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INHIBITORY PROCESSES IN TEMPORAL SELECTION

by

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Summary

This thesis is concerned with the issue of how humans select visually presented objects for action when those objects are presented rapidly and for very brief durations. Results have shown that when two events or objects occur within about half a second of each other, people find it difficult to accurately report one or both events (Kanwisher, 1987; Pashler, 1994; Raymond, Shapiro & Arnell, 1992). The experiments in this thesis examined the role of inhibitory processes in resolving this problem. This was accomplished by developing a hybrid Negative Priming- Rapid Serial Visual Presentation paradigm.

Results from Experiment 1 showed that distractors presented in close temporal proximity to a target, negatively prime a related probe stimulus. This effect was termed 'post-target inhibition'. Subsequent experiments demonstrated that a) post-target inhibition results from selecting a target stimulus b) the locus of this inhibition is at the level of response representations and c) post-target inhibition interacts with the Attentional Blink phenomenon.

Inhibition has long been a mechanism implicated in aiding spatial selection. This work provides a bridge between the domains of spatial and temporal selection since it suggests that the latter also relies on inhibition.

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CHAPTER 1 - INTRODUCTION

How do we partition our experiences of everyday life into episodes or events that make sense to us? When there is enough of a temporal interval between events this is not a problem, for example, watching TV in the morning is not confusable with eating dinner in the evening. However, studies have shown that when two events or objects occur within about half a second of each other, people find it difficult to accurately report one or both events (Kanwisher, 1987; Pashler, 1994; Raymond, Shapiro & Arnell, 1992). From this robust finding we can deduce that objects occurring very close in time interfere with each other at some level of information processing in the brain. In order to select one or both objects for action, this interference must be resolved somehow. This is the problem of temporal selection, which is the theme of this dissertation. To pre-empt subsequent chapters, it is suggested that temporal selection may be aided by the inhibition of irrelevant stimuli.

Binding and Selection

Selection in the spatial domain

In order to successfully act on an object, a percept of the object must be formed along with an appropriate response. This involves operations to bind different features of an object together. There are numerous models and explanations for how this occurs, however, two of the most well expounded theories of binding are

Feature Integration theory (Treisman, 1986; Treisman, 1993; Treisman & Gelade, 1980) and Guided Search theory (Wolfe, Cave & Franzel, 1989). According to Feature Integration theory, visual scenes are composed of low-level features such as colour, size and orientation. Visual search of these features can proceed in parallel. Attention is then focused to bind these features into conjunctions i.e. objects. Visual search of these conjunctions proceeds in a serial fashion. As evidence for this, Treisman demonstrated that the time taken to respond to a target in a briefly presented stimulus array (e.g., a red X among green Xs and red Os), increases linearly as a function of the number of distractors (e.g., green Xs and red Os) also present (Figure 1).
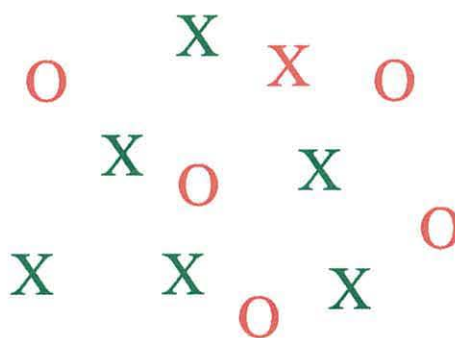
Figure 1. An example of a visual search task in which the participant has to detect the presence or absence of a red X as quickly as possible.

If attention is not focused properly, features of two or more separate objects may be conjoined resulting in an illusory conjunction or binding error. An example of an illusory conjunction would be to report a red X when only green Xs and red Os were presented (Figure 2).
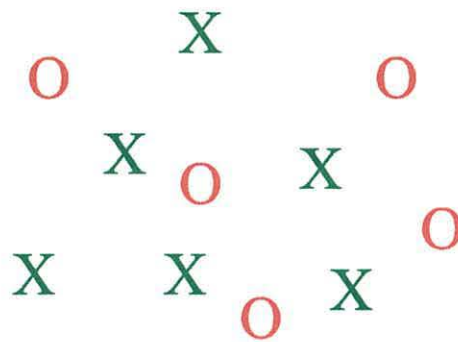
Figure 2. Reporting a red *X* in this case would be an illusory conjunction or binding error.

An alternative model of binding is that of Guided Search. Wolfe et al. (1989) demonstrated that in visual search experiments, triple conjunctions (i.e. Colour x Size x Form) are faster and easier to respond to than standard conjunctions (i.e. Colour x Form). To explain this, Wolfe et al. (1989) hypothesise that participants use cues derived from simple features to divide stimuli into distractors or candidate items. When more cues are available, as in the case of a triple conjunction, this grouping process can proceed more efficiently. Attention is then directed to candidate items. Duncan and Humphreys (1989) showed that guided search can be improved further by grouping stimuli according to homogeneity. The more similar targets are to distractors, the harder it is to select the former. In contrast, the more similar distractors are to each other, the easier it was to select the target. They demonstrated that the serial search pattern observed by Treisman and her colleagues could be eliminated if distractors share features that allow them to be grouped and then discarded *en masse*. In other words,

increasing the number of distractors in the array does not necessarily increase search time if they are homogenous (Figure 3).
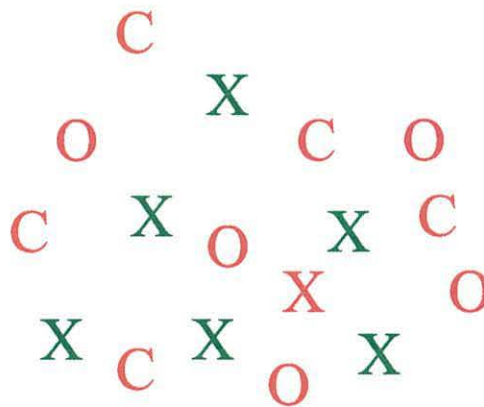
Figure 3. If distractors are homogenous or similar, they may be discarded _en masse_ i.e. red _C_s and red _O_s are both curved.

Selection in the temporal domain

So in order to select an object in the spatial domain attention must be focused such that distractors are segregated from the target(s) (Duncan & Humphreys, 1989). Once this has been achieved the system uses spatial location as a cue to bind features into conjunctions/objects. But what happens when distractors do not share spatial proximity with the target object but are in close temporal proximity? Should not selection proceed in a similar fashion i.e. the focusing of attention? Temporal selection has been studied in numerous 'attentional' paradigms. Typically, these paradigms employ Rapid Serial Visual Presentation (RSVP) streams, in which letters, pictures or words are presented one after the other at rates

of about 10 items a second. Stimuli presented in such close temporal proximity interfere with one another. For example, when asked to identify a target stimulus presented in a RSVP stream, participants will sometimes substitute the identity of the target with the identity of a neighbouring non-target (see Figure 4). These intrusion errors are also known as temporal binding errors in reference to the mechanism that has apparently broken down. Most of the work on this topic has concentrated on post-target intrusion errors (Broadbent, 1977; Gathercole & Broadbent, 1984; Lawrence, 1971). However, recent research has shown that depending upon the target task, the pattern of errors may shift from a post-target to a pre-target pattern (Botella, Garcia and Barriopedro, 1992).
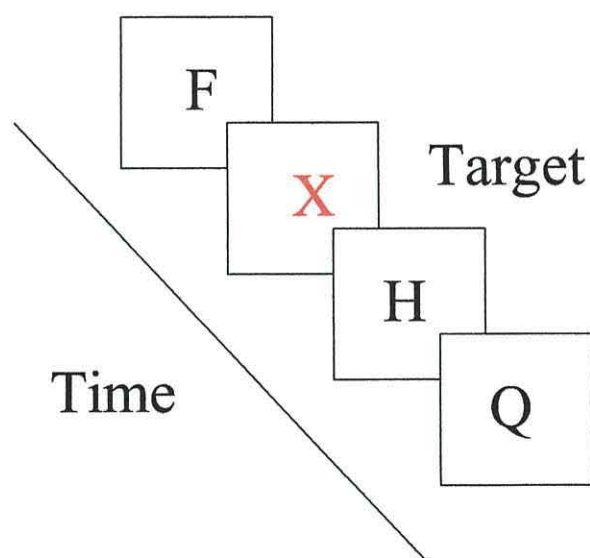
Figure 4. When the participant has to report the identity of the red letter, they will sometimes substitute the identity of the non-target immediately following i.e. reporting *H* instead of *X*. These errors are known as intrusion or temporal binding errors.

It is worthwhile explaining some terminology that has been used in studies of intrusion errors (see Lawrence, 1971). The target's *key dimension* is the dimension on which the target may be identified. For example, in a task where a participant is required to identify a red letter amongst black letters in an RSVP stream, the *key dimension* is COLOUR. The *key feature* that allows identification of the target is RED. The *response dimension* is the dimension of the target that should be reported. In this case, the participant is required to report the identity of the red letter, so the *response dimension* is IDENTITY. The identity of that letter is the *response feature* e.g. the letter 'X'.

Models based on serial and parallel processes have been put forward to account for intrusion errors. Broadbent and his colleagues proposed a serial model (Broadbent, 1977; Gathercole & Broadbent, 1984) in which post-target errors result from delays in processing the key feature. According to this model, if processing of the key feature is delayed then another stimulus (e.g. the +1 item) will have been presented by the time that response dimension processing is engaged, resulting in substitution of the +1 item's response feature for that of the target. Serial models of intrusion errors do not predict pre-target patterns. Also, they provide no framework for an explanation of how temporal binding is achieved. Parallel models of intrusion errors are based upon early work on binding (Treisman & Gelade, 1980). The code co-ordination model of Keele and Neill (1978) holds that target features need time in order to be bound together. If other items are presented in close temporal proximity then features from different stimuli will be simultaneously active with those of the target. When the key feature is detected the

system chooses the response feature with the highest activation. Under different experimental conditions the time taken to produce key and response features may vary causing a predominance of pre-or post-target intrusion errors. For example, when detection of the key feature is quick and detection of the response feature takes a long time, the most active response feature will most probably belong to a pre-target stimulus.

Botella et al. (1992) provided evidence that different target response features result in different patterns of intrusion errors. They had participants report either the colour or identity of a target uppercase word in an RSVP stream of lowercase words. They observed any intrusion errors from stimuli in positions –2 to +2 in relation to the target. They found a predominance of post-target errors when a colour response was required and a pre-target pattern when the identity of the word was required.

Perhaps the most cogent account of illusory conjunctions in the time domain has come from a paper by Botella, Barriopedro and Suero (2001). They make a distinction between correct target responses due to successful focusing of attention, and fortunate conjunctions (resulting in a correct response) resulting from a sophisticated guessing mechanism when focusing has not been achieved. In this model, temporal binding begins in two modules that process in parallel. Module K detects and processes the key dimension whilst Module R processes the response dimension. It is important to note that features processed in these modules are maintained in the system for a while after which time their activation levels begin to decay. If the focusing of attention happens in time then binding of the target is

achieved without error. If it does not, the sophisticated guessing mechanism is engaged and one of the response features currently being processed is selected and combined with the key feature. Which response feature is selected depends upon the relative activation levels of those features at the critical moment when the key feature is detected. The response feature with the highest activation is likely to belong to the target or a stimulus in close temporal proximity to the target and may result in a 'lucky hit' or an intrusion error.

Botella and his colleagues do not explicitly describe how this focusing of attention is achieved which circumvents their sophisticated guessing mechanism and results in successful temporal binding. Similarly, Treisman and Gelade (1980) and Wolfe et al. (1989) do not explicitly describe how attention is focused such that distractors are segregated from candidate targets in the spatial domain. So how *is* focusing achieved? The answer to this question is relevant to interpret results from several temporal selection paradigms in which interference between two targets in close temporal proximity results in response impairment to one or both targets. Examining these paradigms in more detail will yield clues as to how attention is focused in time.

Interference between Two Temporally Proximal Objects/Targets

As already stated, when two targets are presented within about half a second of one another, we find it difficult to report both objects. Generally, it is the second target that cannot be reported accurately or quickly. This is the result of an overlap in

processing between the two objects. A good way of visualising this effect in terms of information processing is to think of closing an application on a slow computer. Most of us know (through painful experience!) that on an old machine, if we close down an application and then immediately try and open a new one, a number of things can happen. The machine might crash or it might take an inordinately long amount of time for the new application to open. The computer is busy processing your last command (i.e. close the old application) and can't cope with a new task so soon after the first (i.e. open a new application). When presented with two temporally proximal tasks, our brains face the same problems that old computers face. That is not to say that our brains deal with this problem in the same way that computers do.

There are a number of paradigms in the field of temporal attention, which measure this dual-task interference. These include the *attentional blink* (AB), the *psychological refractory period* (PRP) and *repetition blindness* (RB). These paradigms and the theories relating to them will be reviewed in some detail.

The Attentional Blink (AB)

In a typical AB experiment, participants view an RSVP stream of letters. Amongst those letters, and at varying points in the stream, there are two targets defined by some target feature (e.g. colour or identity): T1 and T2. The targets occur at varying SOAs (Stimulus Onset Asynchrony) away from one another corresponding to their positions in the stream relative to one another (see Figure 5).

In the experimental condition, known as the Dual-Task condition,

participants have to wait until the end of the stream and are then required to

identify (or in some cases, detect) both targets. Whilst participants can report the

identity of T1 without much difficulty, the percentage of trials in which they can

correctly report T2 is comparatively lower.
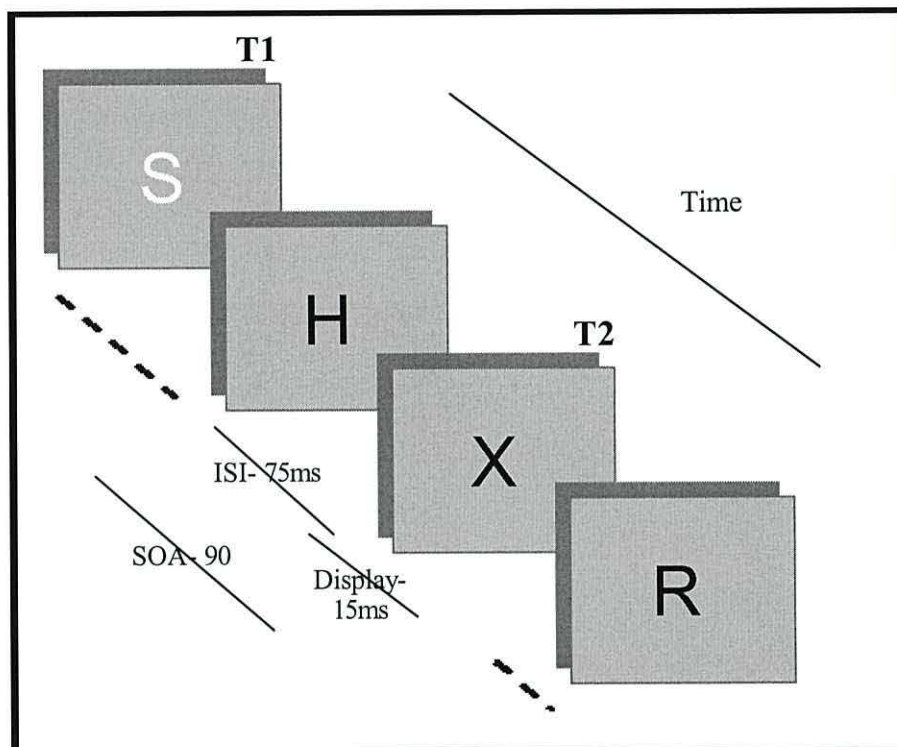
Figure 5. The Attentional Blink RSVP – Adapted from Shapiro, Raymond & Arnell (1994). SOA and ISI are respectively, 'Stimulus Onset Asynchrony and 'Inter Stimulus Interval'.

The crucial point is that this post-target response deficit is contingent upon

the temporal distance or SOA between the two targets. Basically, the closer T1 is

to T2 in time, the worse participants' performance. This deficit in reporting T2

lasts approximately 500ms after presentation of T1 (see Figure 6). It should be

noted that in some cases T2 is unimpaired if it is presented in the position

immediately after T1 (i.e. the T1+1 position), a phenomenon known as Lag 1

sparing.

In contrast to the Dual-Task condition is the control condition, known as the

Single-Task condition, in which participants are instructed to ignore T1 and only

report T2. In this condition, report of T2 is not impaired and there is no effect of

SOA. Raymond and Shapiro (1992) termed this post-target response deficit the

'Attentional Blink' because its time-course (approximately 500ms) resembles that

of an eye-blink.
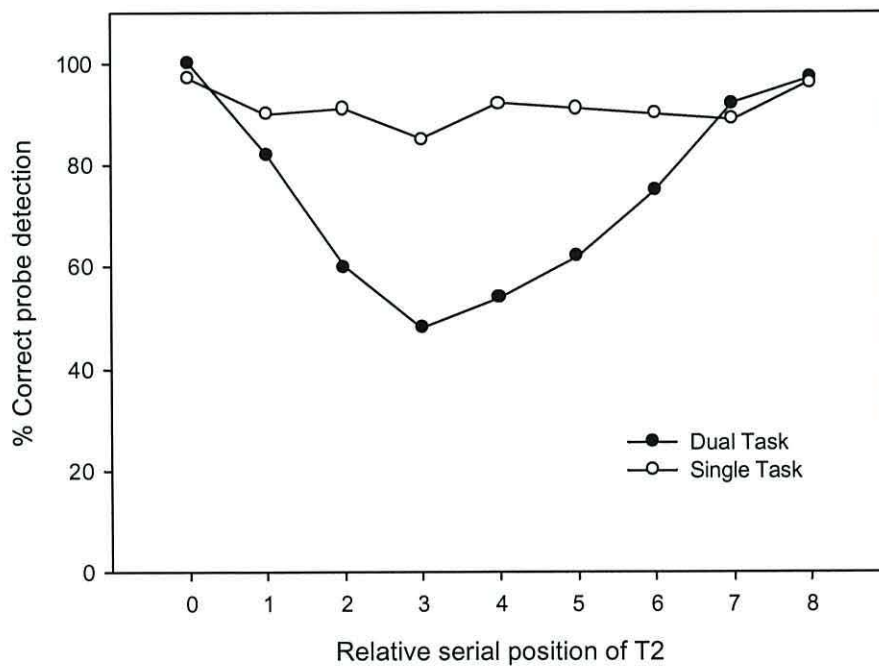
Figure 6. Percentage of trials in which T2 was identified correctly as a function of serial position. Adapted from Raymond, Shapiro & Arnell (1992). They had participants identify the white letter in the stream and detect the presence or absence of a black *X*.

Theoretical explanations of the AB fall into two main categories: online and offline accounts. Online accounts posit that the deficit occurs before T2 enters short-term memory (STM). In contrast, offline accounts postulate that the deficit occurs after T2 enters STM. Current online accounts include the *two-stage model* (Chun & Potter, 1995), the *central interference model* (Jolicoeur, 1998a, 1998b) and the *attentional dwell model* (Duncan, Ward & Shapiro, 1994; Ward, Duncan & Shapiro, 1996).

In their 1995 paper in which they propose the *two-stage model*, Chun and Potter suggest that T1 report is accomplished in two stages. In the first stage, nearly all the items in the RSVP stream are identified and short-lived representations are formed. The second stage facilitates final consolidation and report of the target. This latter stage is thought to be capacity limited such that T2 cannot enter until T1 has been fully processed. Thus, this model could be viewed as a limited capacity model that results in serial processing of the targets. This is similar to a model proposed by Broadbent (1977) in which attentional selection is accomplished in two discrete stages, an early perceptual stage followed by a more complex identification stage (Broadbent and Broadbent, 1987). An interesting caveat is Chun and Potter's interpretation of Lag 1 sparing. As already noted, the phenomenon of Lag 1 sparing is characterised by a pattern of results in which T2 is reported on a high percentage of trials when it occurs immediately after T1 (i.e. the T1+1 position in the RSVP). It has been hypothesised that T2 is processed together with T1 as a consequence of its temporal proximity. Chun and Potter state that in this situation, both T1 and T2 can enjoy Stage 2 processing. This seems to be at

odds with the primary assumption of the model, which is that two targets (i.e. T1 and T2) cannot be processed simultaneously in Stage 2 because of limited capacity.

The *central interference model* (Jolicoeur, 1998a, 1998b) is similar to the two-stage model in that it consists of a bottleneck that leads to serial processing of the targets (i.e. T1 and T2). The main difference is that the central interference model postulates numerous operations that may interfere with short-term consolidation of T2, including response selection and task switching. The model is based upon, among other things, the finding that when an immediate response is required to T1 (rather than delayed in the normal AB paradigm) the magnitude of the AB is greater (Jolicoeur, 1998). Selecting a response for T1 is thought to tap a central capacity limited resource and results in delayed processing of T2. This model has also been used to account for the Psychological Refractory Period discussed in more detail on p. 15.

In contrast to the two-stage model and the central interference model which posit bottlenecks leading to serial processing of T1 and T2, the *attentional dwell model* (Duncan, Ward & Shapiro, 1994; Ward, Duncan & Shapiro, 1996) assumes that processing of T1 and T2 can occur in parallel. However, when the targets appear in close temporal proximity, competition arises for visual-processing capacity such that one wins (T1) at the expense of the other (T2). Ward et al. (1996) had participants attend to two digits presented simultaneously for the T1 task, which was followed by T2 (a letter). When participants had to respond to all three items their T2 performance was more impaired than if they only had to report one item from the T1 display. However, the AB effect did not last twice as long

(e.g. a second) when participants were required to report two digits compared with when they only had to report one. This led Ward and his colleagues to argue that the digits were not being processed sequentially but in parallel. This is a rather large claim since it relies on the assumption that the drain on visual processing capacity is a linear function of the number of visual tasks undertaken. This experiment on its own does not support such an assumption. According to their model, competition for limited parallel processing is resolved over about half a second: the length of the AB.

As previously stated, the online accounts mentioned above all share in common the assumption that the AB occurs before T2 enters short-term memory (STM). Perhaps the most well expounded offline theory of the attentional blink is the *retrieval interference model* (Raymond, Shapiro & Arnell, 1995; Shapiro, Raymond & Arnell, 1994). In this model, T1 and its mask (T1+1) compete with T2 and the T2+1 item in Visual Short Term Memory (VSTM). The T1+1 item enters as a result of its temporal proximity to the target and takes time to be either discarded or processed. If the probe occurs too soon after the T1 and its mask, there will not be enough room in VSTM for it to reside and incur processing. This model assumes that the AB occurs after T2 has entered STM. The importance of the item immediately following T1 was highlighted in an experiment in which the T1+1 item was omitted and a blank interval inserted (Raymond at al., 1992). This manipulation effectively eliminated the AB, suggesting that perceptual confusion between a target and the stimulus presented immediately can dramatically influence temporal selection.

The question of whether the AB is an online or offline phenomenon is still open. Wong (2002) conducted a study in which participants made a speeded response to the presence of T2 and subsequently reported the identity (non-speeded) of T1 and T2 at the end of the trial. Both targets were Latin letters amongst Arabic digit filler items. An AB (i.e. the non-speeded response to T2) was observed despite the fact that participants had made a prior online speeded response to T2. Wong claims this finding is at odds with the retrieval interference model of the AB, which posits that retrieval of T2 from STM is the cause of the deficit (Raymond et al, 1995; Shapiro et al, 1994). Why this should be the case is unclear since speeded and non-speeded responses may require different levels of processing. In the case of the non-speeded responses, participants had to identify T2, whereas in the case of the speeded responses participants merely had to detect T2. This makes it problematic to compare the two measures.

On balance, there appears to be more evidence for online rather than offline accounts of the AB. Both Ward et al. (1996) and Jolicoeur (1998) have demonstrated that the response demands of T1 have a large role to play in responding to subsequent objects. Further evidence for the role of response competition in temporal selection can be gleamed from another paradigm known as the Psychological Refractory Period (PRP).

The Psychological Refractory Period (PRP) and the Attentional Blink (AB)

PRP experiments are similar to AB experiments in that the participant views an RSVP stream of letters, words or pictures in which are embedded two targets (T1 and T2). The main difference is that in PRP experiments, participants are required to make a speeded response to each target as soon as it occurs. As in the AB, T1 and T2 occur at varying positions and SOAs away from one another. The PRP effect is an increase in response times to T2 as SOA decreases.

PRP is thought to result from a central bottleneck that delays T2 processing if it occurs in close temporal proximity to T1 (Jolicoeur, 1999; Jolicoeur, Dell'Acqua & Crebolder, 2001; Ruthruff & Pashler, 2001). This bottleneck is thought to exist primarily at the response-selection stage such that a response for T2 cannot be selected until the response for T1 has been selected (Pashler, 1994). In support of this, increasing the number of response alternatives for T1 lengthens response times to T2 as SOA shortens (Van Selst & Jolicoeur, 1997).

Recently a number of researchers have tentatively suggested that PRP and the AB may share a common cause. Hybrid designs in which participants are required to make a speeded response to T1, T2, or T1 and T2 have revealed interference between targets but to slightly varying degrees (Jolicoeur, 1999, Jolicoeur et al, 2001; Ruthruff & Pashler, 2001; Wong, 2002). This has been taken as evidence of a central bottleneck that delays processing of T2 whether an online (PRP) or offline (AB) response is required. There are some problems with a central bottleneck theory. Ruthruff et al (2001) had participants make a non-speeded

response to a T2 that was preceded either by an auditory tone or a visual letter (i.e. T1). A central bottleneck theory predicts an equal amount of interference when T1 is a tone or letter. Contrary to this prediction, less interference was observed when T1 was a tone compared to if it was a letter. This suggests that perceptual interference may still play a role in the AB, if only an additive one.

Another major temporal selection paradigm is Repetition Blindness (RB). RB studies have demonstrated that stimuli presented in close temporal proximity may interfere with one another on different levels of representation.

Repetition Blindness (RB)

In a typical RB study, participants view an RSVP stream of visual stimuli (e.g. letters, pictures or words) and are subsequently required to report as many of the stimuli as they can. Repetition blindness refers to the decrement in reporting the identity of a stimulus if it has already been presented to the participant. An example would be an RSVP stream of words in which the word 'plant' is repeated. On subsequent recall, the participant will most likely omit the second occurrence of this word. Performance on repeated words is compared with performance for unrepeated items. As with the AB and PRP there is a relationship between accuracy of recall (of the repeated word) and the SOA between the two words. RB lasts approximately 300-400ms after which time recall of the second stimulus is unimpaired (Chun, 1997).

Kanwisher (1987) originally proposed that RB is caused by a failure to differentiate between instances of the same event. When the first instance of the stimulus occurs (lets call it T1), a token episodic memory is formed but if the temporal lag between this and the second instance of the stimulus (T2) is too short, the first token interferes with the formation of a second distinct token with the result that only the first stimulus is reported. Neill, Neely, Hutchison, Kahan & VerWys (2002) are in agreement with the token-individuation hypothesis but argue that participant expectations may determine whether the token originates from the first or second instance of the stimulus. They conducted a study in which two letters were presented sequentially to the left and right of fixation. They cued report of either letter allowing them to observe RB of both the first and second instance in repeated letter trials. They found that whether the to-be reported letter was cued by a spatial bar (appearing to either the left or right of fixation) or a phrase (i.e. 'second letter?') differentially effected whether report of the first or second instance of the stimulus was impaired.

Other researches have claimed that RB is a perceptual phenomenon (Johnston, Hochhaus & Ruthruff, 2002). In Experiment 1, Johnston et al. (2002) minimised memory demands by having participants only count whether there were one or two targets in a RSVP stream rather than identifying them. They observed strong RB in this case and argue against an episodic locus for the phenomenon. In Experiments 3 and 4, they had participants make an online speeded response to the first target, minimising memory demands. Again they found strong RB, which in their view, suggests an earlier locus for RB than memory interference. Luo and

Caramazza (1995; 1996) argue that RB occurs as a result of the refractory period of neurones (in long-term memory) associated with the first target. In other words, when neurones associated with the first target fire, there is a brief period during which they are insensitive to stimulation resulting from the presentation of an identical stimulus.

Repetition Blindness (RB) and the Attentional Blink (AB)

Work by Marvin Chun has demonstrated that though the AB and RB have several similarities there are also conditions in which they can be fully dissociated (Chun, 1995; 1997). Chun (1997) found that increasing target-distractor discriminability (distractors are filler items in the RSVP) reduced the magnitude of the AB but had no appreciable effect on the magnitude of RB. This suggests that RB is mediated by target-target discriminability whilst the AB is more influenced by target-distractor discriminability (Raymond et al., 1992). In the same paper, he changed the targets (T1 and T2) to enhance their episodic distinctiveness. T1 and T2 were different colours (red or green) and the filler items or distractors were black letters. This eliminated RB but not the AB. Chun concludes that the AB and RB are caused by different attention mechanisms.

Temporal Selection: Simple Inhibition?

So here we have three phenomena in which report of a second target is impaired if it occurs within about half a second of the first: the AB, PRP and RB. Despite the plethora of theoretical models that have been proposed to account for these phenomena we can draw several firm conclusions. Selection of a target in time has an effect on and is affected by other items presented in close temporal proximity. More specifically, a target that is selected effects the processing of subsequent items, such that participants are impaired in retrieving those representations. The reverse is also true when the SOA between the two items is short. For example, Chun and Potter (1995) found that when T2 occurred in the T1+1 position, report of T1 was impaired. The item immediately following a target has a large impact on its processing and the processing of subsequent items (Raymond et al., 1995). Online requirements such as perceptual confusion (Raymond et al., 1992) and response selection (Jolicoeur, 1998) impair and delay the retrieval of subsequent items.

Attempts to link the AB, PRP and RB have met with little success. This is to be expected when one considers that the root mechanisms of each phenomenon are still hotly debated. Without a general *a priori* hypothesis as to why these phenomena occur in humans it is likely that attempts to link them will continue to be unsuccessful. There is one commonality that may yield a clue to a possible unified model. The impairment in reporting T2 is a result of selecting T1. In the absence of T1, T2 is reported on nearly every trial. There are two ways of

interpreting this fact that are in essence identical but lead to very different approaches to further investigation. The first interpretation is as follows:

'Successfully selecting T1 causes the participant not to report T2'

The second interpretation is:

'Not reporting T2 causes T1 to be successfully selected'

Researchers studying the AB, PRP and RB have tended to opt for the first interpretation. This has led them to postulate models in which T2 is not fully processed because T1 is using up a limited capacity resource. This is not a bad interpretation *per se* as there must be some limited resource or bottleneck somewhere. If this were not the case, then participants would be able to report both T1 and T2 all of the time. The problem is that it leads to a quagmire of potential models. For example, where is this limited capacity resource/bottleneck; is it in attention, working memory, episodic memory, verbal short-term memory or maybe response selection?

On the other hand if one were to favour the second interpretation, then this lends itself to a very simple conclusion. T2 is inhibited in order to minimise the interference caused to T1. Not only is this explanation simple but it also provides the basis for a unified explanation of several temporal selection phenomena. Such a model might also explain how attention is 'focused' such that intrusion/temporal

binding errors are minimised (Botella, Barriopedro and Suero, 2001). In the spatial domain, inhibition has long been a mechanism implicated in reducing interference between targets and distractors. One very popular paradigm, in which inhibition has been theorised to play a major role, is *negative priming.*

Negative Priming (NP)

The basic NP paradigm consists of a prime and probe trial. In the prime trial, a target stimulus (e.g. letter, picture or word) is presented simultaneously with a distractor stimulus. Participants are required to make a speeded response to the target stimulus. This display then disappears and is replaced with the probe trial display, which also consists of a target and distractor stimulus. Again a speeded response to the target stimulus is required. In the critical ignored repetition condition, the distractor in the prime display is repeated as the target in the subsequent probe display (see Figure 7). Participants are slower to respond in this condition compared with a condition in which the probe target is a novel unrepeated stimulus.

Tipper (1985) originally proposed the selective inhibition account, which holds that the internal representation of the distractor stimulus in the prime display is inhibited such that residual inhibition is still present when the representation is retrieved in the probe display. This causes slowing in the participant's response. Houghton and Tipper (1994) suggest that negative priming is the result of selecting against a distractor, in order to attend a target. A target template containing

stimulus features is compared against perceptual input. Inputs/stimuli that match this template receive excitatory feedback and those that do not (i.e. the distractor stimulus) receive inhibitory feedback.

Target

| O | X | O | Prime Display |

| H | O | H | Probe Display |

Distractor   Distractor
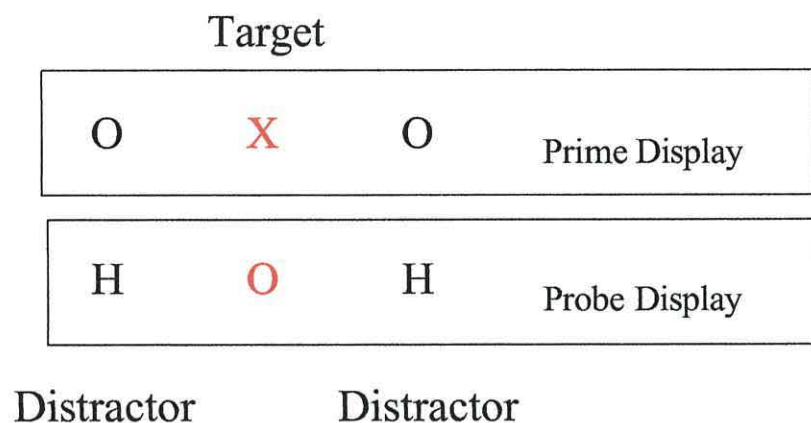
Figure 7. In the *ignored repetition condition,* the distractor on the prime trial is repeated on the probe trial.

There are those who disagree with an inhibitory interpretation of negative priming. One alternate account is the episodic retrieval model (Neill, 1997). This theory contends that when a target is present with a distractor, the latter is processed with a "do not respond" tag. When the distractor subsequently becomes the target, the "do not respond" tag interferes with processing, manifested in a slowing of reaction times. Fox and de Fockert (1998) conducted a study in which they manipulated the intensity contrast between letter displays and the background in both the prime and probe trial. They found greatest NP when the intensity contrasts were identical in prime and probe trials and interpreted this as evidence to support an episodic retrieval account of negative priming. In other words, the greater the similarity between prime and probe trials, the greater the ease with which the "do not respond" tag can be retrieved.

Several researchers have found that negative priming does not occur in the absence of a distractor on the probe trial (Lowe, 1979; Milliken & Joordens, 1996). Lowe (1979) found negative priming occurred on probe trials when there was a conflict (i.e. a distracting letter) but not on trials when there was no conflict (e.g. a colour-patch). This finding is problematic for an inhibitory account of negative priming. Tipper and Cranston (1985) suggest that the subject relinquishes the template used for selective targeting if he or she anticipates no interference on the probe trial or if a non-conflict probe is very different from a conflict probe. More recently, Houghton and Tipper (1994) have argued that in the critical ignored repetition condition, the probe target has been inhibited to the extent that its activation is below that of the probe distractors, thus creating costs (increased response times). These costs reflect the time taken to raise the activation of the probe target above that of the probe distractors in order to respond. When there are no probe distractors present, there are no concomitant costs and hence negative priming will not be observed. Others have taken Lowe's finding as evidence of an episodic retrieval model of negative priming (Neill, 1997).

An alternative theory holds that negative priming is due to poor temporal discrimination between the ignored distractor and the subsequent identical target (Milliken, Joordens, Merikle & Seiffert, 1998). Milliken et al. (1998) suggest that when a target is presented, we categorise it as new or old. New items require further perceptual processing whilst old items can be retrieved direct from memory. The difficulty arises when attempting to categorise a previously ignored distractor that might be labelled old or new. This ambiguity delays processing of the target

and results in negative priming. In Experiment 1a they required participants to ignore a single white prime word presented for 200ms. This was followed 500ms later by a red target word that was interleaved with a green distractor word. When the prime word corresponded with the subsequent target word, negative priming was observed. Milliken et al. (1998) argues against a selective inhibition account (Houghton and Tipper, 1994) on the basis that there is no selection requirement when the prime word is presented. Tipper (2001) argues that since the white word did not match the target template (i.e. a red word); it is no surprise that inhibitory feedback was triggered and negative priming observed.

Yet another explanatory model of negative priming was originally proposed by Park and Kanwisher (1994). They argue that negative priming is due to a perceptual or feature mismatch between items in the prime and probe display. For example, in the critical ignored repetition condition, the distractor stimulus is presented and they would argue 'bound' to a particular location in the prime trial. In the subsequent probe trial, the same distractor now occurs in a different location. Park and Kanwisher argue that this mismatch is what causes slowing of the participant's response. Recently Fuentes, Humphreys, Agis, Carmona & Catena (1998) have argued against a feature mismatch theory. They were investigating how perceptually grouping items on the prime display affected priming on the probe display. They used a physical-matching task in which participants had to respond as to whether or not the red target letters in the prime and probe display were the same or different. Green distractor letters flanked the target letters. In Experiment 3, a box surrounded the distractors and the target (see Figure 8).

B A B   Prime

C B C   Probe
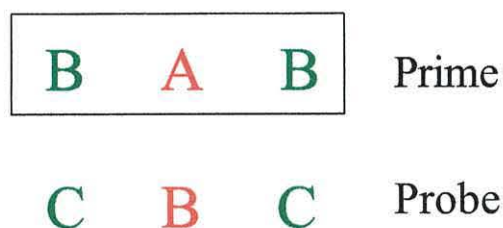
Figure 8. Showing perceptual grouping in the critical ignored repetition condition of Fuentes, Humphreys, Agis, Carmona & Catena (1998).

They observed a reversal of the negative priming effect (i.e. positive priming). They argued that this effect was due to perceptual grouping of the distractor with the target such that both received facilitatory processing. In their paradigm, there was a perceptual mismatch (i.e. colour and location) between the distractor on the prime display and the target in the probe display. Under these conditions, a feature mismatch account would predict negative priming. In contrast to this, positive priming was observed.

Other evidence against a feature mismatch account of negative priming comes from a study conducted by Baylis, Tipper and Houghton (1997). In this experiment, participants chose which of the stimuli on the prime display to respond to. Baylis et al. predicted that since the participant did not have an established target template at the point of selection, there would be nothing to compare the distractor against and hence, no negative priming should be observed. This was indeed the case. Since there was a mismatch between the distractor and target in the ignored repetition condition, a feature mismatch account would have predicted that negative priming should still be observed. This result also contradicts an episodic retrieval account of negative priming since in the case where the

participant chooses which stimulus to respond to, distractors not chosen should still be given a 'do not respond' tag and hence, negative priming should still be observed.

Regarding the episodic vs. inhibitory accounts of negative priming, Tipper (2001) comments "Negative priming appears to be currently undergoing…dichotomization, but perhaps integration is more fruitful. Thus negative priming cannot be adequately modelled by an approach that deals only with inhibitory processes at encoding, neither by an approach that deals only with the retrieval of episodic information…" (p.11). Tipper cogently argues that inhibition and retrieval accounts are not mutually exclusive but just emphasise different processes. Inhibitory accounts emphasise encoding of stimulus representations during the prime display. In contrast, episodic accounts emphasise the necessary retrieval of those coding states. However, Tipper does criticise the mechanism of encoding that proponents of episodic retrieval argue for: "…a major problem for models that apply tags, is that they are infinitely flexible and can therefore explain all data in a post hoc fashion by producing a new tag, or label, to suit" (p.9).

On the face of things it seems that of all the explanations posited to account for negative priming, the selective inhibition hypothesis can account for the majority of the data. It is for this reason that an inhibitory account will be favoured throughout this thesis, although the relevance of other models will be discussed when appropriate. In the next couple of sections, the neurophysiological evidence for inhibitory processes will be examined.

Evidence from Special Populations

Whilst cognitive psychologists have been reluctant to include inhibition in their attentional models, neurophysiologists have long appreciated the role of inhibition in the brain. Indeed, the role of inhibition has only really been studied extensively in a couple of cognitive paradigms: negative priming and *inhibition of return* (IOR). In the latter paradigm, participants are typically cued to a location on a computer screen by means of a briefly presented stimulus, which then disappears. A target is then presented somewhere on the screen that requires a speeded response (e.g. detection). Critically, the location of the cue is non-predictive of the location of the target. However, on a percentage of trials the target appears in the same position that the cue previously occupied. In this condition and depending on the SOA between presentation of the cue and target the speed of participants' responses to the latter are differentially affected. Typically when the target appears within about 300ms of the cue, participants are faster to respond to a target which appears in the same position. At longer ISIs participants are slower to respond. It has been suggested that attention is inhibited from returning to a location that has previously been searched and not yielded behaviourally relevant information (Posner & Cohen, 1984). This is the case when a non-predictive cue is presented. For example, when searching our environment for food or potential danger, it would be inefficient to return our attention to locations that we have already searched. Tipper, Driver and Weaver (1991) demonstrated that participants also

inhibit returning to an object (rather than a location) that is not behaviourally relevant.

Several researchers have demonstrated that schizophrenic patients show reduced IOR. The underlying physical pathology of schizophrenia remains a contentious point however there is no debate that schizophrenia results from a biological disorder of the brain. Fuentes, Boucart, Vivas, Alverez and Zimmerman (2000) demonstrated that schizophrenic patients showed normal Stroop interference even when stimuli were presented at inhibited locations. In the standard Stroop paradigm, participants are slower to report the colour of the incongruent word. This is because the participant cannot help but read the colour-word, which interferes with naming the colour. Fuentes et al. (2000) used this paradigm in conjunction with a standard IOR paradigm. A peripheral cue drew attention to an irrelevant location. A central cue then appeared in order to draw attention back to fixation. A target colour word was presented 500ms later in either the cued or uncued position. On some trials the colour of the target word was incongruent with the identity of the word i.e. the word RED printed in green. If inhibition were applied to the location of the cued target then there should have been a reduction in the amount of interference caused by the Stroop effect (i.e. when the colour and identity of the word were incongruent). When the target colour word appeared in the cued location, healthy adults showed a reduction in Stroop interference (i.e. faster response times). Schizophrenic patients, on the other hand, showed no reduction in Stroop interference. In other words, the time they took to name an incongruent colour word was irrelevant of whether the target word appeared in a

cued or uncued location. This demonstrates that schizophrenic patients did not inhibit the cued location, as is the case in a standard IOR paradigm with healthy participants.

People with some form of lesion or degeneration of the brain typically show reduced negative priming. That is, in the critical ignored repetition condition, their response latencies to the probe target are shorter than normal adults. This indicates that they have trouble inhibiting the prime distractor. Reduced negative priming has been found in frontal lobe patients (Metzler & Parkin, 2000), older adults (Verhaeghen & Meersman, 1998), schizophrenic patients (MacQueen, Galway, Goldberg & Tipper, 2003) and patients with Parkinson's disease (Filoteo, Rilling and Strayer, 2002)

In the Stroop negative priming task, participants are presented with a colour word and are required to report the colour of the word with an incongruent identity (e.g., the word BLUE written in red). Participants are slower to respond when the colour to be reported corresponds to the incongruent word on the previous trial. Salo, Robertson and Nordahl (1996) demonstrated that Stroop negative priming was reduced in schizophrenic patients.

Reduced inhibitory control has been hypothesised to account for the behaviour of people suffering from attention-deficit/hyperactivity disorder (ADHD). Marriott (2000) demonstrated that hyper-active boys showed reduced negative priming in both a spatial localisation and letter identification task.

Interestingly, the same kinds of patient groups who show reduced negative priming also show impaired performance in temporal dual-task paradigms such as

the attentional blink. Indeed, a more severe or prolonged AB has been demonstrated in older adults (Lahar, Issak and McArthur, 2001), ADHD patients (Hollingsworth, McAuliffe and Knowlton, 2001) and frontal lobe patients (Richer and Lepage, 1996).

If the inability to report T2 is the result of inhibitory feedback, then one would predict that those patient groups who show a larger AB should also show a larger negative priming effect (i.e. greater inhibition). According to studies outlined above, the inverse is true. Patient groups who produce a larger blink exhibit reduced negative priming. On the face of things, these findings would seem to provide evidence against an inhibitory account of the AB. This issue is addressed again in Chapter 5 in which an inhibitory hypothesis of the AB will be rendered that can account for the contradictory evidence from patient groups.

Inhibition in the Temporal Domain

Negative priming (NP) studies have typically presented a target and distractor simultaneously. However, there have been a couple of studies in which the target and distractor were presented sequentially. Moore (1996) varied the onset of a distractor that appeared with a target. The target appeared for a fixed duration (300ms). In the early onset condition, the distractor was presented for the first 150ms of the target's duration. In the late onset condition, the distractor was presented for the second 150ms. NP was observed in the early onset condition but not the late onset condition. The lack of NP in this case would seem to go against

the basic assumption of an inhibitory account of temporal selection. However, Moore (1996) acknowledges that the failure to obtain NP in this case may have been due to the ease with which participants could identify the target, given that it had been on screen 150ms before the distractor was presented. By decreasing the exposure time of the target and distractor it is likely that NP would have been observed (see Experiment 1).

Neill (1997) conducted another experiment in which the distractor appeared after the onset of the target. The flanker letter (i.e. distractor) was displayed either simultaneously to the target (early onset) or 400ms after the onset of the target (late onset). Neill found negative priming only when the prime and probe trials shared the same distractor onset conditions. This was taken as evidence to support an episodic retrieval model of negative priming. Neill believes that the onset manipulation establishes a context that enables retrieval of the distractor, albeit with a "do not respond" tag. There are several differences between the Neill (1997) and Moore (1996) papers on which the former comments. Neill suggests that the greater distractor onset of 400msec, compared with 150msec, serves to "enhance the differential encoding of context in the early-onset and late-onset conditions (Neill, 1997, p. 1296)". Another difference noted between the two experiments was that Neill used flanker letters as distractors while Moore had overlapping target and distractor letters. Neill believes that the latter method decreased discriminability between the target and distractor and so prevented a context being established for retrieval. As already noted, these kinds of retrieval effects are not inconsistent with an inhibitory account of negative priming if what is being

retrieved is the activation state of the distractor (Tipper, 2001) and as such, these results offer encouraging evidence for the assertion that post-target distractors may be inhibited.

Inhibition and the Attentional Blink

The research conducted on negative priming and delayed onset distractors is somewhat inconclusive. However, there remains the intriguing possibility that stimuli in close temporal proximity to a target object are inhibited. In other words, just as distractors that occupy a different spatial location to the target receive inhibition in the negative priming paradigm, so inhibition could be applied to distractors that occupy a different temporal location to the target. In the case of the AB, participants may be impaired in responding to T2 because it has been inhibited in order to successfully attend and select T1. In other words, the AB may not result from a lack of attention but as a consequence of temporal selection. Interestingly, there *have* been previous attempts to explain the AB in terms of inhibition.

In their first AB paper, Raymond et al. (1992) posited that the cause of the AB was inhibition of post-target stimuli such that the second target (T2) is not processed at all. However, it is important to note that the use of the word 'inhibition' as used by Raymond and colleagues is somewhat different to the way it would be used in studies of negative priming, in which distractor stimuli are first processed and only afterwards are their representations inhibited. On the contrary,

the hypothesis of this dissertation is that post-target stimuli *are* processed but their representations are subsequently inhibited.

Against an inhibitory account of temporal selection, some have cited papers demonstrating that stimuli occurring after a target can prime subsequent probes (Joula, Duvuru & Peterson, 2000; Maki, Frigen & Paulson, 1997; Martens, Wolters & Raamsdonk, 2002; Shapiro, Ward and Sorenson, 1997). In Experiment 2 of their study Shapiro et al. (1997) had participants attend an RSVP stream of words with three targets, T1, T2 and T3. T2 was positioned within the normal duration of the blink and T3 outside of the blink. Participants had to correctly identify all three targets at the end of the trial (non-speeded response). On some trials, T2 and T3 were semantically related (e.g. doctor-nurse). They showed that even when T2 could not be reported; it nevertheless semantically primed T3 such that T3 accuracy was improved if it was related to T2. They interpret their results in terms of types (abstract categories) and tokens (specific examples of these categories). They maintain that the AB is a failure to extract tokens but not types. The finding that items presented after a target positively prime a subsequent probe (Maki et al., 1997; Joula et al., 2000, Martens et al., 2002) is a problem for an inhibitory account of temporal selection. However, when considering these findings one must bear in mind research which has shown that objects in our environment have multiple cognitive representations and that inhibition and facilitation can differentially affect these representations.

Evidence from the semantic priming literature has shown that depending on task demands, distractor stimuli can receive excitatory or inhibitory processing.

Marí-Beffa, Fuentes, Catena and Houghton (2000) conducted a study with trials consisting of a prime and probe display, much like in studies of negative priming. In both the prime and probe displays a central target was presented simultaneously with two distractors (presented above and below the target). Participants were split into two groups depending on the task they were required to perform during the prime display. One group was required to make a lexical decision in which they made a speeded response to the target by determining whether it was a word or pseudoword. In the other group participants undertook a letter search task in which they determined as quickly as possible if the letter that appeared at fixation on the previous trial was now the target or not. In the probe display, both groups of participants made a lexical decision task identical to that made by participants in the lexical decision group for the prime display.

In one condition the distractor in the prime display was semantically related to the target in the probe display. Their results indicated that the polarity of semantic processing depended on the prime display task. When participants performed the letter search task, the target in the probe display received positive semantic priming (i.e. decreased response times). In contrast, when participants performed a lexical decision task during the prime display, the target in the probe display received negative semantic priming (i.e. elevated response times).

The results from Marí-Beffa et al. demonstrate that depending on the target task, distractor stimuli are processed differently which in turn has implications for an inhibitory account of temporal selection. In the Shapiro et al. (1997) paper both the target and distractor (i.e. T2) tasks involved identification of a token and so it is

at this stage of information processing that the distractor would potentially interfere with the target. Hence, T2's token would have to be inhibited to secure successful T1 identification. Therefore, if T3 possessed the same token as T2 (i.e. it was the same word) perhaps negative rather than positive priming would be observed. However, since the target and distractor task did not require extraction of types (abstract categories), there is no reason why semantic processing of the distractor (T2) should be inhibited. This could explain why T3 received positive priming in their experiment.

Experiments in this Thesis

In this chapter, several dual-task paradigms have been examined which utilise RSVP procedures (i.e. the AB, PRP and RB). Explanations of these phenomena all revolve around the idea of some deficit or lack of attentional resources. In contrast, explanations of dual-task paradigms in the spatial domain emphasise that target stimuli are selected against distractor stimuli. In negative priming, distractors are inhibited in order that the target is selected. A case could be made that the same kind of selection mechanisms may exist in the temporal domain. For example, post-target response deficits such as the AB may reflect inhibition of T2 in order to select T1.

Temporal binding is thought to be achieved via the focusing of attention on a target, but, as previously stated; models of binding do not provide a mechanism for this focusing (Botella et al., 2001). One possibility is that focusing is achieved

via the inhibition of pre- and post-target stimuli. Consider for a moment the concept of a temporal snapshot. This snapshot will include the target and stimuli in close temporal proximity. Because of this fact, features from targets will simultaneously be present with features from non-targets. However, once the target key feature is detected, features belonging to non-targets may be inhibited.

In order to posit a role for inhibition in temporal selection the following basic assumption must be proved:

'Distractors in close temporal proximity to a target are inhibited'

Chapter 2 includes two experiments that address this issue using a negative priming paradigm in which distractors are presented after a target requiring identification. To pre-empt the findings of that chapter, it was shown that distractors received inhibitory feedback as a consequence of selecting the target. Chapter 3 examines how the similarity between the target and distractor affects the degree of inhibition that the latter receives. Also examined in this chapter are issues concerning the activation of response templates and the effect on inhibitory feedback. Chapter 4 includes four experiments that attempt to pin down the locus of this temporal inhibitory effect by dissociating object- and response-based components. Chapter 5 addresses directly the utility of an inhibitory model in explaining the attentional blink. Chapter 6 examines all experiments with regard to the gender of the participant. Chapter 7 is the general discussion in which the evidence for an

inhibitory account of temporal selection will be reviewed and evaluated. Chapter 8 includes ideas for further investigation.

CHAPTER 2 – POST-TARGET INHIBITION

A Post-Target Inhibition Paradigm

The experiments described in this chapter have much in common with the AB paradigm[1]. A target red letter is briefly presented in an RSVP stream of black letters. The distractor is one of the black letters that follow the target in the stream and is presented at varying SOAs from the target. This distractor would occupy the place of T2 in a standard AB procedure. At the end of the trial, participants are required to make a speeded response to the identity of the last black letter in the RSVP stream. This last item in the stream is referred to as the probe. On any given trial, the probe is either the same or different to the distractor letter.

It should be noted that the term 'inhibition' will be employed in this chapter to describe whatever happens to the distractor which leads to a detriment in responding to the probe. This could be episodic or inhibitory processing. The aim of these experiments is to find evidence for a mechanism of temporal selection that is required to deal with items that appear in close temporal proximity to the target. This mechanism does not involve any processing deficit, but a different kind of processing that will prevent it from interfering with the target for a particular action. Thus, for the time being any model explaining negative priming effects could be used for this purpose.

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[1] This chapter is based upon Loach, D. & Mari-Beffa, P. (2003). Post-target inhibition: A temporal binding mechanism? *Visual Cognition, 10(5),* 523-526.

If post-target stimuli are inhibited, then reaction times to a probe that is the same as the distractor letter should be slow compared to reaction times to a probe which is different from the distractor letter. The procedure outlined above could be considered closer to the negative priming paradigm than to the AB paradigm. In the latter paradigm, participants are required to respond to the stimulus that interferes with T1 i.e. T2. In the present paradigm, as in the negative priming paradigm, participants ignore the distractor. For this reason it seems appropriate to adopt predictions based upon studies of negative priming. The most obvious prediction from a negative priming point of view is that as interference between the target and distractor is increased, so should the concomitant negative priming. Thus it was predicted that negative priming should be greatest when the distractor letter is close to the target, as a distractor presented at early SOAs has the greatest potential to interfere with target selection. The duration of negative priming from the target was predicted to mirror that of the AB i.e. approximately 500ms. After this time participants no longer show a decrement in reporting T2 (Shapiro, 2001). Thus, at SOAs greater than 500ms, no inhibition was predicted.

EXPERIMENT 1 – Post-Target Inhibition

Method

<u>Participants</u>

Twenty-five undergraduate students from the University of Wales, Bangor participated in this experiment in order to obtain course credits (19 females, 6 males). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

<u>Stimuli and Apparatus</u>

The experiment was run on a Pentium II PC. The software for designing and running the experiment was E-Prime Release Candidate 2. During the experiment, a 40-W lamp facing the rear white wall behind the computer provided dim illumination. The RSVP stream consisted of black letters with one red target letter (Size 60; Arial font) subtending approximately 1.9 x 2.1 of visual angle. The target, distractor letter and probe were drawn from the letters X, H, S and O. The non-target or filler letters in the RSVP were generated randomly from letters of the alphabet excluding the target letters.

Design and Procedure

The independent variables were Repetition and SOA. There were two levels of Repetition corresponding to trial type (Repeated and Unrepeated). In a Repeated trial, the distractor letter and probe letter were identical (e.g. H and H). In an Unrepeated trial, the distractor letter and probe letter were different (e.g. X and H). There were five levels of SOA corresponding to the five SOAs between the target and distractor letter (90ms, 270ms, 450ms, 630ms, and 810ms). The levels of both independent variables were varied randomly from trial to trial.

The experiment consisted of 360 trials (36 trials per condition) with 30 practice trials. The RSVP stream consisted of random black letters from the alphabet (excluding the target letters) presented at fixation in the centre of a computer screen. Each letter was presented for 25ms and there was an Inter Stimulus Interval (ISI) of 65 ms. The red target letter could appear in position 4, 5 or 6 in the stream. The distractor letter could appear in position 1, 3, 5, 7 or 9 after the target (i.e. SOA 90ms, 270ms, 450ms, 630ms, and 810ms). The probe letter was always the last black letter in the stream and stayed on the screen until the participant made a response (see Figure 9).

The number of items in the RSVP stream depended on the position of the distractor letter in the stream. There were always 10 items after presentation of the distractor letter so the stream length varied from 15 to 25 items. The red target letter was never the same as the distractor letter or probe.

Participants were first required to make a speeded response to the identity of the probe letter at the very end of the stream, by pressing a key on a computer keyboard. The four response keys were 'z', 'c', 'b' & 'm' on the standard QWERTY keyboard, re-labelled to the corresponding target letters X, H, S and O. Next, participants responded to the identity of the red target letter by pressing another key on the keyboard. Only accuracy was measured here. At the end of a trial, participants were prompted to press the spacebar to continue to the next trial.
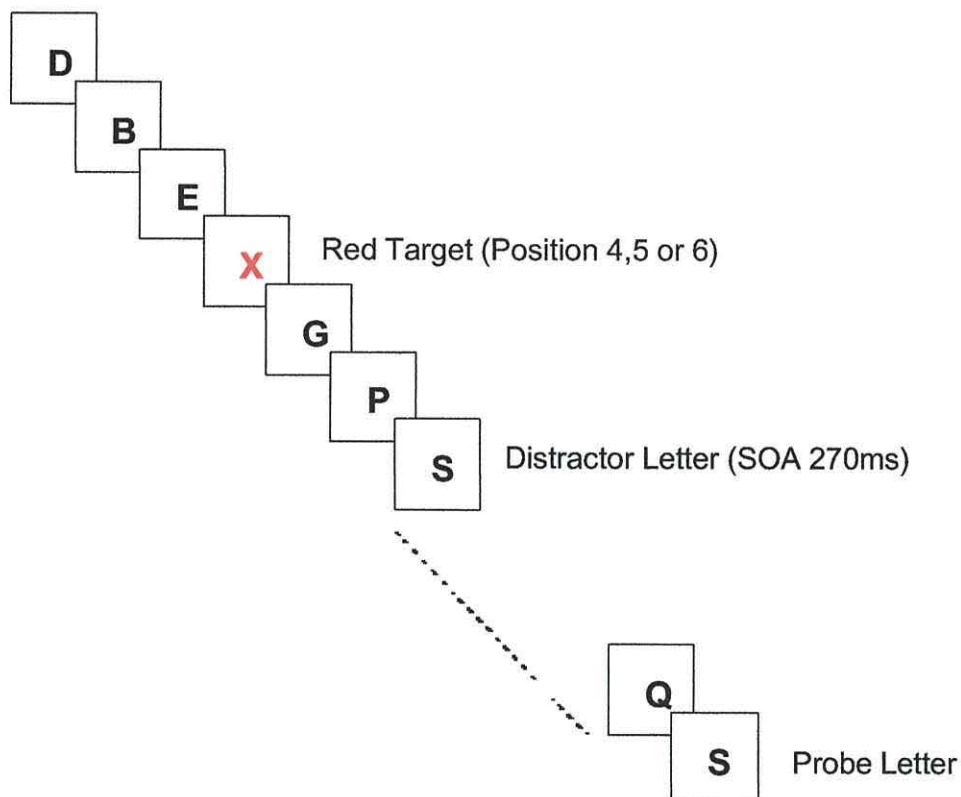
Figure 9. A Repeated trial where the distractor letter and the probe letter are the same.

Results and Discussion

Individual participant data were summarised using median response time to the probe letter. Trials were only included for analysis if the participant correctly identified the red target letter and the probe letter. This resulted in an average of 79% of the data for each participant being analysed. Data from each of the three target positions (4, 5 & 6) were collapsed for analysis. Inhibition was deemed present if participants showed the negative priming effect, that is, if they were slower to respond to the probe when it was the same letter as the distractor letter (Repeated condition); compared to if the letters were different (Unrepeated condition).
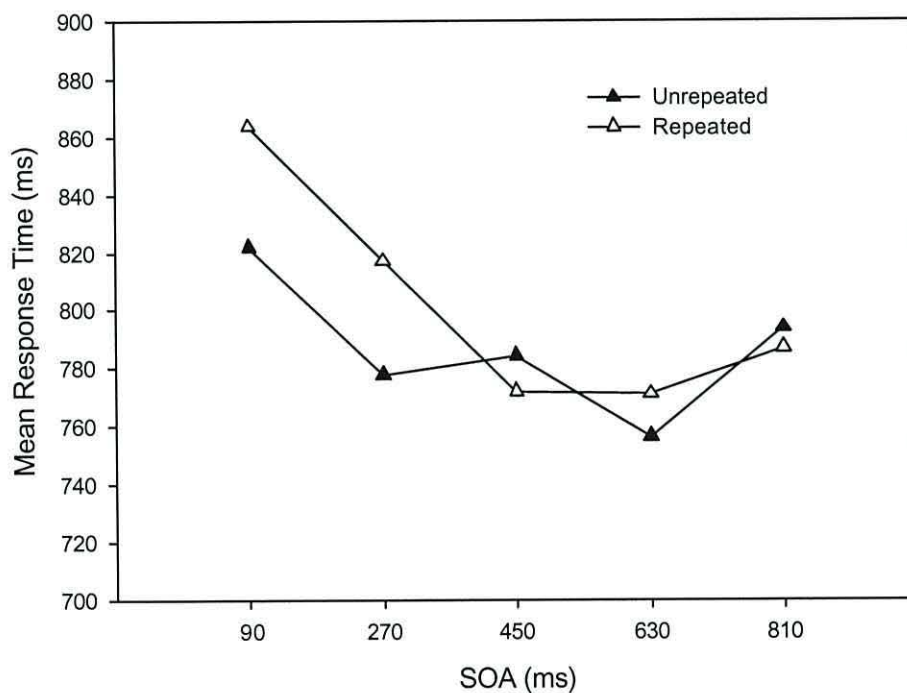
Figure 10. Experiment 1 – Mean response times to the probe letter in Repeated and Unrepeated conditions at each SOA.

A Repeated-Measures ANOVA was carried out on both independent variables. There was a main effect of Repetition, $F(1, 24) = 7.13$, $p = .01$, in which response times to repeated items were slower than to unrepeated items. Also, there was a main effect of SOA, $F(1, 24) = 12.74$, $p < .01$, due to an increase in response times when the distractor appeared in close temporal proximity with the target. There was no significant interaction between Repetition and SOA, $F(1, 24) = 1.67$, $p = .18$. This lack of a significant interaction was expected given the high number of levels that were included in the design in order to explore all the range of SOAs at which negative priming might have been occurred. Accordingly the different ranges of SOAs were collapsed into two categories, short (including 90 and 270 ms) and long SOA (450, 630, 810 ms), and the data were analysed through a new 2 (Repetition: repeated, unrepeated)) x 2 (SOA: short, long) repeated-measures ANOVA. As in the previous analyses, there were significant main effects of Repetition and SOA [$F(1,24) = 9.16$; $p = .01$; and $F(1,24) = 22.08$; $p < .001$, respectively]. Now the interaction between Repetition and SOA was significant, $F(1, 24) = 4.46$, $p = .045$.

Greatest negative priming effects were observed at early SOAs (i.e. SOA 90ms, SOA 270ms) and after approximately 500ms, no inhibition was observed, a pattern that mirrors the AB quite closely. To confirm that the inhibition at these early SOAs was significant, paired samples t-tests (2-tailed) were carried out between Repeated and Unrepeated conditions at SOAs of 90ms and 270ms. The difference between the means at 90ms was significant, $t(24) = -2.08$, $p = < .05$, as

was the difference at 270ms, $t(24) = -2.49, p = < .05$. No priming effects were significant at further SOAs.

Table 1. Red Target Letter Errors

Repetition	SOA				
	90ms	270 ms	450 ms	630 ms	810 ms
Unrepeated	9.80	5.52	5.12	6.58	5.72
Repeated	9.92	5.79	6.57	5.90	4.92

Note. Percentage of target errors at each SOA and in each Repetition

As predicted, the pattern of results closely resembles that of several temporal selection phenomena including the AB and PRP. Table 1 shows the percentage of target errors participants made at each SOA and in Repeated and Unrepeated conditions. When the distractor letter appeared at SOA 90ms (i.e. T+1), report of the target was particularly impaired relative to other SOAs. This pattern of errors is consistent with the finding by Chun and Potter (1995) who demonstrated that when T2 appeared in the position immediately after T1, report of T1 was impaired.

Temporal binding errors were investigated in order to support the idea that the negative priming effect is linked to a mechanism that prevents the system from committing these identification errors. Figure 11 shows the pattern of temporal binding errors that participants made at each SOA. It is clear that at SOA 90ms,

participants are most at risk from binding errors. However, binding errors were less frequent at 270ms despite substantial inhibition at this SOA. It appears that the pattern of binding errors does not correspond perfectly with the pattern of inhibition observed in this experiment. So it is unlikely that there is an exact linear relationship between the amount of inhibition a distractor letter receives and the likelihood that it will be substituted for the target. As noted in the introduction, the item immediately after the target is crucial for producing post-target response deficits. For example, Raymond et al. (1992) found that omitting the T1+1 item effectively eliminated the attentional blink. It is possible that post-target inhibition is initiated by interference between the target and the item immediately following and that this inhibition also affects subsequent items.
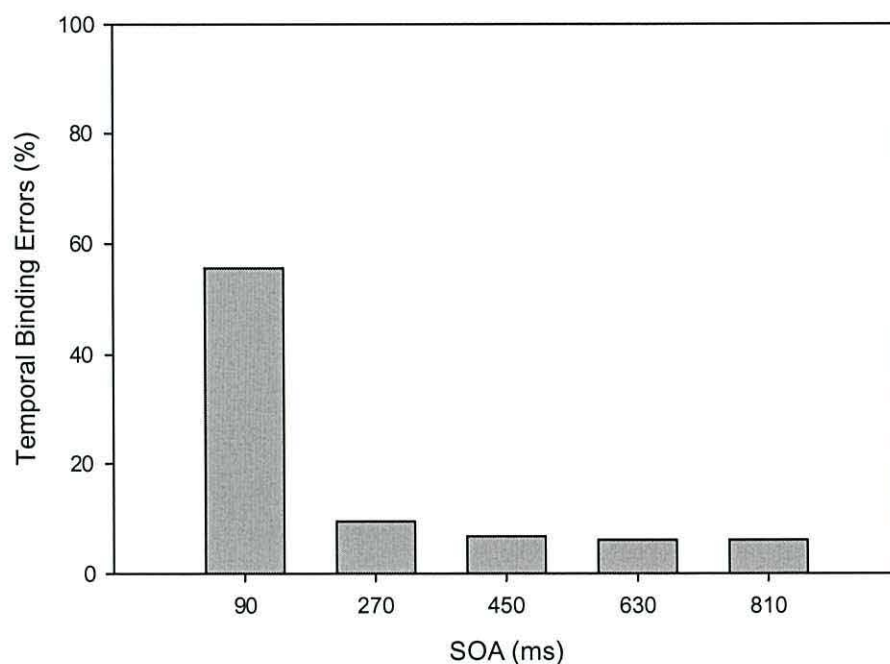
Figure 11. Experiment 1 – Percentage errors when the participant incorrectly identified the target and instead reported the distractor letter.

Houghton and Tipper (1994) have argued that inhibition is a selection strategy. In order to select a stimulus that matches the target template, distractor stimuli that do not match the template are inhibited. Duncan and Humphreys (1989) also allude to some mechanism by which distractor stimuli are disregarded in order for selection to occur. It will be argued throughout this thesis that post-target inhibition is a selection mechanism. If true, then one would expect this inhibition to be absent or dissipate sooner, if a response to the target were not required. This manipulation was carried out in Experiment 2.

EXPERIMENT 2 – No Target Selection

In Experiment 2, participants were no longer required to respond to the red target letter but just to respond to the probe letter. However, they were instructed to attend to the RSVP stream from beginning to end. It was predicted that no inhibition would be present because there was no requirement to select the target.

Participants

Twenty-five undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits (22 females, 3 males). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

Design and Procedure

The experiment consisted of 360 trials with 30 practice trials. The design and procedure was identical to that of Experiment 1, except that participants were not required to respond to the red target letter nor were they told of its inclusion in the RSVP.

Results and Discussion

As in Experiment 1, individual participant data were summarised using median response time to the probe letter. Trials were only included for analysis if the participant correctly identified the probe letter. In this experiment, an average of 95% of the data for each participant was analysed. As in Experiment 1, it was judged that in order to confirm whether negative priming was observed at different SOAs it was necessary to collapse the different ranges of SOAs into two categories, short (including 90 and 270 ms) and long SOA (450, 630, 810 ms) As in Experiment 1, the data were analysed through a new 2 (Repetition: repeated, unrepeated)) x 2 (SOA: short, long) repeated-measures ANOVA. There were no significant main effects of Repetition and SOA [$F(1,24) = .39$; $p = .53$; and $F(1,24) = 3.19$; $p = .09$, respectively]. Also, the interaction between Repetition and SOA was not significant, $F(1, 24) = 2.26$, $p = .14$.
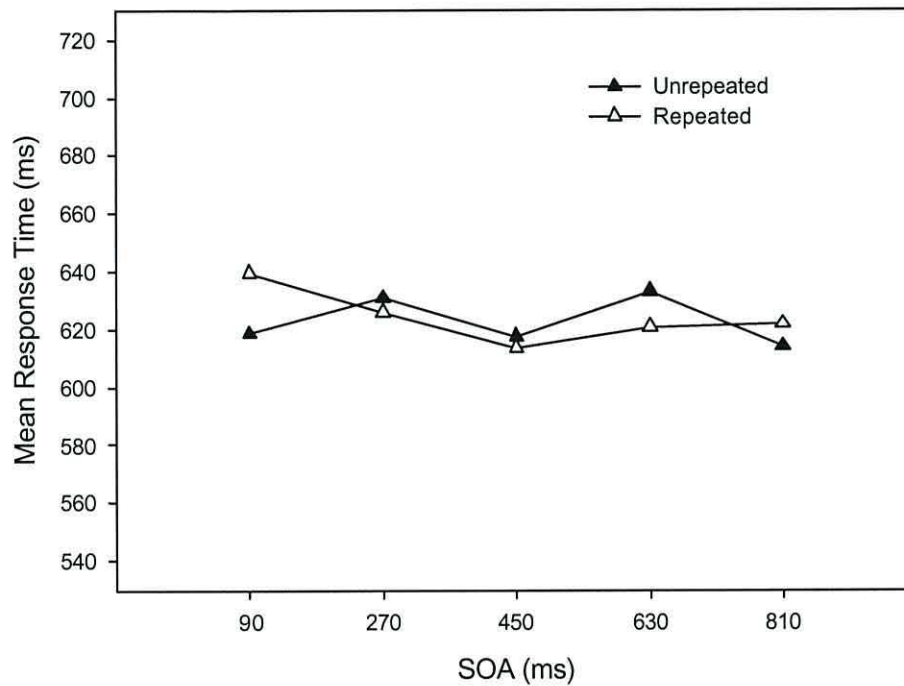
Figure 12. Experiment 2 – Mean response times to the probe letter in Repeated and Unrepeated conditions at each SOA.

On the whole, response times to the probe in Experiment 2 were faster than in Experiment 1. This is not surprising when noting that in Experiment 1 participants had to hold the target letter in working memory, which doubtless interfered with their response to the probe. In contrast, participants in Experiment 2 were told nothing of the target letter and were certainly not required to hold it in working memory.

It appears that the act of selecting the red target letter in Experiment 1 is responsible for the inhibition of post-target stimuli. As noted in the introduction, there is an ongoing debate as to whether or not selection demands are necessary to

observe negative priming (Milliken, Joordens, Merikle & Seiffert, 1998; Neill & Westberry, 1987). The variety of procedures used across experiments makes a comparison with the present paradigm problematic. However the results of Experiment 2 support the view that selection demands affect the magnitude of post-target inhibition.

Contrasts between Experiments 1 and 2

As Experiments 1 and 2 had nearly identical designs (with the only difference being that in Experiment 2, participants were not required to respond to the target letter) it was possible to include the data from both experiments in a new mixed factorial design. Now there were three independent variables: Repetition, SOA and Experiment (Experiment 1 and Experiment 2). A mixed design ANOVA revealed that negative priming changed depending on the experiment, $F(1, 48) = 4.83, p = .03$. Essentially, negative priming was greater in Experiment 1 as compared to Experiment 2. Also, negative priming changed depending on the SOA, $F(1, 48) = 6.26, p < .01$.   Response times in Experiment 1 were greater than in Experiment 2, $F(1, 49) = 15.39, p < .01$. This was probably because in the first experiment participants had to hold two items (the target and the probe) in working memory compared with only one (the probe) in the second experiment.

CHAPTER DISCUSSION

Houghton and Tipper's inhibition model (1994) holds that negative priming results from selecting the target against the distractor. It makes sense that a target and distractor that occur closer in time to one another will interfere more with one another and consequently, the latter will receive more inhibition. In this model, inhibition results from a mismatch between a distractor stimulus and a target template. In order for this model to account for the findings observed in Experiment 1, it must be assumed that the target template is not relinquished after target offset and is applied to post-target stimuli. The benefit of not relinquishing the template is that the participant avoids committing temporal binding errors. There are many features that distinguish a distractor from a target in NP experiments; the distractor may occupy a different spatial location to the target or it may be a different size or colour. Most critically, the distractor may also occupy a different temporal location to the target (e.g. Experiment 1, the AB and PRP). It seems unlikely that the post-target inhibition observed in Experiment 1 does not interact on some level with phenomena such as the attentional blink and the psychological refractory period.

Another interesting finding was that negative priming was achieved without any conflict in the probe display. This is contrary to much research suggesting that negative priming is contingent upon selection during presentation of the probe (Milliken & Joordens, 1996; Neill, Kahan & VerWys, 1996). The conflict or selection requirement around the target display may result from the temporal proximity of post-target items. This was seemingly absent during the probe display

as it was the last item in the RSVP stream. However, conflict could have arisen from items prior to the probe (i.e. P-1 & P-2). If this were the case, then one would predict that items appearing prior to a target might also receive inhibition in order to aid target selection.

Experiment 1 replicates the basic findings from Moore (1996), in the sense that a longer temporal separation between target and distractor onsets resulted in a reduction of negative priming. However, Moore (1996) failed to observe negative priming in her experiment in which the distractor was presented 150ms after the onset of the target (see introduction). In contrast in Experiment 1, negative priming was observed at SOAs up to 270ms. It is likely that the nature of the RSVP stream used made it that much harder to select the target, such that it was necessary to inhibit the distractor letter. For example, the target in the Moore (1996) experiment was presented for 150ms compared with just 25ms in our RSVP. Also, in Experiment 1, the target was preceded and followed by rapidly presented letters, which may be confused with the target letter and result in a temporal binding error. There was no such temporal selection pressure in Moore's experiment and as such, participants did not initiate a post-target inhibition strategy.

Experiments 1 and 2 support the basic assumption of a role for inhibition in temporal selection. That is, distractors occurring in close temporal proximity to a target are inhibited. However, many questions remain unanswered. Chapter 3 comprises two experiments. The first of these attempted to explore the effect of both interference and template activation on post-target inhibition. For example, if post-target inhibition were a selection mechanism by which interference between

targets and distractors is reduced, then one would predict that greater interference would result in greater post-target inhibition. This issue was addressed by manipulating visual similarity between the target and distractor. Also, examined in this experiment was the effect of having separate target templates for the target and distractor. The question is, does a distractor from a different template still interfere with target selection and thus warrant inhibitory feedback? The role of target templates was investigated further in Experiment 4.

CHAPTER 3 – PERCEPTUAL FACTORS AND TEMPLATE ACTIVATION

Perceptual Interference and Temporal Selection

One way in which the interference between target and distractor could be increased is to vary their perceptual similarity. Duncan and Humphreys (1989) demonstrated that in a simple letter search experiment, similarity between targets and non-targets (i.e. distractors) decreased search efficiency. In their experiments, similarity was indexed by the orientation of non-target Ts amongst target Ls. Ts that were rotated 180° or 270° were judged to be more similar to Ls than Ts rotated 0° or 90°. Surprisingly, the issue of perceptual similarity between targets and distractors in the negative priming paradigm has received little attention. What few studies there are manipulate similarity by means of colour (Baylis and Driver, 1992; Fox, 1998; Gamboz, Russo & Fox, 2000). When targets and distractors were in similar colours (or similar shades of colour), negative priming was greater than if they were dissimilar. This provides additional evidence that negative priming results from the act of selecting a target. When target-distractor discriminability is decreased, then selecting the target becomes that much more difficult and the distractor must be inhibited more as a result.

In the AB paradigm, perceptual interference has mainly been studied from the point of view of T1 and the item immediately following (i.e. T1+1). Raymond et al. (1995) used an RSVP stream of black letters and found when T1+1 was a pattern of dots (dissimilar condition), the AB was significantly attenuated compared with a condition in which the T1+1 item was a black letter (similar

condition). Ward, Duncan & Shapiro (1997) varied the similarity between T1 and T2 in an RSVP stream and found that when T1 and T2 were both white letters, a larger AB was observed.

So there is some evidence that perceptual similarity between targets and distractors increases interference and selection difficulty. In Experiment 3, the perceptual similarity between the target and post-target distractor was varied. If post-target inhibition is a mechanism for reducing interference between the target and distractor letters, then greater inhibition should be observed when the two are similar letters.

Another question that this experiment was attempting to answer relates to the role of target template activation during the task. In Experiment 1, targets and distractors were from the same target template (i.e. X, H, S and O) and all four items were likely in working memory during target selection, in order to facilitate attending to the target. Upon identification of the target it is possible that other items on the template were automatically inhibited in order to increase the contrast between the target (e.g. X) and non-targets (e.g. H, S & O) on the target template. If this is true then the inhibition would have been observed irrespective of whether or not the distractor was presented. To test this possible explanation in Experiment 3; target and distractor were from different templates.

EXPERIMENT 3 – Similarity and Template Activation

Method

<u>Participants</u>

Twenty undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits (17 females, 3 males). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

<u>Design and Procedure</u>

The experiment consisted of 360 trials (18 trials per condition) with 30 practice trials. The procedure was similar to Experiment 1, the only difference being that there were eight response keys. The probe letter could be either K, V, Q or C and required a speeded response. After responding to the probe, participants were then required to make a response to the red target letter which could be either X, Y, O and D. The letters were chosen so that the visual similarity between the red target letter and the distractor letter could be manipulated. 'X' and 'Y' were judged to be similar to 'K' and 'V'. Similarly, 'O' and 'D' were judged to be visually confusable with 'Q' and 'C' (Podgorny and Garner, 1979). The four response keys for the probe letter were 'w', 'r', 'u' and 'o' corresponding to the target letters K, V, Q and C. The four response keys for the target letter were 'z', 'c', 'b' and 'm' corresponding to the target letters X, Y, O and D.

The independent variables were Repetition and SOA and Similarity. There were two levels of Repetition corresponding to trial type (Repeated and Unrepeated). In a Repeated trial, the distractor letter and probe letter were identical (e.g. V and V). In an Unrepeated trial, the distractor letter and probe letter were different (e.g. K and V). There were five levels of SOA corresponding to the five SOAs between the target and distractor letter (90ms, 270ms, 450ms, 630ms, and 810ms). The levels of all three independent variables were varied randomly from trial to trial.

There were two levels of Similarity: Similar and Dissimilar (see Table 2).

Table 2. Possible Target-Distractor/Probe combinations by Similarity

Similarity	Target	Distractor/Probe
Similar	X	K or V
Similar	Y	K or V
Similar	O	Q or C
Similar	D	Q or C
Dissimilar	X	Q or C
Dissimilar	Y	Q or C
Dissimilar	O	K or V
Dissimilar	D	K or V

Results and Discussion

Individual participant data were summarised using median response time to the
probe letter. Trials were only included for analysis if the participant correctly
identified the red target letter and the probe letter. In this experiment, an average of
77% of the data for each participant was analysed. The data were analysed through
a 2 (Repetition: repeated, unrepeated)) x 2 (SOA: short, long) x 2 (Similarity:
similar, dissimilar) repeated-measures ANOVA. There were no significant main
effect of Repetition $((F(1,19) = 1.39; p = .25))$ but there was a main effect of SOA,
$F(1,19) = 10.94; p = .004$. The interaction between Repetition, SOA and Similarity
was also significant, $F(1, 19) = 4.83, p = .04$. Figures 13 and 14 show the data split
up by Similarity.
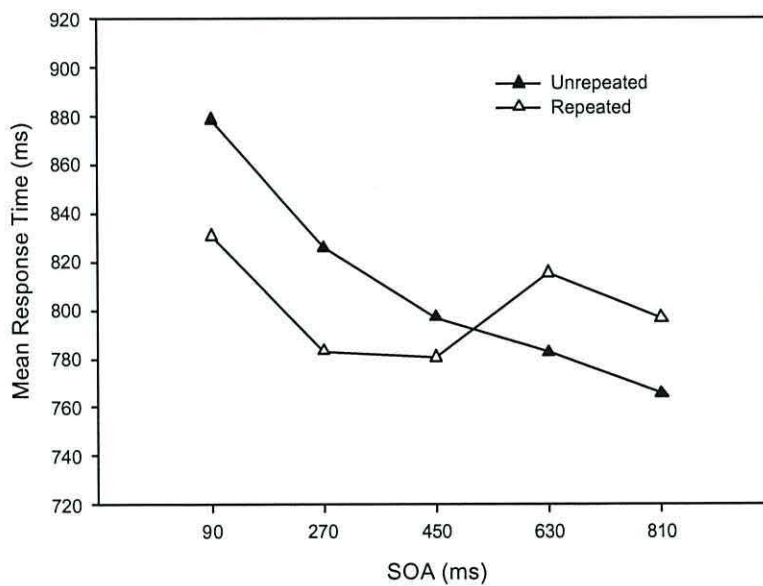
**Figure 13. Experiment 3 – Mean response times to the probe when the target
and distractor were similar letters.**
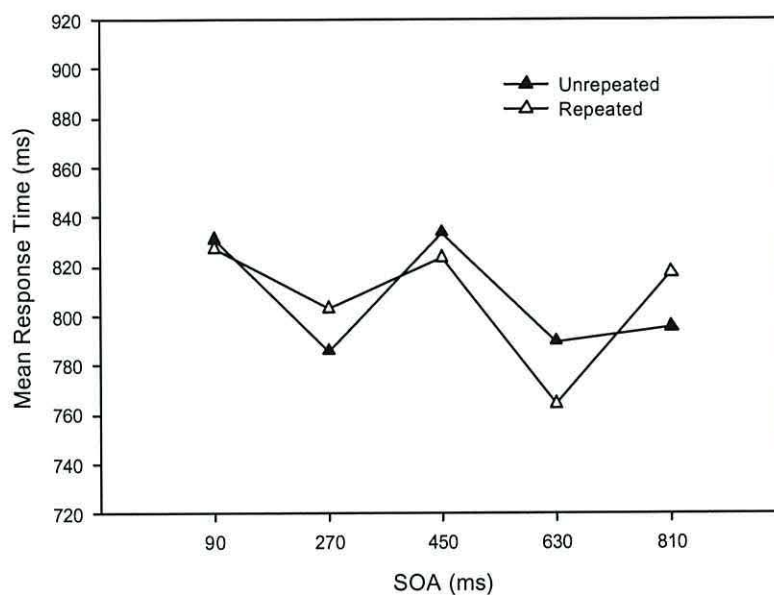
Figure 14. Experiment 3 – Mean response times to the probe when the target and distractor were dissimilar letters.

Figure 13 shows positive priming of the distractor changing quite rapidly to negative priming at around SOA 450ms. One possible explanation for this effect is that low level target features (e.g. shape and orientation of lines) are facilitated in working memory prior to the onset of the target, in order to facilitate the participant detecting the key feature. Of course, once the key feature has been detected the activation is lowered to prevent a similar stimulus from interfering with the target. By SOA 630ms low level features associated with the target are inhibited.

It is not immediately obvious why there was no post-target priming effect when the target and distractor were dissimilar, (see Figure 14). Such an effect would be expected when one considers the results from Experiment 1 in which the target and distractor were dissimilar letters and yet post-target inhibition was observed. It might be that post-target inhibition is dependant on distractor representations being

active during target selection (as would be the case when the target and distractor were on the same stimulus template). May be these representations were not active in this task because participants were not expecting to respond to stimuli on the distractor/probe template until the end of the trial when the probe was presented. Experiment 4 sought to further investigate the issue of template activation by ensuring that whilst the target and distractor/probe templates were separate, both were active during target selection.

EXPERIMENT 4 – Simultaneously Active Templates

Experiment 4 had participants respond to two target templates, one for the red-target letter and another for the probe/distractor letter. However in this experiment, the target templates were interchangeable from trial to trial. Participants were told that there were two target letter pairs or templates (X, H & S, O) and that the red-target letter might be from either pair. They were also told that if the red-target letter was from Template 1 (i.e. X or H), the probe would always be from Template 2 (i.e. S or O) and vice versa. This was to ensure that while both the red-target letter and probe/distractor letter were from different templates (as in Experiment 3), both target and distractor representations would be active during selection (as was the case in Experiment 1, where the target and distractor were drawn from the same template). It was predicted that the results of Experiment 4 would be similar to those of Experiment 1.

Method

<u>Participants</u>

Twenty undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits (19 females, 1 male). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

Design and Procedure

The experiment consisted of 360 trials (36 trials per condition) with 30 practice trials. The procedure was identical to that of Experiment 1. Participants were required to make a speeded response to the probe letter and were required to make an unspeeded response to the target letter at the end of the trial. One target pair consisted of the letters X and H whilst the other consisted of the letters S and O. X and H were responded to with the keys 'z' and 'c'. S and O were responded to with the keys 'b' and 'm'. Participants were told that if the red target letter was X or H, then the last black letter (i.e. the probe) would always be either S or O and vice versa (see Table 3). The levels of both independent variables (Repetition and SOA) were varied randomly from trial to trial.

Table 3. Possible combinations of target and distractor/probe letters.

Target	Distractor/Probe
X	S or O
H	S or O
S	X or H
O	X or H

Results and Discussion

Individual participant data were summarised using median response time to the probe letter. Trials were only included for analysis if the participant correctly identified the red target letter and the probe letter. In this experiment, an average of 82% of the data for each participant was analysed. As in previous experiments the data were collapsed into a in a new 2 (Repetition: repeated, unrepeated)) x 2 (SOA: short, long) repeated-measures ANOVA. There were no significant main effect of Repetition (($F(1,19) = .94$; $p = .34$)) but there was a main effect of SOA, $F(1,19)$ $=33.77$; $p < .01$. The interaction between Repetition and SOA was not significant, $F(1, 19) = 2.17$, $p = .15$.
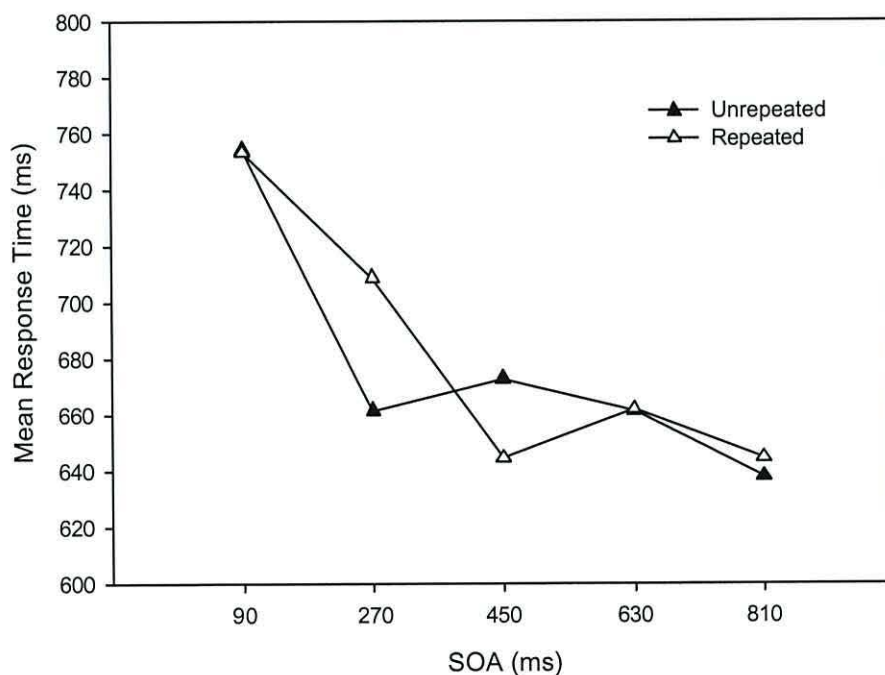
Figure 15. Experiment 5 – Mean response times to the probe letter in Repeated and Unrepeated conditions at each SOA.

Figure 15 shows that the only potential effect of Repetition was at SOA

270ms. A paired samples t-test revealed that this difference was marginally

significant (allowing for the Bonferroni correction), $t(19)= -2.56, p = .019$. What

might seem like facilitation at SOA 450ms was in fact not significant, $t(19) = 1.20$,

$p = .24$. On inspection, there appears to be a difference in the Unrepeated condition

between SOA 90ms and SOA 270ms. A paired samples t-test confirmed this,

$t(19)= 2.78, p = .01$. Figure 10 in Experiment 1 shows a similar trend in the

Unrepeated condition. Why are response times in the Unrepeated condition so

slow at SOA 90ms compared with SOA 270ms and why is there is there no relative

increase in response times in the Repeated condition at this SOA indicating

inhibition? The answer to both of these questions has to do with the gender of the

participants, an issue which is discussed in more detail in Chapter 6. For the sake

of continuity, all issues relating to gender will be discussed in that chapter and will

not be dealt with in experimental chapters[2]. Although the results of this experiment

were largely insignificant, the trend towards inhibition at SOA 270ms would seem

to suggest that post-target priming effects can be obtained when the target and

distractor are from different stimulus templates.

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[2] With one exception, the only statistically significant effect of gender is in Experiment 8. For this
reason, this effect will be dealt with in the results section of that experiment.

CHAPTER DISCUSSION

It appears that what matters is not whether the target and distractor are from different templates (as in Experiment 3) but whether or not both templates are active during selection of the target (as in Experiment 4). In other words, post-target distractor letters are not inhibited unless they are active on a target template during presentation of the target. This suggests that competition between rapidly presented distractor stimuli arises due to top-down activation of those representations. This is consistent with Houghton and Tipper (1994) who argue that inhibition is the result of selecting the target against the distractor on an internal template. If this template is not active during selection of the target then inhibition will not be observed (see Baylis et al, 1997). But what activates such a template? The results from Experiment 3 and 4 would seem to suggest that a target template becomes active when there is the possibility that the participant will have to respond to stimuli on that template. This leads to the idea that post-target inhibition and temporal selection as a whole may be mediated by a large response-based component.

Chapter 4 includes four experiments that examine the relative contributions of object- and response-based components to post-target inhibition.

CHAPTER 4 – THE LOCUS OF POST-TARGET INHIBITION

When a distractor is presented in close proximity to a target it is processed in such a way that an identical probe is negatively primed (see Experiments 1). But on what basis is its influence exerted? For example, take a situation where the post-target distractor at SOA 270ms is the letter S responded to by pressing the key 'b'. There are two explanations which might account for the negative priming observed when an identical probe is presented and these explanations suggest different loci of interference. It may be that the *object* itself is inhibited i.e. the letter S. When that object is subsequently retrieved from working memory (i.e. when a response to an identical probe is required) it takes longer to identify, resulting in slowing of the participant's response. This object-based explanation is the one most often used to explain the phenomenon of negative priming. The other possibility is that the *response* to the distractor is inhibited, i.e. the 'b' key response. When an identical probe is presented, participants are slower to retrieve that response representation. This issue has been examined from the perspective of standard negative priming experiments in which the target and distractor are presented simultaneously in the prime display.

Evidence for a Response-Based Component

Marí-Beffa and Houghton (submitted) conducted a flanker negative priming experiment in which a target number from 1 to 4 was presented at fixation in the

middle of a computer screen (see Figure 16). To the left and right were distractor numbers. Participants had to press 'v' on a keyboard if the target was either 1, 2, 3 or 4 and 'm' if the target was 5, 6, 7 or 8. When the probe target was different to the prime distractor, negative priming was observed if they shared the same response (e.g. press 'v'). Marí-Beffa and Houghton concluded that during the prime display participants had negatively primed the response associated with the prime distractor. This effect was stronger when the prime target and prime distractor shared incongruent responses (i.e. if there was response competition during selection of the prime target). Indeed, when response competition was absent during the prime display, NP was smaller and disappeared with practice.

1, 2, 3, 4 - press 'v'   5, 6, 7, 8 - press 'm'

Target

2	5	2	Prime Trial
6	1	6	Probe Trial

Distractor   Distractor
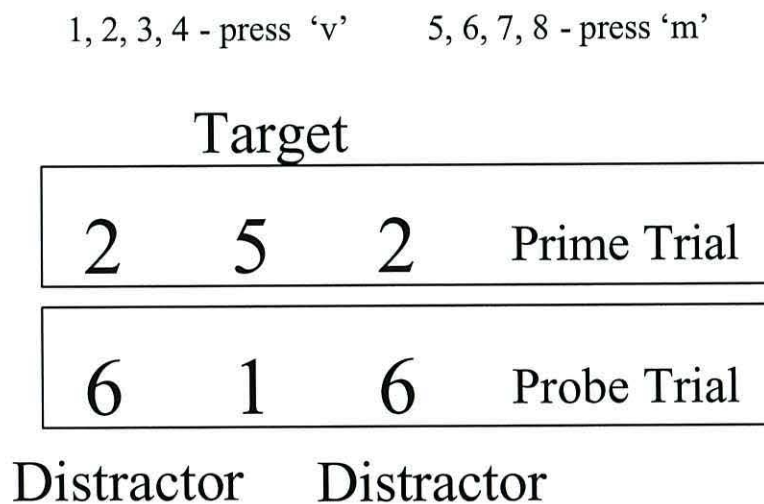
Figure 16. In the *response-based condition* the distractor on the prime trial and the target on the probe trial shared the same response e.g. 'v'.

If replicated, this would for the first time demonstrate a dissociation between object- and response-based components of negative priming. Response-based inhibition in the context of negative priming makes intrinsic sense. We

might have multiple objects in our mind at any one time, but we can only act/respond to them one at a time.

Tucker and Ellis (1998) argue that perceiving objects (or scenes) results in the activation of motor representations associated with those objects. They cite evidence from the stimulus-response compatibility (SRC) paradigm, which involves the participant responding with their left or right hands to targets presented to the left or right of fixation. When the position of the target is congruent with the hand used to respond (i.e. a left target, responded to with the left hand), participants show quicker response latencies than if the two were incongruent (i.e. a left target, responded to with the right hand). The idea here is that the target automatically activates an appropriate response. However, it is also possible that responses become activated in a top-down fashion (see Experiments 3 & 4). The SRC effect can also be demonstrated when the target location is irrelevant for making a response (Simon, 1990). In the Simon effect, some feature of the target other than its location (e.g. its colour or shape) determines whether a left- or right-handed response is required. As in the SRC paradigm, response times are quicker when the target-cued location corresponds with that of the response.

In the Stroop paradigm, participants are slower to report the colour of the ink in which an incongruent word is presented. This is because the participant cannot help but read the colour-word, which interferes with naming the colour of the word. In Stroop negative priming, the colour to be reported corresponds to the incongruent word (the prime) on the previous trial. Macleod (1991) demonstrated that in Stroop NP, the effect is much larger (i.e. slower responses) when the

response to the colour of the word is highly associated with the response to the incongruent prime word (i.e. when they are both naming tasks). Stroop NP is most likely due to response suppression of the prime word.

Converging evidence for action- or response-based mechanisms of selection comes from a paper by Tipper, Lortie and Baylis (1992). They conducted an experiment in which participants had to make reaches to light-emitting diodes (LEDs) on a stimulus board. Using a negative priming procedure they showed that when reaching for a target LED, distractor LEDs produced differing amounts of interference depending on the starting point of the hand. For example, when the reaching hand started at the front of the display, distractors in the front row produced more interference than distractors in the back row. Conversely, when the reaching hand started from the back of the display, significantly greater interference was observed from distractors at the back of the display. Tipper and his colleagues posited a hand-centred framework of selection to explain these results.

The evidence outlined above suggests that presenting an object activates an associated response. If two stimuli evoke different responses then these responses may compete with one another leading to potential errors in performance. This is the logic for positing a response-based component to post-target inhibition. The target and distractor letters both have responses associated with them that may compete with one another (especially at short SOAs). In order to successfully bind a response to the target it may be necessary to inhibit the response associated with the distractor letter.

Evidence for a Purely Perceptual/Object-Based Component

Response competition may be the reason why negative priming is observed in a lot of studies. However, there are some experiments in which it is difficult to see the role that response competition would play. For example, when the target in the prime trial and the target in the probe trial require different modalities. Tipper, MacQueen and Brehaut (1988) conducted a study in which a verbal response was required in the prime display and a manual key press was required in the probe display. Negative priming was unaffected, indicating a central locus independent of response modality. However, Marí-Beffa et al. (submitted) makes the following point "In the process of selecting the correct response, all activated responses to the distractor are inhibited. Hence response inhibition may still play a role when modality switches".

Neill, Lissner & Beck (1990) conducted a negative priming experiment in which participants judged whether the second and fourth letters of a five-letter string were the *same* or *different* (i.e. AGAGA). In the ignored repetition condition, the distractors were repeated in the probe display (i.e. SASAS). Again, participants were required to judge whether the second and fourth letters were the *same* or *different*. Negative priming was observed even when the response to the prime and probe trials were identical i.e. both '*same*'.

Further evidence against a purely response account of NP comes in the form of lexical decision tasks in which target and distractor are both words and the participant merely has to determine whether the target is a word or non-word

(Marí-Beffa , Houghton, Estevez, & Fuentes, 2000). NP is observed even though participants do not have to compute a discrete response to the target and distractor. However, this does not preclude the possibility that a specific response *was* computed and then subsequently inhibited.

Experiments in this Chapter

The aim of the experiments in this chapter was to determine at what level of representation the distractor is affected in post-target inhibition. In other words, is the object itself inhibited i.e. the letter 'S', or is the response to that letter inhibited i.e. the response associated with the letter 'S'. This was accomplished using a similar procedure to that used by Marí-Beffa and Houghton (submitted). As already noted, Marí-Beffa et al. had participants make a speeded-response to a target letter, flanked by two distractor letters in both prime and probe trials. In the object-based condition, the prime distractor was the same letter as the probe target. In the critical response-based condition the prime distractor was a different letter to the probe target but nevertheless shared the same response. Negative priming was observed in both of these conditions with one caveat. In the response-based condition, NP was greater and longer lasting if the response to the prime target was incongruent with that of the prime distractor i.e. they were associated with different key presses. In other words, response-based inhibition seems to be largely contingent upon response competition between the target and distractor. This makes sense; if target and distractor are not competing at the response level, then

there is no point in inhibiting the response of the distractor, as the output of the action will always be correct.

As Experiments 5 to 8 in this chapter have a lot in common, it seems prudent to include a general method. Where an individual experiment deviates from the general method, a separate methods section will be included.

General Method

Design and Procedure

Experiments 5 to 8 used the same RSVP procedure outlined in previous chapters but with a few important differences. As before a red target letter was followed by a distractor letter and then a probe letter at the end of the stream. Now however, the distractor letter was red (like the target) instead of black. This change was designed to amplify the interference between the target and distractor letter, thus increasing the need for inhibition and consequently improving the likelihood of observing negative priming. This change was also designed to make a comparison between these experiments and a subsequent attentional blink experiment, more compelling (i.e. in Experiment 9, the second red letter became a target: T2). Participants were told that they would see two red letters flash up in the RSVP stream and that they were only to concern themselves with the first of these letters (i.e. the target letter).

Another difference between the experiments in this chapter and earlier ones is the number of SOAs included. Experiments 1 to 4 tested SOAs 90ms, 270ms, 450ms, 630ms, and 810ms. Evidently, post-target inhibition dissipates by SOA 450ms and so there seemed little point in including SOAs 630 and 810ms. Thus, only the first three SOAs of 90ms, 270ms and 450ms were included in the design.

The number of items in the RSVP stream depended on the position of the distractor letter in the stream. There were always 10 items after presentation of the distractor letter so the stream length varied from 15 to 22 items. The red target letter was never the same as the distractor letter or probe.

In order to dissociate object- from response-based components of post-target inhibition, it was necessary to move away from a procedure in which each target letter (i.e. X, H, S and O respectively) had its own discrete key press response (i.e. 'z', 'c', 'b' and 'm' respectively). Instead, there were three target letter triplets (G-P-X, D-J-Z and L-N-S), each associated with a different response. The three triplets were not the same from experiment to experiment. Table 4 shows the letter triplets and associated responses used in each experiment. For example, in Experiment 5, if the participant saw the letter G, P or X, they had to press '1' on the keyboard. Similarly if they saw the letter D, J or Z they had to press '2'; if L, N or S was presented then they had to press '3'. When responding, participants used the first three fingers of their right hand on the number '1', '2' and '3' keys on the number pad of a conventional keyboard

The independent variables were Repetition and SOA. There were a total of four levels of Repetition corresponding to trial type: Object-Repeated, Object-

Unrepeated, Response-Repeated and Response-Unrepeated. However, in any given experiment only two of these trial types were analysed, the other two trial types are included but only as catch trials (not analysed). For example, Experiment 5 consists of 270 trials, 180 of which are experimental trials and 90 are catch trials. Of the 180 experimental trials, half are Object-Repeated trials, the other half are Object-Unrepeated trials. Of the 90 catch trials, half are Response-Repeated trials, the other half are Response-Unrepeated trials. Catch trials were not analysed and the logic behind their inclusion is dealt with in the individual experimental methods sections.

Table 4. Target letter triplets and associated responses in Experiments 5-8.

Experiment	Letter Triplets	Responses
5	GPX, DJZ, LNS	1,2,3
6	GPX, DJZ, LNS	1,2,3
7	ABC, JKL, STU	1,2,3
8	ABC, JKL, STU	1,2,3

What follows is a description of all four trial types. In an Object-Repeated trial, the target and distractor shared the same response and the distractor was the same letter as the probe. This is a pure measure of object-based priming, without the confound of response competition between the target and distractor (Marí-Beffa

et al., submitted). In an Object-Unrepeated trial, the target, distractor and probe shared the same response (i.e. press '1') but were all different letters (i.e. G, X, P). In a Response-Repeated trial, the target and distractor were associated with different responses and the distractor was a different letter to the probe but was associated with the same response. This is a pure measure of response-based priming as the only link between the distractor and probe is a congruent response. In a Response-Unrepeated trial, the target, distractor and probe were different letters and were associated with different responses.

It is important to note that when a response-based effect is alluded to in subsequent experiments, it does not necessarily refer to actual inhibition of a motor response. For example, this design is not capable of determining whether an actual motoric action (pressing the '1' key) is inhibited or if target letter triplets are grouped into categories and it is these categories which are subsequently inhibited. If the latter were true, it is almost certainly the case that these super-ordinate representations (e.g. the category '1') are at a stage of processing that is immediately prior to initiating a motor response. It is for this reason, that labelling effects obtained from these trial types, 'response-based', is justified.

There were three levels of SOA corresponding to the three SOAs between the target and distractor letter (90ms, 270ms and 450ms). The levels of both independent variables were varied randomly from trial to trial.

EXPERIMENT 5 – Object-Based Post-Target Inhibition I

The aim of Experiment 5 was to investigate an object-based component to post-target inhibition. It was predicted that the results would mirror those of Marí-Beffa et al. (in preparation) and that the distractor letter/object would be inhibited.

Method

Participants

Seventeen undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits (13 females, 4 males). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

Design and Procedure

The experiment consisted of 180 experimental trials with 90 catch trials and 30 practice trials. There was also a training phase of 30 trials before the practice trials. In a training phase trial, a fixation cross appeared on screen for 500ms and was then replaced by a blank screen for 2000ms after which one of the nine target letters would flash-up until the participant responded by pressing either 1,2 or 3 as quickly as possible. If the participant responded in over 1000ms, a message would appear on screen saying 'Too slow'. This was given to emphasise to the participant that speed was important.

The procedural requirements of the participant were identical to those in Experiment 1. The RSVP stream consisted of random black letters from the alphabet (excluding the target letters) presented at fixation in the centre of a computer screen. Each letter was presented for 25ms and there was an Inter Stimulus Interval (ISI) of 65 ms. The red target letter could appear in position 4, 5 or 6 in the stream. The red distractor letter could appear in position 1, 3 or 5 after the target (i.e. SOA 90ms, 270ms and 450ms). The probe letter was always the last black letter in the stream and stayed on the screen until the participant made a response.

The target, distractor and probe letters were drawn from the triplets GPX, DJZ and LNS. These were chosen on the basis that they were judged to be highly discriminable from one another. If the participant saw either letters G, P or X they were instructed to press the key '1'. If they saw D, J or Z they pressed '2'. If they saw L, N or S they pressed 3 (see Figure 17). One of the problems with this design was that in subsequent analysis, if the participant responded by pressing '1', it is impossible to tell whether they saw the letter G, P or X. For example, if the target letter was P but the participant thought they saw an X, they will respond by pressing '1' and this will be counted as a correct response. The long and short of this is that response accuracy may not be a very good measure of the participant's performance, though it may still be used as a guide.
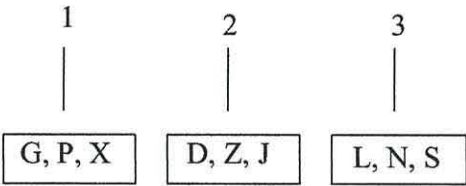
Figure 17. Target letter triplets and their associated response keys.

The two trial types that constituted the 180 experimental trials were Object-Repeated and Object-Unrepeated trials. Figure 18 illustrates both of these trial types. Response-Repeated and Response-Unrepeated catch trials were included as without these, the participant would no doubt realise that the target and probe were always from the same response set and so would not necessarily have to attend the target to respond 'correctly'. By including 90 catch trials the participant could not be sure that the target was from the same response set as the probe and so had to attend the former.
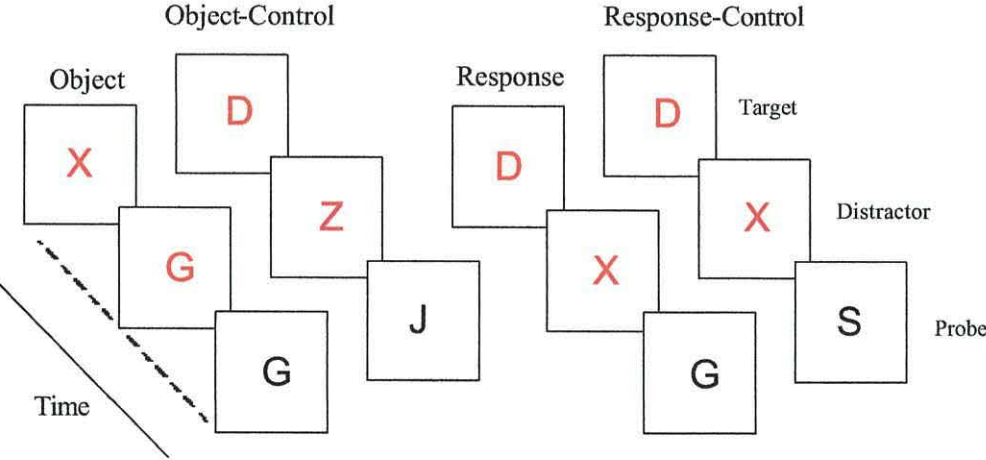
Figure 18. Illustrating Object-Repeated and Object-Unrepeated experimental trial types and Response-Repeated and Response-Unrepeated catch trials.

Results and Discussion

A Repeated-Measures ANOVA was carried out on both independent variables;

Repetition (Object-Repeated, Object-Unrepeated) and SOA (90ms, 270ms 450ms).

Catch trials were not analysed. There was no main effect of Repetition, $F(1, 16) =$

$.01, p = .92$, or SOA, $F(1, 16) = 2.76, p = .07$. Also, there was a non significant

interaction between Repetition and SOA, $F(1, 16) = 1.25, p = .29$.
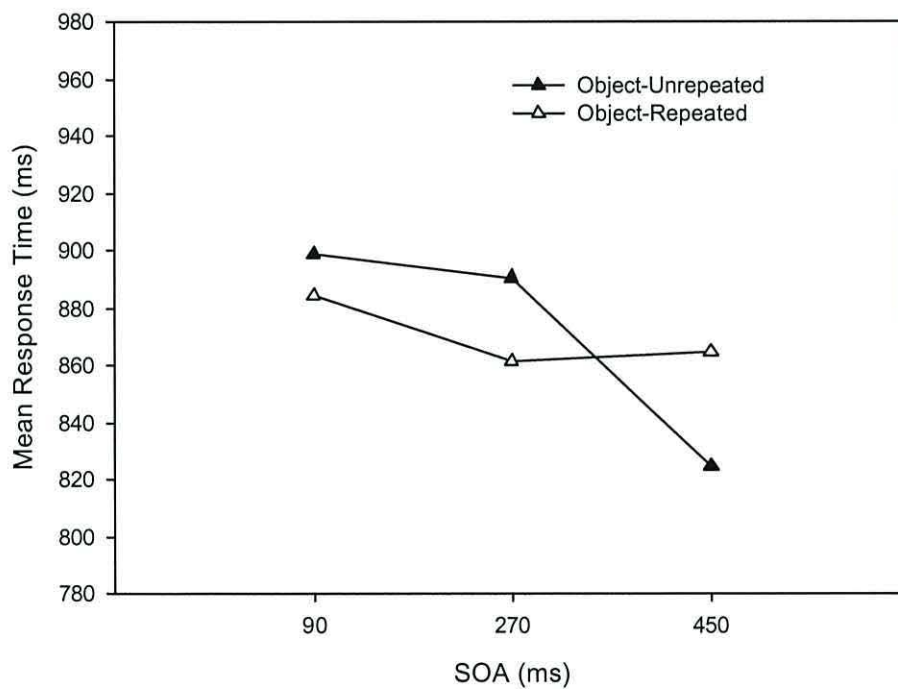
Figure 19. Experiment 5 – Mean response time to the probe in Object-Repeated and Object-Unrepeated conditions.

It is not possible to conclude much from these results due to the lack of a

significant interaction. However, it seems unlikely that object-based factors do not

play a role in post-target inhibition. With this in mind, the object-based component

was examined again in Experiment 7. Experiment 6 followed the same procedure

to Experiment 5 but tested the role of response-based factors in post-target

inhibition.

EXPERIMENT 6 – Response-Based Post-Target Inhibition I

Experiment 6 used Response-Repeated and Response-Unrepeated experimental trials. As in the previous experiment catch trials were included. These were Object-Repeated and Object-Unrepeated trial types.

Method

<u>Participants</u>

Seventeen undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits (15 females, 2 males). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

<u>Design and Procedure</u>

The design and procedure was identical to that of Experiment 5 except that the experimental trials consisted of Response-Repeated and Response-Unrepeated trials and the catch trials consisted of Object-Repeated and Object-Unrepeated trials.

Results and Discussion

A Repeated-Measures ANOVA was carried out on independent variables;

Repetition (Response-Repeated, Response-Unrepeated) and SOA (90ms, 270ms

450ms). Catch trials were not analysed. There was no main effect of Repetition,

$F(1, 16) = .01, p = .91$, or SOA, $F(1, 16) = .32, p = .72$. Also, there was a no

significant interaction between Repetition and SOA, $F(1, 16) = .23, p = .79$.
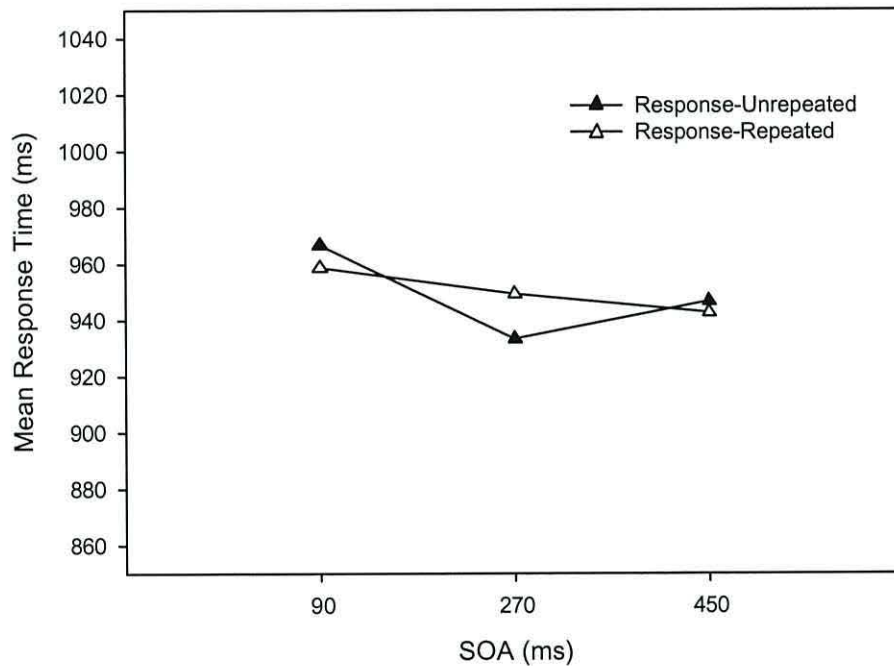
Figure 20. **Mean response time to the probe in Response-Repeated and Response-Unrepeated conditions.**

The lack of a significant interaction makes it difficult to draw any

conclusions.

Experiments 5 and 6 failed to replicate the results of Marí-Beffa et al. (in preparation) who identified distinct object- and response-based components of negative priming. During both of these experiments participants would frequently comment that they found the experiment 'hard'. They also had difficulty 'remembering all the letters'. It is likely that they had difficulty forming mental templates of which letters shared the same response. Experiments 7 and 8 used target letters that the participant could easily group into response categories. It was predicted that this would yield significant data and distinct object- and response-based components.

EXPERIMENT 7 – Object-Based Post-Target Inhibition II

This experiment was identical to Experiment 5 except that it used different target letters. It utilised Object-Repeated and Object-Unrepeated experimental conditions with Response-Repeated and Response-Unrepeated catch trials.

Method

Participants

Twenty undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits. There were an equal number of males to females (i.e. 10/10). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

Design and Procedure

The design and procedure was identical to Experiment 5 except that the target triplets were different. Figure 21 shows the target letter triplets used in Experiments 7 and 8.

Figure 21. New target letter triplets and their associated response keys.

Each triplet consists of consecutive letters in the alphabet and the triplets correspond roughly to the beginning, middle and end of the alphabet. It was predicted that the participant would find these triplets easier to remember and also easier to link with an associated response.

Results and Discussion

A Repeated-Measures ANOVA was carried out on independent variables; Repetition (Object-Repeated, Object-Unrepeated) and SOA (90ms, 270ms 450ms). Catch trials were not analysed as there were insufficient trials for comparison. There was a main effect of Repetition, $F(1, 19) = 4.44, p = .04$. The main effect of SOA was not significant, $F(1, 19) = .22, p = .80$. There was a significant interaction between Repetition and SOA, $F(1, 19) = 4.50, p = .01$.
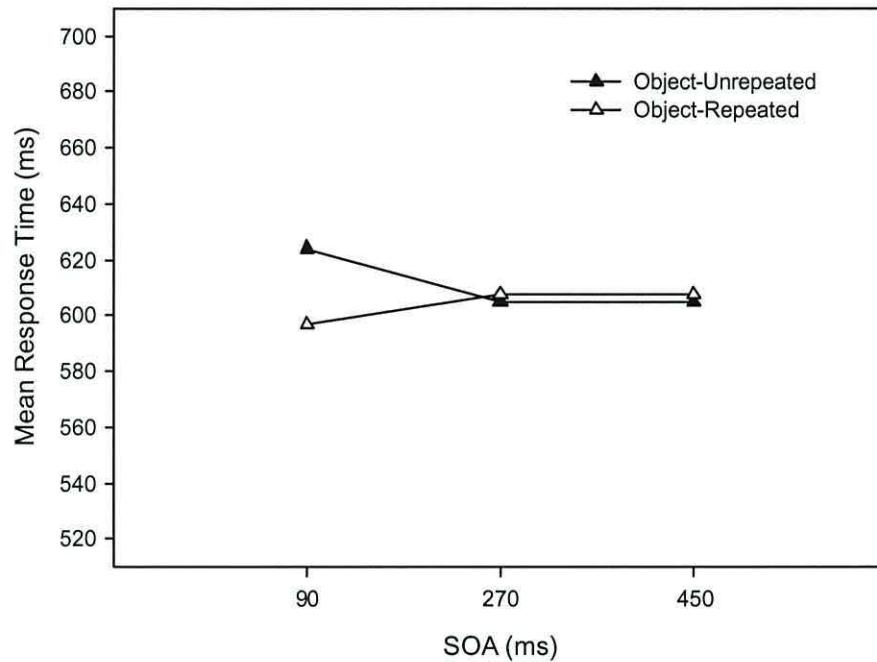
Figure 22. Experiment 7 – Mean response time to the probe in Object-Repeated and Object-Unrepeated conditions.

Overall response times in this experiment (with the new letter triplets) compared with those of Experiment 5 (with the old letter triplets) are considerably reduced suggesting that adopting the new target letter triplets did indeed reduce task difficulty.

The only appreciable effect of Repetition seems to be at SOA 90ms, a suggestion supported by a paired samples t-test which revealed a significant difference at this SOA, $t(24)$= -3.80, $p < .01$. When the distractor and probe letters were identical, participants were significantly faster to respond to the probe than if the two letters were different. This suggests that far from inhibiting the distractor letter (note: we are talking about the distractor object i.e. the actual letter 'B', **not**

its associated response), participants actually facilitate it leading to *positive* priming of an identical probe. This facilitation is short lasting and only distractors in the +1 position (i.e. SOA 90ms) seem to be affected.

This result suggests that the post-target inhibition observed in Experiment 1 is not applied at the object level. In other words, the letter itself (e.g. the letter J) is not inhibited, indeed, it is facilitated. It would seem odd to facilitate the +1 distractor considering that this is the item most commonly substituted for the target when the participant makes an (intrusion) error (Botella, Garcia and Barriopedro, 1992). It makes sense therefore to assume that participants make +1 intrusion errors *because* they facilitate the +1 object/letter. Indeed, the pattern of activity corresponds quite nicely with the pattern of intrusion errors observed in Experiment 1 (see Figure 11).

One can imagine a scenario in which prior to the onset of the target, all potential target letters (comprising the target template ABCJKLSTU) are highly activated in working memory. This would increase the efficiency with which the target template could be compared with the letters in the RSVP stream and the target detected. So when the target flashes up it is highly activated. Subsequent to target onset, it is necessary to rapidly lower the activation of other items on the target template as these are now competing for further processing. However this takes time, during which the +1 item will have flashed up. Consequently, the +1 item will have an activity state that is lower than that of the target but still high enough to positively prime an identical probe. By the time the +2 item flashes up, the activation levels of items on the target template will have returned to baseline

and positive priming will not be observed. The word 'baseline' is used guardedly here as all of the items on the target template were no doubt, highly primed compared with other items of the alphabet. Use of the word 'baseline' here merely denotes that all items on the target template share a roughly equal activity state.

The explanation above is quite similar to one posited to explain Lag-1 sparing which is a phenomenon usually observed in attentional blink studies. The phenomenon of Lag 1 sparing is characterised by a pattern of results in which T2 is reported on a high percentage of trials when it occurs immediately after T1 (i.e. the T1+1 position in the RSVP). Shapiro and Raymond (1994) suggested the concept of a sluggish attentional gate which opens to allow T1 access to further processing but is slow to close such that sometimes the item presented immediately afterwards (i.e. the T1+1 item) also gets through. The present data demonstrate that the T+1 item does indeed receive significant processing. Studies of intrusion errors tell us that this can have negative consequences for report of the target.

Experiment 7 demonstrates that the locus of post-target inhibition does not operate on an object-based representation. It was predicted therefore that Experiment 8 which examined a response-based component would yield longer lasting inhibition.

EXPERIMENT 8 – Response Based Post-Target Inhibition II

This experiment was identical to Experiment 6, except that it used the new target template (see Figure 21). It utilised Response-Repeated and Response-Unrepeated experimental trials with Object-Repeated and Object-Unrepeated catch trials.

Method

<u>Participants</u>

Twenty undergraduates from the University of Wales, Bangor, participated in this experiment in order to obtain course credits. There were an equal number of males to females (i.e. 10/10). Participants were aged 18-45, with normal or corrected to normal vision and were not dyslexic.

<u>Design and Procedure</u>

The design and procedure was identical to Experiment 6 except that the target triplets were different. Figure 21 shows the target letter triplets used in Experiments 7 and 8.
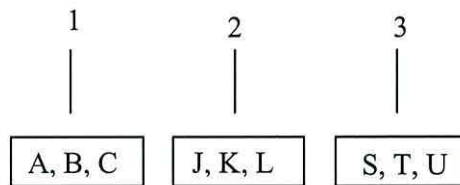
Results and Discussion

A Repeated-Measures ANOVA was carried out on independent variables;

Repetition (Response-Repeated, Response-Unrepeated) and SOA (90ms, 270ms

450ms). Catch trials were not analysed as there were insufficient trials for

comparison. There was a no main effect of Repetition, $F(1, 19) = 1.35, p = .25$.

The main effect of SOA was significant, $F(1, 19) = 1.43, p < .01$. The interaction

between Repetition and SOA was not significant, $F(1, 19) = 1.43, p = .25$.
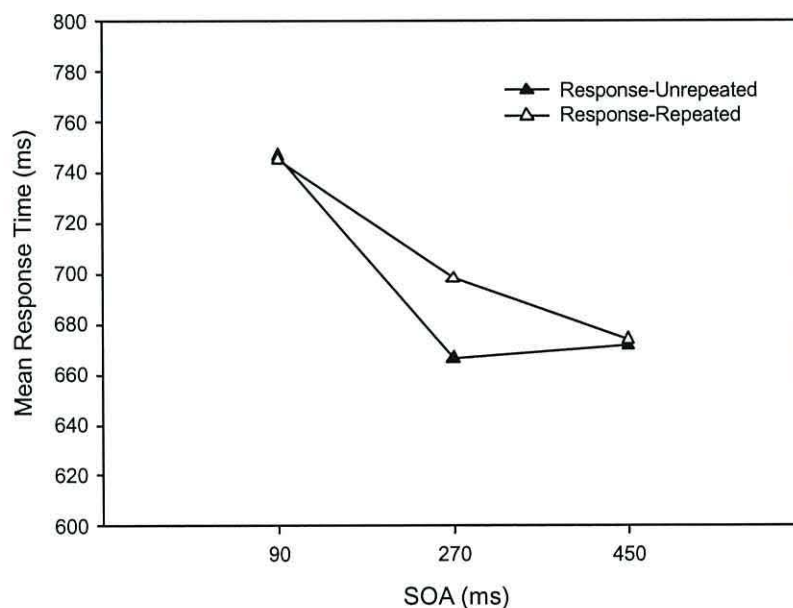
Figure 23. Experiment 8 – Mean response time to the probe in Response-Repeated and Response-Unrepeated conditions.

It was noted by the experimenter (myself) that throughout testing, some

participants would show positive priming at SOA 90ms, whilst others would show

negative priming. This could account for why there was no effect of Repetition at

this SOA and might also account for the lack of an overall interaction. Upon closer inspection, the differences seemed to correspond to the gender of the participant. It is for this reason that this experiment and the one prior to it have an equal ratio of males to females. The interaction between gender and post-target inhibition is mainly dealt with in Chapter 6. However, since the only statistically significant evidence for an effect of gender is in this experiment, the issue will be dealt with here as well.

A second Repeated-Measures ANOVA was carried out only this time the between subjects variable of Gender was included. There was a significant interaction between Repetition, SOA and Gender, $F(1, 19) = 13.14, p < .01$. In order to find where Gender was interacting with Repetition and SOA, three One-Way ANOVAs were carried out (Table 5).

Table 5. One-Way ANOVAs examining the interaction between Repetition and Gender at each SOA.

Repetition x Gender	F	p
SOA 90ms	14.81	<.01
SOA 270ms	.83	.37
SOA 450ms	1.66	.21

The gender of the participant only seems to have an effect on the data at SOA 90ms. Figures 24 and 25 show the data for males and females.
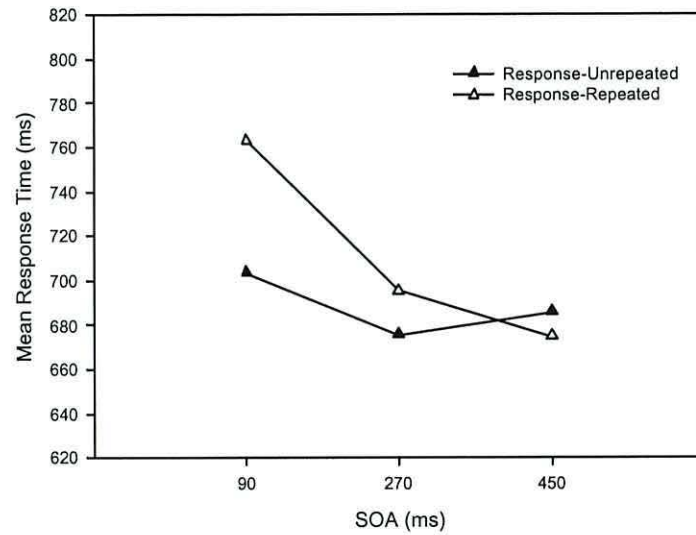
Figure 24. Experiment 8 MALES – Mean response time to the probe in Response-Repeated and Response-Unrepeated conditions.
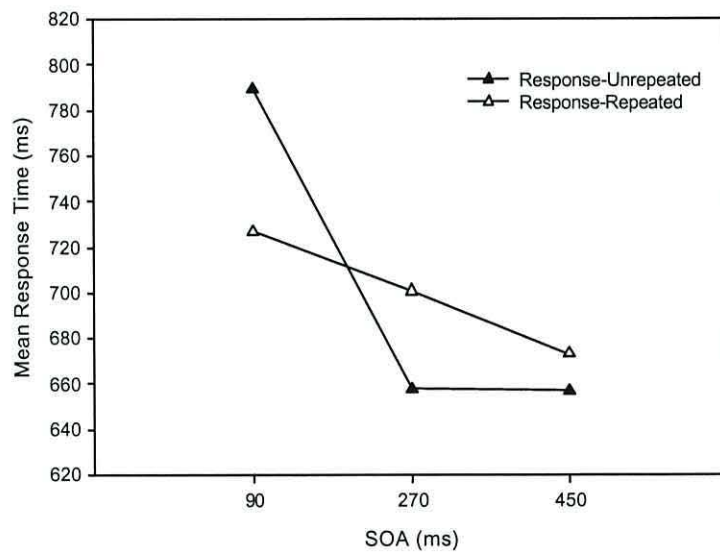
Figure 25. Experiment 8 FEMALES – Mean response time to the probe in Response-Repeated and Response-Unrepeated conditions.

A further two Repeated-Measures ANOVAs showed that the interaction between Repetition and SOA was significant for both male $((F(1, 9) = 3.77, p = .04))$ and female $((F(1, 9) = 13.70, p < .01))$ data sets.

Both males and females show a trend towards inhibition at SOA 270ms. It is important to emphasise here that this is *not* inhibition applied to the distractor letter itself (e.g. the letter S) but to the response associated with that letter (e.g. the response '3'). When comparing the time-course and polarity of the effects observed in Experiments 1 and 4, it is clear that these do not correspond with the object-based component demonstrated in Experiment 7, rather they resemble the response-based component observed in this experiment. It stands to reason that in Experiments 1 and 4, participants were not inhibiting the letters X, H, S or O, but *were* inhibiting their associated response representations.

Before examining the dissimilarities between males and females it seems prudent to examine what they have in common. As stated before, both males and females show a trend towards inhibition at SOA 270ms. The question arises, why inhibit the response to an object at this SOA? One explanation could be that letters from the target template in the stream automatically evoke their associated responses and that these have to be inhibited to prevent responding until the end of the trial (see Tucker and Ellis, 1998; Macleod, 1991). There are a couple of problems with such an interpretation. Firstly, it suggests that the response to the highly salient target would need to be inhibited even more than the to-be ignored distractor response. Secondly, this account would hold that since a distractor at SOA 90ms and a distractor at SOA 450ms both evoke responses, there should be

no difference in the magnitude of inhibition observed at these SOAs. This was clearly not the case (see Figure 23) and a more sophisticated explanation is necessary.

The fact that inhibition diminishes as the SOA between the target and distractor increases suggests that the inhibition observed in this experiment reflects interference between two temporally proximal stimuli (see Experiment 2), in this case, the target and distractor. Let us assume for a moment that the target and distractor both feed-forward activation to their respective responses. The problem is that the target and distractor objects have both fed forward activation through the system and as a result, there are two active responses both competing to be bound with the target. This could result in a binding error, specifically; the distractor's response could be bound with the target object in which case the participant would commit an intrusion error (Botella et al., 2001). One obvious way of resolving this competition would be to inhibit the response associated with the distractor. This explains why response inhibition of the distractor is observed but does not explain the mediation of this effect with SOA. This problem is overcome simply by positing that the magnitude of inhibition applied is proportional to the interference between the responses. This interference is greatest when the two responses are both highly active i.e. when the target and distractor occur in close temporal proximity to one another. For example, at SOA 450ms activation of the target response will likely have dissipated and so the potential for interference with a now active distractor response will be considerably reduced.

When the distractor object is especially active (i.e. at lag 1), the amount of activation fed-forward to its associated response will be commensurately large and the competition between the target and distractor responses will become critical. This then ties in with the findings of Botella and his colleagues who find that intrusion errors most commonly originate from the +1 item.

In their selective inhibition model, Houghton and Tipper (1994) maintain that negative priming is due to the inhibition of a highly active distractor representation which is interfering with selection of the target. In other words, inhibition is applied only after a distractor representation is activated. The data from female participants would seem to support this idea as there is a pattern of initial facilitation (at SOA 90ms) followed by a period of inhibition (SOAs 270 & 450ms). A 2 (Repeated, Unrepeated) x 2 (Male, Female) mixed ANOVA showed a significant difference between males and females at SOA 90ms, $F(1, 18) = 14.81, p = .001$. It seems that likely that both genders initially activate the distractor and then inhibit it, but that males are able to initiate inhibition quicker than females. In support of this delayed time-course hypothesis, the pattern of inhibition at SOA 90 and 270ms in the male data set looks very similar to the pattern of inhibition at SOA 270 and 450ms in the female data set (see Figures 24 and 25). In concordance with this hypothesis, SOAs 90 and 270ms in the male data set were compared against SOAs 270 and 450ms in the female data set in a new 2 (SOA1, SOA2) x 2 (Repeated, Unrepeated) x 2 (Male, Female) ANOVA. As predicted, the interaction between Repetition, SOA and Gender was not significant, $F(1, 18) = .18, p = .67$. There was a main effect of Repetition, $F(1, 18) = 9.41, p = .007$.

Interestingly the interaction between Repetition and SOA was also significant, $F(1, 18) = 5.15, p = .03$, confirming that the magnitude of inhibition diminished with increasing SOA.

One prediction arising from the idea that females are slower in initiating inhibition of an activated distractor representation is that they should produce more target errors than males. Indeed, this is the case, out of 180 experimental trials, females made on average 47.4 errors whilst males made only 30.7 errors, a significant difference, $t(18)= 2.69, p < .02$. Another prediction arising from this experiment is that positive rather than negative priming might be observed with male participants if the SOA between the target and distractor were reduced from 90ms, reflecting initial activation of the distractor.

CHAPTER DISCUSSION

At this point it seems prudent to briefly review the experiments in this chapter. Chapter 4 included four experiments that attempted to dissociate object- from response-based components of post-target inhibition. Experiments 5 and 6 did not produce significant data. Despite this fact, the pattern of data from these two experiments did correspond to some degree with Experiments 7 and 8 that used the same procedure but with different target letter triplets. These new target letter triplets were designed to make the task easier for the participants to remember and thus easier to form into a target template. Table 6 shows the mean number of correct target responses. It is clear that the new letter triplets reduced task difficulty. Remember that due to the 3/1 letter to response mapping, the actual accuracy of the participant is most likely less than that shown.

Table 6. Mean percent correct target responses.

Experiment	Target accuracy
Exp. 5. Object-Based I	86.1%
Exp. 6. Response-Based I	66.3%
Exp. 7. Object-Based II	93.9%
Exp. 8. Response Based II	78.3%

Experiment 7 showed that when the distractor is presented immediately after the target, it receives facilitatory processing. It was speculated that this might be the reason why items appearing in the T+1 position are especially prone to be substituted for the target when the participant makes a temporal binding error.

Experiment 8 showed a response-based component of post-target inhibition that lasted until SOA 270ms. It was postulated that the inhibition observed in Experiments 1 and 4 is due to this component. The effect of Repetition at SOA 90ms was demonstrated to interact with gender. Males inhibit the response to the T+1 item, whilst females show facilitation. It is suggested that females are slower to engage inhibition of an activated response representation.

Despite their differences, it is clear from Figures 24 and 25 that both genders inhibited the distractor response representation at 270ms. Since the response-based component lasted longer than the object-based component, it was predicted that the former was a more likely candidate to explain other temporal selection phenomena such as the AB, PRP and RB. This prediction was tested in Chapter 5.

CHAPTER 5 – RESPONSE INHIBITION AND THE AB

Experiment 9 used a procedure similar to that of the attentional blink paradigm in order to establish a direct link between that phenomenon and post-target response inhibition. This experiment was identical to Experiment 8 with only three differences. Firstly, there were no object-based catch trials (see Figure 26). Secondly, participants were now required to respond to the second red letter, which was designated as T2. Thirdly, T2 (which was previously the distractor letter) always appeared in position +3 (i.e. SOA 270ms). There were number of reasons for this, the most important being that in AB studies, report of T2 is typically at its lowest at around 300ms. Also, bearing in mind the gender differences in response-based inhibition at SOA 90ms, it seemed prudent to omit this SOA. And lastly, it was necessary to reduce the number of SOAs probed in order to ensure there were enough AB and non-AB trials. As in a standard attentional blink task, an AB-trial is defined as when the participant fails to correctly identify T2. A non-AB trial is defined as when the participant correctly identifies T2.
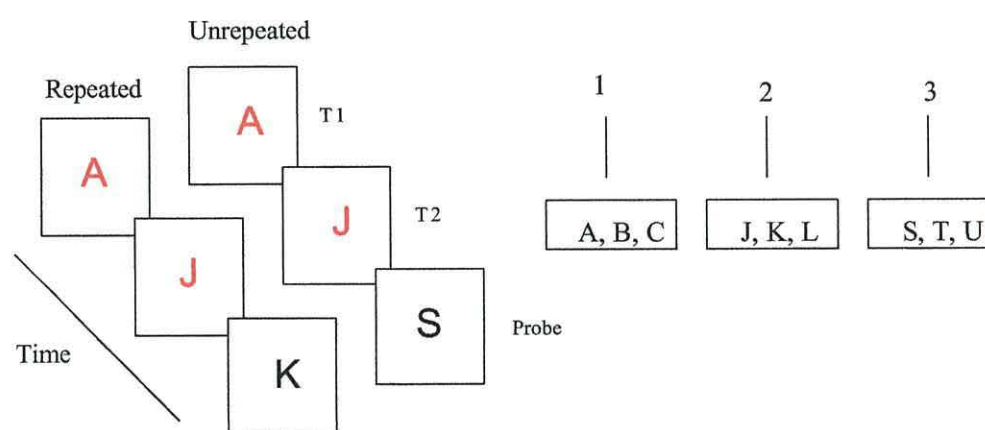
Figure 26. Illustrating (response-based) Repeated and Unrepeated trials in a hybrid AB experiment with target letter triplets and associated responses.

As previously mentioned, having three letters linked to a single response means that accuracy does not necessarily reflect whether or not the participant saw the actual target that was presented. However, this problem was considered to be quite minor and any interaction between inhibition and AB magnitude could be seen to be more believable as a result of this source of 'random variation'.

EXPERIMENT 9 – Response Inhibition and the AB

Method

Participants

Eight undergraduate females from the University of Wales, Bangor, participated in this experiment in order to obtain course credits. As both males and females demonstrate response-based inhibition at SOA 270ms, it was deemed unimportant to balance gender.

Design and Procedure

The design and procedure was similar to Experiment 8 except that participants were required to respond to both red letters. Participants made a speeded response to the probe and then non-speeded responses to both red letters; T1 and T2.

There were 270 experimental trials (with a training phase of 30 trials and 30 practice trials. The independent variables were Repetition and T2 Accuracy.

Repetition was comprised of the two trial types Response-Repeated and Response-Unrepeated. There were two levels of T2 Accuracy, corresponding to whether the participant correctly identified T2 (Correct and Incorrect).

Results

A Repeated-Measures ANOVA was carried out on both independent variables. There was no main effect of Repetition, $F(1, 7) = .09$, $p = .77$, or T2 Accuracy, $F(1, 7) = .06$, $p = .81$. The interaction between Repetition and T2 Accuracy was significant, $F(1, 7) = 8.75$, $p = .02$.
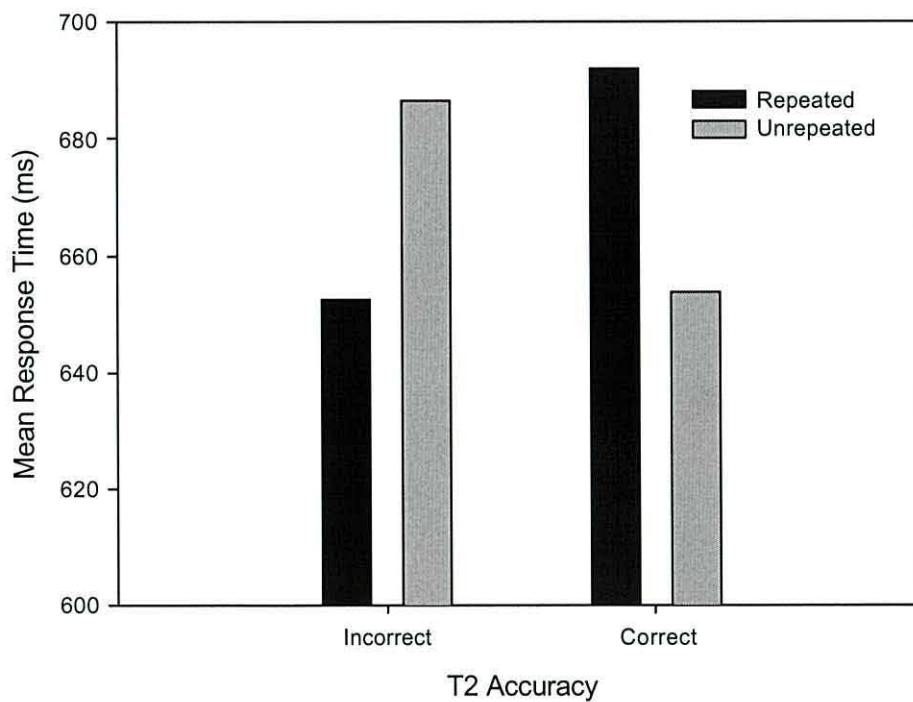
Figure 27. Graph showing mean response times to the probe by T2 accuracy.

When participants correctly identified T2, inhibition of its associated response was observed. In contrast, on trials in which T2 was incorrect, facilitation was observed.

Table 7. Mean percentage T1/T2 accuracy

	T1 Correct	T1 Incorrect
T2 Correct	61.7	2.2
T2 Incorrect	19.6	10.9

Note. Trials only included if the participant correctly identified T1 and the Probe.

Table 7 above shows that the average participant could report T1 and T2 only 61.67% of the time, a sizeable attentional blink.

CHAPTER DISCUSSION

The data from Experiment 9 can be interpreted in several ways.

Explanation 1: The effect is due to the participant withholding the response to the distractor.

It could be argued that the distractor is inhibited for an entirely different reason than its temporal proximity to T2. It might be that participants inhibit the T2 response in order to prevent executing it before the end of the RSVP stream. In cases when the T2 response is repeated as the probe, this would lead to negative priming. There are problems with this explanation. Firstly, whilst it can explain inhibition when T2 is correct, it cannot explain facilitation when T2 is incorrect. Secondly, this kind of queuing explanation cannot account for the attenuation of inhibition with SOA. In other words, a distractor that occurs at SOA 450ms would need to be withheld just as much as a distractor that is presented at SOA 270ms. This latter point cannot be totally discounted as T2 only appeared at SOA 270ms in this experiment. However, Experiments 1, 4 and 8 show that post-target inhibition *is* mediated by SOA suggesting that were a second SOA probed in this experiment, there would be attenuation of the effect.

Explanation 2: The effect is due to the distractor and probe stimuli both trying to access the same response.

A second explanation of the data relates to interference between T2 and probe

responses. For example, elevated response times to the probe could result from interference caused by T2 and the probe both trying to access the same response (e.g. '1'). Alternatively, slower response times could reflect the time taken to unbind T2 from its response in order to temporarily bind that response to the probe (which participants respond to before T2). But why facilitation when the participant responds incorrectly to T2?

It might be that although T2 has not been successfully bound to its response that response is nevertheless highly activated thus facilitating the speed with which it can be bound to the probe. Again, this explanation cannot be totally disproved, but data from previous experiments in this thesis shed considerable doubt as to its validity. For example, an explanation based on interference would predict that when a distractor/T2 and probe are identical, then there should be no need to temporarily unbind T2. Nor should there be any interference caused by two objects both trying to access the same response since the two objects are identical. Thus, a model based on interference between the distractor/T2 and the probe would predict either no effect or facilitation when the distractor and probe stimuli are identical. This was the case in Experiment 1 where contrary to this explanation, inhibition was observed. Also, this explanation could not account for any effect of SOA as the interference exists between the distractor/T2 and the probe, the temporal distance between which is kept static (i.e. 10 items or 900ms).

Explanation 3: Participants are inhibiting the response to T2 whether they get it correct or incorrect.

It is clear to see from Figure 27 that response times in the Unrepeated condition were high or low depending on whether or not the participant correctly reported T2. When T2 was reported incorrectly, response times in the Unrepeated condition were higher than when T2 was reported correctly. Also, the inverse symmetry between the positive priming when participants get T2 incorrect and negative priming when participants get T2 correct, is hard to ignore. Why should this be the case? When participants incorrectly reported T2 they chose the same response as T1 only fifteen percent of the time. In this experiment, T2 was never the same as T1 and this contingency is probably the reason why participants only made the same response to T1 and T2 occasionally. The other eighty-five percent of the time participants mistakenly chose the response associated with neither T1 nor T2. On Unrepeated trials this would always be the same response as that associated with the probe. The figure below illustrates this pattern of errors.

Actual Response
1   3   85% of trials
1   1   15%of trials

| | |
| | |

T1   T2

Correct   1   2
Response

Figure 28. Showing types of T2 errors when both the probe and T1 are correct

Participants may have inhibited the response associated with the letter that they mistakenly thought was T2. Thus, the Unrepeated condition would become the Repeated condition and vice versa. This would explain why in Figure 27, response times are high in the Unrepeated condition and low in the Repeated condition when the participant incorrectly reported T2. In other words, what looked like facilitation of the T2 response could have been inhibition of a response associated with a letter that the participant mistakenly thought they saw. If correct, this would mean that response inhibition and the attentional blink are independent of one another. It may be that the same factors that cause the attentional blink also result in post-target response inhibition but that one does not cause the other.

Explanation 4: Response Inhibition mediates the attentional blink.

It could be argued that in order for a response to be successfully bound to a target, other responses that are simultaneously active must be inhibited. It stands to reason that since T1 and T2 occur in such close temporal proximity; their respective response representations will be active at the same time. Hence there is the potential for the wrong response to be bound to the wrong object. To prevent this from happening and to aid binding of both targets, the T2 response is inhibited (most likely via lateral inhibition from the T1 response representation). Thus, on occasions when T2 cannot be reported (i.e. an AB deficit occurs), this is caused not by the presence of response inhibition but rather from its absence.

According to this explanation, the ability to correctly report T2 is not contingent upon the degree to which the response to that stimulus is facilitated or inhibited, but rather upon the contrast in activity between T1 and T2 response representations. This assumes a binding mechanism that is sensitive to the input of competing representations. When inhibition of the T2 response is not initiated, that representation remains highly activated (facilitating a related probe response) and the resulting mutual interference between T1 and T2 results in a binding error. T1 is more likely to be bound correctly, as it had sole access to binding resources before the onset of T2.

In artificial neural networks, an inhibited node is usually unlikely to exert any influence on other nodes. This could potentially contradict the claim that an inhibited response (i.e. T2) can nevertheless be bound to other representations. It is important to remember however, that in order to successfully complete the task, all response representations are likely highly activated throughout the experiment. Thus, an 'inhibited' representation (relative to inactive or facilitated representations) is still active enough to communicate with and exert influence on other representations. In other words, it is inhibited relative to other response representations but has an activity state well above zero.

The idea that the AB is caused by the absence of inhibition associated with T2 ties in with neurological studies of negative priming and the attentional blink. Special groups (e.g. older adults, ADHD sufferers, frontal lobe patients etc.) who demonstrate poor T2 performance (relative to healthy young adults) in an AB task, also show reduced negative priming. As noted in the introduction, these findings

do not support a simple inhibitory model of the AB in which T2 cannot be reported because it has been inhibited. However, if the AB is caused by the absence of inhibition (as outlined above) then these results suddenly make sense. People with damage to the areas of their brain responsible for inhibitory control show a larger AB because of their inability to resolve the competition between T1 and T2 response representations.

There is some converging evidence for an inhibitory account of the AB from a study conducted by Shapiro et al. (1997). In Experiment 1 of this study, participants had to identify a white T1 number amongst black filler numbers. T2 was an uppercase black letter which participants had to identify. T3 occurred in position T2+3 (SOA 270ms) and was a lower case black letter (see Figure 29). Again, participants had to identify this target. All target responses were non-speeded and occurred after the RSVP stream. On match trials, T2 had the same identity (i.e. big 'E', small 'e') and on mismatch trials they had a different identity (i.e. big 'E', small 'n').
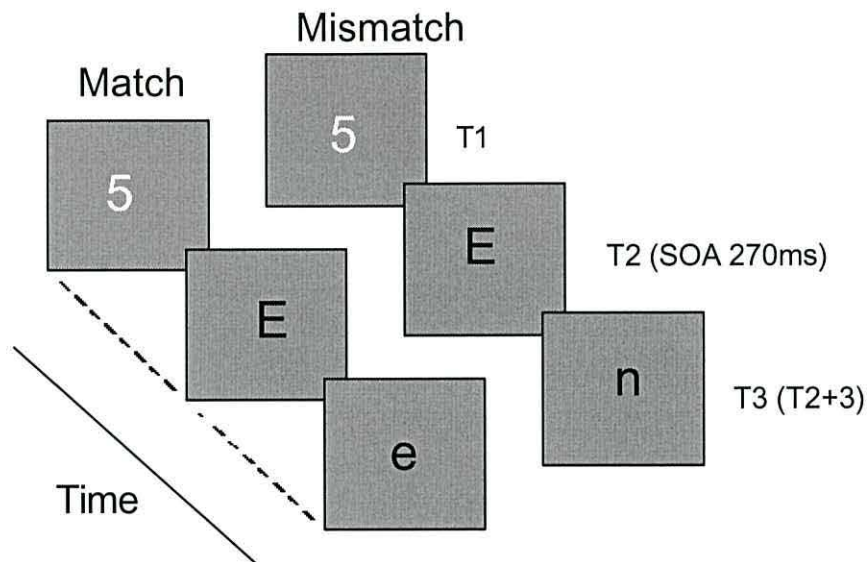
Figure 29. Showing match and mismatch trials. Adapted from Shapiro, Driver, Ward & Sorensen (1997).

Shapiro et al. (1997) found that when participants did *not* report T2 correctly they were more likely to report T3 correctly on match trials compared to mismatch trials. Conversely when T2 was correct they were more likely to report T3 correctly on mismatch trials compared to match trials. In other words, when T2 was incorrect, it positively primed correct report of T3. When T2 was correct, it negatively primed correct report of T3. These results would seem to correspond well with the results from Experiment 9 in this thesis. Shapiro and his colleagues argued that the AB prevents tokens (i.e. identities) being formed but does not prevent the forming of type representations (i.e. abstract categories). Thus they argue that when T2 was correct, it interfered with forming another token for T3. In other words when T2 was correct, repetition blindness impaired participants' ability to respond to a T3 with the same identity. When T2 was incorrect (i.e. a token was

not formed), T3 did not suffer from token interference and since the forming of type representations is not hindered in the AB, T3 could enjoy facilitation in this case.

These results could just as easily be explained in terms of the inhibitory account of the AB. In contrast, there are at least two reasons why a repetition blindness account could not explain the results from Experiment 9. Firstly, repetition blindness has only been observed at SOAs of up to half a second. The SOA between T2 and the probe in Experiment 9 was always 900ms. Secondly, repetition blindness occurs when items have the same identity or look very similar. In Experiment 9, T2 and the probe were different letters entirely; the only thing they had in common was that they were associated with the same response.

So what about an inhibitory account of the Shapiro et al. findings? There is one major difference that would seem to make such a comparison problematic. In Experiment 9, the probe/T3 required a speeded response whereas in the Shapiro et al. study, it was non-speeded. Could inhibition associated with T2 affect the chances that a related T3 would be reported correctly? Neill and Terry (1995) used a flanker task to show that identification accuracy of a probe that was related to a previously ignored distractor could indeed be impaired. Thus, it is possible that what Shapiro and his colleagues interpreted in terms of a RB effect, was in fact the same response-based inhibitory effect observed in Experiment 9. One test of this would be to replicate their experiment but to increase the SOA between T2 and T3 so as to discount repetition blindness as the source of the effect.

Despite the differences between the two experiments the fact remains that the observed results were virtually identical and that whilst a repetition blindness account can explain one but not the other, an account based upon response inhibition can explain both.

As mentioned in the introduction, current models of the AB can be dissociated into online and offline accounts. Online accounts posit that the deficit occurs before T2 enters short-term memory (STM). In contrast, offline accounts postulate that the deficit occurs after T2 enters STM. A similar (but not identical) distinction could be made between different inhibitory accounts of the AB. To be clear, an online account would posit that inhibition of T2 is still present in the system when the probe is presented and it is this residual processing that is responsible for the effect. In contrast, an offline account posits that T2 is encoded with an inhibitory state and it is this state that is subsequently retrieved when the probe is presented. These accounts will be discussed in turn.

A online explanation of the AB and response inhibition

By this account inhibition associated with the T2 response stays in the system for a while, but will eventually dissipate. In all the experiments in this thesis, there was a 900ms lag between the distractor/T2 and the probe (ten letters). Thus an online account would have to posit that residual inhibition was present in the system for at least this interval. Previous research has shown that standard negative priming can

be observed with intervals between the prime distractor and probe target of up to 1200ms (Allport, Tipper & Chmiel, 1985; Tipper & Driver, 1988).

But how can an online explanation account for the facilitation observed when T2 was reported incorrectly? One could argue simply that for some reason or other, inhibition of the T2 response was not engaged. In this case, both T1 and T2 responses will be highly activated and as already noted this could lead to a binding error. The facilitation associated with the T2 response remains in the system long enough to prime the response associated with the probe.

An offline explanation of the AB and response inhibition

An offline account posits the same reason for inhibition of the T2 response, as the online account. That is, the T2 response is inhibited in order to increase the contrast between T1 and T2 response representations for the purpose of binding. The difference is that this model assumes that inhibition dissipates quickly and is then re-instated on presentation of the probe.

Tipper and his colleagues have recently argued that activity states (in their example, inhibition) are encoded into memory along with their associated event (Tipper, 2001; Tipper, Grison and Kessler, 2003). In the case of negative priming, distractors on the prime trial are encoded with an inhibitory state (or tag) that is retrieved when an identical item is presented as the target in the probe trial, leading to slowing of the participant's response to that stimulus. Borrowing from this idea, both T1 and T2 will be encoded with a kind of episodic tag (Neill, 1997) which

represents the activity of that representation at the time of presentation. It is not unreasonable to posit that this 'tag' includes information as to the activity of the target response at the moment of successful binding. Thus, when a subsequent probe is presented which requires the same response as T2, the inhibition associated with T2's response is re-instated and response times to the probe are slowed.

But what about the case when T2 is not reported? In this case, facilitation of the T2 response was observed. How is this facilitation re-instantiated (upon presentation of the probe) when successful binding was not accomplished? It might be that in this case, there is partial binding of the target of an order sufficient to re-instate facilitation when a subsequent probe is presented but insufficient to ensure that the participant responds correctly.

But which explanation is the right one?

The first two explanations outlined above posited that the effect in Experiment 9 results from some form of conflict between the distractor and probe. Both of these explanations have problems associated with them, not the least of which is that neither predicts an effect of SOA.

The third explanation posited that what appeared as response facilitation on T2 incorrect trials was in fact response inhibition resulting from the participant choosing a response that was related to the probe on Unrepeated trials. The Shapiro et al. (1997) experiment discussed earlier would seem to contradict this

explanation. In fact, it supports the fourth explanation given which was that response inhibition *does* mediate the AB. This is because in the Shapiro et al. procedure, T2 and T3 could any letter from a wide range of letters (i.e. A, D, E, N, R, T or Y). Thus when participants got T2 incorrect, it is unlikely that the participant would substitute the identity of a letter that required the same response as the probe on Unrepeated/mismatch trials. This result suggests that facilitation of response times could still be observed in the case when T2 is reported incorrectly. Also supportive of an inhibitory account of the AB, is the data from special groups (ADHD sufferers, older adults and frontal-lobe patients) who show a larger AB and reduced negative priming (i.e. reduced inhibitory control).

In conclusion, the findings from Experiment 9, Shapiro et al., (1997) and special group studies would seem to support the forth explanation which is that the absence of response inhibition associated with T2, causes the AB. With regards to an online or offline inhibitory account of the AB, it seems that the online account can better explain the presence of facilitation when the participant incorrectly reported T2 and so this explanation is favoured.

CHAPTER 6 – ISSUES RELATING TO GENDER

It was only when experiments 7 and 8 were being run in tandem that a relationship between gender and post-target inhibition was discovered. It is for this reason that only these two experiments have equal numbers of males to females. Nevertheless, there are some consistencies between experiments which seem to suggest 1) females show either less inhibition than males or facilitation at SOA 90ms 2) females are generally slow to respond to the probe when a distractor appears at SOA 90ms. As already noted, the only significant effect of gender is in Experiment 8 (see Table 8 below).

Table 8. Showing interactions between Repetition, SOA and Gender by experiment.

		RATIO			
Experiment	Total *n*	F/M	% Females	% Males	GenderXRepetitionXSOA
1 - Basic Effect	25	19/6	76	24	p = .08
2 - Control	25	22/3	88	12	p = .23
3 - Similarity	20	17/3	85	15	p = .72 (XSimilarity)
4 - Templates	20	19/1	95	5	p = .66
5 - Object I	17	15/2	88.2	11.8	p = .89
6 - Response I	17	15/2	88.2	11.8	p = .68
7 - Object II	20	10/10	50	50	p = .33
8 - Response II	20	10/10	50	50	p < .01
9 - AB	8	8/0	100	0	n/a

Note. In Experiment 3, the analysis included the variable of Similarity.

Apart from experiments 7 and 8 the only other experiment to have a reasonable ratio of males to females was Experiment 1 (19 females to 6 males). Also, the gender analysis was marginally significant in this experiment ($p = .08$). Figures 30 and 32 show the data from Experiment 1 split by gender.
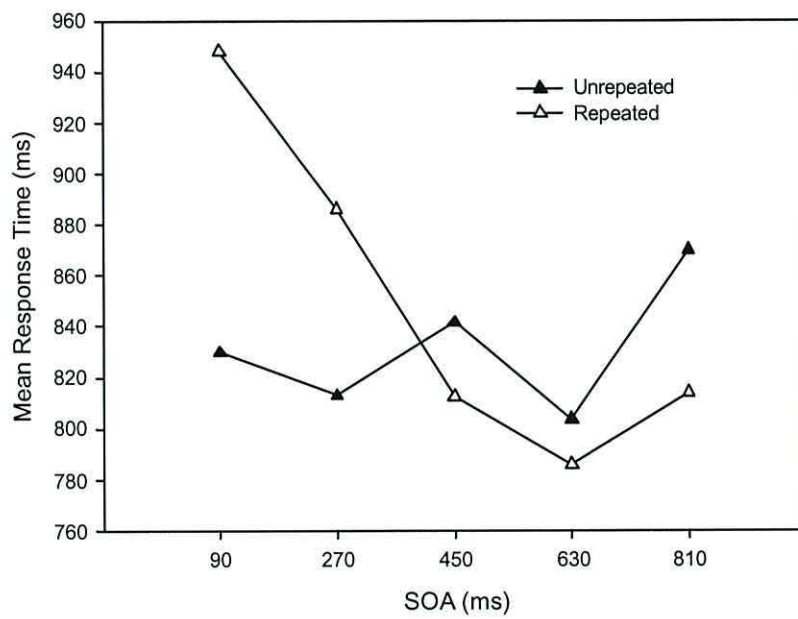
Figure 30. Experiment 1 MALES - Mean response time to the probe in Repeated and Unrepeated conditions.
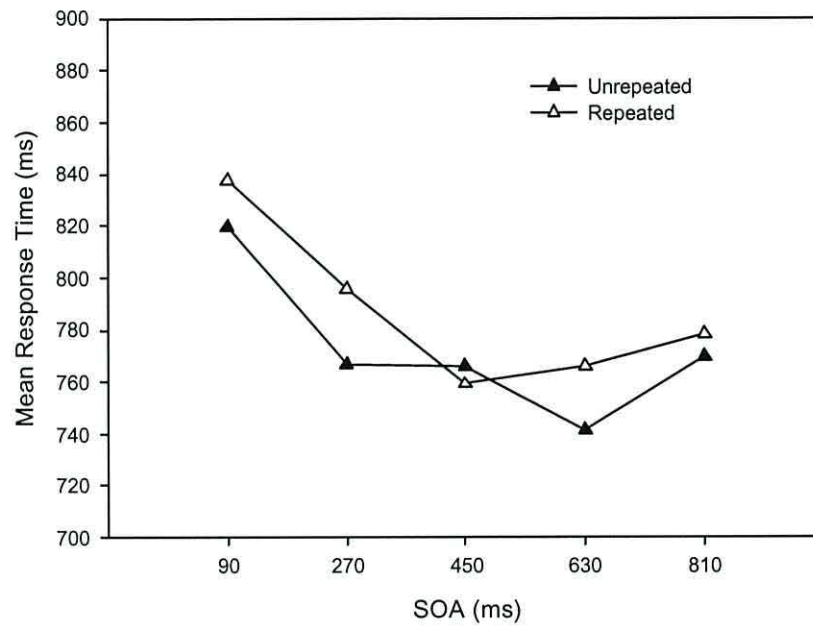
Figure 31. Experiment 1 FEMALES - Mean response time to the probe in Repeated and Unrepeated conditions.

Males showed more inhibition at SOA 90 and 270ms compared with females. Also, the difference in response times between SOA 90 and 270ms in the Unrepeated condition was smaller in males than females. This is consistent with the findings from Experiment 8 where there were marked differences in response-based inhibition between the genders (see Figures 24 & 25). Figure 32 shows response times in the Unrepeated condition collapsed across Experiments 1 and 8.
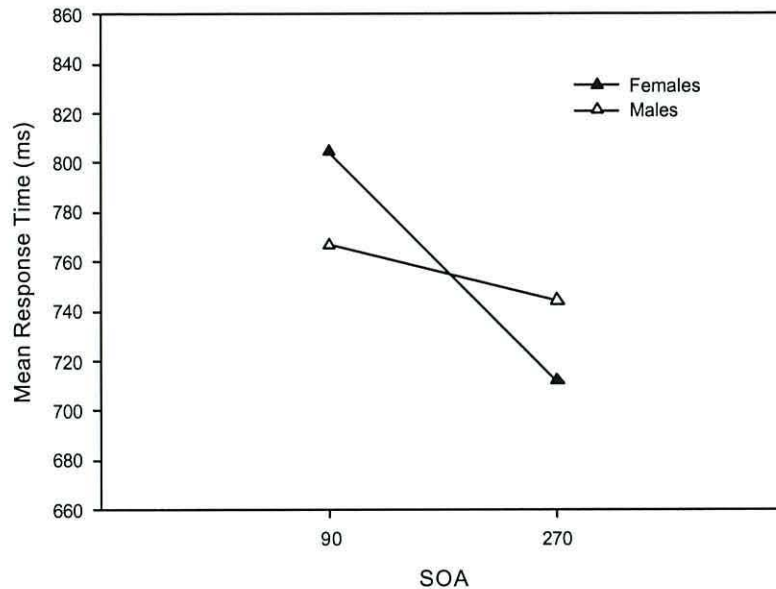
Figure 32. Mean response times at SOAs 90 and 270ms in the Unrepeated condition collapsed across experiments 1 and 8.

Since there is no relationship between the distractor and the probe (neither identity nor response) in the Unrepeated condition, it seems logical to conclude that the apparent jump in response times at SOA 90ms is caused by general taxing of the system when a distractor is presented immediately after the target. This is consistent with the finding that the T+1 item is extremely important in temporal selection (Botella, 2001; Chun & Potter, 1995; Raymond et al., 1992). Figure 32 shows that females are more susceptible to this general interference than are males. Also, females tend to show less inhibition at SOA 90ms (Experiment 1) or even facilitation (Experiment 8). This could explain why no inhibition was observed at SOA 90ms in Experiment 4 as in that experiment the ratio of females to males was 19/1. It might also explain why there was a significant difference in response times

in the Unrepeated condition between SOA 90 and 270ms. What is it about gender that causes the differences at the T+1 position? Unfortunately there is no literature pertaining to temporal selection and gender. It may be that females cannot initiate inhibition to the same extent as can males. Whatever the reason, it is clear that gender effects in temporal selection deserve further investigation.

CHAPTER 7 – GENERAL DISCUSSION

The experiments in this thesis have demonstrated that distractors that occur in close temporal proximity to a target negatively prime a related probe. This effect was termed 'post-target inhibition' in reference to the mechanism (i.e. inhibition) that has been favoured throughout this thesis to account for the negative priming phenomenon. Experiment 1 showed that post-target inhibition lasts at least 270ms after target onset. In Experiment 2, participants were no longer required to respond to the red target letter and post-target inhibition was effectively eliminated. This demonstrated that the effect is a result of selecting a target amongst rapidly presented items that could potentially interfere with the selection.

Experiment 3 attempted to investigate the role of perceptual similarity between the target and distractor. When the target and distractor were similar letters, the latter produced positive priming at early SOAs switching to negative priming at later SOAs. One explanation was that low level target features were activated in order to facilitate target detection. This had the effect of priming a distractor that was similar perceptually. Once the key feature was detected, this activation would change to inhibition in order not to activate features associated with a behaviourally irrelevant stimulus i.e. the distractor. It was argued that the absence of post-target inhibition when the target and distractor were dissimilar letters was due to the inactivity of the target template associated with the distractor during target selection. This may have been because participants were not expecting to respond to items on this template until the end of the trial when the

probe was presented. In Experiment 4 the target and distractor templates were both active during target selection. Whilst the results were not significant a t-test showed that post-target inhibition was present at SOA 270ms indicating that distractor representations must be active during target selection in order for interference to be present and for subsequent inhibition to be applied to those representations.

Experiments 5 to 8 attempted to dissociate post-target inhibition into object- and response-based components. In these experiments the target template was made up of three target letter triplets, each with an associated response. The results from Experiments 5 and 6 were not significant. It was argued that participants were having a hard time forming response categories. For this reason, the target letter triplets were simplified to three consecutive letter triplets in Experiments 7 and 8.

Experiment 7 demonstrated that if the distractor was presented immediately after the target, then its associated object representation (i.e. the letter identity) was facilitated. Experiment 8 showed that distractor response representations are inhibited for at least 270ms after target presentation. This latter effect was mediated by the gender of the participant. Experiment 9 demonstrated an interaction between post-target inhibition and the attentional blink. What follows is a discussion of the implications of these data for other areas of attention research.

Implications for Negative Priming and Other Inhibitory Phenomena

The most important finding in terms of negative priming is that the effect can be observed in the temporal domain as well as in the spatial domain. It has been shown in at least three experiments in this thesis, that distractors presented in close temporal proximity (within 270ms) to a target negatively prime a related probe stimulus.

Selective Inhibition and Episodic Retrieval

In negative priming, response times to a previously ignored distractor presented simultaneously with the target are slowed. Both the selective inhibition and episodic retrieval accounts of this phenomenon posit that NP is caused by events that occur during target selection. Tipper and his colleagues have argued that attended stimuli are compared against a target template. Those stimuli that do not match the target template (i.e. distractors) receive inhibitory feedback. This interferes with responding to a subsequent identical probe. The implications of the experiments in this thesis for the selective inhibition account of negative priming are that selection continues after the offset of the target stimulus and that post-target stimuli are also compared against the target template.

Tipper and his colleagues argue that inhibition is a means of overcoming interference between the target and distractor on the prime trial. Originally Tipper proposed that during the prime trial, inhibition was applied to the distractor representation and slowly decayed with time (Tipper, 1985). If the probe occurred

before the inhibition associated with the distractor had completely dissipated, then NP would be observed. For this explanation to account for the results in this thesis, it would have to be argued that residual inhibition was still present 900ms after the onset of the distractor. This is the lag between the distractor and the probe (i.e. 10 items with an SOA of 90ms each). It would also have to posit that the items in between the distractor and probe did not interfere with the decay of that inhibition. Tipper, Weaver, Cameron, Brehaut and Bastedo (1991) have shown that negative priming can survive intervening items between the prime and probe trials as long as the intervening item is not a novel one or the ignored distractor. In the experiments in this thesis the distractor is never repeated and the letters presented between the distractor and the probe could hardly be considered novel. One prediction of this theory would be that were the temporal lag between the distractor and the probe to be substantially increased, NP would not be observed.

Other researchers have disputed the assertion that NP results from the need to inhibit the distractor. Neill has argued that the distractor on the prime trial is encoded with a 'do not respond tag' which leads to disruption when a response is required to an identical probe stimulus (Neill, 1997). As already noted, these two accounts of negative priming do not contradict one another if one simply posits that the 'do not respond' tag is based upon the activity state of the distractor at the time of encoding (Tipper, 2001). In other words, inhibition associated with the prime distractor is encoded along with that item and is then re-instated on the probe trial resulting in slowing of the participant's response. The problem here is the means by which inhibition (or a 'do not respond' in the case of the episodic retrieval

model) is re-instated. Both the selective inhibition account and the episodic retrieval account posit that the inhibition/episode is retrieved when an identical object is subsequently presented as the probe. But in Experiment 8, the distractor and probe were different letters (i.e. the response-based component), so how could the inhibition/episode be retrieved? Obviously, one would have to argue that in this case, the probe response is the cue for re-instating response inhibition associated with the distractor.

Incidentally, the concepts of retrieval of inhibitory states vs. residual inhibition (described above) do not necessarily conflict with one another. It is possible that both mechanisms run in parallel or that depending on task-demands, one or other of them is involved.

It is difficult to see how an episodic retrieval account of NP such as that proposed by Neill (1997) could account for the data in this thesis. For example, the inhibition observed in Experiments 1, 4 and 8 is mediated by the SOA between the target and distractor. Generally speaking, this inhibition is greater at short SOAs and then disappears by SOA 450ms. How could a simple 'do not respond' tag account for changes in effect magnitude with SOA? The same argument could be levelled against an episodic retrieval account of NP. Namely, shouldn't a 'do not respond tag' produce the same amount of NP in every situation? So then why is greater NP observed when selection difficulty between the target and distractor is increased? It has been argued that in this situation the distractor is processed to a deeper level resulting in a memory tag which is that much more robust (see Fox,

1995). The more robust the 'do not respond' tag is, the greater the disruption (and consequent negative priming) when an identical probe is subsequently presented.

So in order for an episodic retrieval account to explain the data from this thesis one would have to argue that distractors presented until at least 270ms after the target are encoded with a 'do not respond' tag. To explain the differences in NP observed with SOA, one would have to posit that distractors presented in close temporal proximity to the target are processed to a deeper level resulting in a more robust tag and greater NP. Whilst this is certainly possible, it implies that the effect is determined by a reciprocal relationship between the target and distractor. At this point, the episodic retrieval account is sounding more and more like the selective inhibition model.

An additional difficulty for the episodic retrieval account is the fact that in Experiment 9 (i.e. the AB experiment), negative priming was observed when the participant got T2 correct. Presuming that the participant would not wish to give T2 a 'do not respond' tag (given that they are required to report it), an episodic retrieval account cannot explain this effect. There are many problems with using a retrieval account based on tags to explain the results from this thesis. However, most of these problems disappear if one posits the retrieval of inhibitory states rather than tags; inhibitory states which are produced as a result of selecting a target against post-target distractors.

Feature Mismatching and Temporal Discriminability

Park and Kanwisher (1994) argued that negative priming is due to a mismatch between the distractor on the prime trial and the same item as the target on the probe trial. In the case of a word-based negative priming task, the distractor word on the probe trial may occupy a different location (e.g. left of fixation) or be a different colour than the target word in the ignored repetition condition. The data from Experiment 1 does not support a mismatch model as the distractor and probe letters were always black and presented at fixation. There was no mismatch and yet negative priming was still observed. Similarly in Experiment 8, negative priming was observed despite the distractor having a different identity to the probe (the response-based component). The mismatch theory contends that for negative priming to occur, the distractor and probe must have the same identity in order for there to be a discrepancy when perceptual features associated with that identity differ.

With regard to the first of these criticisms, it could be argued that a mismatch is created as a result of the distractor and probe sharing different temporal locations. Were this the case, then the mismatch theory becomes the temporal discriminability theory. This latter theory proposed by Milliken at al. (1998) holds that when a prime trial distractor is repeated as the target in the probe display, it could be characterised as new or old and it is this temporal mismatch that leads to slowing of the participant's response. The same criticism of an episodic retrieval account of negative priming can be levelled at the temporal

discriminability theory. Namely, that it cannot account for the attenuation of negative priming with SOA (between the target and distractor) given the fact that the ISI between the distractor and the probe was kept constant (900ms/10 items). In other words, if negative priming is due to the temporal lag between the prime and the probe, then the magnitude of negative priming observed should always be the same if this lag is kept constant. It could be argued that at short SOAs, the distractor is processed differently, thereby effecting the temporal mismatch in such a way that the magnitude of negative priming changes.

The concept of a distractor presented in close temporal proximity to a target being processed differently, than one that is temporally distant, could be used to support an episodic retrieval and temporal discriminability model of the data in this thesis. The problem is that this explanation is post-hoc and it is not clear how such a suggestion could be instantiated in either of these models. On the contrary, the idea that negative priming fluctuates with the level of interference between the target and distractor is at the heart of the selective inhibition account of negative priming. Thus, such an account can easily explain the effect of SOA in these experiments.

Inhibitory Tagging

The theories of selective inhibition and episodic retrieval have much in common. Whilst the former emphasises encoding of the distractor, the latter emphasises retrieval of an attentional state. As already noted, these theories need not be mutually exclusive and may be synthesised into a model whereby inhibitory tags

are retrieved on presentation of the probe stimulus (Tipper, 2001: Tipper, Grison and Kessler, 2003). A similar idea has been put forward by Fuentes, Vivas & Humphreys (1999) to account for the inhibition of return phenomenon (IOR). In IOR, when a target appears in a previously ignored location, response times are slowed. Fuentes et al. used an IOR task in conjunction with a flanker interference task. In the latter task, participants are presented with a target that is flanked by a distractor. Both the target and the distractor may be a letter or number. Participants make a speeded response as to whether the target is a letter or number. Response times are slowed when the target and distractor have opposite responses associated with them i.e. the target is a letter and the distractor is a number, compared with when the two are congruent (i.e. letter – letter). Flanker interference is thought to reflect response competition between the target and distractor. Fuentes et al. had participants attend three boxes, one central and one on either side. As in the standard IOR procedure, one of these boxes was cued. In this case, the box was thickened temporarily. The cue was non-predictive of the location of the subsequent target. Participants made a speeded response as to whether the target was a letter or number.
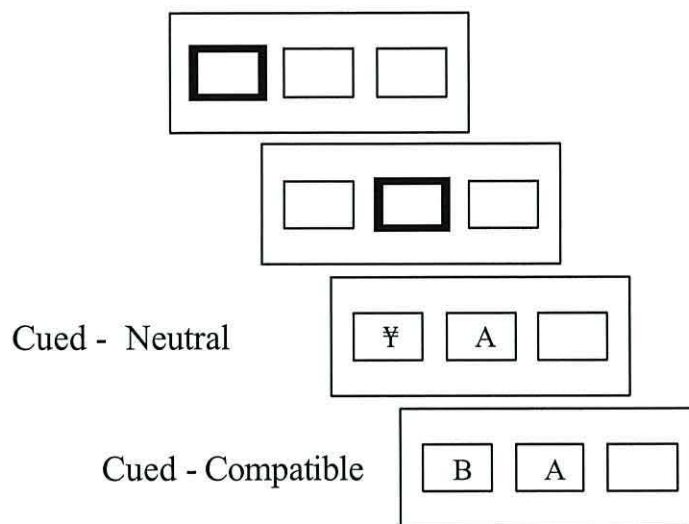
Figure 33. IOR procedure in conjunction with flanker interference task. Adapted from Fuentes, Vivas & Humphreys (1999).

In the Cued – Compatible condition, the target was flanked by distractor of the same response type (i.e. letter – letter). In the Cued – Neutral condition, a distractor of a different response type (i.e. letter – symbol), flanked the target. Fuentes et al. found that the usual flanker interference effect was reversed. Participants were slower to respond in the Cued – Compatible condition relative to the Cued – Neutral condition.

This result ties in nicely with the data from Experiment 8. In the Fuentes et al. experiment, the distractor that flanked the target was inhibited because it occurred in a location that had previously been ignored (the cued location). Because the target required the same response as the distractor in the Compatible condition, it was similarly affected. This condition could be considered analogous to the Response-Repeated condition in Experiment 8 in which the distractor

response was inhibited *not* because of its location, but because of its temporal proximity to the target. This had the effect of slowing participant responses to a probe that shared an identical response, just as RTs were slowed to a response compatible target in the Fuentes et al. experiment.

Fuentes at al. suggests that the cued location in the IOR paradigm is given an inhibitory tag. This tag affects the distractor when it appears subsequently in the cued location. The Cued – Compatible condition provides converging evidence for the results of Experiment 8 in this thesis, in which response times to a target (the probe in Experiment 8) are slowed depending on whether or not it is linked to a response representation that has previously been inhibited. Also, the concept of inhibitory tagging represents an integration of the selective inhibition and episodic retrieval models of negative priming which could potentially be used to explain post-target inhibition.

Implications for Temporal Dual-Task Paradigms (AB, PRP & RB)

There are numerous models that have been proposed to account for the Attentional Blink (AB), the Psychological Refractory Period (PRP) and Repetition Blindness (RB). The majority of these models posit that for some reason or other T2 is not processed completely and that some target representations are not activated above a threshold necessary for consolidation or binding. This idea of incomplete processing of T2 (a target that participants 'want' to identify/detect) implies that a behaviourally irrelevant distractor item should be processed to very low level, if at

all. On the contrary, the results from this thesis demonstrate that relatively high–level distractor representations e.g. response representations (Experiment 8), are being activated and then subsequently inhibited. None of the models put forward to account for the AB, PRP and RB would predict that a distractor item could negatively prime a probe stimulus when the two are only related by their associated response.

As noted in the introduction, researchers have tended to view phenomena such as the attentional blink (AB), the psychological refractory period (PRP) and repetition blindness (RB) as disparate phenomena. This belief has come from studies that show a change in the magnitude of one effect but not the other, as a result of some experimental manipulation (Chun, 1997). Given that the paradigms are already different in many ways, it is not surprising that a given manipulation differentially affects one phenomenon. It does not automatically follow that the same cognitive processes do *not* subserve both effects. An additional problem is that there is no consensus within each paradigm as to the source of the effect. In the case of the attentional blink, some believe that memory processes are responsible (Raymond et al., 1992) whilst others believe that a central limitation of attention is to blame (Jolicoeur, 1998). The important point here is that the solution likely reflects all of these mechanisms; so that labelling a phenomenon as 'memory-based' for example, could never tell the whole story.

What is needed is a mechanism that can operate on many different stimulus representations e.g. semantic, response, long-term, short-term, categorical etc. This premise is at the heart of the selective inhibition model in which task demands

determine the level on which two stimuli interfere with each other and consequently, the level on which inhibition will act on those stimulus representations. The data from Experiments 7 and 8 demonstrate that inhibition may affect one level of stimulus representation (i.e. a response-based representation) but not another (i.e. an object-based representation). There is also converging evidence from another paradigm that inhibition can effect more long-term memory-based distractor representations. By manipulating the contextual saliency of stimuli in the standard IOR procedure, researchers have observed the effect when the SOA between the cue and the target is 13 minutes (Tipper et al., 2003).

Inhibition is a flexible entity that can affect several levels of stimulus representation depending on task demands. It is therefore a very good candidate for a unified model of the phenomena such as the AB, PRP and RB, the causes of which have been attributed to many different levels of processing. As noted in the introduction, there are several striking similarities between these paradigms. Firstly, report of T2 is impaired if it occurs within 300-500ms of T1. Secondly, the effects all depend on whether or not the participant is required to report the first target. When participants do not select T1, there is no impairment in reporting T2. With regards to these similarities, it has been shown that a) post-target inhibition lasts at least 270ms after target onset and b) post-target inhibition is virtually eliminated when selection of the target is not required.

The AB, PRP and RB have been hypothesised to involve processing of perceptual, attentional and memory-based stimulus representations to differing

degrees. I have argued that this reflects differences in the task demands of each of the three phenomena. Experiments 7 and 8 demonstrated that task demands modulate which distractor representations are accessed and then subsequently inhibited or facilitated.

The aim of Experiment 9 was to see whether response-based post-target inhibition was heavily involved in the attentional blink paradigm. Of the two inhibitory components dissociated in Experiments 7 and 8, it was judged that the response-based component shared a more similar time-course to the AB and thus was more likely related to this phenomenon. There was a significant interaction between the presence of inhibition and the participant's ability to detect T2. Several possible interpretations of the results were discussed. One of these proposed that the AB results from the *absence* of response inhibition associated with T2. In this explanation, inhibiting the T2 response reduces the interference between the two targets thus increasing the likelihood that both responses will be bound correctly. When response inhibition is not initiated, then T1 and T2 responses are both highly activated and the potential for binding errors (especially a T2 error) increases.

Another potential explanation for the data was that response inhibition was being applied irrespective of whether or not the participant correctly identified T2. When the participant incorrectly identified T2 he/she instead chose a response that by chance was the same as the probe in Unrepeated trials. Thus Unrepeated trials became Repeated trials and vice versa. This kind of explanation goes against a response inhibition account of the attentional blink. It may be that the same

mechanisms that cause the attentional blink also cause post-target response inhibition.

The results from Experiment 9 are inconclusive, as are the arguments that other post-target deficits such as PRP and RB result from inhibition. However, the experiments in this thesis do offer substantial support for the role of inhibitory mechanisms in temporal dual-target selection. If in the future, it were to be demonstrated that T2 (depending on whether or not it was accurately recalled) negatively primed a related probe in each of the three paradigms discussed, then this would surely be a strong case for arguing that these are inhibitory phenomena.

Implications for studies of Temporal Binding

The aim of this thesis has been to argue that inhibition can aid selection in the temporal domain just as it does in the spatial domain, by reducing interference from distractor stimuli. When trying to select a target amongst distractors there exists the potential to commit an intrusion or binding error. When this happens, the identity of one of the distractors is substituted for that of the target. Botella et al. (2001) argued that binding of a target presented in close temporal proximity to distractors, is achieved with the aid of two modules, one detecting the key feature (Module K) and the other detecting the response dimension (Module R). If attention is focused in time, then these features are bound correctly and the participant responds correctly to the target. If attention is not focused in time, then the system uses a sophisticated guessing mechanism whereby the response feature

with the highest activation is bound to the key feature. Sometimes this results in a correct response or 'lucky hit' but sometimes it results in an intrusion error.

As already noted, Botella and his colleagues do not explicitly describe how attention is focused such that the correct response is bound with the correct identity. Results from this thesis demonstrate that post-target distractors are inhibited. This could be the 'focusing of attention' to which Botella and his colleagues allude.

In the selective inhibition account, visual input is compared against a target template. Input that matches the template receives excitatory feedback whilst input that does not, receives inhibitory feedback. Applying this concept to temporal binding, when the key feature is detected there will be a number of active representations in the system belonging to distractors that were presented before and after the target. These distractor representations can then be compared against the target template and those that do not match receive inhibition. If this inhibition is not initiated in time then the sophisticated guessing mechanism comes into play which binds the response with the highest activation to the key feature. Given the results of this thesis, it is likely that inhibition plays a crucial role in preventing temporal binding errors.

SUMMARY

The experiments in this thesis have demonstrated that a distractor presented in close temporal proximity to a target negatively primes a related probe. It has been argued by me that this reflects an inhibitory selection mechanism that serves to reduce interference caused by the distractor to the target, whilst the latter is undergoing binding operations. The locus of this interference is at the level of response representations. Post-target inhibition is likely involved in minimising competition between the target and distractor responses that could lead to a temporal binding error.

This work has far-reaching implications for temporal dual-task deficits (e.g. the AB, PRP and RB) since it provides an *a priori* hypothesis as to the basic mechanism mediating these effects, a hypothesis that has been lacking before now. Also, it provides a vital missing piece of the puzzle in studies of temporal binding errors, that is, how attention is focused in time.

CHAPTER 8 – FUTURE EXPERIMENTS

In the previous sections, the implications for several areas of attention have been discussed in relation to the experiments in this thesis. These areas included negative priming and other inhibitory phenomenon, temporal dual-task deficits and temporal binding. In this chapter, ideas for future investigations will be proposed that address some of the questions left unanswered. Some of the proposed experiments are important to determine the precise mechanisms involved in post-target inhibition, whilst others would inform the study of other related phenomena.

Residual inhibition or retrieval?

Does the negative priming observed in the current experiments result from residual inhibition or inhibition that is encoded during target selection and then subsequently retrieved when the probe is presented? As previously stated, Tipper and his colleagues (Tipper, 1985, Tipper and Cranston, 1985) first argued that distractor stimuli were inhibited in the negative priming paradigm and that this inhibition stayed in the system long enough to affect a probe that was related to the distractor by identity. Recently however, Tipper has argued that inhibition could also be encoded with the episode that triggered it (i.e. presentation of the distractor) and subsequently re-instantiated upon presentation of a probe that serves as a cue for retrieval (Tipper et al., 2003). These two viewpoints need not be mutually exclusive but it would be interesting to determine their relative contributions to the negative priming observed in the post-target inhibition paradigm. This could be

accomplished by varying the interval between the distractor and the probe. In the current experiments there have always between ten rapidly presented items between the two giving an inter stimulus interval (ISI) of 900ms. The prediction would be that if the negative priming is due to residual inhibition, then increasing the ISI should reduce the size of the effect. The inverse should also be true were the ISI decreased. On the other hand, if the negative priming reflects encoding of the distractor along with its inhibitory activity state and the subsequent retrieval of that episode, then changing the ISI should not make that much difference. The logic here is that an episodic memory trace should decay at a much slower rate than the activity settings of the system during selection. Thus a future experiment could be to replicate the basic procedure from Experiment 1 but with ISIs of 600ms, 900ms and 2000ms. If there were no significant change in the magnitude the effect over these ISIs then it would lend weight to the assertion that the negative priming in this paradigm reflects retrieval of inhibitory states.

What is the role of perceptual similarity?

Experiment 3 attempted to assess the effect of perceptual similarity between the target and distractor on post-target inhibition. There was an interesting trend towards facilitation of a similar distractor at early SOAs (see Figure 13). This may reflect bottom-up activation of target features in working memory, in order to improve target detection. It may be that in the case where the target and distractor have features in common (i.e. in the Similar condition of Exp. 3); the distractor

enjoys the same high activity state as the target and so positively primes an identical probe. A similar pattern (early facilitation) was also observed in Experiment 7 in which object-based distractor representations positively primed an identical probe. Therefore, the role of perceptual confusability remains an interesting topic.

One could address the issue by having a target template that included letters from which could be formed target-distractor pairs that were more or less visually confusable than other combinations. Table 9 shows the possible conditions with the target template consisting of the letters X, K, N, C, O, and Q where X-K-N and C-O-Q are considered similar target-distractor pairs whilst all other combinations are considered dissimilar.

Table 9. Showing examples of target-distractor combinations by condition.

Condition	Target	Distractor	Probe
Repeated – Similar	X	K	K
Repeated – Dissimilar	K	C	C
Unrepeated – Similar	C	O	Q
Unrepeated – Dissimilar	O	X	K

The prediction would be that increasing the similarity between the target and distractor letters should result in greater negative priming and that, as in other experiments, the effect should be mediated by SOA.

Does post-target inhibition mediate the AB?

As discussed in previous sections, there are a number of explanations for the results of Experiment 9 in which a significant interaction was found between the magnitude of the attentional blink and response inhibition. One theory was that what seemed like facilitation when the participant correctly identified T2 was in fact, inhibition of a response associated with a target that the participant incorrectly thought they saw. By this explanation, response inhibition was independent of the AB deficit. There are a two ways in which this explanation can be tested experimentally. The first of these would be to increase the number of possible response alternatives. In Experiment 9, participants responded by pressing '1' if they saw the letters A, B or C, '2' if they saw the letters J, K or L and '3' if they saw the letters S, T or U. By including a 4th possible response (i.e. the keypress'4'), the likelihood that when they get T2 incorrect they will choose a response that by chance will be the same as the probe in the Unrepeated condition will be significantly reduced. This would effectively produce a new base-line measure in which participants get T2 incorrect and choose a response that is not the same as the probe and that can be compared against the Repeated condition. If inhibition were observed using this new baseline it would support the assertion that

response-based inhibition does not cause the attentional blink since it is observed on both AB and non-AB trials. If on the other hand facilitation were observed under the same circumstances, it would go some way to supporting the claim that T2 accuracy does indeed depend on whether or not T2 is inhibited or facilitated.

Adding another response with three subordinate distractors would mean that participants would have to remember four responses and a total of twelve possible targets. This might be too taxing for participants. Therefore it may be preferable to include the 4th response but reduce the number of targets associated with each response by one so that there were only eight possible targets (see Figure 34).
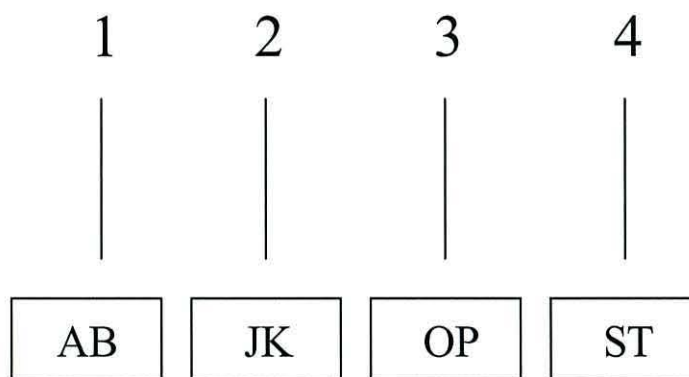
Figure 34. Target letter pairs with four response alternatives in a hybrid response-based AB experiment.

Having just two letters per response would not be possible in an experiment that was investigating object-based post-target inhibition (i.e. Experiment 7) as the target, distractor and probe must all be from the same response set thus three letters per response are required.

Even if adding a fourth response alternative does not provide evidence for a response-based inhibitory account of the attentional blink, there remains the possibility of an interaction between the AB and an object-based component of processing. In Experiment 7, the object identity of the distractor was facilitated if it occurred in the position immediately following the target. No priming, either positive or negative, was observed at the longer SOAs of 270ms and 450ms. As already noted, there is considerable evidence that the presence or absence of the T1+1 item can determine whether or not a blink is observed (Raymond et al., 1992; Giesbrecht and Di Lollo, 1998). It might be the case that the AB depends on whether the T+1 item receives positive or negative priming. In such an experiment, the probe would always be Repeated or Unrepeated in relation to the T+1 item. T2 would appear in position T+1 (SOA 90ms) or T+3 (SOA 270ms). This means that on half the trials, T2 would be related to the probe and on the other half not. This would enable us to determine 1) whether priming of the T+1 item interacts with the AB when it is a target (i.e. T2) and 2) whether priming of the T+1 item affects the likelihood that a subsequently presented target (T2 at SOA 270ms) will be blinked. Of course, the same problem that was present in Experiment 9 is also a factor here. That is, when the participant blinks T2 they may substitute the identity of a letter, which will be related to the probe on Unrepeated trials, thus 'flipping' the conditions. Also, on half the trials, T2 and the distractor will be different items (i.e. the T+1 distractor and T2 at SOA 270ms). Thus, it is necessary to have five identities per response. However, since the target(s), distractor and probe all come

from the same response set in the crucial object-based conditions, it would only be necessary to have two response sets (see Figure 35)[3].
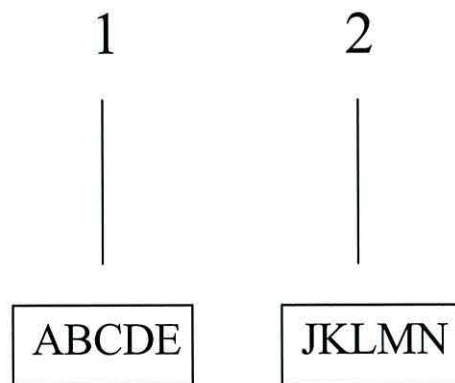
Figure 35. Identities and responses in a hybrid object-based AB experiment

A clear way of determining whether the AB and post-target inhibition really interact with one another would be to replicate Experiment 1 and take out the T+1 item. If the two phenomena are related then taking out the T+1 item should eliminate post-target inhibition as it does the AB (Raymond at al., 1992).

Do the AB, PRP and RB share a common inhibitory mechanism?

As already stated, the AB, PRP and RB have different task demands and so it is not surprising that they have been attributed to different mechanisms. However, there is the possibility that the three have in common an interaction between participants' ability to identify T2 and post-target inhibition. It is likely that the locus of

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[3] Two response sets are needed because there must also be some response-based catch trials in which the probe requires a different response to the targets, thus making this response unpredictable.

inhibition would vary depending on the paradigm since different target representations are required to a greater or lesser degree. For example, in the case of repetition blindness in which responding to the identity of a repeated T2 is impaired, it may be that there will be a strong object-based inhibitory component. In contrast, the psychological refractory period might have a strong response-based component reflecting the need of participants to make an online speeded response to T1. By running hybrid inhibitory experiments it would be possible to determine whether these phenomena have a common inhibitory mechanism, albeit an inhibitory mechanism that affects different representations depending on task demands.

Does post-target inhibition prevent temporal binding errors?

Most of the work on this topic has concentrated on post-target intrusion errors (Broadbent, 1977; Gathercole and Broadbent, 1984; Lawrence, 1971). However, recent research has shown that depending upon the target task, the pattern of errors may shift from a post-target to a pre-target pattern (see Botella et al., 2001). Botella, Garcia and Barriopedro (1992) had participants report either the colour or identity of a target uppercase word in an RSVP stream of lowercase words. They observed any intrusion errors from stimuli in positions –2 to +2 in relation to the target. They found a predominance of post-target errors when a colour response was required and a pre-target pattern when the identity of the word was required. If inhibition is a means of preventing temporal binding errors then the pattern of

inhibition should mirror the direction of the intrusion errors observed by Botella and his colleagues. This hypothesis could be tested by varying the target task (i.e. colour or identity) and by probing distractors that occur before as well as after the target.

Which features of a target do we process first?

There is a long-running debate in the object recognition literature concerning the order in which we process object features when we are trying to recognise that object. That is, whether we process the global shape of an object first or its local constituent parts. This is especially relevant to studies of temporal selection since objects or targets are typically presented very rapidly and so efficient identification is important. Navon (1977) conducted a series of experiments in which participants were presented with compound or hierarchical stimuli consisting of large letters (the global form) made up of smaller letters (the local form). Sometimes the global and local representations were congruent (i.e. the same letter) and sometimes they were incongruent (i.e. different letters).

Congruent   Incongruent

```
  U        U      U          U
  U        U      U          U
  U        U      U U UU U
  U        U      U          U
  U        U      U          U
     U U U
```
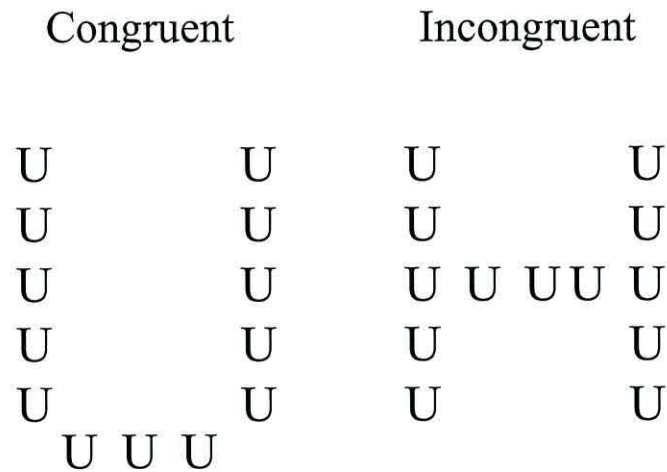
Figure 36. Congruent and incongruent hierarchical/compound letter stimuli.

Participants had to make a speeded response to a target letter that was either the local or global form. Response latencies to the global form were quicker than to the local form stimulus. Also, response times indicated that the global form interfered with the local form identification but that the local form did not affect responses when the participant was required to identify the global form. These two findings led Navon to conclude that global object representations are processed before local representations. In other words, he viewed object recognition as a global to local or top-down process. The effects he observed have been termed 'global precedence'.

The paradigm in this thesis is an ideal tool for confirming whether or not global representations are processed earlier than local representations. To my knowledge RSVP procedures have never been used to test this idea. In such an experiment, the target and distractor would both be compound letters. The target

would be a congruent compound letter whilst the distractor would be an

incongruent compound letter. The probe would also be a congruent compound

letter that corresponded to the identity of either the local or global distractor form

(see Figure 37). The probe task would be a speeded response.
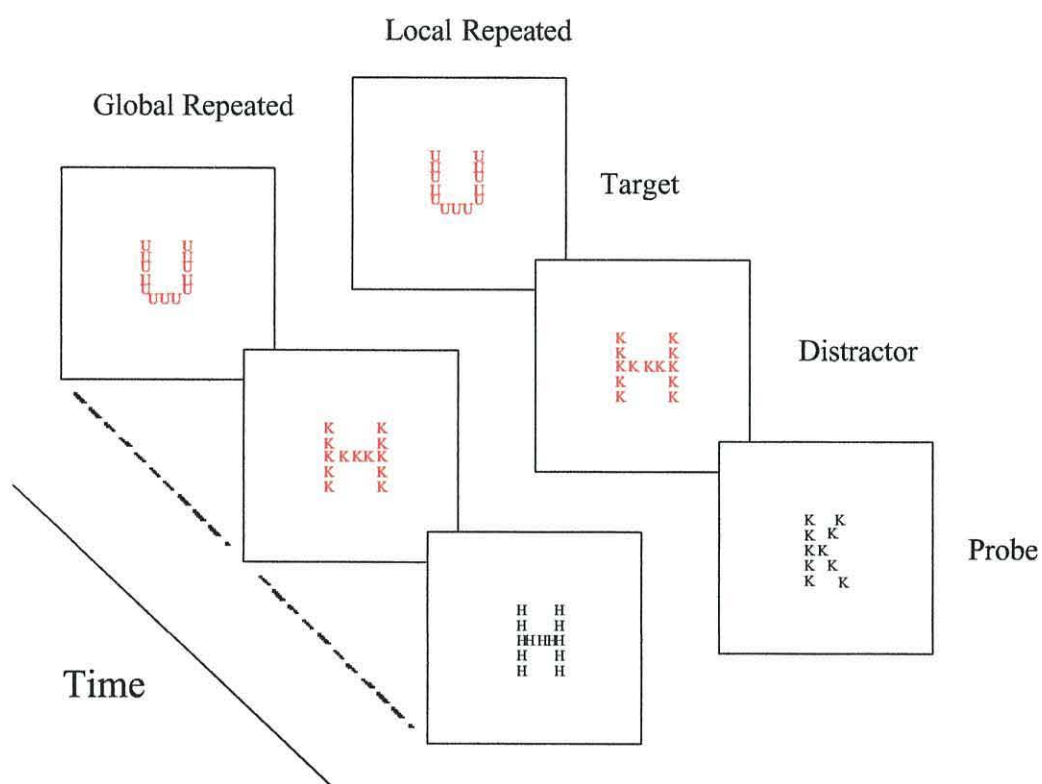
Figure 37. An example of Repeated conditions in which the distractor and probe correspond by their local or global forms.

The logic is that if a global distractor is being inhibited, at say 270ms, the target is

being processed on a global level at that SOA. As already mentioned, at the heart

of the selective inhibition model is the assumption that if a distractor is being

inhibited on a particular level of representation it is because it is interfering with

target processing on the same level. Thus it is possible to determine the time-course of global and local processing in relation to the target. According to the global precedence viewpoint global-inhibition should be observed at early SOAs whereas local-inhibition should be observed at later SOAs. If the time-course of global and local inhibition is similar than it could be argued that local and global processing proceeds in parallel. A further manipulation could be to change the target task so that participants were required to respond to the local form instead of the global form. This could have the effect of reversing the time-course of local and global inhibition.

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APPENDIX

Table A1. Raw data from Experiment 1, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | | | | | |
| | Unrepeated | | | | | Repeated | | | | | | |
Subject	90	270	450	630	810	90	270	450	630	810	Means	Std. Dev.
1	688	661	600	668	606	652	664	657	630	713	653.65	34.66
2	815	692	778	846	798	833	903	733	720	844	796.05	65.69
3	1037	1043	909	973	1025	958	995	907	1067	968	988.05	55.09
4	909	869	891	821	849	911	957	838	870	837	875.00	42.10
5	745	557	576	565	556	670	596	537	581	575	595.80	63.51
6	855	837	796	886	800	820	836	779	776	858	824.20	36.54
7	1093	899	915	881	935	994	980	1030	908	967	960.15	66.28
8	765	763	809	776	799	814	823	831	720	803	790.25	33.95
9	1303	1284	1256	969	1497	1568	1506	1329	1271	1095	1307.60	185.03
10	777	837	856	802	782	824	769	770	899	731	804.50	49.58
11	612	571	534	578	515	659	653	549	592	547	580.85	48.69
12	615	552	546	558	572	632	542	557	566	518	565.65	33.90
13	1077	1112	1087	1096	1141	1202	1102	1122	1172	1155	1126.45	40.15
14	871	774	898	706	692	973	869	775	659	807	802.40	100.56
15	780	762	784	750	761	810	787	747	738	782	769.90	22.14
16	816	801	695	750	696	875	688	747	680	722	746.95	64.97
17	983	1025	962	906	1051	1054	991	996	1051	1126	1014.35	60.75
18	564	528	531	517	587	592	518	531	547	595	550.85	30.99
19	818	799	971	1035	927	1180	843	749	749	945	901.55	137.55
20	754	737	756	613	765	728	779	676	764	668	723.85	53.82
21	538	563	562	512	538	600	543	542	568	578	554.40	24.88
22	662	546	566	552	617	635	584	555	583	578	587.70	38.35
23	676	597	579	610	592	681	670	579	575	563	612.05	45.77
24	626	624	683	577	683	647	656	638	610	635	637.85	32.21
25	1172	1012	1069	964	1065	1287	1175	1125	984	1062	1091.40	99.32
Means	821.90	777.70	784.24	756.34	793.76	863.92	817.12	771.86	770.98	786.76		
Std. Dev.	196.95	200.97	198.28	176.63	231.09	245.63	229.66	213.11	205.66	196.01		

Table A2. Raw data from Experiment 2, including standard deviation and mean scores.

	Response Time - all participants											
	Unrepeated					Repeated						
Subject	90	270	450	630	810	90	270	450	630	810	Means	Std. Dev.
1	707	749	689	731	660	822	766	679	764	710	727.55	48.74
2	628	815	657	679	663	666	695	648	672	688	681.10	50.89
3	636	642	641	589	612	653	619	616	667	639	631.30	22.58
4	574	516	575	582	583	571	565	579	542	549	563.50	21.76
5	559	548	567	519	534	537	536	552	573	504	542.75	21.49
6	577	600	636	564	615	624	648	657	548	554	602.20	39.84
7	773	800	693	874	808	833	782	752	763	735	781.20	51.09
8	516	488	509	507	511	494	503	470	524	525	504.55	16.87
9	673	589	628	633	611	664	659	608	618	608	628.90	28.04
10	567	564	550	556	587	599	561	549	527	554	561.05	20.25
11	549	549	600	590	592	545	570	530	626	613	576.25	32.37
12	607	644	601	691	614	652	641	600	658	648	635.50	29.64
13	622	603	616	610	623	705	638	626	606	615	626.10	29.57
14	767	824	776	981	725	783	740	736	749	831	791.05	75.67
15	607	607	535	531	532	581	520	568	511	539	552.85	35.27
16	533	605	538	571	550	557	552	564	576	563	560.85	20.55
17	566	645	604	580	581	602	606	629	579	599	599.00	24.27
18	599	649	640	679	659	650	636	661	662	675	650.80	23.00
19	866	813	851	889	869	926	873	848	892	930	875.55	35.55
20	692	646	749	690	618	578	663	652	676	660	662.35	45.70
21	545	560	540	501	553	567	533	548	575	541	546.25	20.63
22	628	650	590	583	558	596	624	573	577	587	596.35	28.50
23	569	581	561	543	602	636	567	582	543	562	574.50	28.07
24	531	515	509	555	521	556	564	551	516	548	536.45	20.40
25	571	577	585	604	573	595	592	569	577	566	580.75	12.68
Means	618.36	630.94	617.48	633.12	614.02	639.60	626.02	613.70	620.62	621.62		
Std. Dev.	86.06	97.63	83.70	123.12	84.09	103.73	90.10	80.39	94.18	99.61		

Table A3(a). Raw data from Experiment 3 when the target and distractor were SIMILAR, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | | | | | |
| | Unrepeated | | | | | Repeated | | | | | | |
Subject	90	270	450	630	810	90	270	450	630	810	Means	Std. Dev.
1	907	748	787	784	791	876	826	832	790	783	812.35	48.32
2	951	826	942	828	902	828	814	850	762	771	847.15	65.18
3	828	624	734	600	777	781	801	743	660	622	716.90	83.48
4	930	806	637	937	784	774	904	783	847	949	835.00	97.96
5	857	1048	958	848	816	881	895	815	946	941	900.35	73.38
6	613	593	527	584	618	582	611	533	538	604	580.20	34.97
7	784	965	724	821	839	883	761	1040	711	932	845.90	108.30
8	884	641	608	731	787	824	653	690	897	610	732.40	109.83
9	1277	1313	1200	1120	965	1492	1160	959	1293	1154	1193.20	161.87
10	925	924	1084	938	930	901	963	968	986	894	951.25	54.90
11	494	600	532	506	524	549	538	599	535	531	540.75	34.81
12	532	556	497	502	506	514	495	575	576	429	518.05	44.15
13	1550	1481	1411	1467	1360	1418	1196	1473	1171	1568	1409.40	134.20
14	895	726	778	826	749	829	752	651	769	880	785.30	73.72
15	1009	957	895	771	780	869	912	799	982	869	884.15	83.54
16	872	724	787	705	681	823	757	729	825	748	764.95	60.44
17	1008	1067	861	850	746	985	865	732	1069	732	891.40	133.31
18	668	647	695	591	613	625	568	558	554	612	613.10	47.22
19	911	600	663	596	544	496	556	578	772	667	638.20	123.15
20	681	671	623	649	601	688	637	702	626	641	651.70	32.50
Means	878.65	825.75	797.03	782.53	765.55	830.88	783.05	780.33	815.38	796.73		
Std. Dev.	239.49	252.10	234.57	226.05	192.38	255.66	193.24	216.08	212.81	250.99		

Table A3(b). Raw data from Experiment 3 when the target and distractor were DISSIMILAR, including standard deviation and mean scores.

	Response Time - all participants											
	Unrepeated					Repeated						
Subject	90	270	450	630	810	90	270	450	630	810	Means	Std. Dev.
1	856	898	757	776	845	901	892	959	838	684	840.50	81.41
2	892	702	752	813	841	957	899	869	828	850	840.25	73.41
3	818	752	765	696	686	848	638	634	743	749	732.85	70.47
4	982	761	734	848	827	933	786	903	640	833	824.60	100.52
5	986	945	933	889	932	914	944	1051	917	748	925.80	76.83
6	535	545	604	577	521	614	584	586	539	550	565.45	31.56
7	1031	914	945	728	892	906	1083	861	708	862	892.95	116.31
8	709	830	779	621	713	665	645	838	662	945	740.55	104.23
9	1052	1113	1115	1118	996	1170	1016	928	1209	1203	1091.90	92.68
10	1022	970	946	925	968	848	952	991	872	850	934.30	59.83
11	471	503	601	556	512	663	538	513	479	553	538.75	58.26
12	540	512	524	513	497	607	541	541	465	497	523.65	37.94
13	1580	1420	1319	1399	1273	1199	1402	1380	1201	1709	1388.15	159.85
14	765	807	873	850	774	766	867	801	893	731	812.65	55.08
15	720	706	979	921	900	903	589	937	860	773	828.60	125.49
16	827	668	816	761	765	840	756	678	723	786	762.00	58.93
17	916	878	1376	909	987	827	1056	1051	930	1046	997.40	154.20
18	600	554	607	580	678	656	632	723	683	662	637.40	52.42
19	610	522	566	574	626	650	594	567	497	601	580.45	46.07
20	715	722	687	741	681	683	648	668	600	723	686.65	41.71
Means	831.23	785.98	833.75	789.68	795.63	827.43	802.98	823.85	764.30	817.63		
Std. Dev.	250.74	226.92	234.35	212.46	191.88	168.97	228.67	215.58	210.80	269.39		

Table A4. Raw data from Experiment 4, including standard deviation and mean scores.

	Response Time - all participants											
	Unrepeated					Repeated						
Subject	90	270	450	630	810	90	270	450	630	810	Means	Std. Dev.
1	783	799	739	596	712	804	743	783	689	693	733.90	64.26
2	591	567	559	542	504	679	645	582	547	539	575.40	52.19
3	734	669	687	716	659	754	636	676	656	702	688.60	37.19
4	1226	709	756	713	862	980	831	721	803	883	848.30	158.58
5	547	518	534	533	574	606	562	595	527	539	553.35	29.80
6	651	561	624	542	500	653	545	551	555	489	566.90	57.53
7	1287	1044	1058	959	1025	1200	1134	970	995	1041	1071.30	105.25
8	724	654	619	600	608	703	698	620	627	588	644.10	48.02
9	561	579	520	550	466	527	487	487	454	461	509.10	44.56
10	752	681	670	989	682	883	956	829	742	667	784.95	122.06
11	1025	595	971	623	624	958	608	566	584	642	719.45	184.81
12	586	561	541	515	502	522	565	520	539	559	540.85	26.44
13	577	499	520	475	492	577	515	486	614	487	524.10	48.00
14	648	593	613	629	631	634	625	618	648	573	621.10	23.41
15	703	639	655	647	574	737	671	591	627	617	645.90	49.09
16	686	698	609	841	643	829	855	595	602	564	692.05	111.07
17	808	648	678	731	655	785	788	721	692	724	722.90	56.38
18	936	887	914	846	894	892	892	877	1034	979	914.90	54.89
19	499	460	481	489	461	535	477	416	439	485	474.15	32.81
20	760	872	712	690	693	803	946	691	868	661	769.45	97.57
Means	754.08	661.50	672.83	661.18	637.95	752.95	708.73	644.65	661.95	644.58		
Std. Dev.	215.11	144.66	154.67	150.08	149.38	174.43	179.65	140.20	159.80	160.91		

Table A5. Raw data from Experiment 5, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | |
| | Unrepeated | | | Repeated | | | | |
Subject	90	270	450	90	270	450	Means	Std. Dev.
1	764	663	703	647	579	732	681.25	66.08
2	877	736	856	894	797	748	818.00	67.48
3	896	919	900	897	882	913	900.92	13.12
4	718	727	713	721	642	630	691.58	43.68
5	580	513	495	628	467	565	541.17	60.08
6	835	824	757	718	834	663	771.50	71.54
7	942	1083	1037	1039	1117	1043	1043.50	58.87
8	820	944	872	822	1013	764	872.25	91.81
9	677	970	604	834	631	886	766.75	150.23
10	1055	1125	1032	1016	997	981	1034.33	51.43
11	747	620	551	686	572	491	610.75	93.66
12	1057	1035	826	852	1145	1216	1021.58	155.89
13	1183	1276	965	1280	1130	1055	1148.08	124.47
14	946	802	1001	929	939	853	911.42	71.45
15	1256	1124	1103	1219	1093	1214	1168.17	69.64
16	995	973	834	963	930	914	934.75	57.47
17	936	810	775	895	880	1036	888.58	92.87
Means	898.85	890.68	824.79	884.53	861.53	864.76		
Std. Dev.	178.24	204.59	175.46	184.09	216.43	213.46		

Table A6. Raw data from Experiment 6, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | |
| | Unrepeated | | | Repeated | | | | |
Subject	90	270	450	90	270	450	Means	Std. Dev.
1	867	906	807	836	844	757	836.00	50.94
2	639	779	782	747	850	788	764.00	69.90
3	847	536	629	870	709	586	696.17	138.16
4	759	867	891	945	883	820	860.83	64.13
5	595	548	565	698	556	638	599.83	58.21
6	1074	905	760	990	847	870	907.67	110.78
7	1103	1047	891	1174	978	1015	1034.50	98.47
8	809	698	882	838	802	719	791.17	70.30
9	976	950	1115	958	934	1022	992.33	67.30
10	1064	1079	1041	890	1192	980	1040.83	101.41
11	1412	1299	1479	1187	1321	1613	1385.17	149.83
12	1055	888	973	988	964	1013	980.17	55.76
13	1186	886	1002	899	929	843	957.42	123.87
14	881	998	941	942	932	1047	956.58	57.73
15	903	795	934	1000	847	838	886.00	74.47
16	1286	1442	1281	1393	1426	1292	1353.33	75.16
17	980	1241	1120	950	1124	1182	1099.25	113.65
Means	966.71	933.12	946.59	958.88	949.21	942.41		
Std. Dev.	215.83	242.47	224.26	167.72	214.71	253.42		

Table A7. Raw data from Experiment 7, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | |
| | Unrepeated | | | Repeated | | | | |
Subject	90	270	450	90	270	450	Means	Std. Dev.
1	584	517	506	511	518	536	528.42	28.80
2	504	488	515	471	532	494	500.50	21.26
3	466	460	463	452	447	467	459.00	8.12
4	594	579	597	565	570	575	579.67	12.82
5	589	510	520	574	557	534	547.25	31.14
6	683	623	628	610	635	632	635.00	25.14
7	851	833	816	854	830	726	818.25	47.57
8	713	720	682	665	633	697	684.67	32.55
9	695	738	750	713	749	672	719.42	31.83
10	636	596	647	598	620	660	626.17	26.14
11	570	609	613	586	614	614	600.92	18.54
12	648	591	570	613	591	612	604.00	26.68
13	588	574	543	545	552	562	560.58	17.76
14	725	628	643	620	685	714	669.08	44.99
15	507	495	514	514	524	529	513.83	12.12
16	473	467	482	454	436	501	468.83	22.48
17	633	657	686	603	651	668	649.42	28.78
18	823	766	694	789	754.5	704.5	755.17	49.34
19	528.5	546	570	534.5	565	591	555.83	23.75
20	675	705	659	672	690.5	670	678.58	16.45
Means	624.15	605.03	604.85	597.03	607.60	607.73		
Std. Dev.	106.10	105.27	93.98	104.55	100.67	80.09		

Table A8(a). Raw data from MALE participants in Experiment 7, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | |
| | Unrepeated | | | Repeated | | | | Std. |
Subject	90	270	450	90	270	450	Means	Dev.
1	883	752	824	941	915	771	847.67	77.57
2	776	775	895	900	780	874	833.17	62.37
3	782	759	712	771	725	722	745.00	29.17
4	579	596	573	629	539	568	580.50	30.08
5	729	670	667	768	756	670	709.92	46.57
6	654	662	655	665	685	599	653.17	28.96
7	823	758	772	987	799	732	811.58	91.31
8	632	630	613	609	596	594	612.08	16.10
9	505	468	482	522	473	491	489.92	20.38
10	675	685	665	844	686	729	713.92	67.32
Means	703.65	675.45	685.70	763.35	695.20	674.80		
Std. Dev.	116.30	95.15	121.23	155.25	131.12	112.97		

Table A8(a). Raw data from MALE participants in Experiment 7, including standard deviation and mean scores.

| | Response Time - all participants | | | | | | | |
| | Unrepeated | | | Repeated | | | | Std. |
Subject	90	270	450	90	270	450	Means	Dev.
1	632	566	582	620	578	580	593.00	26.43
2	715	591	597	711	611	639	643.83	56.07
3	697	675	614	753	699	643	680.17	48.43
4	1018	712	794	966	864	940	882.17	114.82
5	925	746	676	758	800	662	761.17	95.58
6	694	624	604	645	641	627	639.08	30.52
7	891	720	780	816	755	754	785.75	60.39
8	946	763	717	791	732	660	768.08	97.78
9	673	587	621	645	669	660	642.50	33.13
10	705	593	585	564	660	566	612.08	57.22
Means	789.50	657.55	656.95	726.85	700.85	673.00		
Std. Dev.	139.08	73.86	80.34	116.62	88.09	106.64		