. In Experiment 14, I presented three non-overlapping stimuli at Study and Test. At Study, participants attended to the two flanker stimuli whilst ignoring (though fixating upon) the centrally presented stimulus. At Test, the centrally presented stimulus was attended and was either repeated or novel. The flanker stimuli at Test were all novel. Here RTs for repeated (previously unattended) centrally presented stimuli that received a congruent or incongruent response were compared to novel baseline. None of these studies found convincing evidence for the binding of a response to an unattended task-irrelevant stimulus.

Finally, in Experiment 15 I used a similar three stimulus presentation to Experiment 14 at Study and Test. At Test, I repeated previously attended flankers and presented novel central stimuli. The question was whether the presentation of previously attended flankers would result in the automatic retrieval of a previously encoded S-R binding and affect processing of the novel attended stimulus. No evidence was found to suggest that previously encoded S-R bindings could be retrieved in the absence of attention. First I focus on whether attention is necessary for the encoding of S-R bindings.

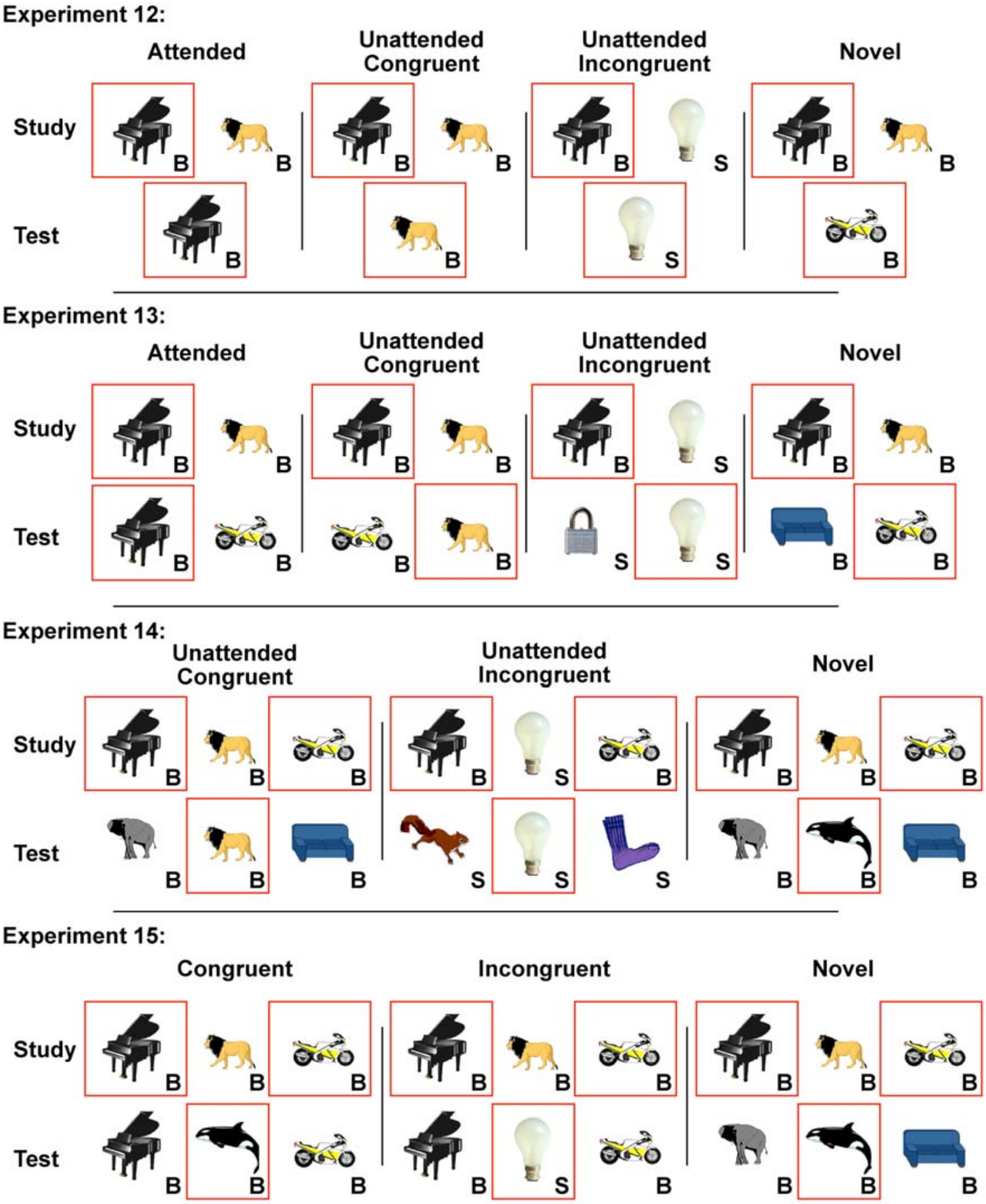

Figure 7.1. Experimental design of Experiments 12-15. Experiment 12 presented two stimuli at Study, with an attentional precue directing participants' attention towards the attended stimulus. At Test, one stimulus (Attended, Unattended Congruent, Unattended Incongruent or Novel) was presented centrally. Experiment 13 presented two stimuli at Study and Test. Attended stimuli at Test were previously Attended, Unattended Congruent, Unattended Incongruent or Novel. The Unattended stimulus at Test was always novel. Experiment 14 presented three stimuli at Study and Test. At Study participants attended to the two flanker stimuli whereas at Test participants attended to the central stimulus. Attended Test stimuli were previously Unattended Congruent, Unattended Incongruent or Novel. Flankers at Test were always novel. Experiment 15 used the same three stimulus design at Study and Test however repeated flankers (i.e., previously attended) rather than the central (i.e., previously unattended) stimulus. Previously seen flankers were either Congruent or Incongruent with the novel central attended stimulus. Note that this figure represents a simplified design of each experiment, as each condition had equal numbers of bigger/smaller stimuli.

7.1 Experiment 12

Experiment 12 was designed to assess whether responses become bound to all stimuli that are present at initial presentation, or whether they only become bound to the task-relevant attended stimulus. In order to achieve this I presented two objects simultaneously during Study trials, one to the right and one to the left of fixation, with attention being cued to one or the other stimulus using an attentional pre-cue. Given participants performed the “bigger-than-shoebox” task on the attended stimulus, I could vary the congruency of response between that given to the attended stimulus and that which would have been given to the unattended stimulus. For example, if the attended stimulus was “bigger”, then the unattended stimulus could either be “bigger” (Congruent) or “smaller” (Incongruent). I then repeated both attended and unattended stimuli at Test in isolation (i.e., one stimulus was presented centrally on each trial) using the same “bigger-than-shoebox” task. This design allowed me to assess priming for previously attended stimuli (Attended), previously unattended stimuli that received a congruent response between Study and Test (Unattended – Congruent) and previously unattended stimuli that received an incongruent response between Study and Test (Unattended – Incongruent). This design is presented in Figure 7.1. I was particularly interested in whether a difference in priming would be seen between the two unattended conditions, given they were unattended and not task-relevant at Study.

7.1.1 Method

7.1.1.1 Participants

18 participants (6 male) gave informed consent to participate in the experiment. The mean age across participants was 24.4 years (σ = 6.0). 5 participants reported as

being left-handed, the remaining 13 were all right-handed. One participant was excluded from subsequent analyses due to a high error rate (>80%), resulting in a total of 17 participants in the main analyses.

7.1.1.2 Materials

Stimuli were 144 coloured images of simple objects (a subset of the main stimulus set used throughout). 50% of the items were classified as “bigger than a shoebox”, the other 50% being “smaller than a shoebox”. Each image was randomly assigned to one of 9 groups, so that each group contained equal numbers of each stimulus classification. This resulted in a total of 16 images per group. 6 groups were used for the conditions of interest (3x2 – Study-context – Attended, Unattended-Congruent, Unattended Incongruent – by Repetition – Repeated, Novel); the remaining 3 groups were used as “filler” items at Study.

7.1.1.3 Procedure

The Study block consisted of 48 separate trials, with two items presented simultaneously per trial. For each trial, a fixation cross was presented for 600ms, followed by the outline of a red square presented either to the right or left of fixation (3^o from centre) that served as an attentional pre-cue. 200ms after the presentation of the attentional cue two differing objects were presented, one to the right and one to the left of fixation (3^o from centre), one of which was within the still present red square. Subjects were told to respond to the item in the red square, and ignore the other object. Objects were present until a response was given, up to a maximum of 2000ms, after which the screen was entirely blank. A total of 2500ms elapsed between the presentation of the objects and the start of the next trial, irrespective of reaction time. The Test block consisted of 96 separate trials, which were identical to the single image centre presentation trials used in previous experiments. Participants carried out the same “bigger than a shoebox?” task used in all previous studies during both the Study and Test block. The same outlier criteria as used in all previous experiments were used. Study trials that received an incorrect response were additionally discarded.

7.1.2 Results and Discussion

After excluding 5.6% of trials with outlying RTs, the percentages of errors are shown in Table 7.1. Analyses of errors are reported in Appendix A-12. A further 2.1% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study. The raw RT data, as shown in Table 7.1, were entered into a 3x2 (Study-context – Attended, Unattended-Congruent, Unattended Incongruent – by Repetition – Repeated, Novel) repeated-measures ANOVA, revealing a significant Study-context x Repetition interaction, *F*(1.6, 25.2) = 7.70, p<.01 (as well as a main effect of Study-context, *F*(1.9, 29.7) = 21.48, p<.001). RT priming effects for unattended stimuli are shown in Figure 7.2-A. Paired t-tests on the priming data from each Study-context condition revealed significantly greater priming for the Attended than both the Unattended-Congruent, *t*(16) = 2.98, p<.01, and Unattended-Incongruent, *t*(16) = 4.05, p<.01, conditions. Despite a significant effect of priming in the Unattended-Congruent, *t*(16) = 2.1, p<.05, but not the Unattended-Incongruent, *t*(16) = .14, p=.89, condition, no significant difference was present between these two conditions, *t*(16) = 1.26, p=.23. Thus, although I was able to produce a significant positive priming effect for unattended (congruent) stimuli, I could find no evidence for S-R effects for stimuli that were unattended at Study. In particular, I saw no evidence for negative priming due to an incongruent response being bound to an unattended stimulus at Study.

Table 7.1. *Mean RTs, RT priming, proportional priming, percentage errors and error priming (plus standard deviations) across Study-context (Attended, Unattended-Congruent, Unattended-Incongruent) and Prime-level (Low-primed, High-primed) for Experiments 12-13. LP = Low-primed; HP = High-primed; Prop. Priming = Proportional Priming. High-primed items were not included in Experiment 12, therefore results are only shown for "Low-primed" for this Experiment. Note that Experiment 13 had a single Novel condition against which to compare repeated stimuli (shown above the RT and error scores for Experiment 13).*

Conditions:	**Attended**		**Unattended-Congruent**		**Unattended-Incongruent**	
	LP	**HP**	**LP**	**HP**	**LP**	**HP**
RTs						
Experiment 12:						
Repeated	**715 (80)**	**HP condition not included in Experiment 12**	**781 (113)**	**HP condition not included in Experiment 12**	**835 (120)**	**HP condition not included in Experiment 12**
Novel	**807 (107)**		**810 (108)**		**832 (127)**	
Priming	**92 (63)**		**29 (57)**		**-3 (88)**	
Prop. Priming	**.11 (.07)**		**.04 (.07)**		**-.01 (.11)**	
Experiment 13:	**Novel condition = 786 (147)**					
RTs	**723 (118)**	**693 (99)**	**806 (156)**	**811 (141)**	**784 (116)**	**797 (148)**
Priming	**63 (69)**	**93 (82)**	**-19 (74)**	**-25 (70)**	**2 (62)**	**-11 (74)**
Prop. Priming	**.07 (.08)**	**.11 (.09)**	**-.03 (.10)**	**-.04 (.09)**	**-.01 (.07)**	**-.02 (.08)**
Errors						
Experiment 12:						
Repeated	**21.7 (9.7)**	**HP condition not included in Experiment 12**	**28.3 (11.9)**	**HP condition not included in Experiment 12**	**33.5 (12.3)**	**HP condition not included in Experiment 12**
Novel	**14.0 (7.2)**		**13.2 (8.5)**		**16.9 (9.3)**	
Error Priming	**-7.7 (10.3)**		**-15.1 (10.8)**		**-16.5 (13.1)**	
Experiment 13:	**Novel condition = 15.8 (7.7)**					
Errors	**20.8 (8.5)**	**27.3 (11.2)**	**30.8 (9.2)**	**26.3 (8.9)**	**31.3 (12.8)**	**37.0 (11.9)**
Error Priming	**-5.0 (12.8)**	**-11.5 (11.4)**	**-15.0 (10.1)**	**-10.5 (9.9)**	**-15.5 (13.7)**	**-21.3 (14.4)**

7.2 Experiment 13

One possible reason for a lack of negative priming for unattended stimuli in Experiment 12 was the presentation of Test stimuli in isolation. Previous negative priming research has suggested that such effects only manifest when at least two items are presented at Test (Allport et al., 1985), producing competition amongst simultaneously presented stimuli that places greater demand on selective attention processes. The single stimulus presentation in the Test phase of Experiment 12 may therefore have not induced sufficient competition for negative priming to manifest. Although it is unclear *a priori* how greater demand on such stimulus selection processes would increase any possible S-R effects, I nonetheless deemed it necessary to include this manipulation in Experiment 13. Trials at both Study and Test in Experiment 13 therefore consisted of two simultaneously presented stimuli, with an attentional pre-cue alerting the participant to the location of the to-be-attended stimulus. This design is presented in Figure 7.1. I also included the Prime-level manipulation introduced in Chapter 2, given I saw larger S-R effects for High-primed stimuli in Chapters 3 and 4. As in Experiment 12, I was particularly interested in any differences between unattended stimuli that received either a congruent or an incongruent response between Study and Test.

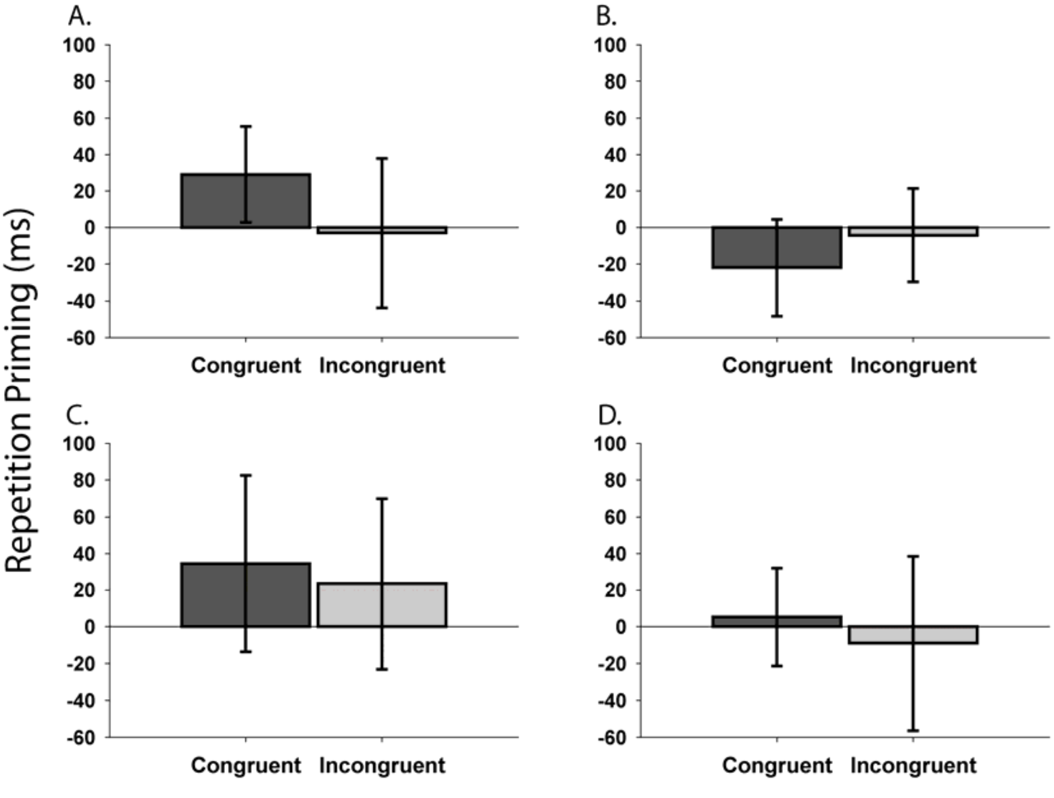

Figure 7.2. Repetition priming (ms) for Unattended-Congruent and Unattended-Incongruent conditions for (A) Experiment 12, (B) Experiment 13 collapsed across Prime-level, (C) Experiment 14 collapsed across Test-context and (D) Experiment 15 collapsed across Study-Context Congruent/Incongruent. Error bars represent 95% confidence intervals (two-tailed).

7.2.1 Method

7.2.1.1 Participants

20 participants (4 male) gave informed consent to participate in the experiment. The mean age across participants was 24.4 years (σ = 4.0). 2 participants reported as being left-handed, the remaining 18 were all right-handed.

7.2.1.2 Materials

Stimuli were 400 coloured images of simple objects. 50% of the items were classified as “bigger than a shoebox”, the other 50% being “smaller than a shoebox”. Each image was randomly assigned to one of 20 groups, so that each group contained equal numbers of each stimulus classification, resulting in a total of 20 images per group. 7 groups were used for the conditions of interest (3x2 – Study-context – Attended, Unattended-Congruent, Unattended-Incongruent – by Prime-level – High-primed, Low-primed – plus a further Novel condition); the remaining 13 groups were used as “filler” items at both Study and Test. Image groups were assigned to each of these 20 groups, and were counterbalanced across participants.

7.2.1.3 Procedure

Experiment 13 consisted of two Study-Test blocks. Each Study block consisted of 120 trials, with 30 stimuli – 10 for each of the three primed Study-context conditions (Attended, Unattended-Congruent, Unattended-Incongruent) – presented once (Low-primed) and 30 stimuli presented three times (High-Primed). High-primed items at Study were paired with the same “filler” stimulus for each presentation. At Test, these 60 stimuli were repeated along with 10 Novel stimuli, resulting in a total of 70 trials. All primed and novel stimuli were presented with “filler” stimuli at Test that were experimentally novel. The trial sequence at both Study and Test was identical to the Study phase trials in Experiment 12. Participants carried out the “bigger-than-shoebox” task to the attended stimulus at both Study and Test. As in all previous behavioural experiments, High-primed items were excluded if an incorrect response was made at any Study phase presentation; all other exclusion criteria remained the same as previous experiments.

7.2.2 Results and Discussion

After excluding 6% of trials with outlying RTs, the percentages of errors are shown in Table 7.1. Analyses of errors are reported in Appendix A-13. A further 4% of Repeated trials were excluded from RT analysis due to incorrect responses given at Study. Given I did not include a Repetition factor in the present experiment (i.e., Repetition was not an orthogonal manipulation), I conducted an ANOVA on the RT priming scores (as shown in Table 7.1). This 3 x 2 (Study-context x Prime-level) repeated-measures ANOVA revealed a main effect of Study-context, $F(1.9, 35.6) = 28.50$, $p<.001$ (as well as a trend towards a Study-context x Prime-level interaction, $F(1.9, 37.2) = 3.08$, $p=.06$). Paired t-tests comparing the priming scores across Study-context revealed significantly greater priming for the Attended than both the Unattended-Congruent, $t(19) = 6.70$, $p<.001$, and the Unattended-Incongruent, $t(19) = 6.78$, $p<.001$, condition. No significant difference was seen between the two Unattended conditions, $t(19) = 1.18$, $p=.25$, nor was priming reliable in either condition (t’s<1.6, p’s>1.2) (see Figure 7.2-B). Experiment 13 therefore replicated the results of Experiment 12 in so far as I could find no evidence for S-R learning effects for stimuli that were unattended at Study. Again, I saw no evidence for negative priming owing to an incongruent response being bound to an unattended stimulus at Study.

7.3 Experiment 14

In Experiment 12 and 13 I presented two non-overlapping stimuli at Study. Participants were pre-cued to attend to one stimulus whilst ignoring the other. One possible reason for my failure to find an S-R learning effect for unattended stimuli may have been this attentional manipulation. In short, such a manipulation may have been entirely effective in focussing attention therefore leaving little processing capacity for the unattended stimulus. In Experiment 14 I therefore presented three different stimuli at Study, one centrally with a left and right flanker. The participants' task was to fixate centrally whilst attending to both flanker stimuli. As such, the central stimulus was unattended (and task-irrelevant) but remained in fixation at all times during the trial. This manipulation was also used as it has previously been shown to produce long-lag negative priming effects, although not in relation to S-R learning (Grison et al., 2005).

At Study, participants were asked "are the flanker stimuli both bigger than a shoebox?". They were required to answer "yes" if both stimuli were bigger and "no" if both were smaller. To ensure participants categorised both flanker stimuli, catch trials were included where one stimulus was bigger than a shoebox and one was smaller than a shoebox. At Test, the stimuli that were presented centrally and not attended at Study were re-presented centrally, together with experimentally novel flankers. Participants' task was to attend to the central stimulus and perform the "bigger-than-shoebox" task whilst ignoring the flankers. This design is presented in Figure 7.1. In order to control for possible flanker effects at Test, both congruent and incongruent Study stimuli were presented with both congruent and incongruent flankers (Test-context). As in Experiments 12 and 13, the unattended stimuli at Study either received a congruent or incongruent response between Study and Test.

7.3.1 Method

7.3.1.1 Participants

13 participants (10 male) give informed consent to participate in the experiment. The mean age across participants was 25.1 years ($\sigma = 3.4$). One participant reported as being left-handed, the remaining 12 were all right-handed.

7.3.1.2 Materials

Stimuli were 364 coloured images of simple objects (50% bigger and 50% smaller than a shoebox). Each image was randomly assigned to one of 26 groups, so that each group contained equal numbers of each stimulus classification, resulting in a total of 14 images per group. 6 groups were used for the conditions of interest (3x2 – Study-context – Congruent, Incongruent, Novel – by Test-context – Congruent, Incongruent). 8 groups were used as flankers for the Congruent and Incongruent trials at Study and the remaining 12 were used as flankers for the 6 conditions of interest at Test. Image groups were assigned to each of these 26 groups and were counterbalanced across participants.

7.3.1.3 Procedure

Experiment 14 consisted of a single Study-Test block. The Study block consisted of 62 trials. 6 of these trials were catch trials, where one flanker was bigger and the other smaller than a shoebox. Of the remaining 56 trials, 28 corresponded to the

Study-context Congruent and 28 to the Incongruent condition. Each set of 28 was further split into the two possible categorisation permutations (i.e., for the Congruent condition "Bigger-Bigger-Bigger" and "Smaller-Smaller-Smaller"; for the Incongruent condition "Bigger-Smaller-Bigger" and "Smaller-Bigger-Smaller"). All stimuli were presented once at Study and participants were asked "are the flankers both bigger than a shoebox?". They were instructed to press the right button for "yes" the left button for "no" and the space bar for catch trials. Each Study trial consisted of a centrally presented fixation cross for 500ms followed by the presentation of three stimuli, one centrally and one to the left and right of fixation, each subtending approximately 3^{o} of visual angle. These stimuli remained on screen until 200ms following response up to a maximum of 3000ms, after which a blank screen was presented for 500ms.

At Test, these 56 primed unattended stimuli were presented along with 28 Novel stimuli. All primed and novel stimuli were presented with flanker stimuli at Test that were experimentally novel. For Study-context Congruent, Incongruent and Novel stimuli, half were flanked with congruent stimuli and half were flanked with incongruent stimuli at Test (Test-context). Participants performed the "bigger-than-shoebox" task on the centrally presented stimulus whilst ignoring the flankers. Each Test trial consisted of a 500ms centrally presented fixation cross, after which three stimuli were presented for 2000ms, followed by a 500ms blank screen.

7.3.2 Results and Discussion

After excluding 5% of trials with outlying RTs, the percentages of errors are shown in Table 7.2. Analyses of errors are reported in Appendix A-14. A further 16% of Repeated trials were excluded from RT analysis due to incorrect responses given at

Study. These RT data were subjected to a 3x2 (Study-context x Test-context) repeated-measures ANOVA that failed to reveal any significant main effects or interactions, *F*'s<.94, p's>.35. Furthermore, no significant RT priming was seen for Study-context Congruent or Incongruent trials, *t*(13)'s<1.41, p's>.18, with no significant difference between these two effects, *t*(13) = .37, p=.72 (collapsed across Test-context) (see Figure 7.2-C). In line with Experiments 12 and 13, Experiment 14 found no evidence of S-R effects for stimuli that were unattended at Study. I also saw no evidence for negative priming due to an incongruent response being bound to an unattended stimulus at Study. Note that these possible unattended S-R effects were not present despite participants fixating on the unattended stimulus at Study in the present experiment. Given the manipulations used at both Study and Test over Experiments 12-14 it is unlikely that responses made to attended stimuli become bound to task-irrelevant distracter stimuli at Study, at least within the present long-lag semantic classification paradigm.

7.4 Experiment 15

In Experiments 12-14 I focussed on the role of attention at encoding (i.e., in the Study phase). Although S-R bindings would seem to require full attention in order to form, it is possible that their retrieval can occur without attention. Experiment 15 used the same three stimulus presentation paradigm as in Experiment 14, attending to the flanker stimuli at Study and the central stimulus at Test. In Experiment 15 however, I presented an experimentally novel central stimulus at Test, whilst repeating the previously attended flanker stimuli in the same locations. As such, any priming effects will have resulted from the repetition of, now unattended, flanker stimuli. Importantly, the response previously made to the flanker stimuli was congruent or incongruent with that made to the experimentally novel centrally presented Test stimulus. This design in presented in Figure 7.1. As such, I could assess whether the repetition of flanker stimuli that were previously attended but now unattended and task-irrelevant could affect the categorisation of a novel centrally presented stimulus.

Table 7.2. *Mean RTs, RT priming, proportional priming, percentage errors and error priming (plus standard deviations) across Study-context (Congruent, Incongruent, Novel) and Test-context (Congruent, Incongruent) for Experiment 14-15. Prop. Priming = Proportional Priming.*

Study-context:	**Congruent**		**Incongruent**		**Novel**	
Test-context	**Congruent**	**Incongruent**	**Congruent**	**Incongruent**	**Congruent**	**Incongruent**
RTs						
Experiment 14:						
RTs	**956 (196)**	**922 (134)**	**962 (212)**	**938 (163)**	**972 (203)**	**975 (210)**
Priming	**16 (110)**	**53 (137)**	**10 (109)**	**37 (96)**		
Prop. Priming	**.01 (.11)**	**.03 (.15)**	**.01 (.11)**	**.03 (.09)**		
Experiment 15:						
RTs	**869 (133)**	**857 (108)**	**829 (118)**	**865 (151)**	**854 (118)**	**852 (121)**
Priming	**-15 (66)**	**-5 (94)**	**25 (50)**	**-13 (102)**		
Prop. Priming	**-.02 (.08)**	**-.01 (.12)**	**.03 (.06)**	**-.02 (.12)**		
Errors						
Experiment 14:						
Errors	**14.8 (12.2)**	**11.5 (13.8)**	**14.3 (14.9)**	**14.3 (14.0)**	**12.1 (10.7)**	**12.6 (12.4)**
Error Priming	**-2.7 (8.5)**	**1.1 (12.7)**	**-2.2 (13.5)**	**-1.6 (11.7)**		
Experiment 15:						
Errors	**10.6 (5.9)**	**13.5 (8.0)**	**12.5 (11.4)**	**13.9 (8.1)**	**9.6 (6.0)**	**13.0 (10.4)**
Error Priming	**-1.0 (9.1)**	**-0.5 (13.4)**	**-2.9 (14.1)**	**-1.0 (13.5)**		

7.4.1 Method

7.4.1.1 Participants

13 participants (3 male) gave informed consent to participate in the experiment. The mean age across participants was 26.9 years (σ = 4.5). One participant reported as being left-handed, the remaining 12 were all right-handed.

7.4.1.2 Materials

352 stimuli from the full stimulus set were split into 22 groups, resulting in 16 images per group. 12 groups were used for the flanker stimuli for the conditions of interest (3x2 – Study-context – Congruent, Incongruent, Novel – by Test-Context – Congruent, Incongruent). Note that although I included Congruent and Incongruent Study-context conditions, this should not affect priming at Test given that the central stimulus at Test was always novel (i.e., the Congruent/Incongruent Study-context conditions could be collapsed into a single condition of Repetition). 6 groups were used as central stimuli during the Test phase and the remaining 4 groups were used as central stimuli during the Study phase.

7.4.1.3 Procedure

Experiment 15 consisted of a single Study-Test block. The Study block consisted of 70 trials. 6 of these were catch trials, where one flanker was bigger and the other smaller than a shoebox. Of the remaining 64 trials, 32 corresponded to the Study-context Congruent and 32 to the Study-context Incongruent condition. At Test, these 64 primed attended flanker stimuli were repeated along with 32 experimentally novel flankers. All primed and novel flankers were presented with novel central stimuli at Test. For the Test-context Congruent condition, the flanker stimuli were paired with a congruent central stimulus whilst for the Test-context Incongruent condition the flanker stimuli were paired with an incongruent central stimulus. The Study and Test tasks were identical to Experiment 14. I was critically interested in whether the Test-context Congruent and Test-context Incongruent conditions varied as a function of whether they were repeated (Study-context Congruent/Incongruent) or novel (Study-context Novel).

7.4.2 Results and Discussion

After excluding 6% of trials with outlying RTs, the percentages of errors are shown in Table 7.2. Analyses of errors are reported in Appendix A-15. A further 12% of Repeated trials were excluded from RT analyses due to incorrect responses given at Study. These RT data were subjected to a 3x2 (Study-context x Test-context) repeated-measures ANOVA that failed to reveal any significant main effects or interactions, *F*'s<1.26, p's>.30. Furthermore, no significant RT priming was seen for Test-context Congruent or Incongruent trials, *t*(13)'s<.40, p's>.70, with no significant difference between these two effects, *t*(13) = .50, p=.62 (collapsed across Study-context Congruent/Incongruent) (see Figure 7.2-D). Therefore I found no evidence to suggest that unattended stimuli can cue the retrieval of S-R bindings when those stimuli were previously attended. Alternatively, such S-R bindings may be retrieved but due to the task-irrelevance of the flankers at Test they do not affect the categorisation of an experimentally novel stimulus. Regardless, Experiment 15 failed to provide evidence of S-R learning effects for unattended stimuli, in line with the results of Experiments 12-14.

7.5 General Discussion

Experiments 12-15 were designed to assess whether attention is necessary for S-R effects to manifest. In Experiments 12-14 I focussed on the role of attention at Study, and found no evidence to suggest that responses made to an attended stimulus can become bound to a co-occurring task-irrelevant unattended stimulus (at least when stimuli are non-overlapping). Whereas in Experiment 12 I tested for possible S-R bindings by presenting previously unattended stimuli in isolation at Test, in

Experiment 13 I presented previously unattended stimuli with another distracter stimulus. This dual presentation at Test has been shown previously to produce robust negative priming effects (at least in immediate repetition paradigms), possibly due to a greater demand on selective attention processes (Allport et al., 1985). Regardless, this manipulation failed to provide evidence for either S-R effects for unattended stimuli or negative priming, at least over the Study-Test lags used in the present thesis.

In Experiments 12-13, participants were required to fixate centrally while stimuli were presented to the right and left of fixation, as such neither the attended or unattended stimulus was ever fixated. In Experiment 14 I therefore presented three stimuli simultaneously, one in the middle of fixation, and one each to the left and the right of fixation. Although participants were required to fixate centrally, they attended to the two flanker stimuli. As such, the central stimulus was fixated but unattended at Study. Despite this manipulation I again failed to provide evidence of S-R effects for unattended stimuli. Finally, in Experiment 15 I switched focus from the encoding to the retrieval of S-R bindings. Repeating previously attended flankers at Test, I again failed to provide evidence of S-R effects for unattended stimuli. This lack of S-R effect across Experiments 12-15 is striking given the dominance of such effects across Experiments 1-11. Taken together, Experiments 12-15 suggest that attention is needed to both encode and retrieve S-R bindings, at least within the present long-lag semantic classification paradigm.

These results are at odds with those of Hommel (2005) and Rothermund et al. (2005). These authors found robust negative priming in immediate repetition paradigms when previously unattended stimuli were repeated and participants were required to make an incongruent response between presentations. One possibility is that although attention may not be necessary for the formation of an S-R binding, such binding may be temporary. Attention therefore may be necessary for the encoding of such bindings into a more stable long-term memory. Another possibility however is that the attentional manipulations used in the present thesis may have been more effective in focussing attention compared to previous studies. In Rothermund et al. (2005), participants were required to attend to the colour of a word and ignore the meaning of the word. Here then, attention was directed towards a particular stimulus characteristic rather than a separate stimulus. Given words are often thought to be read automatically, even when they interfere with current task demands (e.g., Stroop, 1935), such an attentional manipulation is unlikely to have been as effective as the current classification task to an entirely separate stimulus. In Hommel (2005), participants were required to enact a prepared response to an auditory tone whilst ignoring a visual “X” on the computer screen. Again, such a task would seem to require less attentional resources compared to the present classification task. The present results are not able to disentangle these two possibilities, therefore lag and attention remain important issues for future research.

The present results are however consistent with related work using an immediate masked priming paradigm, in which not only spatial (e.g., Lachter et al., 2004) and temporal (e.g., Naccache et al., 2002) attention, but also awareness of a stimulus, seems necessary for the encoding of S-R bindings (even though awareness does not seem necessary for the expression of those bindings; Eckstein & Henson, submitted). Note however that this does not suggest that S-R bindings are not automatically encoded and retrieved (i.e., are not under conscious control). Such encoding and retrieval may be automatic but require full attention in order to occur. I return to this point in Chapter 8.

7.5.1 Chapter Summary

In Chapter 7, I have investigated the role of attention in the encoding and retrieval of S-R bindings. I particular, I wanted to assess whether negative priming is caused by the retrieval of an S-R binding to a previously unattended stimulus. In Experiment 12 I presented two spatially non-overlapping stimuli at Study, and directed attention towards the attended stimulus with an attentional pre-cue. At Test, a single stimulus was presented that was either attended at Study, unattended at Study or Novel. Critically, the responses made at Test to previously unattended stimuli were either congruent or incongruent to those at Study. Although robust priming was seen for previously attended stimuli, no effect of response congruency was seen for previously unattended stimuli. In Experiment 13 I presented two non-overlapping stimuli at Test to increase demands on attentional selection processes. Again, no effects of response congruency were seen for previously unattended stimuli. In Experiment 14 I presented three stimuli, one centrally with two flankers. Whereas participants fixated on the central stimulus, attention was directed to the flankers at Study. At Test, participants attended to the central stimulus that was either repeated (previously unattended) or novel. As in Experiments 12 & 13, no effects of response congruency were seen for previously unattended stimuli. Finally, in Experiment 15 I focussed on whether previously encoded S-R bindings are retrieved at Test without attention. Here I presented novel central stimuli and repeated previously attended flankers. The presentation of previously attended flankers did not affect RTs to novel central stimuli. Thus, Experiment 15 suggests that attention is necessary for the retrieval of S-R bindings.

Taken together, the results of Chapter 7 suggest that attention is necessary for the encoding and retrieval of S-R bindings in long-lag classification paradigms. This therefore answers Question 5 posed in Chapter 1. In the next (and final) chapter, I summarise the results of Chapters 2-7 before answering the five questions posed in Chapter 1. Following this, I focus on how existing S-R and CP theories of priming fail to accommodate all the results presented in this thesis. Finally, I outline a tentative framework for repetition priming designed to incorporate known S-R and CP contributions to repetition priming.

Chapter 8

The Multiple-Route Multiple-Stage framework

The main objective of this thesis was to characterise the role of stimulus-response (S-R) learning contributions to long-lag repetition priming using classification tasks. In particular, the thesis aimed to assess both component process (CP) and S-R learning contributions to priming and relate such effects to repetition-related neural changes (e.g., repetition suppression – RS). In the service of this aim, a combination of behavioural and neuroimaging (fMRI and EEG) techniques were employed. The main results are discussed below, followed by an assessment of current theories of repetition priming. As such theories are not capable of explaining all the data in the present thesis, a novel framework is presented that incorporates known CP and S-R contributions to priming.

8.1 Summary of Results

8.1.1 Chapter 2

In Chapter 2 I introduced a design that incorporated the Start/Switch manipulation of Dobbins et al. (2004) within a Study-Test design, either repeating or reversing the task question between Study and Test (e.g., the Same and Reverse condition). Three experiments revealed significant S-R learning effects across these conditions, with greater priming for the Same than the Reverse condition. These results confirmed that S-R effects could be seen when using somewhat *ad-hoc* classification tasks (e.g., “bigger than a shoebox?”; Experiments 1 & 3) as well as tasks thought to tap more fundamental distinctions within semantic memory (e.g., “is the object man-made?”; Experiment 2). Such effects were also seen when varying either the Study task (Experiment 1-2) or Test task (Experiment 3). Despite the decrease in priming seen in the Reverse condition, significant priming was still present. Although the residual priming in the Reverse task could be taken as evidence for facilitation of component processes (e.g., perceptual/semantic facilitation), it could also be attributed to S-R learning through the repetition of a Classification response (e.g., bigger/smaller – see summary of Chapter 4).

A further manipulation was added to Experiments 1-3 in Chapter 2, whereby the Study and Test task were unrelated (e.g., “bigger than a shoebox” at study and “is the object man-made?” at test). In this Orthogonal condition, the Action (e.g., right/left finger-press) and Decision (e.g., yes/no) responses made at Test were, on average, orthogonal to those made at Study. Classification responses made at Test were unrelated to those made at Study (e.g., “bigger” to “man-made”). This condition was introduced to assess the relative facilitation/interference owing to response repetition/reversal in the Same and Reverse condition respectively. Interestingly, Experiments 1-3 failed to reveal any significant priming in the Orthogonal condition. In other words, once I created a condition that balanced possible facilitation/interference effects due to response repetition/reversal, I saw no evidence of priming. These results suggest that little, if any, priming in the present paradigm is a consequence of facilitation of component processes. The Orthogonal condition also allowed a separation of Congruent and Incongruent responses (at the level of Action and Decision). Analyses of these split data consistently revealed greater priming for Congruent than Incongruent stimuli, a further marker of S-R learning. As such, S-R learning effects were still present despite the fact that responses made at Study were, on average, orthogonal to those made at Test.

In summary, Chapter 2 revealed two possible markers of S-R learning: (1) greater priming in the Same than Reverse condition and (2) greater priming for

Congruent than Incongruent stimuli in the Orthogonal condition. Indeed, little if any priming could be attributed unequivocally to the facilitation of component processes. The dominance of S-R learning was particularly apparent in the Orthogonal condition of Experiments 1-3: when responses at Study were orthogonal to those at Test, no significant priming was present.

8.1.2 Chapter 3

Given the dominance of S-R contributions in Chapter 2, several manipulations were used in an attempt to reveal significant CP contributions in Chapter 3. In Experiment 4, I introduced a Test task in the Orthogonal condition thought to require access to the same size-information needed in the "bigger than shoebox" tasks (i.e., "is the object taller than it is wide?"), in an attempt to boost the contribution from facilitation of conceptual component processes. In Experiment 5, based on previous studies, I presented visual word stimuli rather than pictures of objects to plausibly increase mental imagery processes at Study and Test as well as increase the possibility of facilitation of phonological processes. Finally, in Experiment 6 I degraded picture stimuli at Test to increase the contributions of possible perceptual processes (i.e., object identification processes).

Despite these manipulations, no priming effects were seen that could not be attributed to the retrieval of S-R bindings. Specifically, although I saw significant priming in the Orthogonal conditions of Experiments 5 and 6, this was carried by Congruent stimuli. In other words, priming in the Orthogonal condition was only present when responses (Actions and Decisions) were repeated between Study and Test. No positive priming effects were seen for Incongruent stimuli in any of the Orthogonal conditions of Experiments 1-6.

Experiments 4 and 6 also revealed a further signature of S-R learning: greater priming for High-primed stimuli in the Same condition. These results suggest that repeating a stimulus and response pairing at Study increases priming when the same S-R pairing is repeated at Test. As no difference in priming was seen between High- and Low-primed stimuli in the Reverse condition, this effect could not have resulted from the facilitation of component processes alone. One possibility is that the increase in priming for High-primed stimuli in the Same condition was a result of CP facilitation, however this effect was counteracted by response interference in the Reverse condition. Indeed, this explanation would explain why reduced priming in the High-primed condition of the Reverse condition was not seen, as facilitation of component processes cancelled out the effects of retrieval of an incongruent S-R binding (see section 8.3.4.1). A more parsimonious answer however, is that the increase in priming for High-primed stimuli in the Same condition was due to greater facilitation owing to the retrieval of an S-R binding, facilitation that would not have occurred in the Reverse condition as the response was not repeated between Study and Test. Regardless, this is the first evidence in the current thesis that supports the idea that multiple S-R repetitions (i.e., trials) can result in greater facilitation when the response is repeated at Test. Given I did not see a decrease in priming for High- than Low-primed stimuli in the Reverse condition, Chapter 3 failed to provide unequivocal evidence for interference effects due to the reversal of response between Study and Test.

In summary, Chapter 3 replicated and extended the results of Chapter 2. Three possible markers of S-R learning were revealed: (1) greater priming in the Same than Reverse condition, (2) greater priming for High-primed stimuli in the Same condition coupled with no difference between High- and Low-primed stimuli in the Reverse condition and (3) greater priming for Congruent than Incongruent stimuli in the Orthogonal condition. Again, I failed to reveal any priming effects that were unequivocally a result of facilitation of component processes. The results of Chapters 2 and 3 therefore suggest that S-R contributions dominate in long-lag classification paradigms.

8.1.3 Chapter 4

The results of Chapters 2-3 were explicable solely in terms of S-R learning, provided responses are encoded at multiple levels of representation. In order to explain the significant residual priming in the Reverse condition, responses must be coded at the abstract level of a task-dependent Classification (e.g., bigger/smaller). In the Orthogonal condition however, Classifications made at Study would be irrelevant to those at Test (e.g., bigger/smaller at Study to man-made/natural at Test). The response-congruency effects seen in the Orthogonal condition are possible only if responses are coded at the level of Actions (e.g., right/left finger-press) or Decision (e.g., yes/no). In Chapter 4 I provided direct evidence for the existence of at least three distinct levels of response representation. Experiment 7 provided evidence for responses coded at the levels of Action and Decision, whereas Experiment 8 provided evidence for responses coded at the levels of Decision and Classification. Indeed, once I controlled for S-R learning at all three levels of representation in Experiment 8, no positive priming was seen. These results again underline the dominance and complexity of S-R learning contributions in the present paradigm.

Experiment 9 in Chapter 4 focussed on the level of stimulus representation within S-R bindings. Using the referent change manipulation introduced in Experiment 8 (e.g., “Bigger than X?” to “Bigger than Y?”) to ensure response switches at all three levels of response representation, Experiment 9 tested whether S-R learning effects could be seen when switching from a visual object name at Study (e.g., the word “lion”) to a picture of the same object at Test (e.g., a picture of a lion). This manipulation provided evidence for S-R learning that abstracts away from the specific visual format of the stimulus presented at Study. Experiment 9 also provided preliminary evidence for S-R learning at two distinct levels of stimulus representation; one tied to the specific visual format of a stimulus and one that abstracts away from the visual format. This was evident from the greater S-R effect seen when picture stimuli were presented at both Study and Test (i.e., when there was complete visual similarity between Study and Test presentations), compared to when stimuli were presented as words at Study and pictures at Test. The greater S-R learning effect in the picture-to-picture manipulation can be attributed to the retrieval of S-R bindings at two levels of stimulus representation compared to only one level in the word-to-picture manipulation.

Finally, Experiments 8 and 9 were the first to provide evidence for interference effects owing to response reversal. In Experiment 8, I saw significantly reduced priming for High- than Low-primed Incongruent stimuli. This result suggests that increasing the number of S-R repetitions (i.e., trials) at Study results in greater interference when the response is reversed at Test. In Experiment 9, I saw significant negative priming (i.e., a slowing of RTs compared to novel baseline) for Incongruent stimuli (in the Word-Picture condition). As such, the retrieval of an incongruent S-R binding slowed RTs compared to experimentally novel stimuli. The results of Chapters 3 and 4 therefore provide evidence for both facilitation owing to response repetition (Experiments 4 and 6) and interference owing to response reversal (Experiments 8 amd 9). In summary, Chapter 4 provides evidence for S-R bindings at multiple levels of both stimulus and response representation, as well as evidence for interference effects due to the reversal of response between Study and Test presentations.

8.1.4 Chapter 5

In Chapter 5 I turned my attention to the repetition-related changes in neural activity (e.g., repetition suppression – RS) that are often thought to relate to behavioural priming effects. Experiment 10 used the referent change manipulation introduced in Experiments 8 and 9 to manipulate S-R learning at all three levels of response representation. The picture-to-picture and word-to-picture stimulus manipulation introduced in Experiment 9 was also used to test simultaneously the level of stimulus representation in S-R bindings. This optimised design therefore appropriately controlled for S-R learning at all levels of stimulus and response representation. Using fMRI, Experiment 10 was thus able to assess the sensitivity of RS effects to repetitions/reversals in response, as well as to changes in stimulus format, between Study and Test.

RS was seen in bilateral occipital and temporal ventral visual regions as well as distinct clusters in the inferior prefrontal gyrus. The RS effect in inferior prefrontal regions was shown to be sensitive to reversals in response between Study and Test, showing greater RS for repeated compared to reversed responses. This response-congruency effect was present in both the picture-to-picture and word-to-picture manipulation demonstrating that S-R learning effects in inferior prefrontal regions are present despite switching from words at Study to pictures at Test. Interestingly, response reversals between presentations resulted in greater activation compared to novel stimuli (i.e., repetition enhancement). This suggests that inferior PFC regions may be involved in the resolution of interference resulting from the retrieval of an incongruent S-R binding, increasing activity compared to the novel baseline. These data therefore mirror the behavioural results of Experiments 9 and 10; S-R learning can abstract away from the specific visual format of the stimulus presented at Study, and reversals of response between presentations can result in interference.

The RS effect in occipital/temporal ventral visual regions was shown to be robust to reversals in response between presentations, demonstrating significant RS regardless of whether a response was repeated or reversed. This effect, however, was shown to be sensitive to the word-to-picture stimulus manipulation. Whereas I saw robust RS when the same stimulus was presented between Study and Test (the picture-to-picture manipulation), no RS was seen when the stimulus format changed between Study and Test (the word-to-picture manipulation). As such, the RS in occipital/temporal regions is plausibly a marker of perceptual facilitation in that it is specific to repetition of the same visual stimulus and occurs regardless of response repetitions/reversals. Thus, whereas Chapters 2-4 failed to provide evidence for significant CP contributions to behavioural priming, Experiment 10 demonstrated significant CP contributions to RS. I return to this disconnect between the behavioural priming and neuroimaging results later in this chapter.

In summary, Chapter 5 provided evidence for significant S-R and CP contributions to RS. S-R effects were seen in inferior prefrontal regions in both the picture-to-picture and word-to-picture conditions and were shown to both decrease and increase activation relative to the presentation of novel stimuli. Thus the retrieval of S-R bindings can facilitate and interfere with processing in such regions. CP contributions to RS were seen in occipital/temporal ventral visual regions. This effect was robust to response repetitions/reversals and was specific to repetition of the same visual stimulus between Study and Test and thus is plausibly a result of facilitation of perceptual processes involved in stimulus identification.

8.1.5 Chapter 6

In Chapter 6 I used the same experimental design as Experiment 10 in Chapter 5. Here I used EEG to assess the temporal profile of S-R and CP contributions to repetition-related neural changes. Comparing response-locked event-related potentials (ERPs) across conditions, a significant deflection was seen over left posterior and right frontal electrodes onsetting 170ms prior to response-onset. This deflection was specific to reversals in response between Study and Test, and was shown in both the picture-to-picture and word-to-picture conditions (at least in the peak-sensor analysis). Thus the retrieval of S-R bindings resulted in a deflection that was time-locked to response onset and was shown despite switching from words at Study to pictures at Test.

Comparing stimulus-locked ERPs across conditions, two distinct effects were seen: (1) a significant deflection over parietal and frontal electrodes onsetting 400ms post stimulus-onset for repeated compared to novel items that was specific to repetition of the same visual stimulus (i.e., the picture-to-picture condition) and (2) a significant deflection over central and frontal electrodes onsetting 520ms post stimulus-onset for repeated compared to novel items that occurred regardless of changes in visual format between presentations (i.e., the word-to-picture manipulation). Neither of these effects were significantly modulated by repetition/reversals in response between presentations. Thus Experiment 11 revealed two effects that are plausibly related to the facilitation of component processes. The first was shown to be specific to repetition of the same visual stimulus between presentations and therefore possibly reflects the facilitation of perceptual processes. The second was present despite switching from words at Study to pictures at Test, abstracting away from the specific visual format at Study, and therefore possibly reflects the facilitation of conceptual processes. Importantly, all three effects seen in the EEG data were shown to be topographically distinct, suggesting that each effect has a different neural generator.

In summary, Experiment 11 in Chapter 6 presents ERP evidence for S-R and CP contributions to repetition-related changes in neural activity. S-R effects were shown to be time-locked to response-onset and were present in both the picture-to-picture and word-to-picture conditions, mirroring the behavioural data seen in Experiments 9-11. CP effects were shown to be time-locked to stimulus-onset and plausibly relate to both the facilitation of perceptual and conceptual processes. These effects were shown to be both temporally and topographically distinct, suggesting they are produced by different neural generators at different times.

8.1.6 Chapter 7

In Chapter 7 I switched my focus to the role of attention in both the encoding and retrieval of S-R bindings. In Experiment 12 and 13 two non-overlapping stimuli were presented at Study. Participants attended to one stimulus whilst ignoring the second. Experiment 12 repeated both attended and unattended stimuli at Test. Importantly, unattended stimuli at Study required either the same response at Test or a reversal of response. This response-congruency manipulation failed to reveal any difference in priming. In other words, when an unattended stimulus was repeated and attended at Test, priming was not modulated by its response history. This same result was seen in Experiment 13 when two stimuli were presented at Test as well (and the repeated stimulus was attended). Thus, this lack of S-R learning effect was not a result of a lack of competition between stimuli in Experiment 12 when only one stimulus was presented at Test.

In Experiment 14, three stimuli were presented at both Study and Test. Participants were required to attend to the two flanker stimuli at Study and the central stimulus at Test. Importantly, participants were required to fixate on the centrally presented stimulus at Study despite attending to the flanker stimuli. Thus the central stimulus was fixated but was unattended. Again, the response history of unattended stimuli was manipulated such that they received either the same or the opposite response at Test to that made at Study. As in Experiments 12 and 13, response history had no effect on priming for unattended stimuli. Indeed, no priming was seen for unattended stimuli. Experiments 12-14 therefore suggest that attention is necessary for the encoding of S-R bindings.

Experiment 15 was concerned with the retrieval of previously encoded S-R bindings. Using the same concurrent presentation of three stimuli as in Experiment 14, previously attended flankers were repeated but unattended at Test. Participants were required to attend to novel centrally presented stimuli whilst ignoring the previously presented and attended flankers. Importantly, the correct response to the centrally presented novel stimulus was either congruent or incongruent with that which was given to the previously attended flankers. Experiment 15 failed to provide any evidence for the idea that previously encoded S-R bindings are retrieved regardless of attention; priming for novel stimuli was unaffected by the presentation of previously attended flanker stimuli.

In summary, Experiments 12-15 focussed on the role of attention in both the encoding and retrieval of S-R bindings in long-lag classification paradigms.

Experiments 12-14 suggested that attention is necessary for the encoding of S-R bindings. Experiment 15 suggested that attention is also necessary for the retrieval of previously encoded S-R bindings. As such, Chapter 7 underlines the importance of attention in both the encoding and retrieval of S-R bindings in long-lag classification paradigms.

8.2 Addressing the questions outlined in Chapter 1

8.2.1 Question 1: How dominant are S-R learning contributions within long-lag classification paradigms?

The present thesis demonstrates that S-R learning plays a dominant role in long-lag repetition priming of speeded semantic classification tasks. The basic finding of greater priming for congruent than incongruent responses is not readily explicable by CP accounts. This is because CP theories predict priming can only result from the facilitation of processes that are stimulus specific. Although response-selection processes may have show facilitation, they would need to be bound to a specific (repeated) stimulus in order to contribute to priming (i.e., to generate an RT difference between Novel and Repeated stimuli). The dominance of S-R contributions was such that there was little evidence remaining for any other contributions to priming, contrary to the common assumption that priming reflects the facilitation of one or more component processes (e.g., faster object identification or semantic retrieval). In other words, I did not see significant positive priming when responses were reversed between presentations. This questions prior interpretations of priming in speeded classification tasks, in both healthy participants (e.g., Bowers & Turner, 2003; Bruce et al., 2000; Light, Prull & Kennison, 2000; Thompson-Schill & Gabrieli, 1999;

Vaidya & Gabrieli, 2000; Vriezen et al., 1995), and in amnesic patients (Schnyer et al., 2006).

It is important to note that the present thesis cannot claim that all examples of priming reflect S-R learning, i.e., that there is never a role for the facilitation of perceptual or conceptual processing. Indeed, given the evidence for interference effects due to previously learnt S-R associations (Experiment 8-11), it is plausible that significant perceptual and/or conceptual contributions may have been masked in the present series of experiments (i.e., for Incongruent trials in the Orthogonal condition). Furthermore, the robust priming of accuracy or response times found in identification paradigms (rather than classification paradigms), such as picture-fragment or word-fragment completion tasks, would appear difficult to explain in terms of S-R learning. In these “data-driven” tasks (Jacoby, 1983a; Roediger & McDermott, 1993; Roediger et al., 1989a), a degraded version of a stimulus is often difficult to identify unless an intact version has been seen previously, offering little opportunity for a prior response to be retrieved until the stimulus is identified through priming (e.g., the "Dalmatian dog" example in Roediger & McDermott, 1993; Roediger et al., 1989a). I return to the issue of integrating such component process contributions with S-R learning below.

8.2.2 Question 2: At what level are both stimuli and responses represented within S-R bindings?

S-R learning can occur at multiple levels of stimulus and response representation. In relation to responses, the present thesis found evidence for S-R learning at three distinct levels of representation from the Action (left/right finger press) to the Decision (yes/no) to the task-dependent Classification (bigger/smaller). Indeed, it was only once S-R learning was considered at all three levels of representation that the dominance of such learning was revealed. Evidence for S-R learning was also found at multiple levels of stimulus representation, one tied to the specific visual format of the stimulus and one that abstracts across differing visual formats (i.e., from visual words to object pictures).

8.2.3 Question 3: Does the retrieval of S-R bindings result in facilitation when a response is repeated or interference when a response is reversed?

The present thesis revealed both facilitation and interference due to the retrieval of S-R learning. In Chapter 3 I saw greater priming for High- than Low-primed stimuli that was specific to the repetition of both stimulus and response (i.e., in the Same condition). This suggests that retrieval of an S-R binding facilitates later response selection if the response is repeated. In Chapters 4-6 I saw a slowing of RTs compared to novel stimuli (i.e., negative priming) when a response was reversed between presentations. Importantly, this interference only became apparent once S-R learning was reversed at all three levels of response representation.

8.2.4 Question 4: Are repetition-related changes in neural activity, as measured by fMRI and EEG, related to S-R learning or component process contributions to behavioural priming.

Chapters 5 and 6 presented evidence for both S-R and CP contributions to repetition-related neural changes. In Chapter 5 I saw significant RS in occipital/temporal and inferior prefrontal regions. Whereas the RS effect in occipital/temporal regions was attributed to the facilitation of perceptual processes, the RS effect in inferior prefrontal regions was attributed to S-R learning. In Chapter 6 I saw significant repetition effects in the stimulus-locked and response-locked analyses. Whereas the two effects seen in the stimulus-locked analysis were attributed to the repetition of perceptual and/or conceptual processes, the effect seen in the response-locked ERP analysis was attributed to S-R learning.

One issue with the neuroimaging results is why robust CP contributions were present despite the dominance of S-R learning seen in the behavioural data. One possibility is that the binary semantic classification tasks performed on clear images of everyday objects load more heavily on S-R learning processes. In other words, perceptual/conceptual components may contribute only a small portion of the total RT variance in such tasks. This explanation fits with previous studies that have failed to demonstrate a correlation between RS effects in occipital/temporal regions and behavioural priming (a relationship that has been seen in inferior prefrontal regions) (e.g., Dobbins et al., 2004; Horner & Henson, 2008; Orfanidou, Marslen-Wilson & Davis, 2006). An alternative explanation is that neural repetition effects reflect processing largely irrelevant to the behavioural measure of priming in paradigms like the present one. For example, the RS seen in occipital/temporal regions in Chapter 5 may reflect processing arising subsequent to the behavioural response, such as reductions in attention to the object once a decision has been made (Eger et al., 2007). Furthermore, the repetition-related effects seen in the stimulus-locked analysis of Chapter 6 may reflect incidental conscious recollection of the stimulus, a process that may not contribute to RTs in a speeded classification task. This possibility fits with previous EEG data demonstrating significant repetition-related effects over similar electrodes and time-points using direct memory tests (e.g., old/new judgements; Rugg & Curran, 2007).

8.2.5 Question 5: Is attention necessary for both the encoding and retrieval of S-R bindings?

The results of Chapter 7 suggest that attention is necessary for both the encoding and retrieval of S-R bindings. Although these results are at odds with previous research suggesting that S-R bindings can form between a response and an unattended task-irrelevant stimulus in immediate repetition paradigms (Rothermund et al., 2005), this is the first time such effects have been assessed using object picture stimuli in long-lag speeded classification paradigms. One explanation for this discrepancy is that the attentional manipulations used in the present thesis were more effective at focussing attention than previous studies. Indeed, previous research has focussed on directing attention towards stimulus attributes (e.g., colour vs. meaning) rather than separate stimuli, or has used simple intermixed letter stimuli (e.g., Rothermund et al., 2005). Although plausible, negative priming effects have been shown using non-overlapping picture stimuli in short- (Allport et al., 1985) and long-lag (Grison et al., 2005) paradigms. These studies did not focus on S-R effects however. Therefore although more common contributions to negative priming, such as inhibition of stimulus representations (Tipper, 1985, 2001), may be less susceptible to such attentional manipulations, a greater amount of attention may be needed to encode and retrieve S-R bindings.

8.3 Multiple-Routes and Multiple-Stages: the MR-MS framework

The present thesis has presented evidence for S-R learning contributions to behavioural repetition priming at multiple levels of stimulus and response representation. The retrieval of such S-R bindings can facilitate and interfere with processing dependent upon whether the response is repeated or reversed between presentations. Although S-R contributions in general are consistent with Instance Theory and the Event-File theory of Logan and Hommel respectively, certain aspects of the data in the present thesis were not readily explicable by either theory.

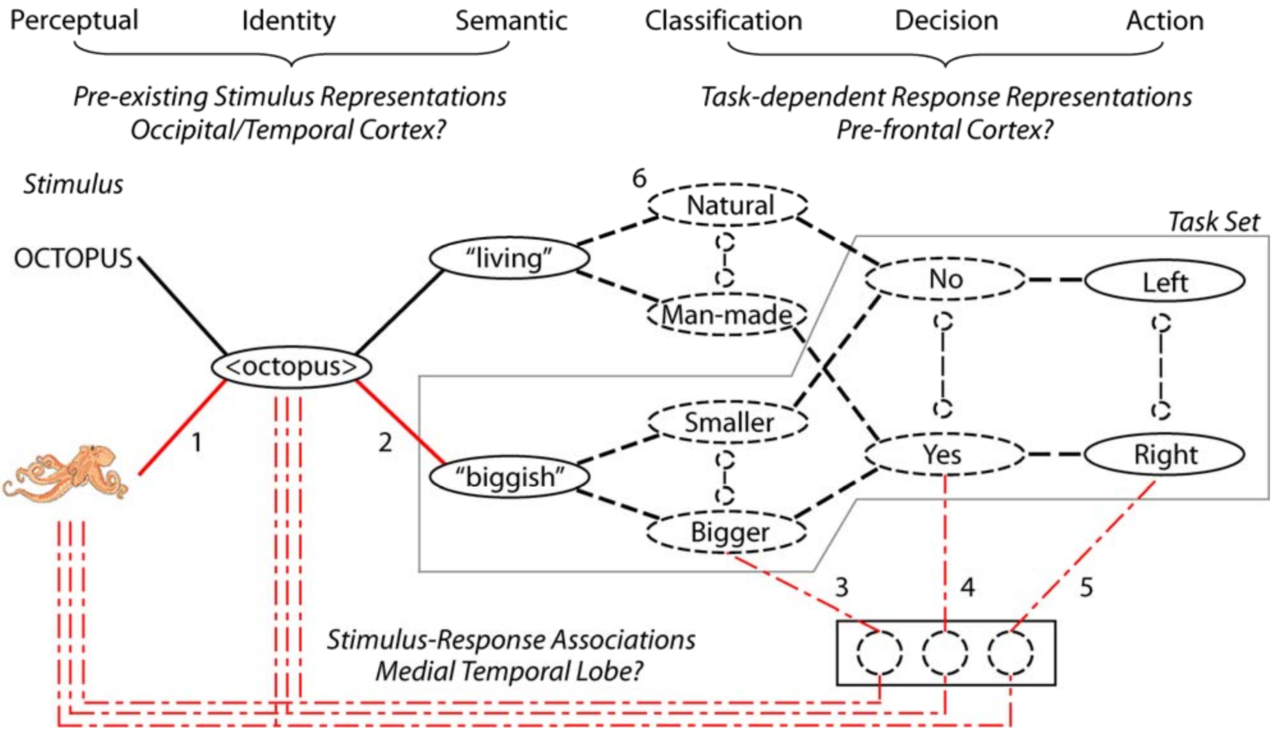

Figure 8.1. Multiple-route multiple-stage (MR-MS) framework. The framework includes a component process and S-R retrieval route to response generation. The component process route includes multiple stages from perceptual to semantic to task-dependent response representations. The response retrieval route allows for S-R binding at multiple levels of stimulus and response representation. The two routes interact in the response representation stage of the component process route. This interaction can result in facilitation or interference dependent on the congruency of response generated by the two routes. Solid lines represent pre-existing (though modifiable) connections between stimulus representations. Dotted lines represent temporary connections between representations specific to the current task set. Red lines represent connections that are capable of showing facilitation (e.g., strengthening).

In the case of Instance Theory, it is unclear why one should see response congruency effects in situations where previous responses are not predictive of the correct response at Test. This was seen in the Orthogonal conditions of Experiments 1-6, where stimuli that received a congruent response showed greater priming than those that received an incongruent response. In a situation in which the task at Test is unrelated to that at Study, Instance Theory predicts that the system reverts to the algorithmic route, effectively ignoring any retrieved S-R bindings. The present results suggest this does not occur, and that retrieval of S-R bindings occurs automatically and affects processing, regardless of its predictive power. A further result that is not readily explained by Instance Theory is the evidence for interference effects due to reversals of response between presentations. If the system does simply revert to the algorithmic route when a retrieved response is not appropriate to the current situation then no nett priming should be seen. To reiterate, Instance Theory predicts that negative priming cannot occur as the response retrieval and algorithmic route are thought to be independent. Such interference requires interactions between the algorithmic and S-R retrieval route and as such would reflect a major departure from the original Instance Theory.

The Event-File theory would seem a more appropriate theory for explaining the interference effects seen following reversals in response in the present thesis. This theory would also seem to readily explain the congruency effects seen in the Orthogonal conditions of Experiments 1-6, in that previous S-R bindings are automatically retrieved and affect processing dependent on the overlap between the present conditions and the retrieved S-R binding. It is unclear, however, how the theory predicts positive priming, given its focus on interference effect arising from prior experience. In particular, it does not specify a mechanism (such as the race in

Instance Theory) by which multiple records can further speed RTs (e.g., for High-primed stimuli in the Same condition of Experiments 4 & 6) (see the General Discussions of Chapters 2 and 3 for more in-depth analysis of these issues).

The results of the present thesis are therefore difficult to explain with either Instance Theory or the Event-File Theory. Furthermore, the clear evidence for S-R learning is inconsistent with a purely modification theory such as a component process account of priming. Although the present thesis failed to reveal priming effects that were unequivocally a result of facilitation of component processes, studies using identification tasks have provided such evidence (e.g., Roediger, 1990; Roediger & McDermott, 1993; Roediger et al., 1989a; Schott et al., 2005). Therefore a theory of priming is needed that allows for a formal integration of these two independent contributions to behavioural priming. The present thesis outlines a tentative framework that explains priming effects in terms of an interaction between a component process (i.e., the algorithmic route) and S-R retrieval route. This framework provides for a natural explanation for both the facilitation and interference effects following retrieval of S-R bindings, a result that present S-R learning theories struggle to explain. Moreover, this framework allows for the integration of S-R and CP theories of priming. I call this the “multiple-route and multiple-stage” (MR-MS) framework (Figure 8.1).

Key assumptions in this framework are that: (1) there are multiple routes to generating the final response: a component process and S-R retrieval route (analogous to Instance Theory); (2) unlike Instance Theory, multiple stages within the component process route can potentially be facilitated by prior performance of those stages; (3) the outputs of the component process and S-R retrieval routes can interact, such that the congruency of response generated by each route can modulate (e.g., facilitate/interfere with) RTs, (4) multiple S-R bindings can be stored from a single stimulus-response pairing (trial), each encoding a differing level of stimulus and response and (5) in line with the task-switching literature, task-demands entail the formation of temporary, task-specific, response representations and mappings between such representations. This framework is also novel in attempting a tentative mapping of these stages/routes onto the brain.

8.3.1 S-R retrieval route

The response retrieval route in the MR-MS framework builds on the Instance Theory of Logan. S-R bindings are automatically encoded during all co-occurrences of a stimulus and response (when that stimulus is attended and consciously perceived) and automatically retrieved at all subsequent encounters (when that stimulus is attended, though not necessarily consciously perceived). These bindings are assumed to be established from a single trial (within a certain experimental context) and to be temporary (in comparison to permanent, though modifiable, associations between pre-existing stimulus representations). These "bindings" could be associative, in that they increase or decrease in strength with repeated stimulus-response pairings, or they could be episodic, with new associations being formed on each such pairing. Note however that an episodic account would lend itself more readily to explaining other factors that affect priming, such as the binding of incidentally co-occuring stimuli (McKoon & Ratcliff, 1986), incidentally co-occurring responses (generated by other stimuli on a particular trial, as in negative priming paradigms; Rothermund et al., 2005), incidentally co-occuring stimulus attributes (Rubin & Koch, 2006), or of representations of the task itself (Koch & Allport, 2006; Waszak & Hommel, 2007).

These S-R bindings are indicated by the dash-dotted lines in Figure 8.1, as distinct from the solid lines that represent pre-existing connections (i.e., previously established from long-term semantic learning). However, the S-R retrieval route differs from Instance Theory in two key ways: (1) any level of stimulus or response representation that is behaviourally relevant at initial encounter will be encoded in a separate S-R binding, and (2) the multiple possible levels of stimuli and responses are simultaneously cued by re-presentation of a stimulus, and interact with the component process route. Such interaction (at specific levels of response representation) could plausibly facilitate and/or interfere with processing, which would be dependent upon the congruency of response generated by each route (see later).

Given that S-R contributions to behavioural priming have been shown to be disrupted in amnesics with damage to medial temporal lobe (MTL) regions (Schnyer et al., 2006) and macaque monkeys with lesions to the hippocampus have shown impairments in learning stimulus-response (but not stimulus-stimulus) pairings (Wise & Murray, 1999), I propose that these S-R bindings are coded in MTL regions. Note though that I make no claim about whether such bindings are retrieved consciously or relate to explicit "episodic" memory (Tulving, 1972).

8.3.2 Component process route

The component process route of the MR-MS framework consists of several levels of stimulus representation, both perceptual and semantic. There may of course be more levels than shown in Figure 8.1, but these are the minimum needed for the present data. The connections between nodes in these layers, shown by solid lines, are pre-existing but modifiable (consistent with component process theories of priming). However, there are a further set of nodes that represent different levels of response representation, which are assumed to be established dynamically as a function of the current task. These are shown by dashed lines in Figure 8.1.

8.3.2.1 Pre-existing stimulus representations

The connections between pre-existing stimulus representations are assumed to be strengthened by prior processing of a stimulus, contributing to the overall measure of priming. Such strengthening may be part of normal learning in this system (Bowers et al., 2002; Marsolek et al., 2006; Stark & McClelland, 2000). These connections are similar to Bower's (1996) Type I associations. Importantly, these connections pass through unique representations of each object, which is what makes priming specific to a given object. In other words, strengthening of the connection between a visual input and the "octopus" concept does not affect the processing of other objects that are linked by different connections. Such strengthening is necessary to explain priming in identification tasks, such as word-stem completion (e.g., Schott et al., 2005), where no obvious S-R pairing is repeated between presentations. The inclusion of unique representations for each object also allows for S-R learning at an abstract level of stimulus representation.

Having said this, the framework is not incompatible with distributed representations of the perceptual input, such that similar inputs (e.g., two similar picture of an octopus) would benefit from prior strengthening of (some of) the connections between the input nodes and the unique object nodes. This would allow some generalisation of priming across different exemplars of an object. Indeed, the framework even allows for some priming, albeit reduced, from pictures to words (and vice versa) within the same task, by virtue of strengthening of connections between the object nodes and semantic features. Although we have not provided evidence for such picture to word priming in the present paper (that is not explained instead by S-R learning), previous research has shown significant priming from pictures to words (Bruce et al., 2000; Vaidya & Gabrieli, 2000; Vriezen et al., 1995) and from spoken to written words (Light et al., 2000; Thompson-Schill & Gabrieli, 1999; Vaidya et al., 1997) when using tasks that require access to similar semantic information (though these studies may also be explicable in terms of S-R learning).

Thus priming can arise from multiple stages within this "modificationist" system. In general, the degree of priming should be related to the degree of overlap in the pathways traversed through this system, which will depend on both the stimulus and the task (Henson, 2003), but keeping in mind that this priming is specific to an object, so cannot reflect a generalised transfer of appropriate processing. Previous fMRI (Henson et al., 2004; Horner & Henson, 2008; Koutstaal et al., 2001; Race et al., 2009; Simons et al., 2003) and neuropsychological (Bondi & Kaszniak, 1991; Keane et al., 1995) studies, as well as the fMRI results from Chapter 5 in the present thesis, would suggest that these abstract visual and semantic representations exist within the occipital and temporal lobes.

8.3.2.2 Task-dependent response representations

Given the task-specific nature of certain response representations (i.e., Decisions and Classifications), such representations are assumed to be temporary; likely limited to the current task or experimental context. For example, representations of a particular Classification (e.g., bigger) or Decision (e.g., yes) would be rapidly constructed at the beginning of an experiment (based on instructions and/or the first few trials). Such representations might relate to the particular “task-set” (Monsell, 1996). They can also be rapidly dismantled under conditions that demand differing representations (e.g., when switching from a "bigger/smaller" to "man-made/natural" task). Such adaptive coding of responses has parallels with the idea of "task-set reconfiguration", whereby task-switches require "the re-tuning of input-output mapping between processing modules" (Monsell, 1996). Here however, the proposal is that such re-configuration is specific to task-dependent response representations (and possibly task-dependent semantic information), rather than the entire processing stream. Previous research has implicated the prefrontal cortex (PFC) in such adaptive (task-relevant) coding (Duncan, 2001).

8.3.3 Interaction between the multiple routes

As shown in Figure 8.1, the output of the perceptual and semantic processing of the stimulus and the retrieval of S-R associations converge on the task-specific response representations. Indeed, these interactions between algorithmic and S-R retrieval routes can occur at multiple levels of response representation. The framework assumes that the final behaviour (action) is reached by a process of accumulation of information at each of these levels, until some criterion is reached (e.g. Laming, 1968; Ratcliff, 1978; Usher & McClelland, 2001). While the framework does not specify the nature of the decision in detail, it seems likely that competition between conflicting responses is involved (indicated by the inhibitory connections in Figure 8.1). This competition would seem necessary to explain why interference can occur when incongruent responses are retrieved from the component process and S-R retrieval routes. For example, in circumstances where the responses (e.g., Classification) are congruent, consistent information from both routes will accelerate the build up of evidence for a given final action. For S-R pairings that have previously occurred multiple times (e.g., High-primed items), the stronger modificationist connections and stronger/greater number of S-R associations will increase this effect. Conversely, in circumstances where the responses from the two routes are incongruent, the accumulation of evidence in competing response representations will act to slow RTs.

Given that this interaction between the multiple routes must occur at the response level, and that we assume these temporary response representations are stored in PFC, then the above response competition must occur within PFC. This is consistent with previous fMRI data (Dobbins et al., 2004; Horner & Henson, 2008; Race et al., 2009; Wig et al., 2009), as well as the fMRI data from Chapter 5 that showed significant RS following response repetition but repetition enhancement (i.e., greater activation) when responses were reversed between presentations. Thus these data show both facilitation and interference from the retrieval of S-R bindings, depending on the congruency of response generated by the component process and S-R retrieval route.

8.3.4 Application of the MR-MS framework to the present data

8.3.4.1 Same and Reverse conditions

It is useful to consider how the MR-MS framework explains the present pattern of results. In Chapters 2-3 I saw significant priming in the Same condition. This is presumed to result from both (1) strengthening of connections between pre-existing representations at one or more stages in the component process route (connections 1 and 2 in Figure 8.1) and (2) congruency between the response generated by the component process and S-R retrieval route, at all levels of response representation (Action, Decision, Classification; indicated by associations 3-5 in Figure 8.1). The significant decrease in priming in the Reverse condition in Chapters 2-3 is then attributed to an incongruency at the level of both Action and Decision response representations (numbered 4-5). However, the framework also predicts that the congruency of response at the level of Classification (numbered 3), coupled with any strengthening of connections between pre-existing stimulus representations (i.e., connections 1 & 2), will facilitate primed items in the Reverse condition. Such facilitation must outweigh the predicted interference effects at the level of Action and Decision to result in significant (although decreased) priming.

Increasing the number of stimulus repetitions in the Same and Reverse conditions (i.e., High-primed items) will both (1) strengthen further the connections between pre-existing stimulus representations and (2) increase the number of S-R bindings. The strengthening of connections between stimulus representations, coupled with the increased number of S-R bindings at all levels of both stimulus and response representation, will increase priming in the Same condition (relative to Low-primed items). In the Reverse condition the strengthening of connections between stimulus representations will result in increased priming. Furthermore, the increased number of S-R bindings at the level of Classification will increase priming (due to repetition of Classification responses regardless of the task direction). The increased number of S-R bindings at Action and Decision levels will produce greater interference than for Low-primed items however. If this increase in interference equals the facilitation resulting from strengthening of connections between stimulus representations (and repetition of Classification responses), no difference in priming for Low- and High-primed stimuli in the Reverse condition would be seen.

8.3.4.2 Orthogonal condition

The response-congruency effects seen in the Orthogonal condition of Chapters 2-3 are explained in the following manner. Firstly, the differing task demands will result in the formation of new task-dependent Classification response representations. For example, if the task was switched from "bigger-than-shoebox?" to "man-made?", the "Bigger" and "Smaller" Classifications used at Study would be replaced by "Man-made" and "Natural" Classifications at Test (numbered 6). Such new Classifications may plausibly connect to different semantic representations depending upon the overlap in semantic processing between Study and Test tasks. For example, whereas the "taller than wide?" task might access similar size-semantics to the "bigger than shoebox?" tasks, the "man-made?" task might require access to different semantic information. Such tasks all require response representations at the level of Action and Decision however, explaining the congruency effects seen in the Orthogonal condition of Chapters 2-3. For congruent stimuli, congruency of response at the level of Action and Decision results in facilitation. For incongruent stimuli, incongruent responses at the level of Action and Decision result in interference. Given Classification responses at Study and Test are unrelated, the retrieval of a Classification response should not facilitate or interfere with processing at Test.

The critical issue in the Orthogonal condition is why no significant CP contributions were seen. The MR-MS framework explains this result in the following manner. Firstly, the retrieval of S-R bindings at Test both facilitated and interfered with processing depending on the congruency of response between the component process and S-R retrieval route. Secondly, repetition resulted in the strengthening of connections between pre-existing stimulus representations in the component process route. This strengthening of connections will have resulted in facilitation regardless of the congruency of response between the two routes. For congruent stimuli, facilitation will occur due to both facilitation of component processes and retrieval of a congruent response, resulting in overall positive priming. For incongruent stimuli, the facilitation caused by repetition of component processes will be counteracted by the interference from retrieval of an incongruent response, resulting in no nett priming.

Although the framework readily predicts this pattern of results, it is perhaps not the most parsimonious of explanations. For example, no nett priming for incongruent stimuli could simply be due to a lack of CP facilitation coupled with effective ignoring of previously retrieved responses. Note however, that the framework makes two specific predictions. Firstly, in circumstances where no strengthening of connections in the component process route occurs, incongruent stimuli should show negative priming (due to interference at the level of Action and Decision representations). This prediction could be tested by switching both stimulus type and task between Study and Test. For example, switching between word and picture stimuli should prevent facilitation from the strengthening of connections between perceptual and stimulus representations (numbered 1), whereas switching between tasks that require access to different semantic information should prevent facilitation owing to the strengthening of connections between stimulus and semantic representations (numbered 2). The framework predicts that S-R bindings will still be retrieved from activation of the same stimulus (but not perceptual) representation, thus resulting in S-R effects. In this situation the framework predicts that incongruent stimuli should show slower RTs than novel stimuli (i.e., negative priming).

Secondly, in circumstances where S-R learning does not occur, positive (and equal) priming should be present for both congruent and incongruent stimuli. This would be due to the strengthening of connections between perceptual and stimulus representations and/or between stimulus and semantic representations. Given the evidence that amnesic patients with damage to the MTL do not show typical S-R effects, this prediction could be tested using such a population. If amnesic patients are impaired in the encoding and retrieval of S-R bindings, they should show significant positive priming in the Orthogonal condition regardless of response congruency. If evidence were produced to support these two predictions it would confirm that the lack of priming seen for incongruent stimuli in the Orthogonal condition was a result of counteracting facilitation and interference effects.

8.3.4.3 Repetition-related changes in neural activity

In Chapters 5-6 I saw evidence for both S-R and CP contributions to repetition-related neural changes (e.g., repetition suppression). Using fMRI I saw significant RS in occipital/temporal ventral visual regions that is most readily explained by facilitation of component processes. The framework explains such reductions in neural activity by the strengthening of connections between pre-existing stimulus representations. Such strengthening could act to speed-up processing time in these regions, resulting in a more rapid curtailing of activity within such regions. Because the BOLD signal integrates over several seconds of neural activity, such curtailment of neural activity would cause a decrease in the BOLD response (although other neural mechanisms for RS exist; Grill-Spector et al., 2006). Chapter 5 also provided evidence for RS in inferior prefrontal regions that was sensitive to response repetitions/reversals. The framework predicts that the component process and response retrieval route interact in prefrontal regions. This interaction should result in neural decreases when the response generated by the two routes is congruent. This is because the congruent information arriving at each response representation will result in the more rapid accumulation of information needed to effect a decision. When the response generated by the two routes is incongruent, neural increases should be seen (compared to experimentally novel stimuli). This is because the incongruent information arriving at each response representation results in competition between the two competing representations, producing greater activity within these regions. The present fMRI results showed repetition suppression following response repetition and repetition enhancement (i.e., greater activity compared to novel stimuli) following response reversal, in line with the predictions of the MR-MS framework.

Finally, the framework predicts that repetition effects resulting from the strengthening of connections between pre-existing stimulus representations should occur prior to effects due to the congruency of response between the two routes. This is because the stimulus representations are upstream of the task-dependent representations where such S-R effects are predicted to manifest. The EEG data presented in Chapter 6 suggests that this is the case. Whereas the repetition effects that were thought to be related to facilitation of component processes occurred 400-600ms post stimulus-onset, the effects thought to be related to S-R learning occurred -200 to -100ms prior to response-onset. Given response onset typically occurred 800ms post stimulus-onset, these data suggest that the component process effects seen in the EEG data occurred prior to the S-R effects. Furthermore, although the component process effects were time-locked to stimulus-onset, the S-R effects were time-locked to response-onset. These data suggest that component process effects reflect the facilitation of processes that are closely tied to the presentation of a particular stimulus. S-R effects however are more closely tied to response preparation (i.e., are locked to response-onset) suggesting they occur further downstream.

8.4 Conclusion

The present thesis presented evidence for the contribution of S-R effects to behavioural priming and repetition-related changes in neural activity. Such S-R effects were found to dominate behavioural repetition priming in long-lag semantic classification paradigms, with little if any evidence for facilitation of component processes. This dominance questions the commonly held assumption that priming reflects the facilitation of one or more component processes, casting doubt on research that utilises priming (e.g., Franks et al., 2000; Thompson-Schill & Gabrieli, 1999; Vriezen et al., 1995; Wig et al., 2005; Xiong et al., 2003) and repetition-related neural changes (e.g., Ghuman et al., 2008; Koutstaal et al., 2001; Simons et al., 2003; Wig et al., 2005) as a means to study underlying mental and neural representations.

S-R learning was found to occur at multiple levels of stimulus and response. The retrieval of such S-R bindings was found to facilitate processing when the retrieved response was congruent with the response required on repetition of a stimulus, and interfere with processing when the retrieved response was incongruent. These S-R effects were found only after stimuli were attended at both initial and subsequent presentation, suggesting that attention is necessary for both the encoding and retrieval of S-R bindings.

fMRI and EEG data found evidence for both S-R and CP contributions to the repetition-related changes in neural activity associated with behavioural priming. Whereas CP contributions were found in occipital/temporal ventral visual regions, as shown using fMRI, and were locked to stimulus-onset, as shown using EEG, S-R contributions were found in inferior prefrontal regions (fMRI) and were locked to response-onset (EEG). Both the fMRI and EEG data suggest that such CP and S-R contributions to repetition-related neural changes are spatially distinct, with differing underlying neural generators.

Given current theories of priming are not able to encompass all the results presented in the present thesis, a novel framework of priming was introduced. The multiple-route multiple-stage (MR-MS) framework includes two routes to response selection, a component process and S-R retrieval route. It is the interaction of these two routes within prefrontal regions that is capable of explaining the facilitation and interference effects following response repetition/reversal respectively in the present data. This dual route framework is also able to incorporate much of the literature on priming that has demonstrated both CP and S-R contributions to priming. Furthermore, this framework incorporates results from fMRI and EEG experiments on priming, embedding CP and S-R effects within specific brain regions. Overall, this framework is designed to encompass a wide range of cognitive neuroscientific research, highlighting the importance of S-R learning effects within stimulus repetition (i.e., priming) experiments.

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Appendices

Analyses of error rates and proportional measures of priming are reported below.

Chapter 2

A-1 Experiment 1

The error data were entered into a 3x2x2 (Task x Repetition x Prime-level) ANOVA that revealed a significant effect of Task, *F*(1.9, 21.2) = 59.74, p<.001, reflecting greater accuracy for the "man-made" Orthogonal task compared to the "bigger than shoebox" task in both the Same, *t*(11) = 8.66, p<.001, and Reverse, *t*(11) = 10.78, p<.001, conditions (Same vs. Reverse, *t*(11) = .50, p=.63). No main effect of Repetition was present, *F*(1, 11) = .01, p=.93, although the Repetition x Prime-level interaction was close to significance, *F*(1.7, 18.8) = 3.53, p=.06. Despite this trend for a significant interaction, no repetition effects were seen for any of the three Tasks individually (*t*'s < 1.96, p's>.08) when collapsing across Prime-level.

The mean RT data for Novel stimuli alone were entered into a 3x2 (Task x Prime-level) ANOVA revealing a main effect of Task, *F*(1.7, 18.4) = 10.12, p<.01. Further tests revealed longer RTs for the Same and Reverse compared to the Orthogonal condition, *t*'s>3.61, p's<.01, presumably because participants found the "man-made" task easier than the "bigger-than-shoebox" task. To control for these baseline RT differences, a proportional priming measure ((Novel-Repeated)/Novel) was used in a 3x2 (Task x Prime-level) ANOVA. This revealed a main effect of Task, *F*(1.6, 17.2) = 10.42, p<.001, replicating the Task-by-Repetition interaction for the subtractive measure of priming reported in Chapter 2. Proportional priming was greater in the Same relative to Reverse, *t*(11) = 3.64, p<.01, and Orthogonal, *t*(11) =

4.61, p<.01, conditions (Reverse vs. Orthogonal, *t*(11) = 1.42, p=.18). Proportional priming was significant in both the Same, *t*(12) = 8.60, p<.001, and Reverse, *t*(12) = 2.82, p<.05, conditions, but not the Orthogonal condition, *t*(12) = .72, p=.49.

A-2 Experiment 2

A 3x2x2 ANOVA on errors revealed a significant main effect of Task, *F*(1.5, 25.8) = 92.69, p<.001, reflecting greater accuracy in the Orthogonal compared to both the Same, *t*(17) = 11.67, p<.001, and Reverse, *t*(17) = 9.56, p<.001, conditions (Same vs. Reverse, *t*(17) = .66, p=.52). No main effect of Repetition was present, *F*(1, 17) = .53, p=.48, nor did this factor interact significantly with any other (*F*'s<2.33, p's>.13).

ANOVA on the mean RT data for Novel items in Experiment 2 showed a main effect of Task, *F*(1.4, 24.5) = 24.44, p<.001. Further tests revealed shorter RTs for the Same and Reverse compared to the Orthogonal condition, *t*'s>4.70, p's<.001. Therefore, a 3x2 (Task x Prime-level) ANOVA was performed on the proportional priming scores. This showed a significant main effect of Task, *F*(1.7, 29.3) = 9.74, p<.001, replicating the Task-by-Repetition interaction for the subtractive measure of priming reported in Chapter 2. Proportional priming was greater in the Same relative to the Reverse, *t*(17) = 4.18, p<.01, and Orthogonal, *t*(17) = 4.28, p<.01, conditions (Reverse vs. Orthogonal, *t*(17) = 0.56, p=.58). Proportional priming was significant in the Same condition, *t*(17) = 5.98, p<.001, but not the Orthogonal condition, *t*(17) = .60, p=.56, though failed to reach significance in the Reverse condition, *t*(17) = 1.10, p=.29, unlike when using the subtractive measure.

A-3 Experiment 3

A 3x2x2 ANOVA on errors revealed a trend towards a Task x Repetition interaction, *F*(1.6, 17.5) = 3.42, p=.07, reflecting greater accuracy for repeated stimuli in the Same, *t*(11) = 2.78, p<.05, but not the Reverse or Orthogonal conditions (*t*(11)'s<1.0). Therefore repeating a response between Study and Test led to greater accuracy than when a response was reversed. These results reinforce the effect of priming, in that repetition of stimuli in the Same task both increased priming and reduced errors in relation to the Reverse task. No further main effects or interaction approached significance, *F*'s<1.7, p's>.21. In particular, no main effect of Task was seen as the task at Test remained constant in Experiment 3 (but the Study task varied).

ANOVA on mean RTs for Novel items in Experiment 3 failed to reveal any main effects or interactions, *F*'s<2.4, p's>.12. Nonetheless, A 3x2 ANOVA on the proportional priming data was performed, revealing a main effect of Task, *F*(1.7, 18.6) = 6.40, p<.01, replicating the Task x Repetition interaction for the subtractive measure of priming seen in Chapter 2. Post-hoc tests revealed significantly greater priming in the Same than Reverse, *t*(11) = 2.76, p<.05, and Orthogonal, *t*(11) = 3.18, p<.01, condition (Reverse vs. Orthogonal, *t*(11) = 1.35, p=.20). Furthermore, significant priming was seen in the Same, *t*(11) = 5.69, p<.001, and Reverse, *t*(11) = 2.52, p<.05, condition but not Orthogonal condition, *t*(11) = .95, p=.37.

Chapter 3

A-4 Experiment 4

A 3x2x2 ANOVA on errors revealed a main effect of Task, *F*(1.3, 22.7) = 23.66, p<.001, reflecting greater accuracy in the Same than Reverse condition, *t*(17) = 4.42, p<.001, and the Reverse than Orthogonal condition, *t*(17) = 3.72, p<.01 (Same vs. Orthogonal, *t*(17) = 5.92, p<.001). The greater accuracy in the Same compared to Reverse condition may reflect the greater amount of experience participants had with the “bigger than shoebox” compared to the “smaller than shoebox” task (given the task at Study was always “bigger than shoebox”). No main effect of Repetition was present, *F*(1, 17) = 1.13, p=.30, nor did this factor interact with any other (*F*’s<.81, p’s>.44).

ANOVA on mean RTs for Novel items in Experiment 4 revealed a main effect of Task, *F*(1.6, 27.8) = 39.62, p<.002. Further tests revealed shorter RTs for the Same than the Reverse condition, *t*(17) = 3.59, p<.01, and the Reverse than Orthogonal condition, *t*(17) = 6.08, p<.001 (Same vs. Orthogonal, *t*(17) = 7.29, p<.001). Although the longer RTs in the Orthogonal condition were expected, given the difficulty of the “taller-than-wide” task, it is unclear why the Reverse condition produced longer RTs than the Same condition. In any case, a 3x2 ANOVA on the proportional priming data revealed a significant main effect of Task, *F*(1.5, 25.3) = 23.55, p<.001 (the Task x Prime-level interaction also approached significance, *F*(1.9, 32.3) = 2.66, p=.09), replicating the Task-by-Repetition interaction for the subtractive measure of priming seen in Chapter 3. Priming was greater in the Same compared to the Reverse, *t*(17) = 6.74, p<.001, and Orthogonal, *t*(17) = 5.44, p<.001, conditions (Reverse vs. Orthogonal, *t*(17) = 1.78, p=.09). Proportional priming was significant in the Same condition, *t*(17) = 8.79, p<.001, and a trend in the Reverse condition, *t*(17) = 1.69, p=.12, but not in the Orthogonal condition, *t*(17) = .37, p=.72.

A-5 Experiment 5

A 3x2x2 ANOVA on errors revealed a main effect of Task, *F*(1.5, 26.1) = 19.58, p<.001, reflecting greater accuracy in the Same than Reverse condition, *t*(17) = 3.05, p<.01, and the Reverse than Orthogonal condition, *t*(17) = 3.10, p<.01 (Same vs. Orthogonal, *t*(17) = 6.67, p<.001). No main effect of Repetition was present, *F*(1, 17) = .05, p=.83, however a significant Task x Repetition interaction was seen, *F*(1.7, 28.3) = 3.53, p<.05. Post-hoc tests revealed significantly greater errors for Repeated stimuli in the Reverse condition compared to the Same condition, *t*(17) = 3.17, p<.01. Indeed, there was a significant effect of Repetition in the Reverse condition, *t*(17) = 2.75, p<.05, that was not present in the Same, *t*(17) = 1.42, p=.17, or Orthogonal, *t*(17) = .92, p=.37, conditions. These results reinforce the effect of priming, in that repetition of stimuli in the Reverse task both reduced priming and increased errors compared to the Same task.

ANOVA on mean RTs for Novel items in Experiment 5 revealed a main effect of Task, *F*(1.8, 30.2) = 63.27, p<.001. Further tests revealed shorter RTs for the Same than the Reverse condition, *t*(17) = 2.40, p<.05, and the Reverse than the Orthogonal condition, *t*(17) = 7.37, p<.001 (Same vs. Orthogonal, *t*(17) = 11.08, p<.001). A 3x2 (Task x Prime-level) ANOVA on the proportional priming data revealed a significant main effect of Task, *F*(1.8, 29.8) = 21.65, p<.001 replicating the Task-by-Repetition interaction for the subtractive measure of priming reported in the main paper. Priming was greater in the Same compared to the Reverse, *t*(17) = 5.32, p<.001, and Orthogonal, *t*(17) = 7.11, p<.001, conditions (Reverse vs. Orthogonal, *t*(17) = 0.03, p=.98). Proportional priming was significant in the Same condition, *t*(17) = 10.03, p<.001, a trend in the Reverse condition, *t*(17) = 1.52, p=.16, and significant in the Orthogonal condition, *t*(17) = 2.24, p<.05.

A-6 Experiment 6

A 3x2x2 ANOVA on errors revealed a main effect of Task, *F*(1.5, 24.9) = 15.73, p<.001, reflecting greater accuracy in the Same, *t*(17) = 4.77, p<.001, and Reverse, *t*(17) = 3.82, p<.001, condition compared to the Orthogonal condition (Same vs. Reverse, *t*(17) = .78, p=.48). No main effect of Repetition was present, *F*(1, 17) = .30, p=.59, nor did this factor significantly interact with any other (*F*'s<1.47, p's>.24).

ANOVA on mean RTs for Novel items in Experiment 6 revealed a main effect of Task, *F*(1.4, 23.3) = 31.11, p<.001. Further tests revealed shorter RTs for the Same than the Reverse condition, *t*(17) = 5.59, p<.001, and the Reverse than the Orthogonal condition, *t*(17) = 3.71, p<.01 (Same vs. Orthogonal, *t*(17) = 7.33, p<.001). A 3x2 ANOVA on the proportional priming data revealed a significant main effect of Task, *F*(1.7, 28.4) = 27.90, p<.001 (the Task x Prime-level interaction also approached significance, *F*(1.6, 26.5) = 3.48, p=.06), replicating the Task-by-Repetition interaction for the subtractive measure of priming reported in the main paper. Further tests revealed significantly greater priming in the Same than Reverse condition, *t*(17) = 3.15, p<.01, and Reverse than Orthogonal condition, *t*(17) = 3.67, p<.01 (Same vs. Orthogonal, *t*(17) = 8.98, p<.001. Proportional priming was significant in the Same, *t*(17) = 16.45, p<.001, Reverse, *t*(17) = 11.03, p<.001, and Orthogonal, *t*(17) = 3.13, p<.05, conditions.

Chapter 4

A-7 Experiment 7

A 3x2x2 (Task x Repetition x Prime-level) ANOVA on errors failed to reveal any significant main effects or interactions (Repetition, *F*(1, 17) = .11, p=.75).

A 3x2 (Task x Prime-level) ANOVA on mean RTs for Novel items in Experiment 7 did not reveal any reliable differences, *F*'s<2.28, p's>.12. Nonetheless, analysis of proportional priming was performed for completeness. A 3x2 (Task x Prime-level) ANOVA on the proportional priming data revealed significant main effects of Task, *F*(1.5, 24.7) = 23.62, p<.001, and Prime-level, *F*(1, 17) = 8.20, p<.05. The main effect of Task replicates the Task-by-Repetition interaction for the subtractive measure of priming reported in the main paper. The main effect of Prime-level replicates the Prime-level-by-Repetition interaction for the subtractive measure of priming, showing greater priming for High- than Low-primed items irrespective of Task. Further tests revealed significantly greater priming in the Same-Action Same-Decision than Different-Action Same-Decision condition, *t*(17) = 3.00, p<.01, and Different-Action Same-Decision than Different-Action Different-Decision condition, *t*(17) = 3.99, p<.01. Proportional priming was significant in the Same-Action Same-Decision, *t*(17) = 13.13, p<.001, Different-Action Same-Decision, *t*(17) = 10.14, p<.001, and Different-Action Different-Decision, *t*(17) = 2.43, p<.05, conditions.

A-8 Experiment 8

A 2x2x2x2 (Classification-congruency x Decision-congruency x Prime-level x Repetition) ANOVA on errors failed to reveal a main effect of Repetition, *F*(1, 23) = 1.39, p=.25, however a Repetition x Prime-level interaction was present, *F*(1, 23) = 5.00, p<.05, reflecting fewer errors for Low-primed repeated stimuli (compared to Novel), *t*(23) = 2.08, p<.05, that was not present for High-primed repeated stimuli, *t*(23) = .21, p=.84. An Classification-congruency x Prime-level interaction was also present, *F*(1, 23) = 9.37, p<.001, reflecting greater errors for High- than Low-primed Classification-incongruent stimuli, *t*(23) = 2.37, p<.05, that was not present for

Classification-congruent stimuli, *t*(23) = 1.47, p=.19.

A 2x2x2 (Classification-congruency x Decision-congruency x Prime-level) ANOVA on mean RTs for Novel items in Experiment 8 revealed a significant Classification-congruency x Decision-congruency x Prime-level interaction, *F*(1, 23) = 10.30, p<.01, plus a main effect of Classification-congruency, *F*(1, 23) = 37.00, p<.001. A 2x2x2 (Classification-congruency x Decision-congruency x Prime-level) ANOVA on proportional priming showed a significant Decision-congruency x Prime-level interaction, *F*(1, 23) = 6.80, p<.05 (Classification-congruency x Prime-level, *F*(1, 23) = 2.15, p=.16), plus main effects of Decision-congruency, *F*(1, 23) = 23.37, p<.001, and Prime-level, *F*(1, 23) = 6.25, p<.05 (the main effect of Classification-congruency also approached significance, *F*(1, 23) = 3.94, p=.06). Further analyses (as in the main text) revealed significantly greater priming for Low- than High-primed Incongruent trials for both Decision-, *t*(23) = 3.73, p<.01, and Classification-congruency, *t*(23) = 2.68, p<.01, which was not present for Congruent trials, *t*'s<.95, p's>.35. Furthermore, priming was significantly greater for Congruent than Incongruent trials for both Decision-congruency, *t*(23) = 4.88, p<.001, and Classification-congruency, *t*(23) = 2.08, p<.05. Therefore, effects of both Classification- and Decision-congruency were still present despite making allowances for baseline RT differences.

A-9 Experiment 9

A 2x2x2x2 (Stimulus-type x Congruency x Prime-level x Repetition) ANOVA on errors revealed significant main effects of Prime-level, *F*(1, 15) = 6.41, p<.05, reflecting greater accuracy for High- than Low-primed stimuli, and Congruency, *F*(1, 15) = 100.89, p<.001, reflecting greater accuracy for Congruent than Incongruent stimuli. No main effect of Repetition was seen, *F*(1, 15) = .54, p=.48, nor did this factor interact with any other, *F*'s<2.3, p's>.15.

A 2x2x2 (Stimulus-type x Congruency x Prime-level) ANOVA on mean RTs for Novel items in Experiment 9 revealed a significant main effect of Prime-level, *F*(1, 15) = 8.04, p<.05, reflecting faster RTs for Low- than High-primed stimuli (note that stimuli are arbitrarily split between these conditions, so this effect is likely to be a Type I error), and Congruency, *F*(1, 15) = 70.99, p<.001, reflecting slower RTs for Incongruent than Congruent stimuli. A further Stimulus-type x Congruency interaction was seen, *F*(1, 15) = 5.78, p<.05, reflecting a greater Congruency effect in the Word-Picture than Picture-Picture condition. Given these Novel RT differences, a 2x2x2 (Stimulus-type x Congruency x Prime-level) ANOVA on the proportional priming data was performed. This revealed significant main effects of Stimulus-type, *F*(1, 15) = 5.07, p<.05, revealing greater priming for the Picture-Picture than Word-Picture condition, and Congruency, *F*(1, 15) = 56.81, p<.001, revealing greater priming for Congruent than Incongruent stimuli. These main effects however were superseded by a Stimulus-type x Congruency interaction, *F*(1, 15) = 4.68, p<.05, revealing a greater Congruency effect in the Picture-Picture than Word-Picture condition. Thus, these data replicate the main findings of the subtractive priming analyses.

Chapter 5

A-10 Experiment 10

A 3x2 (Stimulus-type – Picture-Picture, Word-Picture, Novel x Congruency) ANOVA on errors revealed a main effect of Congruency, *F*(1, 17) = 11.10, p<.01, reflecting greater accuracy for Congruent than Incongruent stimuli. No further main effects or interactions were present, *F*'s<.13, p's>.83.

Given RTs were faster for Novel Congruent than Incongruent stimuli, *t*(17) = 6.08, p<.001, the proportional priming data were entered into a 2x2 (Stimulus-type – Picture-Picture, Word-Picture x Congruency) ANOVA. This revealed main effects of Stimulus-type, *F*(1, 17) = 71.02, showing greater priming for the Picture-Picture than Word-Picture condition, and Congruency, *F*(1, 17) = 23.92, p<.001, with no interaction between the two factors, *F*(1, 17) = .39, p=.54. Thus these results replicate the Repetition x Congruency effects seen in the Picture-Picture and Word-Picture subtractive priming analyses.

Chapter 6

A-11 Experiment 11

A 3x2 (Stimulus-type x Congruency) ANOVA on errors revealed a main effect of Stimulus-type, *F*(1.5, 26.2) = 5.68, p<.05, reflecting greater accuracy for Novel than Picture-Picture stimuli, *t*(17) = 2.67, p<.05, but not Novel than Word-Picture stimuli, *t*(17) = 1.31, p=.21. A main effect of Congruency was also revealed, *F*(1, 17) = 24.60, p<.001, with greater accuracy for Congruent than Incongruent stimuli. These effects however were superseded by a Stimulus-type x Congruency interaction, *F*(1.6, 27.4) = 6.01, p<.01. Post-hoc tests of error priming (Novel – Repeated) revealed a significantly greater accuracy for Novel than Incongruent stimuli in the Picture-Picture, *t*(17) = 3.39, p<.01, and a similar trend in the Word-Picture condition, *t*(17) = 2.04, p=.06. No error priming was seen for Congruent stimuli, *t*(17)'s<.96, p's>.35.

Thus, the retrieval of an Incongruent response resulted in decreased accuracy compared to Novel stimuli.

Given RTs were faster for Novel Congruent than Incongruent stimuli, *t*(17) = 5.70, p<.001, the proportional priming data were entered into a 2x2 (Stimulus-type x Congruency) ANOVA. This revealed main effects of Stimulus-type, *F*(1, 17) = 52.73, p<.001, reflecting greater priming for the Picture-Picture than Word-Picture condition, and Congruency, *F*(1, 17) = 27.66, p<.001, reflecting greater priming for Congruent than Incongruent stimuli, as well as a Stimulus-type x Congruency interaction, *F*(1, 17) = 12.42, p<.01, reflecting a greater Congruency effect in the Picture-Picture than Word-Picture condition. These analyses therefore replicate the Repetition x Congruency interactions seen in the Picture-Picture and Word-Picture subtractive priming analyses as well as the significant difference in Congruency effect seen across the Picture-Picture and Word-Picture conditions.

Chapter 7

A-12 Experiment 12

A 3x2 (Study-context – Attended, Unattended-Congruent, Unattended-Incongruent x Repetition) ANOVA on errors revealed main effects of Repetition, *F*(1, 16) = 90.15, p<.001, reflecting greater errors for Repeated than Novel stimuli, and Study-context, *F*(2.0, 31.3) = 5.17, p<.05, reflecting greater errors for Unattended-Incongruent than Attended stimuli, *t*(16) = 3.21, p<.01, and a trend for greater error for Unattended-Congruent than Attended stimuli, *t*(16) = 2.04, p=.06. No Study-context x Repetition interaction was present, *F*(1.6, 25.6) = 2.57, p=.11.

Despite an 3-way ANOVA comparing Novel RTs across Study-context failing to reveal a significant effect, *F*(1.3, 21.4) = 1.94, p=.18, the proportional priming data were entered in a 3-way (Attended, Unattended-Congruent, Unattended-Incongruent) ANOVA. This revealed a significant effect of Study-Context, *F*(1.9, 29.9) = 9.54, p<.01, showing greater priming in the Attended than both the Unattended-Congruent, *t*(16) = 3.05, p<.01, and Unattended-Incongruent, *t*(16) = 4.35, p<.01, condition. Although priming was significant in the Unattended-Congruent, *t*(16) = 2.09, p<.05, but not the Unattended-Incongruent, *t*(16) = .37, p=.71, condition no significant difference was seen between these conditions, *t*(16) = 1.48, p=.16. These results therefore replicate the main subtractive priming analyses in that no effect of congruency was seen for previously unattended stimuli.

A-13 Experiment 13

A 3x2 (Study-context x Prime-level) ANOVA on error priming revealed a main effect of Prime-level, *F*(1, 19) = 8.36, p<.01, reflecting greater error priming (Repeated > Novel) for High- than Low-primed stimuli, and Study-context, *F*(1.7, 32.5) = 15.81, p<.001, reflecting greater error priming for Unattended-Congruent than Attended stimuli, *t*(19) = 2.99, p<.01, and a borderline effect for greater error priming for Unattended-Incongruent than Unattended-Congruent stimuli, *t*(19) = 2.18, p=.06. No Study-context x Prime-level interaction was present, *F*(2.0, 37.7) = .15, p=.86.

Despite the fact than Novel stimuli were not included as a factorial manipulation in the present experiment (i.e., there was a single Novel condition), the proportional priming data were entered into a 3x2 (Study-context x Prime-level) ANOVA revealing a significant effect of Study-context. Post-hoc tests revealed significantly greater priming for Attended than Unattended-Congruent, *t*(19) = 5.96, p<.001, and Unattended-Incongruent, *t*(19) = 7.91, p<.001, stimuli. No significant difference was seen between the two Unattended conditions, *t*(19) = 1.26, p=.22, nor did these conditions demonstrate significant priming, *t*(19)’s<1.9, p’s>.08. Therefore, as in the subtractive priming analyses, no significant effect of congruency was seen for unattended stimuli.

A-14 Experiment 14

A 3x2 (Study-context x Test-context) ANOVA on errors failed to reveal any significant effects or interactions, *F*’s<.48, p’s>.51. Although no difference in RTs was seen between the two Novel conditions, *t*(12) = .12, p=.91, the proportional data were entered into a 2x2 (Study-context x Test-context) ANOVA. This analysis failed to reveal any main effects or interactions, *F*’s<.31, p’s>.59.

A-15 Experiment 15

A 3x2 (Study-context x Test-context) ANOVA on errors failed to reveal any significant effects or interaction, *F*<1.9, p’s>.19. Although no difference in RTs was seen between the two Novel conditions, *t*(12) = .07, p=.94, the proportional data were entered into a 2x2 (Study-context x Test-context) ANOVA. This analysis failed to reveal any main effect or interactions, *F*’s<1.3, p’s>.30.