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An Investigation of Masked Priming Mechanisms in Binary Classification Tasks

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Graduate Program in Psychology
A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

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AN INVESTIGATION OF MASKED PRIMING MECHANISMS IN BINARY CLASSIFICATION TASKS

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by

Jason R. Perry

Graduate Program in Psychology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

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Abstract

The goal of the present research was to examine the nature of masked priming with an emphasis on the influence of stimulus-response (S-R) associations. In *Chapter 2*, both the magnitude of the category congruence (priming) effect and the nature of the priming distance effect were assessed in two number classification tasks. Participants made either magnitude (i.e., is the target larger or smaller than ‘5’?) or identification judgments (i.e., press one button if the target is a ‘1’, ‘2’, ‘3’ or ‘4’ or the other button if the target is a ‘6’, ‘7’, ‘8’ or ‘9’). Priming distance effects in both tasks indicated that, regardless of task instructions, semantic activation played a key role in producing masked priming even when the identification task showed evidence of priming from S-R associations. In *Chapter 3*, category learning tasks were used involving stimuli having neither the ability to activate semantic information nor any *a priori* response associations. Participants learned, through feedback, artificially-defined category sets. Each category contained a prototype item that served as a masked prime. In the single-session tasks, responses were faster when a stimulus was primed by its own prototype versus the prototype of the other category, however, this (priming) effect only increased in size when participants performed the task over multiple sessions, indicating that it takes considerable time for the S-R associations to develop and impact priming. The research in *Chapters 2* and *3* was based on a prospective view of masked priming. There is, however, an alternative retrospective view supported by numerous demonstrations of prime validity effects (i.e., larger priming effects when the proportion of congruent trials is high). In *Chapter 4*, an arrow classification task with free choice stimuli was used to examine this debate. The prime-target relationship for the arrow targets was either: a) always congruent, b) always incongruent, or c) unpredictive. Prime validity effects for the free choice trials (i.e., trials involving “either way” stimuli, e.g., < >, for which either response was acceptable) occurred using both 77 ms and 165 ms prime-target intervals. The results in the unpredictive conditions support a prospective view of masked priming since they indicate that it was response bias suppression when the proportion of incongruent trials was high that produced the prime validity effects.

Keywords: masked priming, S-R associations, semantic activation, depth of processing, number classification, category learning, arrow classification, task strategies, response biases, prospective view of masked priming, retrospective view of masked priming, prime validity effects, memory recruitment account, priming distance effects

Co-Authorship Statement

The contents of *Chapter 4* were recently published in *Attention Perception and Psychophysics.* The contents of *Chapters 2* have been submitted to the *Canadian Journal of Experimental Psychology*. The contents of *Chapter 3* have been submitted to *Memory & Cognition.*

Each of these manuscripts are by Jason R. Perry and Dr. Stephen J. Lupker. They were all primarily written by Jason R. Perry.

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For the Glory of God who strengthens and helps us and upholds us with His righteous right hand (Isaiah 41:9)

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Chapter 1 – General Introduction

There is a pervasive belief that the presentation of stimuli outside of one's awareness affects behaviour. Advertisers, for instance, have for many years embedded images within their advertisements in order to affect one's desire for the advertised product. Electronic gaming machines have also been programmed to flash winning jackpot symbols in order to influence gamblers' behaviour. Although there is surprisingly little evidence about whether these techniques actually work, there is, as will be discussed, good scientific evidence that the presentation of stimuli outside of one's awareness can affect behavior. The questions addressed in this dissertation concern the nature of the processes by which that happens.

It has been known for some time that information which is not directly attended can influence behaviour. For instance, in the Stroop (1935) task subjects respond to the ink color of a color word (see MacLeod, 1991, for a review). The key finding is that responses are faster when the identity of the ink color and the word are congruent (e.g., the word BLUE written in blue ink) versus when they are incongruent (e.g., the word BLUE written in red ink). The standard explanation for Stroop effects is that the presentation of a stimulus automatically activates the response associated with the irrelevant dimension (i.e., the word's name) even though people are purposely not attending to the word and that processing is slowed down when that response conflicts with the appropriate response.

The notion that non-attended stimuli can impact processing due to the fact that they activate stimulus-response (S-R) associations also plays a crucial role in Klapp and Greenberg's (2009) theory of automaticity as well as Kornblum, Hasbroucq, and

Osman's (1990) dimensional overlap model. It is also an important assumption in research investigating visual selective attention (see Fox, 1995, for a review) and cognitive control (e.g., Bugg, Jacoby, & Chanani, 2010; Jacoby, Lindsay, & Hessels, 2003). In the Stroop task, however, the words are not actually presented outside of one's awareness and are, instead, clearly visible. To investigate the impact of stimuli that are presented outside of awareness, a more recently developed experimental technique of masked priming has typically been employed (e.g., Forster & Davis, 1984; Marcel, 1983).

In a masked priming paradigm, a forward mask precedes a briefly presented prime (typically 60 ms or less) which is then followed by a target stimulus that requires a response. In this situation, participants are typically unaware not only of the prime's identity but also of its existence. According to an S-R association account of masked priming, when the prime stimuli have an associated response (e.g., press the left response key when an arrow points to the left) that response is activated by the prime causing responses to be faster when the target is preceded by a prime which requires the same response as the target (i.e., a congruent trial) as opposed to a prime which requires a different response (i.e., an incongruent trial).

According to this view, subliminal stimuli are processed to only a fairly low level and, therefore, will not likely affect higher-level cognitive processing (e.g., gambling behaviour). Note, however, that there is an alternative view which is that subliminally presented stimuli are processed to the point that semantic information is activated with that semantic information producing the priming effect. Therefore, understanding how S-

R associations and semantic activation interact in order to produce subliminal priming effects is a vital area of cognitive research.

An S-R Association Account of Masked Priming

According to an S-R association account of masked priming, lower-level (non-semantic) associations are formed between target stimuli and their responses due to their repeated presentations and classifications (see, e.g., Abrams, 2005; Abrams & Greenwald, 2000; Damian, 2001; Neumann & Klotz, 1994; Klotz & Neumann, 1999). Once formed, presentation of these stimuli as masked primes produces a bias to respond with their associated response. This response bias aids target responding on congruent trials and interferes with target responding on incongruent trials.

One source of support for an S-R association account comes from Eimer and Schlaghecken's (1998) task in which participants responded to arrow targets that required a directional (i.e., left (<<) or right (>>)) response. These targets were preceded by masked prime arrows. When the interval between the prime and target was brief, responding was faster when the prime and target arrows pointed in the same direction (e.g., Eimer, 1999; Eimer & Schlaghecken, 2002; Schlaghecken & Eimer, 2000, 2002).

Interestingly, Eimer and Schlaghecken's (1998; 2002) results with a longer prime-target interval show exactly the reverse pattern, that is, participants responded significantly faster when the prime and target arrows pointed in opposite directions as opposed to the same direction (a "negative priming effect"). Measurements of event-related potentials (ERPs) helped explain this negative priming effect by demonstrating that a masked arrow prime initially activates the motor response which corresponds to the direction of that prime. However, as time passes this response activation diminishes and the opposite motor response becomes activated.

Further research has shown that, in addition to response latencies, masked arrow primes also affect response selection probabilities in tasks where arrow target trials are interspersed with trials involving either-way targets (< >), targets for which either response is legitimate (see Bodner & Mulji, 2010; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Perry & Lupker, 2010; Schlaghecken & Eimer, 2004; Schlaghecken, Klapp, & Maylor, 2009). Specifically, responses in these “free choice” trials are more frequent and faster when they match the direction of the masked prime at short prime-target intervals, but at longer prime-target intervals the pattern reverses (see especially Schlaghecken & Eimer, 2004). According to an S-R association account these effects occur because the masked prime activates its associated response making that response both more likely and more rapidly executed initially with the opposite response gaining strength as time passes.

Old Versus New Set Priming

A crucial prediction of any type of S-R association account of masked priming is that priming should only occur for primes that have been previously presented and responded to as target stimuli (i.e., “old set primes”), whereas primes which have not been previously responded to as targets (i.e., “new set primes”) should not produce priming since response biases have not been formed for these primes. Support for this prediction comes from Damian’s (2001) physical size (large or small) judgment task in which Dutch concrete nouns were presented as targets and preceded by masked primes. Specifically, a masked priming effect occurred such that responses were faster when both the prime and target corresponded to either large or small items (i.e., a congruent trial) than when the prime and target corresponded to items of opposite sizes (i.e., an incongruent trial) when old set primes were used (Experiment 1), but not when new set primes were used (Experiment 2).

An additional prediction of any type of S-R association account, which will be examined frequently in this dissertation , is that priming driven by response biases should increase in size over trials since response biases are formed and strengthened as a function of exposure to the target stimuli. Damian's (2001, Experiment 1) results using old set primes provide support for this prediction as there was, in fact, an increase in the size of the priming effect over trial blocks.

Evidence for Semantic Activation: Priming from New Set Primes

If all masked priming effects were due to the impact of S-R associations then it is likely that the processing of stimuli appearing outside of awareness only reaches a fairly low level and, therefore, such processing will not likely affect higher-level cognitive processing (e.g., gambling behavior). However, in contrast to Damian's (2001) results, another line of masked priming research has produced numerous demonstrations of priming from new set primes (e.g., Dell'Acqua & Grainger, 1999; Klauer, Eder, Greenwald & Abrams, 2007; Kinoshita & Hunt, 2008; Kunde, Kiesel, & Hoffmann, 2003, 2005; Naccache & Dehaene, 2001; Reynvoet, Caessens & Brysbaert, 2002; Reynvoet, Gevers & Caessens, 2005; Quinn & Kinoshita, 2008; Van den Bussche, Notebaert & Reynvoet, 2009; Van den Bussche & Reynvoet, 2007), results that challenge the notion that masked priming is due solely to S-R associations. That is, if masked primes merely activate learned S-R associations, then masked priming effects should never occur for new set primes because there has been no opportunity to form S-R associations for those primes. The fact that priming from new set primes is a common finding indicates that masked primes are often processed in a way that involves the activation of semantic information and that it is semantic information, as opposed to learned S-R associations, that is responsible for producing priming. The fact that masked primes can activate semantic information supports the possibility that stimuli presented outside of awareness can have a noticeable effect on higher-level cognitive processing.

For the purposes of this dissertation, what needs to be kept in mind is that S-R association and semantic activation accounts are not mutually exclusive. That is, demonstrations of semantically-based priming (i.e., priming from new set primes) does not rule out the possibility that, in some situations (e.g., Abrams & Greenwald, 2000; Damian, 2001), S-R associations may play an important role in producing masked priming effects. That is, even if masked primes inevitably activate semantic information, the possibility that S-R associations are also activated by masked primes and influence subsequent behavior is certainly not excluded. In fact, Kinoshita and Hunt (2008) recently provided data that suggest a role for S-R associations in masked priming even when new set primes are effective primes (i.e., when semantically-based priming arises).

Kinoshita and Hunt (2008): A Two-Component Account of Masked Priming

Kinoshita and Hunt (2008) demonstrated priming in a magnitude judgment task using both old and new set masked primes (replicating Naccache & Dehaene, 2001). However, in contrast to the previous research, Kinoshita and Hunt provided an analysis based on the full latency distributions for each condition. Their analysis demonstrated that, in the longer latency bins (i.e., the right tail of the distribution), the congruent trials in the old set prime condition showed a noticeable slowdown (relative to incongruent trial conditions as well as the congruent prime condition for the new set primes). As a result, old set primes did not produce a masked priming effect in these longer latency bins even though new set primes did.

Kinoshita and Hunt (2008) concluded that their results indicate that masked priming involves two different automatic components. One component reflects the congruence between the prime and target in terms of task-defined features (e.g., size in a size judgment task) and relies upon semantic information activated by the masked prime. The other component is assumed to be transitory and relies upon activation of S-R associations by the masked primes. It is the disappearance of this second component when latencies get to be long which accounts for the lack of priming from old set primes in the longer latency bins.

Kinoshita and Hunt's (2008) results are, therefore, consistent with the notion that masked primes are processed in a way that causes both semantics and S-R associations to be activated and, further, that both play some role in the priming process. Specifically, their results suggest that priming for their new set primes was semantically-based, whereas priming for their old set primes was based mainly on S-R associations. These results, therefore, suggest that there may be a rather complex interaction between the types of information activated by masked primes and the processes that produce masked priming effects.

The Role of Task-Defined Strategies

Recent research has also demonstrated that another factor that influences the nature of any masked priming effects is the nature of the task's requirements. For example, Kunde et al. (2003) demonstrated that priming extended to new set primes when participants were required to make magnitude judgments, but not when participants were required to identify the target with a button press response. Further, the size of the target set (e.g., Kiesel, Kunde, Pohl, & Hoffmann, 2006; Pohl, Kiesel, Kunde, & Hoffmann, 2010) and the category (e.g., Abrams, 2008) also appear to affect whether new set primes produce priming.

Additional support for this idea comes from studies that have demonstrated that when primes and targets vary along two dimensions (e.g., parity and magnitude) masked priming is based solely upon prime-target congruency according to the specific judgment task (e.g., parity or magnitude) that the participant was engaged in (e.g., Bodner & Dypvik, 2005; Eckstein & Perrig, 2007; Klinger, Burton & Pitts, 2000). Studies have also shown that factors such as the targets' features (e.g., Pohl et al., 2010) and orientation (e.g., Elsner, Kunde & Kiesel, 2008), whether participants perform lexical decisions or same-different classifications (e.g., Norris & Kinoshita, 2008), and whether double-digit magnitude judgments (i.e., is the two-digit target greater than or less than '55'?) are made based only upon the identity of the first digit or the identity of the second digit (e.g., Greenwald, Abrams, Naccache & Dehaene, 2003) also affect the nature of any masked priming effects. Taken together, these results suggest that the source of any observed priming effects (i.e., S-R associations or semantic activation) is very much dependent on both task instructions and participants' processing strategies which also implies a fairly complex interaction between the types of information activated by masked primes and the processes that produce masked priming effects.

Masked Prime Processing Mechanisms: Prime Validity Effects

The generally accepted "prospective" view of how the mechanisms of masked priming function, regardless of whether masked priming effects are assumed to be due to semantic activation or S-R associations (or both), is based on two key assumptions. The first assumption is that the presentation of a masked prime induces a temporary state of activation in the cognitive system which, in turn, affects the speed with which a subsequently presented target is processed. The second assumption is that, since participants do not report any awareness of these masked primes, any episodic trace left by these primes should be so weak that any effect of the prime must have been due solely to automatic, rather than strategic, activation processes (see Forster & Davis, 1984; Masson & Bodner, 2003). If this second assumption is correct then it suggests that the ability of stimuli presented outside awareness to influence subsequent behavior is somewhat limited.

There is, however, increasing evidence for an alternative "retrospective" view of masked priming which denies both of the assumptions of the prospective view and instead, adopts two markedly different assumptions. The first assumption is that the primes (even when they are presented briefly and masked) form reasonably strong episodic traces. The second assumption is that, in an effort to aid target processing, the cognitive system strategically adjusts the extent to which it relies upon information from these episodic traces (even though the viewer is typically unaware of both the presence of the prime and its identity).

The strongest evidence for a retrospective view has come from Bodner and colleagues who have demonstrated, in a variety of cognitive tasks, that priming effects are larger when the percentage of trials in which the target is related to the prime is high (typically 80%) compared to when it is low (typically 20%) (e.g., Bodner & Dypvik, 2005; Bodner & Masson, 2001, 2003, 2004; Bodner, Masson & Richard, 2006; Bodner & Mulji, 2010; Jaskowski, Skalska & Verleger, 2003; Klapp, 2007). To account for the pervasiveness of these "prime validity" effects, Bodner and Masson (2001; Masson & Bodner, 2003) proposed a "memory recruitment account" which is based on a retrospective view of masked priming. Specifically, when the information that can be derived from a masked prime is often beneficial for target processing (e.g., a prime arrow which often points in the same direction as the target arrow), then the cognitive system adopts a target processing strategy which involves placing some reliance upon information derived from the prime's episodic trace. Because this information (which could be based on either semantics or S-R associations) benefits target processing on congruent trials, a greater reliance on prime information produces a larger priming effect. If this type of view is correct then it implies that people have considerable cognitive control not only over the information that is activated by stimuli presented outside of awareness but also over how that information can affect subsequent behavior.

Dissertation Goals

The masked priming paradigm does appear to provide a means for scientifically investigating how people process stimuli that are presented outside of awareness. Further, as this review of the masked priming literature suggests, the origins of any masked priming effects (i.e., S-R associations or the activation of semantics) are due to a rather complex interaction between task instructions and participants' target processing strategies. The primary goal of this dissertation , therefore, is to investigate this interaction with a frequent emphasis on the question of what role S-R associations do play in the process.

A secondary goal is to provide an additional examination of the prospective versus retrospective views of masked priming. Prime validity effects, effects which challenge the more generally accepted prospective view, have now been found in a multitude of cognitive paradigms (see Masson & Bodner, 2003, for a review). The question, therefore, is whether one can provide an account for these effects within the framework of a prospective view of masked priming or, alternatively, whether the retrospective view, with its assumption that people can actually make controlled use of information from stimuli presented outside of awareness, might be the more accurate view.

Chapter 2: Number Classification

In *Chapter 2* the role of task-defined strategies in producing masked priming in number classification tasks was investigated to determine how S-R associations and semantics interact to produce priming in that task. Doing so involved evaluating the time course (over 1008 trials) of two different data patterns which would serve as markers indicating the source of the priming (i.e., S-R associations versus semantic activation). The first marker was the magnitude of the masked priming effect itself. A priming effect driven by activated semantic information should emerge in the very first trials and maintain itself over the course of the experiment. In contrast, priming due to S-R associations must increase as participants become more familiar with those associations. The second marker was the nature of the priming distance effect. That is, responses in number classification tasks are often faster as the numerical distance between the prime and target decreases (e.g., Koechlin, Naccache, Block, & Dehaene, 1999; Naccache & Dehaene, 2001; Reynvoet & Brysbaert, 1999, 2004; Reynvoet et al., 2002). For example, if the target is the digit ‘4’ in a task in which the digit must be classified as greater or less than ‘5’ then responses will typically be faster if it is primed by the digit ‘3’ compared to the digit ‘1’. These effects must clearly be due to the activation of semantic information.

In Experiment 1 participants made magnitude judgments (i.e., indicated whether the target is less than or greater than ‘5’) to single-digit targets preceded by masked single-digit primes. The results indicated that there were clear masked priming and priming distance effects, both of which remained relatively stable over trials. In Experiment 2, in order to make the use of S-R associations more viable, participants made target identifications (i.e., press one button if the target is a ‘1’, ‘2’, ‘3’ or ‘4’ and a different button if it is a ‘6’, ‘7’, ‘8’ or ‘9’) to the same single-digit prime-target pairs as in Experiment 1. In this situation, there was an increase in the size of the masked priming effect over trials indicating that processing had changed in a way that caused S-R associations to have a greater impact in the priming process. However, as in Experiment 1, there was a clear priming distance effect which did not vary over trials. The presence of a priming distance effect in both experiments indicates that semantic activation continued to play a major role in producing masked priming effects regardless of task instructions. At the same time, the increase in the size of the priming effect in Experiment 2 does demonstrate that task instructions can create a situation in which there is an impact of S-R associations on the priming process.

Chapter 3: Category Learning Tasks with Masked Primes

In *Chapter 3* the development of S-R associations was traced using a masked priming version of a category learning task. In a typical category learning task (e.g., Lamberts, 1995; Nosofsky & Zaki, 2002; Smith & Minda, 1998) participants are repeatedly presented with the same set of artificial stimuli (nonword letter strings in these experiments) and are required to learn, based upon feedback, which target stimuli belong to one category and which target stimuli belong to the other category.

Previous investigations of masked priming used tasks with clearly defined semantic categories (e.g., pleasant/unpleasant, less/greater than 5) which allow for the possibility that either semantics or S-R associations (or both) could generate masked priming effects, complicating the theoretical analysis. In contrast, the items in a category learning task are novel and, thus, have no ability to activate semantic information. Further, as is often the case, at the beginning of the learning process, the stimuli are not associated with either possible response (explicitly or implicitly), unlike, for example, arrow stimuli. Thus, the category learning task is an ideal, but unexplored, task for investigating the development of S-R associations and their ability to produce masked priming.

In Experiment 1 masked priming effects were obtained for both four- and six-letter category sets such that responses were faster when targets were preceded by a masked prime which was the prototype of its category versus the opposite category's prototype. However, there was little evidence that these effects were due to S-R associations as the effects occurred early and did not increase in size over trial segments. In Experiment 2 an increase in the size of the masked priming effects was obtained when participants practiced learning the four-letter category sets over multiple sessions/days. This result provides support for the claim that at least part of the observed priming was due to the development of S-R associations. Taken together, the present results suggest that although some priming occurs early (Experiment 1) it takes considerable practice in order to learn and strengthen the appropriate S-R associations in order for those associations to produce the predicted increase in the size of the masked priming effect (Experiment 2), raising the possibility that the impact of stimuli presented outside of awareness is almost always due to the activation of semantic information.

Chapter 4: Target Arrow Classification with Free Choice Trials

In *Chapter 4*, in an effort to evaluate the debate over the prospective versus retrospective views of masked priming, the mechanisms that are responsible for producing prime validity effects in an arrow classification task with free choice trials (i.e., stimuli that allowed a response in either direction, < > or > <) were evaluated. In this experiment, arrow targets were preceded by masked primes which either a) always pointed in the same direction of the target arrow (100% congruent condition), b) always pointed in the opposite direction (100% incongruent condition), or c) pointed equally often in the same and different directions (unpredictive condition) using prime-target intervals of either 77 ms or 165 ms (a between-subjects manipulation). If the priming pattern for the response biases on the free choice trials in the unpredictive condition mimics the 100% congruent condition then that result would challenge the retrospective view (but could be easily accounted for in the prospective view). However, if the priming pattern in the unpredictive condition mimics the 100% incongruent condition then that would support a retrospective view (and challenge the prospective view).

When the prime-target interval was 77 ms, a prime validity effect occurred for the free choice trials such that there was a bias to respond in the direction of the masked prime in the 100% congruent condition whereas in the 100% incongruent condition response selection was at chance. When the prime-target interval was 165 ms, a prime validity effect occurred such that there was a bias to respond in the direction opposite of the masked prime in the 100% incongruent condition whereas in the 100% congruent condition response selection was at chance. Crucially, the results in the unpredictive condition mimicked those in the 100% congruent condition at both prime-target intervals. The results suggest that these prime validity effects occur as a result of how masked primes in the 100% incongruent condition are processed. These results provide a challenge for a retrospective view of masked priming, but can easily be explained within a framework of a prospective view of masked priming (such as a response bias suppression account).

Chapter 5: Conclusions

This research makes two important contributions to the masked priming literature. First, the results from *Chapters 2* and *3* suggest that previous research that has been taken as evidence for S-R associations (e.g., Damian, 2001) may have an alternative (possibly, semantically-based) explanation. Second, the results from *Chapter 4* pose a formidable challenge to anyone attempting to explain them within a retrospective view of masked priming. In *Chapter 5* the implications of these results for notions of how stimuli presented outside of awareness are processed and for various theories of masked priming are addressed.

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Chapter 2 – Number Classification

In a masked priming paradigm, stimuli that are briefly presented and masked (forward and/or backward) to further decrease their visibility, nonetheless, tend to influence responses to subsequently presented targets. That is, masked prime stimuli tend to influence behavior even when people report no awareness of those stimuli and/or perform poorly on any task requiring a response to those stimuli. A key question that drives much of this research, therefore, concerns the source of these masked priming effects (see Finkbeiner & Forster, 2008; Kiesel, Kunde, & Hoffmann, 2007; Kouider & Dehaene, 2007; Van den Bussche, Van den Noortgate, & Reynvoet, 2009, for recent reviews).

According to one line of research, masked priming is due to stimulus-response (S-R) associations which have developed as a result of continual responding to particular stimuli. That is, when a stimulus (or part of a stimulus) is repeatedly presented as a target, a response bias (i.e., a tendency to respond with the appropriate response) develops. Whenever a stimulus of this sort is then presented as a prime, it creates a bias which aids target responding on prime congruent trials (i.e., when the prime and target require the same response) and interferes with target responding on prime incongruent trials (a position which Kunde, Kiesel, & Hoffmann, 2003, called the "evolving automaticity hypothesis").

A crucial prediction of the evolving automaticity hypothesis is that priming should only occur for primes that have been previously presented and responded to as target stimuli (i.e., "old set primes"), whereas primes which have not been previously responded to as targets (i.e., "new set primes") should not produce priming since response biases have not been formed for these primes. Damian's (2001) physical size (small or large) judgment task provides support for this prediction. Specifically, a category congruence effect, that is, faster responses when both the masked prime and the target corresponded to either large or small objects (i.e., congruent trials) than when the masked prime and the target corresponded to items of opposite size (i.e., incongruent trials), was found when old set masked primes were used (Experiment 1), but there was no category congruence effect when new set masked primes were used (Experiment 2).

Further support for the evolving automaticity hypothesis comes from Abrams and Greenwald's (2000) two-phase pleasantness classification task. In the first phase of their experiment, participants classified word targets as either pleasant or unpleasant in meaning. In the second phase, these same word targets were preceded by briefly presented masked primes. The primes were recombined pairs of practiced word targets that were either hybrid nonwords (Experiment 1) (e.g., HUMOR + TULIP = hulip) or were hybrid words with a valence opposite to that of both members of the pair from which they were constructed (Experiment 2) (e.g., SMUT + BILE = smile). The results were that nonword primes (e.g., hulip) composed of letters from previously-practiced targets of the same category (e.g., HUMOR and TULIP) (Experiment 1) facilitated responses to targets which have the same valence as the practiced targets. More surprisingly, masked word primes having a valence opposite to that of the two words used to construct them (e.g., smile from SMUT and BILE) facilitated responses to the category of the two partial words rather than the category of the whole word. Further, new set masked primes (i.e., positively and negatively valenced words which were not previously seen as targets) had no effect on target responses (Experiment 3).

In contrast to Abrams and Greenwald’s (2000) and Damian’s (2001) results (and challenging the evolving automaticity hypothesis) there are now numerous demonstrations of priming from new set primes. An early demonstration of such an effect was reported by Naccache and Dehaene (2001) who had participants perform magnitude judgments in which target numbers were classified as either less than or greater than 5. In their task, the targets 1, 4, 6, and 9 were preceded by both old set primes (i.e., 1, 4, 6 and 9) and new set primes (i.e., 2, 3, 7 and 8) in addition to a neutral, nonnumeric, stimulus. Their key result was that priming occurred for both types of masked primes (see Kunde et al., 2003; 2005; and Kinoshita & Hunt, 2008, for replications of this result).

Subsequently, a variety of other tasks have also produced category congruence effects using new set primes. For instance, these effects have been reported in both a parity judgment task (i.e., is the target an odd or even number? - Reynvoet, Caessens & Brysbaert, 2002) and in a single-letter judgment task (i.e., is the letter before or after the letter ‘O’ in the alphabet? - Reynvoet, Gevers & Caessens, 2005). Further, priming from new set primes has also been found for target word stimuli in a valence classification task (i.e., is the target word pleasant or unpleasant in meaning?) using both word primes (e.g., Klauer, Eder, Greenwald & Abrams, 2007) and picture primes (e.g., Dell’Acqua & Grainger, 1999) as well as in an animal classification task (i.e., does the target word correspond to an animal or not?) using both word primes (e.g., Quinn & Kinoshita, 2008; Van den Bussche & Reynvoet, 2007, Experiment 3) and picture primes (e.g., Van den Bussche, Notebaert & Reynvoet, 2009).

As this brief summary of the literature indicates, priming from new set masked primes is a very common finding which suggests that activated semantic information is often responsible for producing priming effects (a position which Kunde et al., 2003, called the "elaborate processing hypothesis"). What needs to be kept in mind, however, is that a demonstration that a particular priming effect has a semantic basis does not rule out the possibility that S-R associations may have also played some role in producing that effect. Nor does it rule out the possibility that, in other situations, S-R associations may be the sole source of the priming effect, a notion that is certainly consistent with experiments in which new set masked primes do not produce priming (e.g., Abrams & Greenwald, 2000; Damian, 2001). In fact, support for a role for S-R associations in masked priming even when new set primes are effective primes (i.e., when semantically-based priming arises) comes from a recent paper by Kinoshita and Hunt (2008).

Kinoshita and Hunt (2008): A Two-Component Account of Masked Priming

Kinoshita and Hunt (2008) recently replicated Naccache and Dehaene's (2001) results in a magnitude judgment task using both old and new set masked primes. However, in contrast to the previous research, they provided an analysis based on the full latency distributions for each prime condition. What their analysis demonstrated was that, in the longer latency bins, the congruent trials in the old set prime condition showed a noticeable slowdown (relative to both of the incongruent prime conditions as well as the congruent prime condition involving new set primes). As a result, old set primes did not produce a category congruence effect in these longer latency bins even though new set primes did.

Kinoshita and Hunt (2008) concluded that their results demonstrate that masked priming involves at least two different automatic components, one based upon semantic information and the other based upon S-R associations. One component reflects the congruence between the prime and target in terms of task-defined features (e.g., size in a size judgment task) and relies upon semantic information activated by the masked prime. The other component is assumed to be transitory and relies upon activation of S-R associations by the masked primes. It is the disappearance of this second component when latencies get to be long which accounts for the diminution of priming from old set primes in the longer latency bins.

Kinoshita and Hunt's (2008) results are, therefore, quite consistent with the notion that masked primes are processed to a depth at which both semantics and S-R associations are activated and, further, that both play some role in the priming process. Specifically, their results suggest that priming for their new set primes was semantically-based, whereas priming for their old set primes was based mainly on S-R associations. Note further that priming for their old set primes disappeared entirely when responding was delayed (i.e., in the longer latency bins) even though there was a semantic relationship between the prime and target. Thus, Kinoshita and Hunt's data suggests that there appears to be a rather complex interaction between the types of processes that produce priming effects. The purpose of the present experiments is to gain additional knowledge about the nature of these types of interactions by investigating the role of task-defined strategies in producing masked priming in number classification tasks.

The Role of Task-Defined Strategies

Recent research has provided substantial support for the idea that task instructions play an important role in determining the nature of any observed priming effects. For example, Kunde et al. (2003) demonstrated that priming extended to new set primes when participants were required to make magnitude judgments, but not when participants were required to identify the target with a button press response. Further, the size of the target set (e.g., Kiesel, Kunde, Pohl, & Hoffmann, 2006; Pohl, Kiesel, Kunde, & Hoffmann, 2010) and the category set (e.g., Abrams, 2008) also appear to affect whether new set primes produce priming.

Additional support for this idea comes from studies that have demonstrated that when primes and targets vary along two dimensions (e.g., parity and magnitude) masked priming is based solely upon prime-target congruency according to the specific judgment task (e.g., parity or magnitude) that the participant was engaged in (e.g., Bodner & Dypvik, 2005; Eckstein & Perrig, 2007; Klinger, Burton, & Pitts, 2000). Studies have also shown that factors such as the targets' features (e.g., Pohl et al., 2010) and orientation (e.g., Elsner, Kunde, & Hoffmann, 2008), whether participants perform lexical decisions or same-different classifications (e.g., Norris & Kinoshita, 2008), and whether double-digit magnitude judgments (i.e., is the two-digit target greater than or less than '55'?) are made based upon the identity of the first or second digit (e.g., Greenwald, Abrams, Naccache, & Dehaene, 2003) also affect the nature of any masked priming effects. Taken together, these results clearly demonstrate that the source of any observed priming effects (e.g., semantics or S-R associations) is very much dependent on both task instructions and participant strategies.

The results cited above could be taken as support for the claim that the type of information that is actually activated by the masked primes (i.e., semantics or S-R associations) varies as a function of the target task. Alternatively, it would also support the hypothesis that masked primes automatically activate S-R associations and semantics with the crucial issue being the extent to which either of these factors is relevant to the processing required by the target. That is, what varies between tasks is not whether semantics or S-R associations are activated by the masked primes, but rather how the activated information interacts with task demands to produce priming in a given situation.

The Time Course of the Priming Effects as a Function of Task-Defined Strategies

The goal of the present research was to provide an examination of how S-R associations and semantics interact to produce priming in number classification tasks. Doing so involved evaluating the time course of two different data patterns which would serve as markers indicating the source of the priming (i.e., S-R associations versus semantic activation). The first marker is the size of the category congruence effect itself. Damian (2001) argued that "if the congruity effect depended on automatized mappings between stimuli and their corresponding responses, it should clearly build up across the experiment" (p. 158) and demonstrated that the magnitude of his category congruence effect for old set primes did, in fact, increase across trial blocks. In contrast, if priming is due to semantic activation, then the category congruence effect should appear early in the experiment and vary little in magnitude over trials as demonstrated by Naccache and Dehaene (2001).

The second marker is whether the category congruence effect shows any semantic basis and, if so, how that effect varies as a function of practice with the task. For instance, in both the magnitude judgment task (e.g., Koechlin, Naccache, Block, & Dehaene, 1999; Naccache & Dehaene, 2001; Notebaert, Pesenti, & Reynvoet, 2010; Van Opstal, Gevers, Moor, & Verguts, 2008) and the parity judgment task (e.g., Reynvoet & Brysbaert, 1999, 2004; Reynvoet et al., 2002), tasks in which priming is presumed to be predominantly due to semantic activation, a priming distance effect has typically been observed. That is, responses are systematically faster as the numerical distance between the prime and target decreases. For example, if the target is the digit ‘4’ in a task in which the digit must be classified as greater or less than ‘5’ then responses will typically be faster if it is primed by the digit ‘3’ compared to the digit ‘1’. Whenever priming is at least partly due to semantic activation then a priming distance effect should also be present. However, if priming is ever due solely to S-R associations, then any priming effects that have a semantic basis should not be present. For example, in the present situation there may be a change in the priming distance effect over trial blocks as the strength of the S-R associations increases indicating a diminishing influence of semantics on the nature of target processing.

Based on this discussion there are, essentially, four possible outcomes in a number classification task of the sort used here and previously (e.g., Kinoshita & Hunt, 2008; Naccache & Dehaene, 2001). Crucially, each would produce a different time course for both the category congruence effect and the priming distance effect. One is that priming will be due solely to semantic activation. In that case, both the category congruence effect and the priming distance effect should be present early and remain relatively stable over trials.

The second possible outcome would occur if priming is due solely to the activation of S-R associations as they strengthen over trials. In that case, the category congruence effect should be small or non-existent early in the experiment, but should increase in size over trials. Further, there should be no evidence of any priming distance effect.

The third possible outcome would occur if both semantic activation and S-R associations contribute to the priming effect. In that case, both a category congruence effect and a priming distance effect should be present early due to the activation of semantic information. However, the category congruence effect should increase in size over trials as S-R associations strengthen (i.e., the priming due to S-R associations will enhance the priming due to semantics). In addition, the priming distance effect should remain relatively stable over trials (i.e., this effect will be unaltered by the emerging effect of S-R associations).

The fourth possible outcome would occur as a result of a more complicated interaction among the potential sources of priming. One could propose that participants can strategically alter the basis of their priming effects from semantic activation to S-R associations whenever S-R associations may provide a stronger basis for supporting priming (such as may have been the case both in Kunde et al., 2003, and, for old set primes, in Kinoshita and Hunt, 2008). In this type of situation, there may be a small increase in the size of the category congruence effect across trials (due to reliance being shifted to the more useful S-R associations), but more importantly, there should also be a decrease in the magnitude of the priming distance effect (due to the diminishing role of semantic information in producing priming).

The Present Research

These potential outcomes were examined using single-digit stimuli as masked primes and targets in two number classification tasks. Experiment 1 employed a magnitude judgment task in which all single-digits except ‘0’ and ‘5’ were used as targets so that priming distance effects could be analyzed. Based on Naccache and Dehaene’s (2001) results, the expectation was that both the category congruence effect and the priming distance effect should be present initially and should remain stable over trial blocks. The question of interest was whether S-R associations would also start to play a role, leading to an increase in the size of the category congruence effect over trials.

Experiment 2 involved a change in the task instructions in order to create a situation in which there would be a strong bias to shift toward the strategic use of S-R information/associations. The stimuli were the same as in Experiment 1 but the task was target identification, that is, participants were told to press one button if the target was either a ‘1’, ‘2’, ‘3’ or ‘4’ and to press a different button if the target was either a ‘6’, ‘7’, ‘8’ or ‘9’. Recall that Kunde et al.’s (2003) results suggest that when task instructions require participants to make an identification response to the target then the semantic information activated by the masked primes appeared not to play a role in producing priming (as indicated by the lack of priming from the new set masked primes).

If the task instruction manipulation in Experiment 2 is successful in that it does bias responding in a way that causes S-R information/associations to play more of a role in the process then there should be evidence that the magnitude of the category congruence effect increases over trials. The question of how this process unfolds can then be determined by evaluating the nature of the priming distance effect. As described above, if priming is exclusively due to S-R associations in this type of task, there should be no priming early in the experiment as well as no trace of a priming distance effect at any point. Alternatively, the development of S-R associations may merely serve to enhance semantically-based priming. In that case, the priming distance effect should arise early and remain constant throughout the experiment. Finally, if priming in the early trials is due to semantic activation, but at a later point, there is a strategic shift such that S-R associations assume a dominant role, then the priming distance effect should diminish/disappear as the size of the priming effect grows over the course of the experiment.

Method

Participants

Sixty University of Western Ontario undergraduate students received either $10 or course credit for their participation, 27 in Experiment 1 and 33 in Experiment 2. All had either normal or corrected-to-normal vision.

Materials

Stimuli. The primes and targets were single-digit numbers from ‘1’ through ‘9’ (excluding ‘5’).

In both experiments, participants completed 1008 trials. These trials were divided into 21 blocks of 48 trials each. Within each block, each target was presented six times, each time paired with a different prime. On half of the trials, the target was preceded by a congruent prime (i.e., both the prime and target were either less than or greater than ‘5’) and on the other half of the trials the target was preceded by an incongruent prime (i.e., the prime was less than ‘5’ and the target was greater than ‘5’, or vice versa). Since identity primes were not used, in order to maintain the same number of congruent and incongruent trials not all incongruent prime-target pairs were used.[1] Appendix A contains the stimulus list.

Equipment

Both experiments were run on DMDX experimental software programmed by Forster and Forster (2003). Stimuli were presented on a SyncMaster monitor (Model No. 753DF). Presentation was controlled by an IBM-clone Intel Pentium. Stimuli appeared as black characters on a white background. Responses to stimuli were made by pressing one of two <shift> keys on the keyboard.

Procedure

Each participant sat approximately 18 inches in front of the computer screen. In Experiment 1 participants were instructed to determine if the target digit was either less than or greater than ‘5’ by pressing the right <shift> key if the target was greater than ‘5’ or the left <shift> key if the target was less than ‘5’. In Experiment 2 participants were instructed to press the left <shift> key if the target digit was a ‘1’, ‘2’, ‘3’ or ‘4’ and the right <shift> key if the target digit was a ‘6’, ‘7’, ‘8’ or ‘9’. In both experiments participants were told to respond as quickly and accurately as possible, but they were not told of the existence of the prime.[2]

On each trial the participants saw a string of hash marks (e.g., “###”) for 550 ms followed by a prime digit which was presented for 44 ms. The target digit then appeared in the same screen location for either two seconds or until the participant responded. Participants performed 1008 trials which were divided into 21 blocks of 48 trials each. Participants were given an opportunity to take a break after each block of trials.

Results

Trials in which no response was given or the response latency was either less than 100 ms or greater than 1500 ms were removed from both the latency and error analyses (0.24% of the trials in Experiment 1, 1.95% of the trials in Experiment 2). In addition, incorrect responses were also removed from the latency analyses (4.73% of the trials in Experiment 1, 7.88% of the trials in Experiment 2).

The category congruence effects for both reaction time and accuracy were analyzed using a 3 (trial segment: early (blocks 1-7) vs. middle (blocks 8-14) vs. late (blocks 15-21)) by 2 (category congruence: congruent vs. incongruent) analysis of variance (ANOVA). The priming distance effect for both reaction time and accuracy on the congruent trials (i.e., those trials for which the priming distance between the prime and target is meaningfully defined) was analyzed using a 3 (trial segment: early vs. middle vs. late) by 3 (prime-target distance: one vs. two vs. three) ANOVA. In both Experiments the prime-target distance analysis was restricted to the target set ‘1’, ‘4’, ‘6’, and ‘9’ since prime-target distance cannot be as strongly manipulated for the targets ‘2’, ‘3’, ‘7’, and ‘8’, whereas, for the category congruence effect, all targets were included.

Experiment 1: Magnitude Judgment Task (see Table 1)

Category Congruence Effect. In the latency analysis, there was a marginal effect of trial segment, $F(2, 52) = 2.75$, $p < .08$, $MSE = 457.17$, and a significant main effect of category congruence, $F(1, 26) = 48.74$, $p < .001$, $MSE = 564.36$. Response latencies in the first (481 ms) trial segment were marginally longer than in the second (475 ms), $t(26) = 1.92$, $p <.07$, $SE = 3.44$, and significantly longer than in the third (472 ms), $t(26) = 2.15$, $p < .05$, $SE = 4.52$, trial segments. There was no difference between the third and

Table 1.

Category Congruence Effects and the Priming Distance Effect for the Magnitude Judgment Task – Experiment 1 (Reaction Time in ms, Errors in %).

Category Congruence Effect

Prime Type	Trial Segments: Early	Middle	Late	Overall Mean
Incongruent	493 (5.4)	488 (7.2)	486 (8.0)	489 (6.9)
Congruent	470 (2.3)	462 (2.3)	457 (3.3)	463 (2.6)
CE	23 (3.1)	26 (4.9)	29 (4.7)	26 (4.3)

Priming Distance Effect

Prime-Target Distance	Trial Segments: Early	Middle	Late	Overall Mean
1 Unit	471 (2.2)	460 (3.0)	462 (2.4)	464 (2.6)
2 Units	470 (2.9)	463 (2.8)	455 (4.0)	463 (3.2)
3 Units	484 (3.4)	476 (3.0)	469 (4.5)	476 (3.7)

Note. Early = Blocks 1 – 7, Middle = Blocks 8 – 14, Late = Blocks 15 – 21, CE = Congruence Effect the second trial segments $t(26) = 0.71$, *n.s.* In addition, congruent trials were responded to 26 ms faster than incongruent trials. The interaction was not significant, $F(2, 52) = 1.91$, *n.s.*

In the error analysis, there were significant main effects of both trial segment, $F(2, 52) = 7.09$, $p < .003$, $MSE = 0.001$, and category congruence, $F(1, 26) = 18.73$, $p < .001$, $MSE = 0.004$. The error rate was significantly greater in the third (5.6%) trial segment than in both the first (3.8%), $t(26) = 3.07$, p < .006, $SE = 0.005$, and second (4.8%), $t(26) = 2.26$, p < .04, $SE = 0.004$, trial segments. The difference in error rates between the first and second trial segments was also significant, $t(26) = 2.12$, $p < .05$, $SE = 0.004$. The error rate was also greater for incongruent than congruent trials. The interaction was significant, $F(2, 52) = 4.42$, $p < .02$, $MSE = 0.001$, due to the fact that the magnitude of the priming effect in the first trial segment was significantly less than in both the second, $t(26) = 2.79$, $p < .02$, $SE = 0.006$, and third, $t(26) = 2.45$, $p < .03$, $SE = 0.006$, trial segments. There was no significant difference between the magnitudes of the priming effects in the second and third trial segments, $t(26) = 0.42$, *n.s.*

Priming Distance Effect. In the latency analysis, there were significant effects of trial segment, $F(2, 52) = 3.39$, $p < .05$, $MSE = 1145.30$, and prime-target distance, $F(2, 52) = 12.50$, $p < .001$, $MSE = 383.24$. Responses were significantly longer in the first (475 ms) than in either the second (466 ms), $t(26) = 2.25$, $p < .04$, $SE = 3.60$, or the third (462 ms), $t(26) = 2.32$, $p < .03$, $SE = 4.51$, trial segments. Response latencies did not differ between the second and third trial segments, $t(26) = 0.51$, *n.s.* In addition, responses were significantly longer when the prime-target distance was three versus one, *t*(26) = 3.71, *p* < .002, *SE* = 3.24, or two, *t*(26) = 4.59, *p* < .001, *SE* = 2.98, units (i.e., a priming distance effect). The difference in response latencies when the prime-target distance was one versus two units was not significant, *t*(26) = 0.65, *n.s.* The interaction was not significant, *F*(4, 104) = 0.50, *n.s.*[3]

In the error analysis, neither of the main effects nor the interaction was significant (all *F*s < 1.59).

Experiment 2: Target Identification Task (see Table 2)

Category Congruence Effect. In the latency analysis, there was no effect of trial segment, *F*(2, 64) = 0.05, *n.s.*, but there was a significant main effect of category congruence, *F*(1, 32) = 63.40, *p* < .001, *MSE* = 295.64. Congruent trials were responded to 20 ms faster than incongruent trials. The interaction was also significant, *F*(2, 64) = 5.38, *p* < .008, *MSE* = 131.39, due to the fact that the magnitude of the priming effect in the third trial segment was significantly greater than in the first, *t*(32) = 3.03, *p* < .006, *SE* = 4.28, and marginally greater than in the second, *t*(32) = 1.90, *p* < .07, *SE* = 4.26, trial segments. The difference in the magnitude of the priming effect between the first and second trial segments was not significant, *t*(32) = 1.44, *n.s.*

In the error analysis, there was a marginal effect of trial segment, *F*(2, 64) = 2.54, *p* < .09, *MSE* = 0.001, and a significant main effect of category congruence, *F*(1, 32) = 16.03, *p* < .001, *MSE* = 0.002. The error rate was marginally smaller in the first (7.7%) than in both the second (8.6%), *t*(32) = 1.73, *p* < .10, *SE* = 0.005, and third (8.9%), *t*(32) = 1.90, *p* < .07, *SE* = 0.007, trial segments. There was no significant difference in error rates between the second and third trial segments, *t*(32) = 0.62, *n.s.* The error rate was greater for incongruent than congruent trials. The interaction was significant, *F*(2, 64) =

Table 2.

Category Congruence Effects and the Priming Distance Effect for the Target Identification Task – Experiment 2 (Reaction Time in ms, Errors in %).

Category Congruence Effect

	Trial Segments			
Prime Type	Early	Middle	Late	Overall Mean
Incongruent	502 (9.0)	503 (9.4)	506 (10.6)	504 (9.7)
Congruent	488 (6.4)	484 (7.8)	480 (7.2)	484 (7.2)
CE	14 (2.6)	19 (1.6)	26 (3.4)	20 (2.5)

Priming Distance Effect

	Trial Segments			
Prime-Target Distance	Early	Middle	Late	Overall Mean
1 Unit	487 (7.2)	490 (8.2)	475 (7.0)	484 (7.5)
2 Units	488 (7.3)	482 (8.5)	482 (7.8)	484 (7.9)
3 Units	504 (6.6)	487 (9.4)	494 (9.8)	495 (8.6)

Note. Early = Blocks 1 – 7, Middle = Blocks 8 – 14, Late = Blocks 15 – 21, CE = Congruence Effect

3.25, p < .05, MSE = 0.001, due to the fact that the magnitude of the priming effect was significantly greater in the third versus the second trial segment, $t(32) = 2.82$, $p < .009$, $SE = 0.007$. There was no significant difference between the magnitude of the priming effect for the first trial segment and either the second, $t(32) = 1.45$, *n.s.*, or third, $t(32) = 1.04$, *n.s.*, trial segments.

Priming Distance Effect. In the latency analysis, there was no effect of trial segment, $F(2, 64) = 0.73$, *n.s.*, but there was a significant effect of prime-target distance, $F(2, 64) = 4.04$, $p < .03$, $MSE = 945.90$. Responses were significantly longer when the prime-target distance was three versus one, $t(32) = 2.63$, $p < .02$, $SE = 4.24$, or two, $t(32) = 2.32$, $p < .03$, $SE = 4.49$, units (i.e., a priming distance effect). The difference in response latencies when the prime-target distance was one versus two units was not significant, $t(32) = 0.18$, *n.s.* The interaction was not significant, $F(4, 128) = 1.18$, *n.s.*[4]

In the error analysis there was a significant main effect of trial segment, $F(2, 64) = 3.42$, $p < .04$, $MSE = 0.002$. The error rate in the first (7.0%) trial segment was significantly less than in the second (8.7%), $t(32) = 2.30$, $p < .03$, $SE = 0.006$, and marginally less than in the third (8.2%), t(32) = 1.86, p < .08, SE = 0.008, trial segments. There was no significant difference in error rates between the second and third trial segments, $t(32) = 0.16$, *n.s.* There was no effect of prime-target distance, $F(2, 64) = 1.71$, *n.s.*, nor was the interaction significant, $F(4, 128) = 1.09$, *n.s.*

Post-Hoc Analysis: Comparison Distance Effects

An additional, semantically-based effect often found in number classification tasks is the comparison distance effect in which participants are faster to respond to more-extreme values (e.g., 1 and 9 in a “less/greater than 5” task) than less-extreme values (e.g., 6 and 4) (see Rouder et al., 2005, for a review; Van Opstal et al., 2008). This effect also indicates that semantic information was being used in making target decisions and, therefore, if there are priming distance effects in both experiments, comparison distance effects should also be evident in both experiments. A potential additional issue for understanding the nature of the impact of semantic information in these experiments would be whether this factor might interact with any of the other factors, particularly priming distance. To examine these issues, we performed a 2 (comparison distance: more-extreme [1 and 9] vs. less-extreme [4 and 6]) by 3 (trial segment: early vs. middle vs. late) by 3 (prime-target distance: one vs. two vs. three) by 2 (task instructions: magnitude [Experiment 1] vs. identification [Experiment 2]) ANOVA. Note that since we wished to consider the potential interaction between priming distance and comparison distance, we only used congruent trials in this analysis (i.e., those trials in which the priming distance between the prime and target is meaningfully defined).[5]

In the latency analysis, there was a significant comparison distance effect, $F(1, 58) = 98.58$, $p < .001$, $MSE = 5568.92$, such that responses were slower for less-extreme (i.e., 4 and 6) (501 ms) versus more-extreme (i.e., 1 and 9) (456 ms) target values and a significant interaction with trial segment, $F(2, 116) = 4.81$, $p < .02$, $MSE = 1222.99$. The nature of that interaction was that the difference in latencies between the less-extreme and the more-extreme stimuli was significantly greater in the first segment (512 vs. 458 ms) compared to either the second (497 ms vs. 457 ms), $t(59) = 3.89$, $p < .001$, or third segments (494 ms vs. 452 ms), $t(59) = 2.36$, $p < .001$. The difference between the second and third trial segments was not significant, $t(59) = 0.65$, *n.s.* This pattern was virtually identical in both experiments. None of the other interactions, including the interaction between comparison distance and prime-target distance, approached significance (All *p*s > .23).

In the error analysis, there was also a significant comparison distance effect, $F(1, 58) = 72.73$, $p < .001$, $MSE = 0.01$, such that more error responses were made for less-extreme (8.3%) versus more-extreme (2.8%) target values, which marginally interacted with task instructions, $F(1, 58) = 3.43$, $p < .07$, $MSE = 0.04$. The comparison distance effect was slightly larger (6.6%) in Experiment 2 than in Experiment 1 (4.3%) None of the other interactions involving comparison distance were significant (All *p*s > .36).[6]

The fact that comparison distance did not vary significantly as a function of the prime-target (i.e., semantic) distance suggests that these two semantic factors independently impact the priming process.[7] The fact that comparison distance did not vary significantly as a function of experiment (even though the category congruence effect increased in size in Experiment 2) suggests that, although S-R associations played a larger role in Experiment 2, the nature of semantic processing in that experiment was similar to that in Experiment 1.

General Discussion

The present research is an investigation of the source of masked priming in a number classification task with a specific emphasis on understanding how participants' target processing strategies affect the type of information generating the priming effects. These issues were investigated by assessing, over trials, both a) the magnitude of the category congruence effect and b) the nature of the priming distance effect when using single-digit primes and targets in both magnitude judgment (Experiment 1) and target identification (Experiment 2) tasks. The key assumptions behind this particular approach were that priming effects driven by S-R associations must grow in size as those associations develop and that priming effects driven by semantic information would produce a priming distance effect.

Summary of Results

In Experiment 1 participants made magnitude judgments (i.e., indicated whether the target is less than or greater than ‘5’) to single-digit targets preceded by masked single-digit primes. The results indicate that there was a clear category congruence effect such that responses were slower on incongruent versus congruent trials. There was also a clear priming distance effect such that response latencies were longer when the prime-target distance was three versus one or two units. Both of these effects remained relatively stable over trials (see also Koechlin et al., 1999). In addition, there was a clear comparison distance effect. These results corroborate previous research using the magnitude judgment task (see Kinoshita & Hunt, 2008; Kunde et al., 2003; Naccache & Dehaene, 2001; Van Opstal et al., 2008) and indicate that priming in this type of task is primarily due to semantic activation.[8]

Experiment 2 was an attempt to make the use of S-R associations more viable. Recall that Kunde et al. (2003) reported that new set primes did not produce priming when participants were required to identify the target (as opposed to making magnitude judgments). Hence, an argument can be made that in a target identification task S-R associations play a major role in producing priming effects. The expectation, therefore, was that in the present Experiment 2, in which participants were instructed to identify the targets (i.e., press one button if the target was either a ‘1’, ‘2’, ‘3’ or ‘4’ and a different button if it was a ‘6’, ‘7’, ‘8’ or ‘9’) the size of the category congruence effect should increase over trials as the S-R associations develop and start to affect the priming process. If the size of the category congruence effect does, indeed, increase over trials, the question would then become what happens to the priming distance effect over trials. The nature of this effect would allow us to determine the impact of the change in strategy (i.e., what it meant for participants to shift from a semantically-based processing to one at least partially based on S-R associations).

The size of the category congruence effect in Experiment 2 did significantly increase across trial segments, supporting the notion that S-R associations came to play an influential role in generating priming. However, the pattern of semantic effects was essentially identical to that in Experiment 1. There was a clear priming distance effect such that response latencies were longer when the prime-target distance was three as opposed to one or two units which was as large in the final trial segment as in the first trial segment and there was a clear comparison distance effect. The fact that the priming distance effect did not decrease as the category congruence effect increased indicates that participants did not strategically shift the source of the priming effect from semantics to S-R associations as the S-R associations strengthened. Instead the impact of S-R associations was merely to enhance the category congruence effect once the associations had attained a sufficient level of strength. Taken together, these results support the idea that masked digit primes in a number classification task activated semantic information which then produced priming even in Experiment 2 where S-R associations played a role as well.

Theoretical Implications of the Present Research

I. S-R Association Accounts

The assumption that S-R associations (that are formed and strengthened with practice) drive priming effects plays an influential role in research using masked primes to study motor activation (see, e.g., Eimer & Schlaghecken, 1998, 2003; Klotz & Neumann, 1999; Neumann & Klotz, 1994). In addition, this assumption has been used to explain the results from both Abrams and Greenwald's (2000) and Greenwald et al.'s (2003) studies and has been used to explain why, in certain circumstances, new set primes do not produce priming (e.g., Damian, 2001). In the present experiments, the number of trials (1008 per participant) necessary to produce evidence of the impact of S-R associations was much larger than in those previous experiments that were considered to provide evidence for priming due to S-R associations (e.g., Abrams, 2005; Abrams & Greenwald, 2000; Damian, 2001; Greenwald et al., 2003; Neumann & Klotz, 1994). That fact at least raises the question of whether the priming observed in those experiments was truly due to S-R associations.

Consider, for example, Damian's (2001, Experiment 1) results which are taken as support for an S-R association account. In that experiment, involving physical size judgments, the size of the category congruence effect increased over trial blocks. Each trial block in the experiment involved 24 target presentations (i.e., two presentations of 12 targets). Evidence of priming emerged by the third trial block (i.e., the block in which the target was seen and responded to for the fifth and sixth time). Given the large number of trials necessary to get only minimal evidence of priming from S-R associations in the present Experiment 2, these results raise the question of whether there might be a more viable explanation for Damian’s findings. For instance, as will be discussed below, perhaps rather than S-R associations being developed over trials it may have been the participants’ ability to focus on the specific semantic information required to perform the task (in this case, information concerning the size relationship between the target items and a pre-specified comparison object) that produced the priming effects.

Recent research by Perry and Lupker (submitted) provides additional support for the idea that, in general, S-R associations take time to reach the level of strength necessary to affect priming. In their experiments, participants were repeatedly presented with letter strings (e.g., ‘WARY’ and ‘BARO’) and were required to learn, based upon feedback, which items are members of one category and which items are members of the other category (see, e.g., Smith & Minda, 1998). Each target was preceded by a masked prime which was the prototype of its category and, therefore, had more letters in common with the items in its own category than with items in the other category (e.g., the prototype prime ‘wazy’ shares more letters with ‘WEZY’ and ‘WARY’ than with an item from the other category, for example, ‘BARO’).

Because the category sets were artificially defined, they neither had the ability to produce category congruence effects on the basis of retrieved semantic information nor were they initially associated with either categorical response. However, these primes did produce category congruence effects such that targets were responded to faster when primed by the prototype of their category than when primed by the prototype of the other category very early in the experiment. Nevertheless, in none of Perry and Lupker’s (submitted) one session experiments, involving up to 44 presentations of each target stimulus, was there an increase in the size of the category congruence effect over trials, which should have occurred if the effect was being driven by S-R associations. In a follow-up experiment, Perry and Lupker showed that only when multiple sessions of the category learning task were performed over the course of a week was there any evidence for an increase in the size of the category congruence effect. Even though the stimuli and task used in these experiments are noticeably different from those typically used in the masked priming literature, they do support the notion that it takes some time for S-R associations to develop to the point that they can play an influential role in producing priming.

II. Kunde et al.'s (2003) Action-Trigger Account

According to Kunde et al.'s (2003) action-trigger hypothesis, participants set up action-trigger sets, that is, mappings between possible stimuli and their responses in the target task. Unlike S-R association, these mappings can be instantiated without practice and can include any stimuli that participants might wish to include (i.e., they are not limited only to those stimuli that appear as targets). Responses are facilitated when the prime and target activate the same action trigger and inhibited when they activate different action triggers. This account can readily explain category congruence effects and, because action triggers can be set up for any potential stimuli, it can also easily account for priming from new set primes when those effects emerge.

Unlike an S-R association account, an action-trigger account would certainly be able to explain the basic priming effect observed here. That is, action triggers could be set up for all the primes fairly early in the experiments because they also appeared as targets, allowing primes associated with one button press response to prime targets associated with that response and inhibit targets associated with the other response. The fact, therefore, that category congruence effects emerged in the initial trial segment poses no problem since action triggers do not need practice to develop.

An action-trigger account runs into a problem, however, in explaining the existence of the priming distance effect. According to Kunde et al.'s (2003) action-trigger hypothesis, the only role of semantics is to allow the participant to categorize potential stimuli as appropriate action triggers. For instance, in the present single-digit magnitude judgment task (Experiment 1) all four digits that are less than '5' would be equally associated with (i.e., become action triggers for) one response (e.g., a left button press) and all four digits that are greater than '5' would be equally associated with the other response (i.e., a right button press). Since prime processing is assumed to activate the action triggers and not semantic (i.e., ordinal) information then, contrary to the present results, there is no reason that '3' would be a better prime for the target '4' than '1' is. Given the existence of priming distance effects not only in the present experiments but also in other research (e.g., Koechlin et al., 1999; Naccache & Dehaene, 2001; Notebaert et al., 2010; Reynvoet & Brysbaert, 1999, 2004; Reynvoet et al., 2002; Van Opstal et al., 2008), it appears that the action-trigger account could provide, at best, only a partial account of these results.

An additional problem that the present data would pose for Kunde et al.'s (2003) action-trigger account concerns the increase in the size of the category congruence effect in Experiment 2. Specifically, in order to explain the larger effect size in latter blocks, additional assumptions must be made that would allow the strength of the action triggers to increase with practice. Therefore, although the possibility that participants were implementing a strategy that involved something like action triggers in the present experiments cannot be rejected, their role in producing the priming effects observed here seems likely to have been a minor one.

III. New Set Primes

The ultimate goal of the present line of research would be to provide a full explanation of how changes in participants' target processing strategies could explain why there is priming for new set primes in some circumstances but not in others. Experiment 1 was designed to produce priming due to semantic activation, whereas Experiments 2 was designed to bias a shift towards priming due to S-R associations. Although this manipulation was successful, the existence of a priming distance effect in both experiments suggests that the change in target processing requirements did not induce a shift in the nature of the information activated by the masked primes (i.e., from semantics to S-R associations) which supports the idea that prime processing inevitably activates semantics. Therefore, the question still remains as to why, in some circumstances, there has been no evidence of priming from semantically related new set primes, that is, primes that should be effective if their semantic information is being activated (e.g., Abrams & Greenwald, 2000; Damian, 2001; Kunde et al., 2003).

One possibility is that prime processing does not always activate semantics (i.e., participants may actually have the ability to suppress the automatic activation of semantic information from the prime under certain circumstances). For example, one could argue that in Damian's (2001) experiment involving new set primes, prime processing was suppressed in a way that prevented the primes from activating size information, producing a null priming effect. A similar argument could be used to explain Kinoshita and Hunt's (2008) old set prime data. That is, one could argue that in Kinoshita and

Hunt’s experiments the semantic information from their old set primes, but not from their new set primes, was in some way suppressed as the S-R associations became stronger. Hence, the priming from their old set primes became completely based on S-R associations. As a result, old set primes, but not new set primes, failed to produce priming in the longer latency bins because, as Kinoshita and Hunt argue, activation from S-R associations has a limited time course.

The results from the present Experiments 1 and 2 would, of course, be inconsistent with this idea since those results indicate that the nature of semantic processing did not change as S-R associations started to play a more central role. Nonetheless, the present data pattern does not compel the conclusion that it would never be possible to create a situation where the impact of semantics could be entirely replaced by the impact of S-R associations.

An alternative reason why new set primes may not consistently produce priming is that, in some situations, successful task performance can be achieved very rapidly on the basis of lower-level perceptual information. This sort of explanation fits well with the results of Kunde et al.’s (2003, Experiment 3) target identification task. As described above, in their task participants pressed one button if the target was either a 1 or a 4 and a different button if the target was either a 6 or a 9. After the task was finished, many participants indicated that they developed a perceptually-based response strategy of looking for either a straight line (indicating a 1 or a 4) or a curve (indicating a 6 or a 9). A very surface-level strategy of this sort may prohibit any semantic information generated by either the prime or the target from playing much of a role in driving priming. Note also that most of their new set primes (‘2’, ‘3’, ‘7’ and ‘8’) were actually more consistent with the other response (i.e., ‘2’ and ‘3’ are curvy, unlike ‘1’ and ‘4’) which suggests that even if there was some semantically-based priming, it would most likely have conflicted with the inconsistent perceptual information provided by the perceptual features of some of the new set primes.

It seems unlikely, however, that an explanation of this type would account for all the reported failures to produce priming from new set primes. Another possible explanation for the lack of priming from new set primes would be based on the nature of semantic information activated by the primes and how the usefulness of that information might change as a result of seeing those primes as targets. That is, although primes may inevitably activate semantic information, semantic priming can only occur when the semantic information that is activated by the primes is useful for performing the task. Such a situation may not always exist. For example, in Damian’s (2001) physical size judgment task, there is no guarantee that the size information that was activated by the prime was particularly useful with respect to the specific target task (i.e., deciding whether the target is larger or smaller than some specified object) because, in general, size is more of an absolute rather than a relative concept. Therefore, there may be no reason to expect priming from new set primes. In contrast, in the experiment where old set primes were used, the nature of the semantic information activated by the primes may have become useful as a function of participants gaining practice in dealing with that information. Specifically, as a result of seeing these primes repeatedly as targets and, therefore, continually making relative size judgments in response to them, participants would have gained practice at focusing on the precise information (for those words) that would be useful for performing the task. As a result, old set primes may then have gained the ability to allow participants to rapidly focus on this type of information, producing priming, while new set primes would not have.

This type of explanation could be easily extended to number magnitude judgment tasks like those used in Kunde et al. (2003). Magnitude is an essential semantic characteristic of numbers, however, that magnitude information does not necessarily translate directly into knowledge that the magnitude of the number being perceived is greater than or less than a specific comparison number (e.g., ‘5’). Thus, it is possible that the results of some of Kunde et al.’s experiments, specifically those in which perceptual information could not be used, may be explained in terms of the nature of the interaction between the semantic information that was activated and the specific task demands.

Conclusions

In the present research we investigated the way in which masked primes produced priming by assessing the relationship between the magnitude of both the category congruence effect and the priming distance effect across trials in two number classification tasks. The presence of a priming distance effect (and a comparison distance effect) in both experiments indicates that semantic activation played a major role in producing category congruence effects, regardless of task instructions. The data do, however, support the conclusion that the nature of the task instructions can lead to S-R associations also playing an active role once those associations have reached sufficient strength.

Footnotes

[1] Repetition priming trials (i.e., trials in which the prime and target are identical) were not included in either experiment in order to examine the influence of prime-target congruency independent of any impact of prime-target repetition. It does not appear that this practice has always been undertaken in prior published experiments.

[2] Prime discrimination data were collected based on the parameter display settings using a separate group of participants (see Appendix B for the details). Note, however, that because the focus of the current research is on how participants' target processing strategies might affect the nature of the information producing the priming effect, the visibility of the primes as specifically measured by performance on a prime discrimination task would seem to have little relevance in this situation. What is more relevant is that participants had virtually no knowledge of the primes of the sort that could be used strategically during prime or target processing. That situation was created by using a short prime duration and by the prime being both forward masked and backward masked by the target. Indeed, all participants indicated that they had virtually no knowledge of the primes' existence, much less their identity.

[3] The inclusion of the targets 2, 3, 7, and 8 in the analysis did not alter the results concerning the priming distance effect. That is, there was still a significant effect of prime-target distance, $F(2, 52) = 24.34$, $p < .001$, $MSE = 279.78$, and the interaction between trial segment and prime-target distance was still not significant, $F(4, 104) = 0.16$, *n.s.*

[4] An analysis including the targets 2, 3, 7, and 8 showed a significant effect of prime-target distance, $F(2, 64) = 11.04$, $p < .001$, $MSE = 510.74$. The interaction between trial

segment and prime-target distance was marginal, $F(4, 128) = 2.35$, $p < .06$, $MSE = 501.66$.

[5] We would like to thank Dr. Sachiko Kinoshita for suggesting this particular analysis.

[6] In both the latency and error analyses, the other three main effects, task instructions, priming distance and segment were either significant ($p < .05$) or marginally significant ($p < .10$). Latencies were shorter and error rates were lower in Experiment 1.

[7] One area of debate in numerical cognition concerns the mechanisms that produce comparison distance effects. Van Opstal et al. (2008) recently proposed the monotonic connection view that suggests that comparison distance effects are due to response-related processes (see also Verguts, Fias, & Stevens, 2005). Although not the focus of the current research it should be noted that the lack of an interaction between priming distance and comparison distance in the present experiments does provide indirect support for this hypothesis.

[8] An additional experiment which involved double-digit primes and targets, patterned on Greenwald et al.'s (2003, Experiment 2) magnitude judgment task when the first digit in the target was the informative digit (i.e., the second digit of the target was always an uninformative '5') was also performed. The results paralleled those from Experiment 1 in that there was a clear category congruence effect and a priming distance effect which did not change over trials. The details of this additional experiment are presented in Appendix C.

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Addendum to Chapter 2

As outlined in *Chapter 1*, recent masked priming research indicates that masked primes have the ability to activate both semantics and S-R associations and further suggests that the origins of any masked priming effects are due to an interaction between task instructions and participants' target processing strategies. In *Chapter 2* the nature of this interaction was evaluated in two number classification tasks in which participants were instructed to make either magnitude judgments (Experiment 1) or target identification (Experiment 2) responses. In both experiments, the magnitude of the category congruence (i.e., masked priming) effect and the nature of any priming distance effect were evaluated over the course of 1008 trials. The assumption was that the time course of these two different data patterns would serve as markers indicating whether any observed priming was due to S-R associations or semantic activation.

When participants made magnitude judgments (Experiment 1) there were clear masked priming and priming distance effects which remained relatively stable over trials. These results clearly indicate that priming was primarily due to semantic activation. With respect to the role of S-R associations in producing masked priming, the results when participants made target identification responses (Experiment 2) are particularly informative. There was a significant increase in the size of the category congruence effect indicating that S-R associations did play a role in producing priming when the task became an identification task. However, the presence of a priming distance effect which did not decrease as the category congruence effect increased indicates that, despite the increased influence of S-R associations, semantic activation continued to play a primary role in producing priming.

The results from the number classification tasks (*Chapter 2*), particularly Experiment 2, indicate that even when masked priming is primarily due to the activation of semantics, S-R associations can still play a role. The focus in *Chapter 3* is on the role of S-R associations. In general, previous investigations of masked priming have all used tasks with clearly defined semantic categories (e.g., pleasant/unpleasant, even/odd) which allow semantics to play a central role in producing masked priming. Therefore, in order to investigate the development of S-R associations and their role in producing masked priming a paradigm is needed that will not allow for an impact of semantic activation. One experimental paradigm that should serve this purpose is the category learning task.

In a typical category learning task (e.g., Lamberts, 1995; Nosofsky & Zaki, 2002; Smith & Minda, 1998) participants are repeatedly presented with the same set of artificial stimuli (e.g., nonsense letter strings, bug cartoons) and are required to learn through feedback which target stimuli belong to one category and which target stimuli belong to the other category. This task would be ideal for investigating an S-R association account of masked priming since the items in these category sets are novel and, thus, they have no ability to activate semantic information. Further, at the beginning of the task, the stimuli are not associated with either possible response and so the results should provide insights into how congruence effects develop as the S-R associations for new categories are learned.

In *Chapter 3* a masked priming version of a category learning task was used to trace how the development of S-R associations influence the nature of any masked priming effects when there should no be influence of semantic activation. In these tasks artificial category sets consisted of either 10 four-dimensional (e.g., ‘WAZY’ –

Experiment 1A & Experiment 2) or 14 six-dimensional (e.g., 'KEPIRO' – Experiment 1B) letter strings. The masked primes were the prototypes of each category, that is, letter strings which share most of their letters with the other items in its category and have no letters in common with the prototype of the other category. The results from these experiments should allow for a clearer examination of the role of S-R associations in producing priming than in previous research.

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Chapter 3 – Category Learning Tasks with Masked Primes

In a typical masked priming paradigm a masked prime is briefly presented (typically for 60 ms or less) and is then followed by a target stimulus that requires a response. As a result, participants are typically unaware not only of the prime's identity but also of its existence. Nonetheless, these primes influence target responding. For example, a common finding is a category congruence (i.e., "priming") effect in that responses are faster when the prime and target stimuli require the same response (i.e., a congruent trial) than when the prime and target stimuli require different responses (i.e., an incongruent trial). In a recent review, Kiesel, Kunde and Hoffmann (2007) emphasized that one key goal of research using the masked priming paradigm involves identifying and specifying the mechanisms by which stimuli that people are not consciously aware of are able to produce priming effects (i.e., are able to affect a conscious action).

Brief Overview of Previous Masked Priming Research

According to one line of research, masked primes are assumed to be processed to only a "shallow" level and, therefore, any category congruence effect is presumed to be due to the prime triggering a response (see, e.g., Abrams, 2005; Abrams & Greenwald, 2000; Boy & Sumner, 2010; Damian, 2001; Neumann & Klotz, 1994; Klotz & Neumann, 1999). Specifically, S-R associations are assumed to be formed between target stimuli and their responses due to their repeated presentations and classifications. Once these associations have become sufficiently strong, presentation of these stimuli as primes produces a bias to respond with their associated responses. This response bias aids target responding on congruent trials and interferes with target responding on incongruent trials.

One key prediction of this type of S-R association account is that priming should only occur for primes that have been previously presented and responded to as target stimuli (i.e., “old set primes”). Primes which have not been previously responded to as targets (i.e., “new set primes”) should not produce priming since response biases have not been formed for these primes. Although there have been some demonstrations that priming is restricted to old set primes (e.g., Abrams & Greenwald, 2000; Damian, 2001), there are a variety of classification tasks demonstrating that new set primes do produce priming (e.g., Dell’Acqua & Grainger, 1999; Kinoshita & Hunt, 2008; Klauer, Eder, Greenwald & Abrams, 2007; Kunde, Kiesel, & Hoffmann, 2003, 2005; Naccache & Dehaene, 2001; Reynvoet, Caessens & Brysbaert, 2002; Reynvoet, Gevers & Caessens, 2005; Quinn & Kinoshita, 2008; Van den Bussche, Notebaert & Reynvoet, 2009; Van den Bussche & Reynvoet, 2007).

The fact that new set primes often produce priming indicates that masked priming is not due solely to S-R associations and suggests that masked primes activate semantic information (although see Kunde et al., 2003, for an alternative account that may be viable in certain circumstances). That is, prior conceptual knowledge that defines the relationships between features within a category domain is activated and that information aids target processing (see Kaplan & Murphy, 2000; Murphy & Allopenna, 1994; Murphy & Medin, 1985). For example, Naccache and Dehaene (2001) obtained priming from new set primes in a magnitude judgment task (i.e., is the target less than or greater than “5”?) which they attributed to the masked number prime activating one’s pre-existing knowledge of magnitude relations.

However, even if masked primes do prime through the activation of semantics (e.g., the activation of categorical representations of pre-existing knowledge such as number magnitude) that does not rule out the possibility that S-R associations play some role in masked priming. In fact, a variety of recent theories of masked priming claim that both S-R associations and semantic activation are involved in producing masked priming effects, or, as they have often been referred to in those situations, “category congruence effects” (e.g., Kinoshita & Hunt, 2008; Klauer, Musch & Eder, 2005; Reynvoet et al., 2005). Further, there have been a number of demonstrations suggesting that the source of the masked priming effect can change with simple changes in the nature of the task such as the size of either the target set (e.g., Kiesel, Kunde, Pohl & Hoffmann, 2006; Pohl, Kunde, Kiesel & Hoffman, 2010) or the category involved in the task (e.g., Abrams, 2008).

Investigating S-R Association Mechanisms Using a Category Learning Task

The goal of the present research was to create a paradigm that would document the development of masked priming effects due to S-R associations. To this point, virtually all the tasks that have been used to investigate masked priming have used either stimuli belonging to clearly defined semantic categories (e.g., pleasant/unpleasant, less/greater than 5), or stimuli like arrows which *a priori* invoke response tendencies (e.g., Eimer & Schlaghecken, 1998; Perry & Lupker, 2010). With respect to the former types of tasks, the implication is that either semantics or S-R associations (or both) could produce any observed category congruence effects. With respect to the latter types of tasks, the implication is that the relevant S-R associations may have already developed before the experiment, making it impossible to investigate the nature of their development and impact on the priming process. Therefore, in order to provide an uncontaminated examination of S-R associations, a different type of task and a certain type of stimulus set are needed. The paradigm selected for the present investigation was a masked priming version of a category learning task using letter string stimuli.

In a typical category learning task (e.g., Lamberts, 1995; Nosofsky & Zaki, 2002; Smith & Minda, 1998) participants are repeatedly presented with the same set of artificial stimuli (e.g., nonsense letter strings, bug cartoons) and are required to learn, based upon feedback, which target stimuli belong to one category and which target stimuli belong to the other category. This task has been typically used to investigate the ability and speed with which various artificial category sets are learned, that is, the trajectory of category learning, which is derived by measuring performance accuracy in various time segments over the course of the task.

A category learning task involving artificial stimuli should be optimal for investigating the development of a masked priming effect due to S-R association mechanisms. First of all, the items in these category sets are novel (as noted, in the present experiments they were letter strings) and, therefore, have no ability to activate/retrieve semantic information. That is, since both the stimuli and the response categories are artificial then these stimuli should be viewed as sets of arbitrary features with participants in such a task having no pre-existing knowledge of relations among these features which could facilitate the category learning processing (see Kaplan & Allopenna, 1994). Second, at the beginning of the learning process, the stimuli are not associated with either possible response (either explicitly or implicitly) and, thus, should allow us to trace the development of the priming effect as the S-R associations for new categories are learned.

The artificial category sets that were used in the present experiments consisted of either 10 four-dimensional (e.g., 'WAZY') or 14 six-dimensional (e.g., 'KEPIRO') letter strings. In both cases, the dimensions corresponded to the letter positions with two possible letter identities for each position (for example, in the four-dimensional category set, the first dimension corresponds to whether the identity of the letter in the first position is either a 'B' or a 'W'). For both categories in the four- and six-dimensional stimulus sets, half the letter strings belonged to one category and half belonged to the other category. Each category set also contained a prototype item. That is, a letter string which shares most of its letters with the other items in its category and has no letters in common with the prototype of the other category. These prototypes were used as masked primes in the present experiments (further details about the category sets can be found in the Method section).

The Nature of Masked Priming: An S-R Association Account

The key piece of evidence that would be required in order to demonstrate that a priming effect is due to S-R associations is the growth in the size of that effect over trials. That is, if S-R associations initially have little or no strength then they have no ability to prime during the early trials of an experiment. In order for them to become effective primes, their strength needs to be increased as a result of responding to them when they are presented as targets. There are now three demonstrations of priming effects that increased in size over trials and, therefore, may be due to S-R associations.

Damian (2001) investigated the influence of S-R associations on masked priming using a physical size (large or small) judgment task. When old set primes were used (Experiment 1), a category congruence effect occurred in that responses were faster when both the prime and the target corresponded to either large or small items (i.e., a congruent trial) than when the prime and target corresponded to items of opposite sizes (i.e., an incongruent trial). Damian demonstrated that this effect increased in size across trial blocks and claimed that this increase implicates S-R associations because “if the congruity effect depended on automatized mappings between stimuli and their corresponding responses, it should clearly build up across the experiment” (p. 158). Unfortunately, Damian’s task is one in which semantics can play an important role in producing priming. In fact, as will be discussed in the General Discussion, Damian’s results do have an alternative explanation in terms of how participants use semantic information generated by the masked prime.

Schlaghecken, Blagrove and Maylor (2007) investigated how the incidental learning of S-R associations influences masked priming. In their experiments participants were presented with non-directional arrows (< > or > <) as masked primes (in black) and as visible targets (presented in different colours) and asked participants to respond to the colour of the target. When target shape and colour perfectly covaried (e.g., < > was always blue and > < was always green) category congruence effects emerged in the second half of the experiment. Interestingly, however, the effect was a reverse effect such that responses were slower when the prime and target had the same shapes, indicating that something more complicated than the simple association of stimuli and responses was occurring (e.g., a response suppression mechanism, Eimer & Schlaghecken, 2003, was being invoked).

Boy and Sumner (2010) investigated the relationship between S-R associations and the nature of the congruency effect in a variety of arrow classification tasks. Crucially, in each experiment, Boy and Sumner observed a gradual negative increase across trials in the size the congruency effect which might be considered to be consistent with the idea that S-R associations exert a greater influence on the nature of the priming effect as they are formed and strengthened. Again, however, these congruency effects were reverse priming effects.

The Present Research

As noted, the current research employed a masked priming version of a category learning task to investigate the impact of S-R associations on masked priming. The main question of interest was whether a category congruence effect would emerge over trials for correct responses such that responses to a target would be faster when preceded by its prototype as opposed to the prototype of the other category. This finding would be of particular interest since it would be the first demonstration of a masked priming effect with alphanumeric stimuli which would not have a potential explanation in terms of semantic activation.

If, indeed, priming effects in the present experiments are due to S-R associations then a second expectation arises. Whenever an incorrect response is given on an incongruent prime trial, at least part of the reason would presumably be that the incongruent prime had created a response bias toward the incorrect response. In contrast, incorrect responses on congruent prime trials only occur when participants overcome the response bias (toward the correct response) created by the congruent prime. As a result, an examination of the response latencies for incorrect trials should reveal a reversed category congruence effect. That is, incorrect responses to a target should be faster when preceded by the prototype of the opposite category as opposed to the prototype of its own category.

Method

Participants. Seventy-eight University of Western Ontario psychology undergraduate students received course credit for their participation in this experiment. Thirty-three participated in Experiment 1A (Age Range = 18 to 21, Mean = 18.4) and 45 participated in Experiment 1B (Age Range = 18 to 21, Mean = 18.6). All had either normal or corrected-to-normal vision and were proficient in English.

Materials. The target set consisted of either 10 four-dimensional items (Experiment 1A) or 14 six-dimensional items (Experiment 1B) (see Appendix A). All targets were pronounceable. The dimensions corresponded to the letter positions with the value on each dimension being binary. For example, for the four-dimensional stimuli, the letter in the first position of the item was either a ‘B’ or a ‘W’. For both category sets, half the items belonged to one category (“Category 1”) and the other half belonged to the other category (“Category 2”).

Each category set consisted of a prototype item which shared most of its letters with the non-prototype items in its own category and did not share any letters with the prototype of the other category (i.e., ‘WAZY’ and ‘BERO’). The non-prototype items in the four-dimensional category sets (Experiment 1A) shared three out of four letters with their prototype and only one letter with the prototype from the other category (e.g., ‘WEZY’ or ‘WARY’ for the category with the prototype ‘WAZY’). The non-prototype items in the six-dimensional category set (Experiment 1B) shared either four or five out of six letters with the prototype of their category.

In both experiments, the targets were presented in upper-case (e.g., ‘WEZY’ or ‘BARO’). The primes were either the prototype for the category to which the target belonged (i.e., a congruent prime) or the prototype for the other category (i.e., an incongruent prime).[1] Primes were always presented in lower-case letters (‘wazy’ or ‘bero’). The forward mask consisted of a series of either four (Experiment 1A) or six (Experiment 1B) ‘&’ symbols (e.g., ‘&&&&&&’) with the uppercase targets serving as the backward mask. All stimuli were presented in 14 point Courier New font.

In Experiment 1A, each target was presented 44 times (440 trials in total) in blocks of 10 trials such that each block consisted of a random presentation of all ten items. In Experiment 1B each target was presented 28 times (392 trials in total) in blocks of 14 trials such that each block consisted of a random presentation of all 14 items. In both experiments, each target was preceded equally often by a congruent versus an incongruent prime. Note also that for both experiments the prototypes appeared as both primes and targets.

Equipment. All experiments were run using DMDX experimental software produced by Forster and Forster (2003). Stimuli were presented on a SyncMaster monitor (Model No. 753DF). Presentation was controlled by a Windows-based PC. Stimuli appeared as black characters on a white background. Responses to stimuli were made by pressing one of two <shift> keys on the keyboard.

Procedure. Participants were run individually. Each participant sat approximately 18 inches in front of the computer screen and was told by the experimenter that they would be presented with a series of letter strings and their task was to learn, on the basis of feedback, which letter strings belong to Category 1 and which letter strings belong to Category 2. The participants were instructed to respond by pressing the left <shift> key if they believed the letter string belonged to Category 1 and the right <shift> key if they believed the letter string belonged to Category 2. In addition, participants were instructed to make their responses quickly since the letter string would only be visible for a limited period of time.

Each participant then performed either 440 trials (Experiment 1A) or 392 trials (Experiment 1B). Each trial began with a 440 ms forward mask (e.g., ‘&&&&’) which acted as a fixation cue and was followed by a 55 ms prime which was one of the two prototypes. The prime was then followed by a target which was presented in the same position on the monitor as the forward mask and the prime for a maximum of 900 ms. After each response, participants were given feedback indicating whether their response was correct or not along with their reaction time if the response was correct. If participants did not respond before the target disappeared, the message “No Response” was displayed before the next trial began.

Results

Trials in which either no response was given or the latency was less than 100 ms were excluded from all analyses (4.2% of the trials in Experiment 1A, 3.9% of the trials in Experiment 1B). Error rates (trials when the wrong response was given) were 24.1% in Experiment 1A and 34.3% in Experiment 1B. For each experiment, the data were submitted to 2 (trial segment: early (first half of the trials) vs. later (second half of the trials)) by 2 (category congruence: congruent vs. incongruent) analyses of variance (ANOVA). Separate ANOVAs for the correct response latencies, incorrect response latencies and error rates were run. The results for both experiments are presented in Table 1.

Experiment 1A : Four-Dimensional Category Set

Latency analyses for correct responses.[2] There was a significant main effect of category congruence, $F(1, 32) = 10.04$, $p < .004$, $MSE = 299.86$. Targets were responded to 10 ms faster when the preceding prime was the prototype for their category (514 ms) as opposed to the prototype of the other category (524 ms). There was no effect of trial segment, $F(1, 32) = 0.52$, *n.s.*, nor was the interaction significant, $F(1, 32) = 0.01$, *n.s.*

Error analyses. There was a significant main effect of trial segment, $F(1, 32) = 24.63$, $p < .001$, $MSE = 0.006$, and a marginal effect of category congruence, $F(1, 32) = 3.11$, $p < .09$, $MSE = 0.003$. The error rate was significantly greater in the early segment (28.8%) than in the later segment (21.9%) indicating that participants were learning the categories. The interaction was not significant, $F(1, 32) = 2.08$, *n.s*.

Latency analyses for incorrect responses. Neither of the main effects nor the interaction were significant (all *F*s < 0.53).

Experiment 1B : Six-Dimension Category Set

Latency analyses for correct responses. There was a significant main effect of category congruence, $F(1, 44) = 27.71$, $p < .001$, $MSE = 206.56$. Targets were responded to 11 ms faster when the preceding prime was the prototype of their category (511 ms) as

Table 1.

Results for Category Learning - Experiment 1 (Reaction Times in Milliseconds, Errors in Percent)

	Correct Responses			Incorrect Responses		
Trial Segment	Incongruent Primes	Congruent Primes	PE	Incongruent Primes	Congruent Primes	PE
Four-Dimensional Category Set (Experiment 1A)						
Early	521 (29.1)	511 (28.6)	10	501	502	- 1
Late	527 (23.2)	517 (20.6)	10	506	511	- 5
Six-Dimensional Category Set (Experiment 1B)						
Early	524 (38.8)	511 (37.7)	13	503	515	- 12
Late	521 (33.7)	511 (33.0)	10	505	513	- 8

Note. Numbers in bracket are the error rates. PE = Priming Effect

opposed to the prototype of the other category (522 ms). There was no effect of trial segment, $F(1, 44) = 0.02$, *n.s.*, nor was the interaction significant, $F(1, 44) = 0.50$, *n.s.*

Error analyses. There was a significant main effect of trial segment, $F(1, 44) = 19.14$, $p < .001$, $MSE = 0.006$. The error rate was greater in the early segment (38.3%) than in the later segment (33.4%) indicating that participants were learning the categories. There was no effect of category congruence, $F(1, 44) = 1.38$, *n.s.*, nor was the interaction significant, $F(1, 44) = 0.07$, *n.s*

Latency analyses for incorrect responses. There was a significant reversed effect of category congruence, $F(1, 44) = 11.44$, $p < .003$, $MSE = 390.78$. Responses were 10 ms faster when targets were preceded by the prototype of the opposite category (504 ms) as opposed to their own prototype (514 ms). However, there was no effect of trial segment, $F(1, 44) = 0.01$, *n.s.*, nor was the interaction significant, $F(1, 44) = 0.31$, *n.s.*

Post-Hoc Analysis: Perceptual Overlap

A post-hoc analysis was performed to determine whether the observed category congruence effects were due to the perceptual overlap between the prime and target. In Experiment 1A the primes were either ‘wazy’ or ‘bero’. Note that the prime ‘wazy’ contains three letters that have the same features in both lower and upper case (i.e., “w’, ‘z’, and ‘y’) whereas the prime ‘bero’ has only one (i.e., ‘o’). Therefore, if perceptual overlap was the driving force behind the small priming effect then the targets for the WAZY category should show a larger priming effect than the targets for the BERO category.

To examine this issue, the latency data were submitted to a 2 (category type: WAZY vs. BERO) by 2 (trial segment) by 2 (category congruence) ANOVA. There was no main effect of category type, $F(1, 32) = 0.03$, *n.s.*, and more importantly, there were no significant interactions with category type (All Fs < 1.58). Therefore, it does not appear that perceptual overlap was responsible for the observed priming.

Discussion

One clear result in Experiment 1 was that for both category sets there was a significant category congruence effect for correct response latencies. That is, responses to targets were faster when preceded by their own prototype as opposed to the prototype of the other category. Potential sources of this effect will be discussed further in the General Discussion. However, for now, the most important aspect of these effects is that they do not appear to have been due to S-R associations. If they had been due to S-R associations, their size should have increased over trials. Note also that there was a reverse priming effect for the incorrect response trials in Experiment 1B, however, there was no indication that this effect increased across trial blocks either. Thus, although the data clearly demonstrate priming without the activation of semantics it is difficult to ascribe this effect to the impact of developing S-R associations.

Experiment 2

One possibility for why there was virtually no evidence of an impact of S-R associations (i.e., that the size of the category congruence effect showed little evidence of increasing over trials) may be that the present circumstances did not allow sufficient time for S-R associations to develop. In fact, the high error rates even in the later trial segment suggests that participants were still learning the stimulus features that would allow them to correctly categorize the stimuli and, thereby, allow the appropriate S-R associations to reach a sufficient level of strength to impact priming.[3]

The goal of Experiment 2 was to determine whether the size of the category congruence effect would increase over trials if participants were given considerably more opportunity to form and strengthen their S-R associations. Using the four-dimensional stimuli from Experiment 1A, nine participants performed the categorization task once per day for five consecutive days. If S-R associations produce priming in this task, the expectation is that, with additional practice, we will observe an increase in the size of the category congruence effect for correct response over days as well as an increase in the size of the reverse category congruence effect for incorrect responses.

Method

Participants. Nine University of Western Ontario psychology graduate students received $50.00 each for their participation in this experiment (Age Range = 23 to 33, Mean = 27.4). All had either normal or corrected-to-normal vision and were proficient in English.

Materials. The target set consisted of the 10 four-dimensional items used in Experiment 1A (see the Appendix).

Procedure. The procedure was the same as in Experiment 1A except that each participant performed the task once a day for five consecutive days.

Results

In the present analyses, performance during the first two days of training was compared with performance during the final two days of training (i.e., performance on day 3 was excluded from the analyses although data from day 3 are included in Table 2). For the other four days, trials in which either no response was given or the latency was less than 100 ms were excluded from all analyses (1.6% of the trials). The overall error rate was 19.4%.

The data were submitted to three 2 (training sessions: early [day 1 & day 2] vs. later [day 4 & day 5]) by 2 (category congruence: congruent vs. incongruent) ANOVAs (latencies for the correct responses, latencies for the incorrect responses and the error rates). The results are presented in Table 2.

Latency analyses for correct responses. There was no effect of training sessions, $F(1, 8) = 0.25$, *n.s.*, but there was a significant main effect of category congruence, $F(1, 8) = 11.23$, $p < .02$, $MSE = 254.90$. Targets were responded to 18 ms faster when the preceding prime was its own prototype (480 ms) as opposed to the prototype of the other category (498 ms). Crucially, the interaction was significant, $F(1, 8) = 7.21$, $p < .03$, $MSE = 40.11$, due to the fact that the 23 ms priming effect in the later training sessions was greater than the 12 ms priming effect in the early training sessions.

Error analyses. There was a significant effect of training sessions, $F(1, 8) = 12.27$, $p < .009$, $MSE = 0.009$, but no effect of category congruence, $F(1, 8) = 0.08$, *n.s.* The error rate was greater in the early training sessions (25.5%) than in the later sessions (14.2%), indicating that participants were learning the categories. The interaction was also significant, $F(1, 8) = 5.15$, $p = .05$, $MSE = 0.001$, due to the fact that there was a small positive priming effect in the later sessions (13.4% errors following a congruent prime, 15.0% errors following an incongruent prime) whereas the small difference in the early sessions went in the opposite direction (26.0% errors following a congruent prime, 25.0% errors following an incongruent prime).

Table 2.

Results for Category Learning - Experiment 2 (Reaction Times in Milliseconds, Errors in Percent)

	Correct Responses			Incorrect Responses		
Trial Segment	Incongruent Primes	Congruent Primes	PE	Incongruent Primes	Congruent Primes	PE
Days 1 & 2	501 (25.0)	489 (26.0)	12	503	509	- 6
Day 3	517 (16.9)	499 (14.4)	18	507	528	- 21
Days 4 & 5	495 (15.0)	472 (13.4)	23	467	509	- 42

Note. Numbers in bracket are the error rates. PE = Priming Effect

Latency analyses for the incorrect responses. There was no effect of training sessions, $F(1, 8) = 0.62$, *n.s.*, but there was a marginal reversed effect of category congruence, $F(1, 8) = 3.72$, $p < .10$, $MSE = 1266.90$. More importantly, the interaction was significant, $F(1, 8) = 22.72$, $p < .002$, $MSE = 114.17$, due to the fact that the 42 ms reversed priming effect in the later training sessions was greater than the 6 ms reversed priming effect in the early training sessions.

Discussion

The results in Experiment 2 support the notion that, with additional practice classifying the stimuli, S-R associations become strengthened and, as a result, there is an increase in the size of the category congruence effects. Specifically, both a larger category congruence effect for correct responses and a larger reversed category congruence effect for incorrect responses (i.e., faster responding when the target was preceded by the prototype of the other category as opposed to its own prototype) occurred in the later training sessions in comparison to the early training sessions.

General Discussion

The goal of the present research was to examine the process by which S-R associations begin to produce priming effects in masked priming tasks. We propose that a masked priming version of the category learning task is an ideal task to evaluate S-R association mechanisms since the stimuli in this paradigm have no ability to activate semantic information and are not associated *a priori* with any response.

Participants were repeatedly presented with stimuli from artificial categories consisting of either four- (Experiment 1A & 2) or six- (Experiment 1B) dimensional letter strings and were required to learn, on the basis of feedback, which target stimuli belonged to one category and which target stimuli belonged to the other category. In every experiment, the target stimuli were preceded by a masked prime which was either the prototype of the target’s category or the prototype of the other category.

Summary of Results

In both Experiments 1A and 1B, small but significant category congruence effects emerged. Responses were faster when targets were preceded by the prototype of their category as opposed to the prototype of the other category. In addition, in Experiment 1B there was a significant reversed category congruence effect (i.e., faster responses when the target was preceded by the prototype for the other category as opposed to the prototype of its own category). However, because neither of these priming effects increased in size over trials, the data from those experiments do not provide much support for the notion that these priming effects are due to the impact of S-R associations.

In Experiment 2, participants performed the same (four-dimensional) category learning task as in Experiment 1A once a day for five consecutive sessions in order to investigate whether the lack of growth in the size of the category congruence effect in Experiment 1 may have been due to having insufficient time to fully develop and strengthen the appropriate S-R associations. The results support this idea. Specifically, both the size of the category congruence effect for correct responses and the size of the reversed category congruence effect for incorrect responses was significantly greater in the later training sessions (i.e., the fourth and fifth sessions) than in the early training sessions (i.e., the first and second sessions).

Implications of the Current Research

I. S-R Association Accounts of Masked Priming

In most of the prior studies in which the masked priming effects have been assumed to be due to S-R associations (e.g., Abrams, 2005; Abrams & Greenwald, 2000; Boy & Sumner, 2010; Damian, 2001; Neumann & Klotz, 1994; Klotz & Neumann, 1999) priming was evident quite early. For instance, in Damian's experiment using old set primes, the priming effect was significant by the fifth time participants had seen the primes as targets. In contrast, there was no evidence of an increase in priming over a reasonably large number of trials in the present Experiments 1A and 1B and in Experiment 2 the priming effect grew quite slowly over several sessions. The results from the masked priming version of the category learning task, therefore, suggest that it takes considerable time for S-R associations to develop to the point where they can affect priming, at least when using alphanumeric stimuli that are not initially associated with any particular response as primes and targets.

What must be acknowledged, of course, is that the stimuli and the task used in the present research are noticeably different from those typically used in the masked priming literature. However, the results from the present experiments at least raise the question of whether the prior effects may have an alternative explanation. Specifically, because many of these studies used clearly defined semantic categories it is possible that those effects may have actually been due to changes in the nature of the semantic information activated by the prime over trials. Consider, for example, Damian's (2001) physical size judgment task involving old set primes. In his task, no priming was observed for the old set primes in the first two trial blocks, however, significant priming was observed in the third and subsequent blocks even though, at that point, participants had only seen and responded to each target four times. Clearly, something was changing/developing over trial blocks and Damian's suggestion that it was the strength of the S-R associations is a reasonable hypothesis if one can successfully argue that S-R associations can be sufficiently developed as a result of four responses to a stimulus.

An alternative possibility, however, is that what may have been developing over trials was the participants' ability to retrieve/focus on the specific semantic information which was necessary to perform Damian's (2001) task. In this particular situation, that would be the more detailed size-based information that allows a participant to determine whether the target is larger or smaller than an arbitrarily selected comparison object (e.g., a computer monitor). Perhaps, as participants practiced retrieving this specific size-based information for the targets used in the experiment then those targets may have also started to activate this particular type of information automatically when they were presented as masked primes. If so, Damian's old set primes would then have started to produce priming. In contrast, new set primes, which never appear as targets, would not produce priming because participants would never have had the opportunity to develop the necessary retrieval processes for those stimuli.[4] Further research is needed to determine whether a semantically-based explanation can provide a better account of Damian's results.

II. The Category Congruence Effect in Experiment 1

One question that remains concerns the source of the category congruence effects which arose very early in processing in both Experiments 1A and 1B and in the first session in Experiment 2. A semantic activation account of these effects would be inadequate since the category sets were artificial and, hence, had no pre-existing semantics for the primes to activate. As discussed, an examination of the time course of these effects effectively also rules out any S-R association account since their size does not increase across trials.[5] Nor is it likely that the effects were due to perceptual overlap between the primes and targets. In the following discussion, two other accounts of masked priming effects, one based on perceptual learning and the other based on Kunde et al.'s (2003) action-trigger hypothesis, are considered as potential explanations for these effects.

Perceptual learning. The general idea behind perceptual learning accounts (e.g., Przekoracka-Krawczyk & Jaskowski, 2007; Schlaghecken et al., 2007, 2008) is that participants' performance is altered over trials as they learn (often implicitly) to better attend to various features of the visual display. Such attention to features could then carry over to masked prime processing. The key difficulty, however, with using a perceptual learning account to explain the results in Experiment 1 is that the prior results clearly show that any priming due to perceptual learning takes time to develop. For example, Przekoracka-Krawczyk and Jaskowski had participants classify target arrows preceded by masked primes in an initial training block followed by a test block. Across all their experiments, priming only occurred in the test blocks. Therefore, it does not appear that a perceptual learning account could provide a framework for explaining why priming occurred in the early trials in Experiment 1, although it could provide an explanation for the results in Experiment 2. The same could also be said for other types of automatization accounts (e.g., Logan's, 1988, 1990, instance theory). That is, although these processes may help to explain the effects observed in Experiment 2, they do not appear to hold much promise for explaining the effects observed in Experiment 1.

Action-trigger hypothesis. According to Kunde et al.'s (2003) action-trigger account of masked priming (see also Kiesel et al., 2007) participants set up action-trigger sets, that is, mappings between possible stimuli and their responses in a target classification task. These mappings can involve any stimuli that a participant might choose to include and can be formed quickly and without practice. Responses are facilitated when the prime and target activate the same action trigger and are inhibited when they activate different action triggers. The action-trigger hypothesis was originally proposed by Kunde et al. as an alternative explanation to a purely semantic account of how new set priming occurs in magnitude judgment tasks.

With respect to Experiment 1, an action-trigger account would go as follows. Participants would learn very early that items that belong to the same category have a much stronger family resemblance (i.e., they typically have more letters in common) than items that belong to the other category. They would then use that knowledge to establish appropriate action-triggers for at least some of the stimuli. Since there is no explicit assumption that, once established, strengthening these action-triggers through further practice will produce an increase in the size of the category congruence effect, priming could occur early and (potentially) vary little in magnitude over trials, as observed in Experiment 1.

It would be a bit more difficult to explain the increase in the size of the priming effect over training sessions in Experiment 2 in terms of the action-trigger account. To do so, one would need to assume that their usage was refined based on some sort of build-up of knowledge with exposure/practice, an assumption that is not part of the action trigger account. For example, perhaps the assignment of action triggers early in the experiment (i.e., throughout Experiment 1 and the first day or two in Experiment 2) was not always correct because the participants were still learning the categories. Once the categories were learned (i.e., the later days in Experiment 2), participants may have been able to associate the action triggers with the appropriate stimuli more confidently and/or consistently.

Alternatively, both action triggers and S-R associations may have both played a role in the later sessions in Experiment 2. That is, priming in the initial blocks may have been due to action triggers and their impact may have continued throughout the experiment. The increase in the size of the priming effect in Experiment 2, however, may have been due to the development of S-R associations. The idea that two factors could influence priming at the same time is atypical but certainly not novel (e.g., Kinoshita & Hunt, 2008; Perry & Lupker, submitted) and there is certainly no *a priori* reason why any observed category congruence effect could not have multiple sources. Defining the boundaries of the action-trigger account and how it relates to S-R association accounts, therefore, will be an important issue for future research.

III. An Alternative Account of the Category Congruence Effects in Experiment 2

In the current experiments, semantics was defined as prior conceptual knowledge/representation of a category in terms of the relationships between its individual stimulus features (see Kaplan & Murphy, 2000; Murphy & Allopenna, 1994; Murphy & Medin, 1985). By this definition, stimuli within our categories were not semantically related (as well as being arbitrary). That is, these stimuli were merely nonword letter strings in which the “features” corresponded to the identity of one of two possible letters (e.g., the first letter was either a “W” or a “B”). Therefore, our assumption was that any observed increase in the size of the category congruence effects in Experiment 2 could not have been due to the activation of semantics and must, instead, have been due to additional practice learning and strengthening the appropriate S-R associations.

In theory, however, one could assume that with continued exposure to these stimuli, participants might have begun to develop some sort of conceptual knowledge concerning the relationship among the various features within the category set (see Murphy & Medin, 1985). If so, the masked primes may, then, have started to automatically activate this particular semantic knowledge leading to the observed category congruence effects in Experiment 2. That is, the increase in priming would have been (at least partly) due to the increased activation of semantic information over trials (an explanation that would be somewhat similar to the semantically-based explanation provided earlier for Damian’s, 2001, results).

To the extent that this alternative is correct, it would raise the further question of whether S-R associations were, in fact, at all responsible for the priming pattern in Experiment 2. That is, it would be unclear whether the source of the observed priming was purely “semantic” or whether S-R associations also developed to the point where they also impacted priming (e.g., Kinoshita & Hunt, 2008). This question, of course, also has implications for the role of S-R associations in automaticity (e.g., Klapp & Greenberg, 2009). That is, if semantics can be defined to include any relationship between a stimulus and the knowledge that the stimulus represents then even knowledge about S-R associations would have to be regarded as semantic knowledge. Therefore, semantic knowledge could be the only possible source of priming effects. Hopefully, further research deriving from Murphy and Allopenna's (1994; Kaplan & Murphy, 2000) investigations concerning the impact of conceptual knowledge on artificial category learning (applied to masked priming situations) will allow us to address this issue.

Conclusions

The present research employed a masked priming version of a category learning task to investigate the role of S-R associations in producing category congruence effects in a situation that, by assumption, legislates against any influences of semantic activation. In Experiment 1 priming effects emerged, but did not increase in size over trials. In Experiment 2 priming effects did increase in size, but only after participants performed multiple training sessions. These results, therefore, provide support for the claim that S-R associations (or something conceptually similar such as action triggers) do play a role in masked priming tasks with alphanumeric stimuli (i.e., there is priming in these types of tasks that is not due to the activation of semantic information).

Footnotes

[1] All the primes in the current experiments were old set primes because the prototype items were used as both masked primes and targets. Note that, in the category learning task, category membership is defined by the perceptual features of the stimulus set which, in the present experiments, were the letter identities at each of the letter positions in the stimulus. Therefore, even if the prototype items were never seen and classified as targets, the prototype primes would probably be best thought of as old set primes since they, by necessity, share most of their letters with the other members of their categories (see Abrams & Greenwald, 2000).

[2] Removing the prototype targets (i.e., repetition priming) from this and all subsequent analyses changed none of the significant main effects nor interactions.

[3] A post-hoc analysis based on correct response latencies for the non-prototype targets (i.e., non-repetition priming) was run in order to determine whether the priming effects might vary as a function of the participants' ability to learn the artificial category sets (see Appendix D for further details). For both Experiments 1A and 1B participants were divided into three levels of learning achievement based upon overall error rates in the task. In neither experiment was there an interaction between learning achievement and category congruence nor a three-way interaction of learning achievement, category congruence and trial segment, implying that even the participants who had best learned the categories were still not showing evidence of the patterns predicted by an S-R association account.

[4] This is not the only possible semantically-based explanation. Another, similar, way of thinking about Damian's (2001) results is that what was developing over trials was the

participants' ability to categorize targets (i.e., old set primes) into the ad hoc categories (e.g., Barsalou, 1982) of "things larger or smaller than a computer screen" (see Quinn & Kinoshita, 2008, for a similar proposal). New set primes, in contrast, would not have gained this ability because they never appeared as targets. The authors would like to thank Deanna Friesen for bringing this idea to our attention.

[5] An obvious question is, how early in Experiments 1A and 1B did these effects emerge? To address this question we analyzed the category congruence effects for the non-prototype targets in the first four trial blocks (32 trials in Experiment 1A and 48 trials in Experiment 1B). In both Experiments 1A and 1B there were four presentations of each stimulus (two primed by their own category prototype and two primed by the other category's prototype). In Experiment 1A there was a significant 25 ms effect [497 ms vs. 522 ms, $t(32) = 3.65$, $p < .002$, $SE = 6.80$] and in Experiment 1B there was a significant 16 ms effect [515 ms vs. 531 ms, $t(44) = 2.04$, $p < .05$, $SE = 8.01$]. These results suggest that there is little reason to believe that the category congruence effects in Experiments 1A and 1B required practice in order to develop.

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Addendum to Chapter 3

The generally accepted "prospective" view of how the mechanisms of masked priming work is that a) the presentation of a masked prime induces a temporary state of activation in the cognitive system and b) any effect of the prime must be due solely to automatic, rather than strategic, activation processes (see Forster & Davis, 1984). Probably the most important question for those accepting this view concerns the source of the prime's activation (i.e., S-R associations or semantics).

As noted previously, in general, masked priming research has used clearly defined semantic categories (e.g., categories based on things like shape or magnitude). Much of that research has suggested that the primary source of masked priming in these tasks was likely the activation of semantics. The presence of a priming distance effect in both number classification experiments from *Chapter 2* provides further support for this possibility. In *Chapter 3,* the nature of any category congruence (i.e., masked priming) effects in a masked priming version of a category learning task was investigated. Since the stimuli in this type of task are artificial they a) have no pre-existing ability to activate semantic information and b) are not initially associated with any response. Therefore, this paradigm should be ideal to demonstrate the impact of S-R associations since any congruence effects would have to be due to the impact of S-R associations as they develop.

Recall that Damian (2001) noted that an S-R association account predicts that "if the congruity effect depended on automatized mappings between stimuli and their corresponding responses, it should clearly build up across the experiment" (p. 158). For both the four-letter (Experiment 1A) and six-letter (Experiment 1B) artificial category sets there were category congruence effects such that responses were faster when targets were preceded by their own prototype versus the prototype of the other category. However, contrary to Damian's prediction, for neither category set was there an increase in the size of the category congruence effect. In Experiment 2, the size of the category congruence effect did increase when participants practiced learning the four-letter category set over multiple sessions/days. The results from *Chapter* 3, therefore, provide support for the claim that S-R associations can impact masked priming, although they may need considerable time to develop.

The stimuli and task used in *Chapter* 3 are noticeably different from those typically used in the masked priming literature. However, the fact that it took multiple sessions until the S-R associations in these experiments developed to the point where they affected priming challenges the claims from previous research (e.g., Abrams, 2005; Abrams & Greenwald, 2000; Damian, 2001; Neumann & Klotz, 1994; Klotz & Neumann, 1999) that the source of their masked priming effects were due to the impact of S-R associations. Alternatively, these previous results may have been due to changes in the nature of semantic information activated by the prime over trials (as discussed in the General Discussion sections of both *Chapters 2* and *3*). From a "prospective" view of masked priming these results (along with the results from *Chapter 2*) strongly imply that the primary source of the prime's influence comes from activated semantic information.

There is, however, an alternative "retrospective" view of masked priming which, in contrast to the "prospective" view, assumes a) masked primes form reasonably strong episodic traces and b) the cognitive system strategically adjusts the extent to which it relies upon information from these episodic traces. If this view is correct, the impact of semantic would have to be interpreted in a somewhat different fashion. The strongest piece of evidence for a "retrospective" view is the existence of prime validity effects. That is, larger priming effects when the percentage of trials in which the target is related to the prime is high compared to when it is low (see Masson & Bodner, 2003, for a review).

In *Chapter 4* an initial attempt to investigate prime validity effects involved an arrow classification task with free choice trials. In this experiment arrow targets were preceded by masked primes which either a) always pointed in the same direction of the target arrow (100% congruent condition), b) always pointed in the opposite direction (100% incongruent condition), or c) pointed equally often in the same and different directions (unpredictive condition) using a prime-target interval of either 77 ms or 165 ms (a between-subjects manipulation). The inclusion of an unpredictive baseline along with a more extreme manipulation of congruent/incongruent prime-target trials allows for a closer evaluation of what is producing the prime validity effects and hence, a means of contrasting the prospective versus retrospective view of masked priming.

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Chapter 4 – Target Arrow Classification with Free Choice Trials

In the masked priming paradigm, a forward mask (typically a character string) may or may not be presented prior to a briefly presented (typically 60 ms or less) prime stimulus which is then masked by either a backward mask and/or a target stimulus. The goal of this paradigm is to measure the effect of these masked primes on target processing in order to better understand the mechanisms underlying the processing of subliminal stimuli.

In general, there are two views concerning how the presentation of the masked prime affects target processing (see Masson & Bodner, 2003). The “prospective view” is based upon two assumptions. One assumption is that the presentation of a masked prime induces a temporary state of activation in the cognitive system which, in turn, affects the speed with which a subsequently presented target is processed. The second assumption is that, since participants do not report any awareness of these masked primes, any episodic trace left by these primes should be so weak that any effect of the prime must have been due solely to automatic, rather than strategic, processes (see also Forster & Davis, 1984).

The alternative, “retrospective view” of masked priming is based on the idea that both of the assumptions of the prospective view are incorrect, adopting instead two markedly different assumptions. The first is that the primes (even when they are presented briefly and masked) form reasonably strong episodic traces. The second assumption is that, in an effort to aid target processing, the cognitive system strategically adjusts the extent to which it relies upon information from these episodic traces (even though the viewer is typically unaware of both the presence of the prime and its identity).

The strongest piece of evidence that masked primes do activate episodic traces that could then be used strategically are "prime validity" effects, that is, larger priming effects when the percentage of trials in which the target is related to the prime is high (typically 80%) compared to when it is low (typically 20%). These effects have been found in reaction time latencies across a variety of cognitive tasks (e.g., Bodner & Dypvik, 2005; Bodner & Masson, 2001, 2003, 2004; Bodner, Masson & Richard, 2006; Bodner & Mulji, 2010; Jaskowski, Skalska & Verleger, 2003; Klapp, 2007). To account for these results, Bodner and Masson (2001; Masson & Bodner, 2003) proposed their "memory recruitment account", which is based on the two core assumptions of the retrospective view of masked priming, to explain how the proportion of congruent prime-target trials affects the size of priming effects.

According to the memory recruitment account, "the processing applied to masked primes is encoded in memory and is then recruited to assist with target processing if the list context ….. supports its recruitment" (Bodner & Mulji, 2010, p. 361). That is, when the information that can be derived from a masked prime is often beneficial for target processing (e.g., a prime arrow often points in the same direction as the target arrow), then the cognitive system adopts a target processing strategy which involves placing some reliance upon information derived from the prime's episodic trace. Because this information benefits target processing on related trials, a greater reliance on prime information produces a larger priming effect. In contrast, as Masson and Bodner (2003) have argued, a prospective view of masked priming appears to be unable to explain prime validity effects. If priming were merely due to a temporary change in activation within the cognitive system, that change, and, hence, the size of the priming effect, should not be affected by the proportion of congruent prime-target pairs.

Much of the previous research on the prime validity effect has been done using paradigms in which several different stimuli are used as primes and targets so that each stimulus is seen and classified only once (e.g., lexical decision, naming). The present research investigates these issues in a slightly different situation, one in which only a small set of stimuli is used repeatedly with those same stimuli also acting as masked primes. In these types of situations, the influence of the masked prime on target classification is presumed to be due to specific stimulus-response associations which are formed as a result of classifying a small set of visible stimuli (see Damian, 2001). Specifically, the present experiment was designed to investigate the mechanisms which drive the prime validity effect when the task is a target arrow classifications task (see also Bodner & Mulji, 2010; Klapp, 2007).

Arrow Classification Tasks (With and Without Free Choice Trials)

Eimer and Schlaghecken (1998) provided one of the earliest demonstrations of a masked priming effect in an arrow classification task in which arrow targets that require a directional (i.e., left (<<) or right (>>)) response were preceded by masked prime arrows. Their results were counterintuitive in that participants responded significantly faster when the prime and target arrows pointed in opposite directions as opposed to the same direction (a “negative priming effect”). Measurements of event-related potentials helped explain this negative priming effect by demonstrating that a masked arrow prime initially activates the motor response which corresponds to the direction of that prime. That is, a response priming effect emerged due to the fact that repeated classifications of left and right pointing target arrows strengthened the association between these stimuli and the left and right key responses, associations that are activated by the masked primes. However, as time passes and this response activation diminishes, the opposite motor response becomes activated.

The “facilitation-followed-by-inhibition” pattern from Eimer and Schlaghecken’s (1998) event-related potential measurements suggests that, in an arrow classification task, responses should be faster when prime and target arrows point in the same as opposed to opposite directions (“positive priming”) when the prime-target interval is short, whereas negative priming effects should be obtained when the prime-target interval is long. This response priming pattern has, in fact, been demonstrated in subsequent research (e.g., Eimer, 1999; Eimer & Schlaghecken, 2002; Schlaghecken & Eimer, 2000, 2002).

Further research has shown that, in addition to motor response latencies, masked arrow primes also affect response selection in tasks where arrow target trials are interspersed with a set of either-way targets (< >) for which either response is legitimate (see Klapp & Haas, 2005; Klapp & Hinkley, 2002, Experiment 5; Schlaghecken & Eimer, 2004; Schlaghecken, Klapp, & Maylor, 2009, Experiment 2). Specifically, responses in these free choice trials are more frequent and faster when they match the direction of the masked prime at short prime-target intervals, but at longer prime-target intervals the pattern reverses (see especially Schlaghecken & Eimer, 2004).

Prime Validity Effects in the Arrow Classification Task

Recent research by Klapp (2007) has demonstrated a prime validity effect using masked primes in an arrow classification task. Specifically, Klapp varied the proportion of incongruent prime-target pairs between-subjects from 20% to 50% to 80% using both a relatively long 160 ms prime-target interval (Experiment 2) and a short 32 ms prime-target interval (Experiment 3). When a long prime-target interval was used, negative priming occurred which increased in magnitude as the proportion of incongruent prime-target pairs increased. When a short prime-target interval was used, positive priming occurred which increased in magnitude as the proportion of congruent prime-target pairs increased.

Focusing solely on the positive priming effect, Bodner and Mulji (2010) recently extended Klapp's (2007) research by showing that the proportion of congruent prime-target pairs for the arrow targets also affects response selection on the either-way targets. Specifically, they interspersed free choice trials with arrow target trials and manipulated the proportion of congruent prime-target arrow classification trials between-participants such that half the participants received 80% congruent trials (80/20 condition) and the other half received 20% congruent trials (20/80 condition). Using a prime-target interval of 105 ms they obtained a larger priming effect for the target arrow classification trials in the 80/20 condition (28 ms) than in the 20/80 condition (8 ms) which replicated Klapp's prime validity effect. Further, the proportion of congruent prime-target pairs in the arrow classification trials also influenced response selection on the free choice trials. Responses were faster in the 80/20 condition when the response corresponded with the direction of the masked prime (a 21 ms priming effect), but not in the 20/80 condition (a non-significant 2 ms priming effect) and a response bias emerged such that responses corresponded with the direction of the masked prime on 54.1% of the trials in the 80/20 condition, but response selection was at chance (i.e., 49.1%) in the 20/80 condition.

Bodner and Mulji (2010) proposed that prime validity effects on both the arrow classification and free choice trials fit particularly well within their memory recruitment account. Specifically, priming effects occurred in the 80/20 condition, but were essentially non-existent in the 20/80 condition, because participants in the 80/20 condition were often relying upon episodic traces obtained from prime processing to aid target processing. In the 20/80 condition, however, the proportion of congruent trials was too low to be useful so participants placed virtually no reliance upon the obtained episodic traces produced by prime processing.

The Current Study

What is important to note about Bodner and Mulji's (2010) account is the lack of a role for automatic response activation processes. That is, the only source of priming in their account is the use of episodic information about the prime in order to aid target processing. When the proportion of congruent prime-target trials is high (e.g., the 80/20 condition), recruitment of prime information is frequent and a positive priming effect emerges. In contrast, when the proportion is low (e.g., the 20/80 condition), virtually no recruitment of prime information takes place and, consistent with Bodner and Mulji's results, no priming emerges. Where an account of this sort runs into problems, however, is in explaining negative priming effects (i.e., the fact that, with longer prime-target intervals, incongruent prime-target pairings tend to produce shorter latencies) since the recruitment of prime information can only aid processing. In order to explain inhibition effects, it would appear that Bodner and Mulji's account would have to assume that there is some role for response activation/inhibition processes. If their account were to do so, however, the question would then become, why would activation processes not also play a role on positive priming trials (e.g., when the prime-target interval in the arrow classification task is short)?

The current study is an attempt to evaluate the potential role of automatic response activation processes in the arrow classification task and the implications for Bodner and Mulji's (2010) account of their arrow classification data. To do so, the strongest possible manipulation of prime-target congruency in that task, combined with both a short (i.e., 77 ms) and long (i.e., 165 ms) prime-target interval, was used along with a set of either-way targets. Prime-target congruency for the arrow targets was manipulated between-subjects across three different conditions. In two of these conditions, the prime-target relationship for the arrow targets was either 100% congruent (i.e., the prime arrow always pointed in the same direction of the target arrow) or 100% incongruent (i.e., the prime and target arrows always pointed in opposite directions). The other condition was an unpredictive baseline condition in which arrow targets were preceded equally often by congruent and incongruent masked primes.

The key question concerns how the prime validity manipulation for the arrow targets affects the masked prime's impact (for both the reaction time and response bias) on the intermixed either-way targets, specifically focusing on the relationship between the pattern in the unpredictive condition versus those in the 100% congruent and 100% incongruent conditions. Since the prime is of no use in terms of predicting the target in the unpredictive condition, our working assumption is that participants would have no motivation to recruit prime information in this condition. Thus, any impact of the prime in the unpredictive condition would, presumably, be due to automatic processing of the sort measured by Klapp and Hinkley (2002) and Schlaghecken and Eimer (2004). If performance in the unpredictive condition is equivalent to that in the 100% incongruent condition (i.e., an essentially null priming effect) then, in support of Bodner and Mulji's (2010) claims, the implication would be that priming in the 100% congruent condition was due to the recruitment of prime information to aid target processing with automatic activation processes playing little, if any, role. In contrast, if performance in the unpredictive condition is equivalent to that in the 100% congruent condition then the implication would be that the priming in the 100% congruent condition is essentially due to automatic activation processes rather than recruitment of prime information to aid target processing. Further, it would mean that performance in the 100% incongruent condition was affected by some sort of participant action (e.g., an attempt to suppress an automatic bias created by the prime). A final possibility is that the unpredictive condition would show priming midway between that in the 100% congruent and 100% incongruent conditions. If so, then the implication would be that the primes may be used in both 100% congruent and 100% incongruent conditions to either enhance or diminish the automatic activation initially created by the primes.

Method

Participants. One-hundred-and-forty-seven University of Western Ontario psychology undergraduate students received either course credit or $10 for their participation in these experiments (Age Range = 17 – 53, Median = 23.2). All had either normal or corrected-to-normal vision and were proficient in English.

Materials. There were two types of targets in these experiments. One type was double-headed arrows which pointed either towards the left ('<<') or the right ('>>'). The other type was an either-way target which consisted of one arrow which pointed right and one arrow which pointed left (‘< >’). Primes were also double-headed arrow stimuli which pointed either left (‘<<’) or right (‘>>’). Masks consisted of single-headed arrows pointing to both the left and the right (‘><><><><’). [1] All stimuli were presented in 14-point Courier New font.

There were 360 test stimuli presented in six blocks of 60 trials each. Within each block of trials, there were 20 left-pointing arrow targets, 20 right-pointing arrow targets, and 20 either-way targets. Twenty-four practice trials (eight either-way targets, eight right-pointing arrow targets, and eight left-pointing arrow targets) preceded the test trials. For the arrow practice trials, half of the prime-target pairs were congruent (i.e., the prime and target arrows pointed in the same direction) and the other half were incongruent (i.e., prime and target arrows pointed in opposite directions). For the either-way practice targets, half the targets were preceded by a right-pointing arrow prime and half the targets were preceded by a left-pointing arrow prime.

In terms of the experimental trials, in the unpredictive condition, the prime-target pairs for half the arrow targets were congruent and the prime-target pairs for the other half of the arrow targets were incongruent. In the 100% congruent condition, the arrow targets were always preceded by a prime arrow which pointed in the same direction as the target, whereas in the 100% incongruent condition the arrow targets were always preceded by a prime arrow which pointed in the direction opposite that of the target. As noted previously, this prime-target congruency manipulation was a between-subjects manipulation. In all three conditions, the either-way targets were preceded equally often by either a right-pointing or left-pointing arrow prime.

Equipment. The experiment was run using DMDX experimental software produced by Forster and Forster (2003). Stimuli were presented on a SyncMaster monitor (Model No. 753DF). Presentation was controlled by an IBM-clone Intel Pentium. Stimuli appeared as black characters on a white background. Responses to stimuli were made by pressing one of two <shift> keys on the keyboard.

Procedure. Participants were run individually. Participants sat approximately 18 inches in front of the computer screen and were told by the experimenter that they would have to respond to both arrow targets and either-way targets which would be presented on the screen. For the arrow targets, they were instructed to respond by pressing a key in the direction that the target arrow was pointing (either left or right). For the either-way targets they were told to respond by pressing either the left or right key and it was emphasized that either response was appropriate. For the arrow targets, the participants were told to respond as quickly and as accurately as possible. For the either-way targets, the participants were told to respond as quickly as possible without concerning themselves about which response they were making.

Each participant first performed the 24 practice trials with the experimenter in the room. Following these practice trials and after answering any questions the participants may have had, the experimenter left the room and the participants then performed the experimental trials which consisted of six blocks of 60 trials (there was an opportunity for a break at the end of each block).

Each trial began with a 550 ms arrow mask (e.g., '><><><><') which acted as a fixation cue. This forward arrow mask was then followed by a 44 ms prime double-headed arrow (e.g., '<<') which was backward masked by a 33 ms arrow mask. The backward mask was followed by a 99 ms target which was either a double-headed arrow (i.e., ‘>>’ or ‘<<’) or an either-way stimulus (i.e., ‘< >’). The participants had a maximum of 2.5 seconds to respond to the target stimulus before the next trial began. The key manipulation was the length of the prime-target interval. For 51 participants (17 in each prime condition) the prime-target interval was 77 ms, whereas for 96 participants (32 in each prime condition) the prime-target interval was increased to 165 ms by inserting an 88 ms blank screen between the backward mask and the target. Data collection in the 77 ms condition was completed prior to beginning data collection in the 165 ms condition.

At the end of the experiment, the experimenter asked the participants if they were aware of anything that may have appeared before the target stimulus.

Results

None of the participants reported that they noticed any of the primes on the screen prior to the targets. Therefore, one can assume that participants possessed little or no conscious awareness of the existence of the primes. Prime discrimination tasks were also carried out with separate groups of participants using the display parameters for both prime-target intervals. These data also indicate that participants had little awareness of the primes at either prime-target interval (see Appendix E for a description of the prime discrimination task).

For the arrow targets, latency and error data in the unpredictive condition were analyzed using a 2 (Prime-Target Congruity: congruent vs. incongruent) by 2 (Prime-Target Interval: short vs. long) mixed-design analysis of variance (ANOVA), whereas latency and error contrasts between the 100% congruent and 100% incongruent conditions were analyzed using a 2 (Prime Condition: 100% congruent vs. 100% incongruent) by 2 (Prime-Target Interval: short vs. long) between-subject ANOVA. Latency responses to the either-way targets were analyzed using a 3 (Prime Condition: 100% congruent vs. unpredictive vs. 100% incongruent) by 2 (Response Congruity: congruent vs. incongruent) by 2 (Prime-Target Interval: short vs. long) mixed-design ANOVA. The response bias to the either-way targets was analyzed using a 3 (Prime Condition: 100% congruent vs. unpredictive vs. 100% incongruent) by 2 (Prime-Target Interval: short vs. long) mixed-design ANOVA.

The interactions for both arrow and either-way target data were further analyzed using post-hoc comparisons (using Bonferroni adjustments for multiple comparisons). In addition, incorrect responses to the arrow targets were removed from the latency analyses along with either-way and arrow target trials that were shorter than 150 ms or in which no response was given (9.8% of the arrow target trials, 4.2% of the either-way target trials).[2]

Arrow Targets

Unpredictive Condition. In the latency analysis there was a significant main effect of prime-target congruity, $F(1, 47) = 19.67$, $p < .001$, $MSE = 257.21$. Responses were 15 ms faster when the prime and target arrow pointed in the same direction (312 ms) compared to the opposite direction (327 ms). There was no main effect of prime-target interval, $F(1, 47) = 0.27$, *n.s*. More importantly, the interaction was significant, $F(1, 47) = 57.03$, $p < .001$, $MSE = 257.21$. When the prime-target interval was 77 ms, responses were 41 ms faster when the prime and the target pointed in the same (295 ms) as opposed to the opposite direction (336 ms), $t(16) = 7.42$, $p < .001$, $SE = 5.50$ (i.e., positive priming). However, when the prime-target interval was increased to 165 ms, responses were 11 ms faster when the prime and the target pointed in the opposite (318 ms) compared to the same direction (329 ms), $t(31) = 2.65$, $p < .02$, $SE = 4.01$ (i.e., negative priming).

In the error analysis there were significant main effects of prime-target congruity, $F(1, 47) = 21.85$, $p < .001$, $MSE = 0.005$, and prime-target interval, $F(1, 47) = 9.30$, $p < .005$, $MSE = 0.009$. The error rate was greater when the prime and target arrows pointed in opposite directions (12.7%) as opposed to the same direction (5.8%) and the error rate was greater when the prime-target interval was 77 ms (12.3%) than 165 ms (6.2%). More importantly, the interaction was significant, $F(1, 47) = 41.29$, $p < .001$, $MSE = 0.005$. When the prime-target interval was 77 ms, the error rate was significantly greater when the prime and target arrows pointed in opposite directions (20.4%) as opposed to the same direction (4.1%), $t(16) = 6.79$, $p < 001$, $SE = 0.024$ (i.e., positive priming). However, when the prime-target interval was increased to 165 ms, the error rate was non-significantly greater when the prime and target arrows pointed in the same direction (7.4%) as opposed to the opposite direction (4.9%), $t(31) = 1.53$, *n.s.* (i.e., negative priming).

100% Congruent Versus 100% Incongruent Comparison. For the latency analysis neither the main effect of prime-target interval, $F(1, 94) = 1.47$, *n.s.*, nor the main effect of prime condition, $F(1, 94) = 2.35$, *n.s.*, were significant. The interaction was significant, $F(1, 94) = 9.81$, $p < .003$, $MSE = 3871.40$. When the prime-target interval was 77 ms, responses were 62 ms faster when the prime and target arrows pointed in the same direction (i.e., the 100% congruent condition) (300 ms) than in the opposite direction (i.e., the 100% incongruent condition) (362 ms), $t(32) = 2.89$, $p < .006$, $SE =$

21.34 (i.e., positive priming). However, when the prime-target interval was increased to 165 ms, responses were a non-significant 21 ms faster when the prime and target arrows pointed in opposite directions (304 ms) than in the same direction (325 ms), $t(62) = 1.36$, *n.s.* (i.e., negative priming).

For the error analysis, neither the main effect of prime condition, $F(1, 94) = 0.16$, *n.s.*, nor the main effect of prime-target interval, $F(1, 94) = 0.01$, *n.s.*, were significant. The interaction was also not significant, $F(1, 94) = 0.46$, *n.s.* The error rates did not differ between the 100% congruent and 100% incongruent prime conditions for either the 77 ms, $t(32) = 0.67$, *n.s.*, or 165 ms, $t(62) = 0.23$, *n.s.*, prime-target intervals (5.4% versus 6.3% and 5.7% versus 5.1%, respectively).

Either-Way Targets (see Table 1)

Response Latencies. There was a significant main effect of response congruity, $F(1, 141) = 7.21$, $p < .009$, $MSE = 743.87$. Responses were 9 ms faster when participants chose a response that corresponded with the direction of the prime (374 ms) than when they chose a response that was the opposite direction of the prime (383 ms). There was no main effect of prime-target interval, $F(1, 141) = 0.11$, *n.s.*, but there was a marginal effect of prime condition, $F(2, 141) = 2.79$, $p < .07$, $MSE = 12440.08$. Although only marginally significant, responses were longer in the 100% incongruent condition (401 ms) than in either the 100% congruent (368 ms), $t(96) = 2.02$, $p < .14$, or unpredictive conditions (367 ms), $t(96) = 2.07$, $p < .13$. The 1 ms difference between the 100% congruent and unpredictive conditions was not significant, $t(96) = 0.05$, *n.s.*

All three two-way interactions were significant. To begin with, prime-target interval significantly interacted with response congruity, $F(1, 141) = 27.98$, $p < .001$,

Table 1.

Results for Either-Way Responses (Reaction Times in Milliseconds, Response Biases in %)

Prime-Target Relationship	Response Bias: Congruent	Response Bias: Incongruent	Response Latency: Different	Response Latency: Same	PE
		77 ms Prime-Target Interval			
Baseline	57.6	42.4	372	334	38
Congruent	60.8	39.2	366	333	33
Incongruent	49.4	50.6	431	423	8
		165 ms Prime-Target Interval			
Baseline	47.2	52.8	378	384	- 6
Congruent	49.5	50.5	386	386	0
Incongruent	44.8	55.2	365	386	- 21

Note. Response bias refers to the % of trials in which the response correspond to the direction of the prime. Response latency refers to the speed of the responses based upon the direction of the prime arrow. PE = Priming Effects

MSE = 743.87. When the prime-target interval was 77 ms, participants were 27 ms faster when their response corresponded with the direction of the prime (363 ms) than when it differed (390 ms), $t(50) = 4.93$, $p < .001$, $SE = 5.40$ (i.e., positive priming). When the prime-target interval was increased to 165 ms, however, responses were 9 ms slower when their response was in the same direction of the prime (385 ms) than the opposite direction (376 ms), $t(95) = 2.21$, $p < .03$, $SE = 3.94$ (i.e., negative priming).

Secondly, prime-target interval also interacted with prime condition, $F(2, 141) = 4.18$, $p < .02$, $MSE = 12440.08$. When the prime-target interval was 77 ms, responses in the 100% incongruent condition were slower than in both the 100% congruent (427 ms vs. 349 ms, $t(47) = 2.88$, $p < .006$, $SE = 27.05$) and unpredictive (427 ms vs. 353 ms, $t(47) = 2.74$, $p < .008$, $SE = 27.05$) conditions. There was no difference in response latencies between the 100% congruent and unpredictive conditions (349 ms vs. 353 ms, t(47) = 0.14, *n.s.*). When the prime-target interval was increased to 165 ms, response latencies in the 100% incongruent condition did not differ from either the 100% congruent (376 ms vs. 386 ms, $t(47) = 0.52$, *n.s.*) or unpredictive (376 ms vs. 381 ms, $t(47) = 0.24$, *n.s.*) condition nor was there a significant difference between the 100% congruent and unpredictive conditions (386 ms vs. 381 ms, $t(47) = 0.27$, *n.s.*).

Finally, the interaction between prime condition and response congruity was also significant, $F(2, 141) = 5.15$, $p < .008$, $MSE = 743.87$. Responses were faster when the response corresponded to the direction of the prime than when it differed in both the 100% congruent (359 ms versus 376 ms, $t(47) = 2.90$, $p < .005$) and the unpredictive (359 ms versus 375 ms, $t(47) = 2.82$, $p < .006$) conditions. Responses in the 100% incongruent condition, however, were non-significantly slower when the response corresponded to the direction of the prime than when it differed (405 ms versus 398 ms, $t(47) = 1.07$, *n.s.*). The three-way interaction was not significant, $F(2, 141) = 0.48$, *n.s.*

Response Biases. There was a significant main effect of prime-target interval, $F(1, 141) = 67.09$, $p < .001$, $MSE = 0.004$. The bias to choose a response which corresponded with the direction of the prime was greater when the prime-target interval was 77 ms (55.9%) as opposed to 165 ms (47.2%). There was also a significant main effect of prime condition, $F(2, 141) = 19.29$, $p < .001$, $MSE = 0.004$. Participants were more likely to choose a response which corresponded with the direction of the prime in either the unpredictive (52.4%), $t(47) = 4.08$, $p < .001$, $SE = 0.013$, or the 100% congruent condition (55.1%), $t(47) = 6.15$, $p < .001$, $SE = 0.013$, than in the 100% incongruent condition (47.1%). The difference in the response bias between the 100% congruent and unpredictive conditions was not significant, $t(47) = 2.08$, *n.s*.

In addition, the interaction of prime-target interval and prime condition was also significant, $F(2, 141) = 3.73$, $p < .03$, $MSE = 0.004$. Participants were more likely to choose a response which corresponded with the direction of the prime when the prime-target interval was 77 ms (as opposed to 165 ms) in all conditions - the 100% congruent condition (60.8% versus 49.5%, $t(47) = 5.95$, $p < .001$, $SE = 0.019$), the unpredictive condition (57.6% versus 47.2%, $t(47) = 5.47$, $p < .001$, $SE = 0.019$) and the 100% incongruent condition (49.4% versus 44.8%, $t(47) = 2.47$, $p < .02$, $SE = 0.019$) - with this contrast being slightly smaller in the 100% incongruent condition.

For the 165 ms prime-target interval, the bias to choose a response which corresponded with the opposite direction of the prime was significant in the unpredictive condition, $t(32) = 3.05$, $p < .006$, but not in the 100% congruent condition, $t(32) = 0.5$, n.s. This result suggests that response inhibition may not have occurred in the 100% congruent condition.

Discussion

The current study evaluated the mechanisms driving the prime validity effect in an arrow classification task with free choice trials when the arrow targets were preceded by masked primes which either a) always pointed in the same direction of the target arrow (100% congruent condition), b) always pointed in the opposite direction (100% incongruent condition), or c) pointed equally often in the same and opposite directions (unpredictive condition) while the prime-target interval was either 77 ms or 165 ms. Thus, the current study employed both an unpredictive baseline condition and the strongest possible manipulation of prime-target congruency.

When the prime-target interval was 77 ms, the current study replicated Bodner and Mulji's (2010) pattern of prime validity effects for the either-way targets. That is, responses in the 100% congruent condition were 33 ms faster when the response corresponded with the direction of the prime (333 ms) than when it differed (366 ms), but, in the 100% incongruent condition, responses were only a non-significant 8 ms faster when the response corresponded with the direction of the prime (423 ms) than when it differed (431 ms). Similarly, participants were more likely to choose a response which corresponded with the direction of the prime in the 100% congruent condition (60.8%) but were at chance performance in the 100% incongruent condition (49.5%).

Critically for current purposes, however, performance on the either-way targets in the unpredictive condition mimicked that in the 100% congruent condition. Specifically, responses to either-way targets in the unpredictive condition were 38 ms faster when the response corresponded with the direction of the prime (334 ms) than when it differed (372 ms) (essentially equivalent to the 33 ms effect in the 100% congruent condition) and there was a strong bias (57.6%) to respond in the direction of the arrow (essentially equivalent to the 60.8% bias in the 100% congruent condition). Because the arrow targets in the baseline condition were preceded equally often by left and right pointing arrows and, hence, there would be no overall benefit to recruiting prime information, these results strongly suggest that the pattern in the 100% congruent condition is not the result of participants relying more heavily upon information from the prime's episodic trace when the proportion of congruent trials is high (a key assumption of the memory recruitment account), but is rather due to automatic response activation.

A similar relationship among the three prime conditions emerged with the 165 ms prime-target interval. Note, first of all, that the prime-target interval manipulation worked as predicted, that is, it turned positive priming effects into negative priming effects. For the arrow targets, when the prime-target interval was 77 ms, responses to the arrow targets were 62 ms faster when the prime and target arrows pointed in the same direction (i.e., the 100% congruent condition) than in the opposite direction (i.e., the 100% incongruent condition) and, in the unpredictive condition, responses were 41 ms faster when the prime and the target pointed in the same as opposed to the opposite direction. With a 165 ms prime-target interval, responses were 21 ms faster in the 100% incongruent condition than in the 100% congruent condition and responses in the unpredictive condition were 11 ms faster when the prime and the target pointed in the opposite compared to the same direction.

A similar pattern emerged with the either-way targets. In the 100% incongruent condition, the null bias shown in the 77 ms condition turned into a response bias in the direction opposite to that of the prime (55.2%) in the 165 ms condition whereas the strong evidence for a bias in the direction of the prime disappeared in both the 100% congruent (49.5%) and unpredictive (47.2%) conditions. Further, in the 100% incongruent condition, the null priming effect with a 77 ms prime-target interval turned into a 21 ms negative priming effect with a 165 ms prime-target interval. At the same time, the significant priming effects in both the 100% congruent and unpredictive conditions when the prime-target interval was 77 ms disappeared. What these results indicate is that the prime-target interval manipulation altered the direction of the automatic bias created by the prime as expected based on Eimer and colleagues' results (e.g., Eimer, 1999; Eimer & Schlaghecken, 2002; Schlaghecken & Eimer, 2000, 2002).

Nonetheless, in spite of the complete reversal of the basic priming effect, the pattern among the three prime conditions did not change. Just as with the 77 ms prime-target interval, the results obtained in the unpredictive condition using a 165 ms prime-target interval mimicked those in the 100% congruent condition. Therefore, it would appear that, regardless of what prime-target interval was used, it was the processing operations taking place in the 100% incongruent condition that produced the observed prime validity effects.

The Proposed Response Bias Suppression Account

The explanation we propose for how the 100% incongruent condition is responsible for producing a prime validity effect is that participants in that condition are actively working to suppress the response bias which is rapidly and automatically activated by the prime. That is, in the 100% incongruent condition the response which is automatically activated by the masked prime for the arrow target trials is always incorrect. Therefore, participants will act to suppress this response bias by decreasing the activation of the primed response which, in turn, allows the competing response to become more active. The result is a null positive priming effect and no response bias with a short prime-target interval and a negative priming effect and clear bias against the prime's direction with a longer prime-target interval. In contrast, the results in the 100% congruent and unpredictive conditions are being driven by the automatic activation produced by the prime. Hence, following on Eimer and colleagues' results (e.g., Eimer, 1999; Eimer & Schlaghecken, 2002; Schlaghecken & Eimer, 2000, 2002) there is positive priming with the short prime-target interval and evidence of negative priming at the longer interval.

Note that this account is quite consistent with the fact that, with the 77 ms interval, responses were somewhat slower in the 100% incongruent (427 ms) condition, than in either the 100% congruent (349 ms) or unpredictive (353 ms) conditions, conditions which, once again, mimicked one another. When the prime-target interval was increased to 165 ms, however, there was no longer any difference among the three conditions: incongruent condition (376 ms), congruent condition (386 ms), baseline condition (381 ms). These results, therefore, suggest that participants had considerable difficulty responding in the incongruent condition when the prime-target interval was 77 ms, as would be expected if they were actively working to suppress an automatically activated bias. However, since a longer prime-target interval not only allows more time to suppress that bias but also typically automatically produces an activation pattern that reverses the direction of the initial bias (as documented by Eimer and Schlaghecken, 1998), the overall latency differences between the conditions disappeared.

There are a number of ways that this suppression process might work (see, for example, Tipper's, 2001, review of various mechanism of inhibition of response tendencies and see also Houghton & Tipper, 1994). The present data, however, do not allow a specification of which mechanisms might have been active here. Note also that, in many of the mechanisms discussed by Tipper, the suppression process is not a fully unconscious process (i.e., some conscious activity is being applied to aid the inhibition process). With respect to the present analysis, however, the argument is not being made that the inhibition process necessarily involves conscious activity nor that the process requires conscious knowledge of the relationship between the automatic bias created by the prime and the subsequent direction of the arrow target. Rather, the argument is that, in an effort to facilitate responding, the suppression process may develop unconsciously in much the same way that the process of recruiting episodic trace information is presumed to develop in the memory recruitment account (i.e., without the participants necessarily becoming aware of what they are doing or why).

The Fate of the Memory Recruitment Account

One obvious question is how would the memory recruitment account need to be altered in order to allow it to explain the present data? One possibility is that one could assume that the relationship between use of the prime to aid processing and the proportion of congruent trials is not straightforward. For example, one could argue that if the proportion of congruent trials is at least 50% then participants may always use information from the prime to aid target processing. As a result, performance in the unpredictive and 100% congruent conditions would be expected to be equivalent.[3]

An assumption of this sort would allow the account to explain the results in the 77 ms prime-target interval condition, but it would not allow the account to explain the negative priming in the 165 ms prime-target interval condition. For the memory recruitment account to be able to explain negative priming, some sort of activation process would need to be added to the account. If that process allowed for activation of the response in the direction opposite that of the prime at longer prime-target intervals, then the amended account could explain the change in the either-way target data from positive to zero priming in the 100% congruent and unpredictive conditions and the change from zero to negative priming in the 100% incongruent condition. However, as previously noted, adding this assumption to Bodner and Mulji's (2010) account would raise the question of why the assumption is being made that there is no automatic (positive) activation process when the prime-target interval is short.

Alternative Accounts of Masked Priming in the Arrow Classification Task

I. Variations in Associative Strength Between the Prime and its Response

As previously described, Klapp (2007) reported that the magnitude of priming for arrow targets increased as the proportion of incongruent prime-target pairs varied between-subjects from 20% to 50% to 80% in an arrow classification task using masked arrow primes. According to Klapp, a masked prime becomes associated with a particular response if both the masked prime and the target signal the same response. Prime validity effects, therefore, arise due to the fact that this association becomes stronger (which results in a more effective masked prime) when the proportion of compatible prime-target trials is high.

The key difficulty Klapp's (2007) account would have in explaining the present data is that his account would appear to predict that there should be a difference in the size of the priming effects for either-way targets between the 100% congruent and unpredictive conditions at both prime-target intervals. The nonsignificant differences between these conditions at both prime-target intervals suggest that it is not variations in associative strength between the prime stimulus and its response that is driving the prime validity effects in the current study.

Note, however, that, although the magnitude of priming for either-way targets did not differ between the unpredictive and 100% congruent conditions at either prime-target interval in the current study, the magnitude of priming for the arrow targets did differ between Klapp's (2007) 50% and 80% congruent conditions. Thus, Klapp's account is consistent with his own data. Further, it is unclear what may have produced a discrepancy between Klapp's data and the present data. One could argue that the cognitive system reacts differently to primes when their associated responses are always either consistent or inconsistent with the target compared to when their response consistency varies across trials.[4] In essence, the argument would be that the 100% conditions do not represent the most extreme manipulation of relatedness proportion, but rather represent a qualitative change from relatedness proportions less than 100%. Whether this is the reason for the discrepancy or not remains a question for future research.

II. A Two-Component Account of Masked Priming

Kinoshita and Hunt (2008) recently proposed a two-component account of masked priming/congruence effects in a categorization task. According to their account, there is an unconditional component which reflects priming driven by stimulus-response associations (with "used" primes that had been responded to as targets) and a conditional component which reflects the congruence between the prime and target in terms of task-defined features. Both of these components operate automatically. However, the unconditional component is assumed to be transitory since it either decays rapidly or is actively suppressed, whereas the conditional component is assumed to be independent of response latency since it is time-locked to the target.

Kinoshita and Hunt's (2008) account was derived by applying a latency distribution analysis to a magnitude classification task (i.e., is a target number larger/smaller than 5?) and has yet to be applied to the arrow classification task. However, one can assume that their account would predict that the observed priming effects in that task would be primarily driven by the unconditional component, because the arrow primes had been used as targets. According to their account, priming from this component either decays rapidly in time or is actively suppressed. Response decay alone could not explain the reversal to negative priming at the 165 ms prime-target interval. However, an active suppression mechanism which operates along the lines of what we propose here could. That is, it would have to be a suppression mechanism that is sensitive to the nature of the prime-target relationship (allowing it to play a major role in the 100% incongruent condition) as well as being one that could produce an overall level of activation in the initially primed response that is lower than the resulting level of activation of the opposing response.

III. Adaptation to the Statistics of the Environment Model

In the arrow classification task (with and without free choice trials) there are only two possible responses (i.e., left or right) and a small number of targets (i.e., left arrows, right arrows, and, potentially, two-sided arrows) that are repeated multiple times over the course of the experiment. The mechanism that is posited here to explain prime validity effects, a mechanism that is somewhat different from those proposed by the memory recruitment account, may also explain prime validity effects in other tasks in which stimulus-response mappings can be formed through multiple repetitions of a small set of targets over the course of the experiment. One task in which prime validity effects have occurred which fits this criterion is Bodner and Dypvik's (2005) masked parity judgment task. Whether the mechanism proposed here does, in fact, extend to the masked parity judgment task is currently being investigated.

On the other hand, it is unlikely that the mechanism proposed here can explain prime validity effects in tasks that have a large target set and rarely repeat the targets (e.g., lexical decision, naming). Tasks like these do not allow the development of response biases based on specific stimulus-response mappings which would then become stronger through practice. Thus, those types of tasks would appear to provide better support for the memory recruitment account. Interestingly, however, recent research by Kinoshita, Forster, and Mozer (2008) has challenged the memory recruitment account of prime validity effects in Bodner and Masson's (2004) masked prime naming task, albeit on a different basis than that discussed here. Essentially, Kinoshita et al. argued that the mechanisms that produce prime validity effects in that paradigm are the same mechanisms which produce blocking effects in a naming task (see Lupker, Brown, & Colombo, 1997; Taylor & Lupker, 2001). That is, these prime validity effects are due to the fact that the difficulty of items within a block of trials strongly influences naming latencies.

More specifically, in a masked prime naming task, targets preceded by a masked repetition prime would be easier to process than targets preceded by an unrelated prime. Therefore, when a block of trials contains a large proportion of masked repetition trials there should be a noticeable reduction in response latency for those trials in comparison to when those trials appear in a block with mainly unrelated trials. Such is not necessarily the case for the unrelated trials because participants have somewhat less ability to speed up responding on those (more difficult) trials (i.e., latencies on those trials may be essentially similar in the high and low proportion blocks). Thus, according to Kinoshita et al. (2008), prime validity effects could emerge in this task as a result of the difficulty of the other trials within the block rather than as a result of participants placing more reliance on the prime when there is a large proportion of masked repetition trials (as argued by Bodner and Masson, 2004). The question of whether Kinoshita et al.'s analysis is actually a better explanation of the data from these types of tasks than the memory recruitment account, nonetheless, remains a question for future research.

Conclusions

In the current research, the mechanisms which drive the prime validity effect in an arrow classification task with free choice trials was investigated. The results indicate that varying the validity of the masked arrow primes for the arrow targets produced prime validity effects for both the response speed and bias for the intermixed either-way trials. The use of an unpredictive baseline condition demonstrated that these prime validity effects appear to be mainly driven by the processing in the 100% incongruent condition. That is, the prime validity effects arise as a result of participants automatically suppressing response biases created by the initial automatic activation of the prime when those biases are inconsistent with the majority of the target stimuli. Although this conclusion does not contradict the memory recruitment account in general, it does suggest that at least some of the data taken as support for the memory recruitment account might be explained just as readily by mechanisms more consistent with the prospective view of masked priming (see also Klapp, 2007).

Footnotes

[1] There has been an active debate in recent years concerning the importance of the features of the mask in producing negative priming effects at longer prime-target intervals (see Jaskowski & Przekoracka-Krawczyk, 2005; Kiesel, Berner, & Kunde, 2008; Klapp, 2005; Lleras & Enns, 2004, 2005; Schlaghecken & Eimer, 2006; Sumner, 2008; Verleger, Jaskowski, Aydemir, van der Lubbe, & Groen, 2004). The goal of the current study was not to enter into that debate, but rather it was to create a situation in which the direction of the priming effect would change from positive to negative as the prime-target interval increases while ensuring that the masked primes are subliminal (i.e., prime visibility is minimized). As demonstrated by Klapp (2005), Schlaghecken and Eimer (2006), and Sumner (2008) it is clearly possible to obtain negative priming effects using masks which do not share features with the primes and targets, indicating that negative priming effects are not due to using masks with features. As demonstrated by Lleras and Enns (2004), however, these types of masks both maximize the chances of observing negative priming and more effectively decrease prime visibility. Therefore, we chose to use a mask which shares features with the primes and targets.

[2] To determine whether the congruity effects in the latency data on the arrow target and either-way target trials share a common origin, the correlation between congruity effect sizes was calculated for participants in the unpredictive conditions. A marginally significant correlation, $r(17) = 0.45$, $p < .07$, when the prime-target interval was 77 ms, and a significant correlation, $r(32) = 0.52$, $p < .003$, when the prime-target interval was 165 ms, suggests that these priming effects do, in fact, share a common origin.

[3] We would like to thank Glen Bodner for offering this suggestion.

[4] We would like to thank Glen Bodner for offering this suggestion.

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Chapter 5 – Conclusions and Theoretical Implications

In a typical masked priming paradigm a forward mask precedes a briefly presented prime which is then followed by a target stimulus that requires a response. The key finding of interest is that responses are faster when the target is preceded by a prime which requires the same response as the target (i.e., a congruent trial) as opposed to a prime which requires a different response (i.e., an incongruent trial). This paradigm has been used extensively in cognitive psychology to investigate a) how one processes subliminally presented information and b) the extent to which that information can influence one's subsequent behaviour.

The generally accepted "prospective" view of how the mechanisms responsible for masked priming work is based on two key assumptions (see Forster & Davis, 1984; Masson & Bodner, 2003). The first assumption is that the presentation of a masked prime induces a temporary state of activation in the cognitive system which affects the speed with which a subsequently presented target is processed. The second assumption is that any effect of the prime must be due solely to automatic, rather than strategic, activation processes. A key issue of debate for proponents of a prospective view concerns whether masked primes activate semantic information or whether their impact is due solely to the activation of stimulus-response (S-R) associations (see Finkbeiner & Forster, 2008; Kiesel, Kunde, & Hoffmann, 2007; Kouider & Dehaene, 2009; Van den Bussche, Van den Noortgate, & Reynvoet, 2009, for recent reviews).

A key assumption of any S-R association account is that lower-level (non-semantic) associations are formed between target stimuli and their responses due to their repeated presentations and classifications (see, e.g., Abrams, 2005; Abrams &

Greenwald, 2000; Damian, 2001; Neumann & Klotz, 1994; Klotz & Neumann, 1999). Once formed, presentation of these stimuli as masked primes produces a bias to respond with their associated response. This response bias aids target responding on congruent trials and interferes with target responding on incongruent trials.

Any S-R association account makes two predictions concerning the nature of any priming effects that are due to these response biases. The first is that any priming driven by these biases should increase in size over trials since response biases are formed and strengthened as a function of exposure to the target stimuli (see Damian, 2001). The second, and more often examined, prediction is that primes that have been previously presented and responded to as target stimuli (i.e., "old set primes") should produce priming and primes that have not been previously responded to as targets (i.e., "new set primes") should not produce priming. There have been some demonstrations of this data pattern (e.g., Abrams & Greenwald, 2000; Damian, 2001), however, the more common result is that priming occurs for both old and new set masked primes (e.g., Dell'Acqua & Grainger, 1999; Klauer, Eder, Geenwald & Abrams, 2007; Naccache & Dehaene, 2001; Reynvoet, Caessens & Brysbaert, 2002; Reynvoet, Gevers & Caessens, 2005; Quinn & Kinoshita, 2008; Van den Bussche, Notebaert & Reynvoet, 2009; Van den Bussche & Reynvoet, 2007).

The fact that priming from new set primes is a common finding challenges the notion that masked priming is due solely to S-R associations. Rather, those data indicate that masked priming involves the activation of semantic information and that it is semantic information, as opposed to S-R associations, that is responsible for producing priming in many situations. However, demonstrations of priming from new set primes does not rule out the possibility that S-R associations may still play an important role in producing masked priming effects. That is, even if masked primes inevitably activate semantic information, the possibility that a) S-R associations are also activated by masked primes and b) that they contribute to priming is not excluded.

Recent research has, in fact, provided data that suggests S-R associations do play a role in generating masked priming. For example, Kinoshita and Hunt (2008) provided data based on a latency distribution analysis of a number classification task using both old and new set primes. They argue that their results indicate that masked priming involves two different automatic components, one based on S-R associations and another based upon semantic activation.

Another factor that influences the extent to which S-R associations play a role in generating masked priming is the nature of the task's requirements. That is, factors such as task instruction (Kunde, Kiesel, & Hoffmann, 2003; Norris & Kinoshita, 2008), the size of the target (e.g., Kiesel, Kunde, Pohl, & Hoffmann, 2006; Pohl, Kiesel, Kunde, & Hoffmann, 2010) and category (e.g., Abrams, 2008) set, the specific judgment task the participant was engaged in (e.g., Bodner & Dypvik, 2005; Eckstein & Perrig, 2007; Klinger, Burton & Pitts, 2000), and the targets' features (e.g., Pohl et al., 2010) and orientation (e.g., Elsner, Kunde & Hoffmann, 2008) all appear to affect the nature of any masked priming effects.

This research suggests that the origins of any masked priming effects (i.e., semantic activation or S-R associations) are due to a rather complex interaction between task instructions and participants' target processing strategies. The primary focus of this thesis, therefore, was to further investigate this interaction. Of particular interest was the role that S-R associations would play in the masked priming process. This was done using both number classification tasks (*Chapter 2*) and masked priming versions of category learning tasks (*Chapter 3).*

The perspective adopted throughout the present research was based on the assumptions of the (generally accepted) prospective view of masked priming. There is, however, an alternative “retrospective” view which denies both assumptions of the prospective view and, instead, adopts two markedly different assumptions (see Masson & Bodner, 2003). The first assumption is that masked primes (even when they are briefly presented and masked) form reasonably strong episodic traces. The second assumption is that, in order to aid target processing, the cognitive system strategically adjusts the extent to which it relies upon information from these episodic traces. The strongest piece of evidence for a retrospective view is the existence of prime validity effects in a variety of cognitive tasks, that is, larger priming effects when the percentage of trials in which the target is related to the prime is high compared to when it is low (see Masson & Bodner, 2003, for a review).

If a retrospective view of masked priming is correct then explanations of how masked primes affect priming would have to be somewhat different than if the prospective view is correct. Therefore, a secondary goal of this thesis was to provide a closer examination of the prospective versus retrospective views of masked priming. This was done using an arrow classification task with free choice trials to investigate the origins of prime validity effects in that particular paradigm (*Chapter 4*).

Summary of Results: Chapter 2 – Number Classification

In *Chapter 2* both the magnitude of the category congruence (i.e., masked priming) effect and the nature of the priming distance effect were assessed across 1008 trials in two number classification tasks using single-digit primes and targets. The distinction between tasks was whether the task instructions required magnitude judgments (i.e., is the presented number larger or smaller than ‘5’ – Experiment 1) or identification judgments (i.e., press the left button if the target is a ‘1’, ‘2’, ‘3’ or ‘4’ and the right button if it is a ‘6’, ‘7’, ‘8’ or ‘9’ – Experiment 2). When magnitude judgments were required (Experiment 1) then there were clear category congruence and priming distance effects which remained relatively stable over trials. These results corroborate previous research using the magnitude judgment task (see Kinoshita & Hunt, 2008; Kunde et al., 2003; Naccache & Dehaene, 2001) and indicate that priming in this type of task is primarily due to semantic activation.

In terms of evaluating the influence of S-R associations in producing masked priming, the results when target identification judgments were required (Experiment 2) are particularly informative. In that situation, the results suggest that when the task instructions encourage attention to the S-R mappings then S-R associations do contribute to the priming effect. Specifically, there was a significant increase in the size of the category congruence effect across trials. However, as in Experiment 1, there was also a clear priming distance effect which did not vary over trials.

The key finding from *Chapter 2*, therefore, was the presence of a priming distance effect in both number classification tasks. This particular finding indicates that semantic activation continued to play a major role in producing masked priming effects, regardless of task instructions, even when the increase in the size of the category congruence effect in Experiment 2 indicated that S-R associations also impacted priming.

Summary of Results: Chapter 3 – Category Learning Tasks with Masked Primes

Much of the masked priming research which has produced priming from new set primes (indicating that masked primes activate semantics) has used clearly defined semantic categories. Such was also the case in *Chapter 2* in which there was a semantic distance effect in both number classification experiments, that is, an effect indicating that semantic activation contributed to the priming effects in both experiments. The question arises, therefore, as to whether there exists a paradigm which would produce masked priming effects which do not make use of clearly defined semantic categories and, therefore, must be due to S-R associations.

In *Chapter 3* a masked priming version of a category learning task was used to trace how the development of S-R associations may influence the nature of any masked priming effects. In a typical category learning task (e.g., Lamberts, 1995; Nosofsky & Zaki, 2002; Smith & Minda, 1998) participants are repeatedly presented with the same set of artificial stimuli (e.g., nonsense letter strings, bug cartoons) and are required to learn, based upon feedback, which target stimuli belong to one category and which target stimuli belong to the other category. The artificial stimuli in this paradigm a) have no pre-existing ability to activate semantic information and b) are not initially associated with any response. Therefore, this paradigm should be ideal for investigating masked priming effects which cannot be due to semantic activation and, presumably, must be due to S-R associations.

The artificial category sets that were used consisted of either 10 four-letter (e.g., ‘WAZY’ – Experiments 1A & 2) or 14 six-letter (e.g., ‘KEPIRO’ – Experiment 1B) stimuli. For both category sets, half the stimuli belonged to one category and half belonged to the other category. Each category set also contained a prototype item, that is, a letter string which shares most of its letters with the other items in its category and has no letters in common with the prototype of the other category. These prototypes were used as the masked primes.

In the first experiment, category congruence effects were obtained for both category sets. Specifically, responses to targets were faster when preceded by their own prototype versus the prototype of the other category. However, there was little evidence that these effects were due to S-R associations since the effects occurred early and did not increase in size over trials. In the second experiment, there were significant increases in the size of the category congruence effects when participants practiced learning the four-letter category set over multiple sessions/days. Specifically, both a larger category congruence effect for correct responses and a larger reversed category congruence effect for incorrect responses (i.e., faster responding when the target was preceded by the prototype for the other category versus its own prototype) occurred in the later training sessions (i.e., the fourth and fifth sessions) in comparison to the early training sessions (i.e., the first and second sessions).

The key finding from *Chapter 3*, therefore, was the demonstration that although some priming occurs early (Experiment 1) it takes considerable practice in order to learn and strengthen the appropriate S-R associations to the extent necessary to increase the size of the category congruence effect (Experiment 2). Even though the stimuli and task are noticeably different from those typically used in the masked priming literature, the fact that it took so long for the S-R associations to develop to the point where they affected priming (along with the fact that in *Chapter 2* many trials were necessary to show an increase in priming) challenges the notion that S-R associations play a dominant role in producing priming in many situations.

The Role of S-R Associations in the Priming Process

In this thesis, a specific emphasis was placed on the role of S-R associations in the priming process. The results, as noted, indicate that the nature of the task's instructions influence the role of S-R associations (*Chapter 2*) and that S-R associations will impact priming, but only after considerable practice (*Chapter 3*). Before discussing the results of *Chapter 4* the implications of these results for various accounts of masked priming will be discussed.

A key assumption of any S-R association account is that associations that are formed between target stimuli and their responses produce a response bias when they are presented as masked primes. This assumption plays an influential role in research using masked primes to study motor activation (e.g., Eimer & Schlaghecken, 1998; Klotz & Neumann, 1999; Neumann & Klotz, 1994) and has been used to explain why, in certain circumstances, new set primes do not produce priming (e.g., Abrams & Greenwald, 2000; Damian, 2001). The combined results from Chapters 2 and 3, however, raise the possibility that at least some of the priming effects that were previously attributed to the impact of S-R associations may have instead been due to a semantically-based source.

Consider, for example, the results from Damian's (2001, Experiment 1) physical size judgment task using old set primes which has been taken as support for an S-R association account. Damian demonstrated that the size of his category congruence effect increased over trial blocks. Further, since each trial block involved 24 target presentations (i.e., two presentations of 12 targets) the fact that priming emerged by the third trial block (i.e., the block in which the target was seen and responded to for the fifth and sixth time) has been taken as support for the notion that these S-R associations rapidly develop and impact priming.

In both the number classification task (*Chapter 2 – Experiment 2*) and the masked priming version of the category learning task (*Chapter 3 – Experiment 2*) a large number of trials was necessary before there was any noticeable evidence that S-R associations had an impact on priming. Therefore, these results raise the question of whether there might be an alternative explanation for Damian's results. For instance, rather than S-R associations, what may have been developing over trials was the participants' ability to retrieve/focus on the specific semantic information which was necessary to perform the task.

According to this semantically-based retrieval/focus account, the participants in Damian's (2001) experiments would have adopted a target processing strategy that would allow them to focus on and retrieve more detailed size-based information. This information would then help them determine whether the target is larger or smaller than an arbitrarily selected comparison object. According to this account, as participants practiced retrieving this specific size-based information those targets would start to activate this information automatically when presented as masked primes. Thus, this semantically-based account would predict that old set primes would start to produce priming. In contrast, this account would not predict priming from new set primes since, because those primes never appeared as targets, participants would never have had the opportunity to develop the necessary retrieval processes for those stimuli.

Kinoshita & Hunt's (2008) Two-Component Account of Masked Priming: More Evidence for the Impact of S-R Associations

Kinoshita and Hunt (2008) extended previous research using old and new set masked primes in magnitude judgment tasks (e.g., Kunde, Kiesel, & Hoffmann, 2003; Naccache & Dehaene, 2001) by providing an analysis based on the full latency distributions for each prime condition. Their analysis demonstrated that, in the longer latency bins, the congruent trials in the old set prime condition showed a noticeable slowdown (relative to both incongruent prime conditions as well as the congruent condition for the new set primes). As a result, old set primes did not produce a category congruence effect in these longer latency bins. On the basis of these results, Kinoshita and Hunt concluded that masked priming consists of both a semantic and an S-R association component.

According to Kinoshita and Hunt's (2008) two-component account of masked priming, both semantics and S-R associations play crucial roles in the priming process. If that is correct then old set primes should benefit from both the semantic and S-R association components, whereas new set primes should only benefit from the semantic component. However, the fact that at no point in any of their latency distributions did the old set primes produce more priming than the new set primes suggests that did not occur.

There is a second issue that can also be raised concerning Kinoshita and Hunt's (2008) data that decreases the level of support those data offers for their two-component account of masked priming. In their latency distributions the new set primes always showed an advantage over their corresponding incongruent primes (i.e., there was always a priming effect for the new set primes). This result suggests that the semantic component does not disappear even when latencies are long. However, if semantics continued to play an active role in the priming process then there should have been an advantage for old set primes over their corresponding incongruent primes (i.e., a priming effect for the old set primes) at all points in the latency distribution since these primes should have benefited just as much as the new set primes did from the semantic component. This result, however, did not occur which could only be explained by assuming that priming from the old set primes was entirely due to the S-R association component (i.e., the semantics those primes generated were, for some reason, inoperative).

Kunde, Kiesel, & Hoffmann's (2003) Action Trigger Account: An Alternative to an S-R Association Account

According to Kunde et al.'s (2003) action-trigger account (see also Kiesel et al., 2007) participants establish action-trigger sets, that is, mappings between possible stimuli and their responses in a target classification task. These mappings can involve any stimuli that a participant might choose to include and can be formed quickly and without practice. Responses are facilitated when the prime and target activate the same action trigger and are inhibited when they activate different action triggers.

Kunde et al. (2003) originally proposed an action trigger account as an alternative explanation to a purely semantic account of how new set priming occurs in magnitude judgment tasks. However, the present research raises some issues for this account. One issue is that an action-trigger account has difficulty providing an adequate explanation for the existence of semantic distance effects in the present experiments in *Chapter 2* as well as in other research (e.g., Koechlin et al., 1999; Naccache & Dehaene, 2001; Reynvoet & Brysbaert, 1999, 2004; Reynvoet et al., 2002). According to Kunde et al.'s action-trigger account, the only role of semantics is to allow participants to categorize potential stimuli as appropriate action triggers. For instance, in the present single-digit magnitude judgment task (*Chapter 2 - Experiment 1*) all four digits that are less than '5' would be equally associated with (i.e., become action triggers for) a left button response and all four digits that are greater than '5' would be equally associated with a right button press response. However, since prime processing is assumed to activate the action triggers and not semantic (i.e., ordinal) information then there is no reason that '3' should be a better prime for the target '4' than '1' is.

An additional issue for Kunde et al.'s (2003) action-trigger account concerns the observed increase in the size of the category congruence effect in both the latter trial segments for the target identification task (*Chapter 2 - Experiment 2*) and the latter training sessions in the category learning task (*Chapter 3 – Experiment 2*). An action trigger account would only be able to explain this increase by making an additional assumption that action triggers are not used in an all or none fashion, but that the likelihood of their use increases with practice. Thus, according to this assumption, the assignment of action triggers early in the category learning task (i.e., throughout Experiment 1 and the first two days in Experiment 2) was incomplete because the participants were still learning the categories. However, when the categories were learned (i.e., the latter days in Experiment 2) participants would then be able to associate the action triggers with the appropriate stimuli more consistently resulting in an increase in the size of the category congruence effect.

Summary of Results: Chapter 4 – Arrow Classification Task with Free Choice Trials

The framework used in designing the research in *Chapters 2* and *3* was based on a prospective view of masked priming. As noted, there is an alternative, retrospective view which receives crucial support from numerous demonstrations of prime validity effects (i.e., larger priming effects when the proportion of congruent trials is high versus low) in a variety of cognitive tasks (see Masson & Bodner, 2003, for a review). Given the importance of this theoretical debate, a secondary goal of this thesis was to provide an examination of these issues.

In *Chapter 4* an arrow classification task with free choice trials was used to evaluate the potential role of automatic response activation. In this experiment, arrow targets were preceded by masked primes which either a) always pointed in the same direction of the target arrow (100% congruent condition), b) always pointed in the opposite direction (100% incongruent condition), or c) pointed equally often in the same and different directions (unpredictive condition) using prime-target intervals of either 77 ms or 165 ms (a between-subjects manipulation). The focus was on how this prime validity manipulation for the arrow targets would affect the masked prime's impact (in terms of both the reaction time and response bias) on the intermixed free choice trials (see also Bodner & Mulji, 2010).

When the prime-target interval was 77 ms, participants in the 100% congruent condition responded faster on free choice trials when the response corresponded with the direction of the prime than when it differed (i.e., a positive priming effect). In contrast, in the 100% incongruent condition, there was no difference in response latencies for a left or right response on the free choice trials (i.e., a null priming effect). Similarly, participants in the 100% congruent condition were more likely to choose a response which corresponded with the direction of the prime (i.e., a positive response bias), whereas in the 100% incongruent condition response selection performance was at chance (i.e., a null response bias).

When the prime-target interval was increased to 165 ms, for the free choice trials, the null bias in the 100% incongruent condition with a 77 ms prime-target interval turned into a response bias in the direction opposite to that of the prime (i.e., a negative response bias). In contrast, in the 100% congruent condition the positive response bias turned into a null bias. Similarly, in the 100% incongruent condition, the null priming effect with a 77 ms prime-target interval turned into a negative priming effect with a 165 ms prime-target interval (i.e., responses were faster when the response corresponded with the opposite direction of the prime). Further, in the 100% congruent condition, the significant priming effect with a 77 ms prime-target interval turned into a null priming effect.

The key finding from *Chapter 4,* however, comes from the contrast between performance for the free choice trials in the 100% congruent and the unpredictive conditions. Specifically, at both prime-target intervals, the results in the unpredictive condition mimicked the results in the 100% congruent condition. That is, when the prime-target interval was 77 ms, then there was a positive priming effect for the response latencies and a positive response bias. When the prime-target interval was increased to 165 ms then both the significant priming effect for the response latencies and the significant response bias disappeared (i.e., became null effects). These findings suggest that, regardless of what prime-target interval was used, it was the processing operations taking place in the 100% incongruent condition that produced the observed prime validity effects for the free choice trials.

Implications for a Retrospective View: A Response Bias Suppression Account

According to a retrospective view of masked priming, the sole source of priming is the recruitment of episodic information from the prime to aid target processing. Thus, when the proportion of congruent prime-target trials is high then recruitment of prime information produces priming. On the other hand, when the proportion of congruent prime-target trials is low then minimal recruitment of prime information occurs and no priming emerges. The results from *Chapter 4,* however, challenge this view in at least two different ways.

The first challenge for a retrospective view comes from the contrast between the results using an unpredictive baseline and the 100% congruent prime validity conditions. A retrospective view predicts that prime information would be recruited when the prime was highly informative (i.e., the 100% congruent condition) but not when it was uninformative (i.e., the unpredictive condition). Thus, prime validity effects would be due to a difference in the magnitude of the priming effects between these two conditions. This pattern, however, was not observed.

A second challenge is that a retrospective view cannot easily explain the negative priming effects which occurred using a 165 ms prime-target interval. A retrospective view would predict only positive priming since the recruitment of prime information is assumed to only be done to aid target processing. Additional, and somewhat incompatible, assumptions would have to be made concerning the impact of recruited information in order to explain the obtained negative priming.

In contrast, a prospective view can easily explain the results from *Chapter 4*. Specifically, the proposed reason for why the 100% incongruent condition produced the observed prime validity effects is that participants in that condition were actively working to suppress the response bias which was rapidly and automatically activated by the prime. In the 100% incongruent condition, the response which is automatically activated by the masked prime for the arrow target trials is always incorrect and target processing would benefit from suppressing it. Participants, therefore, attempt to suppress that bias by decreasing the activation of the primed response which allows the competing (correct) response to become more active.

This type of response bias suppression account (which is based upon the assumptions of a prospective view of masked priming) is quite consistent with the observation that there was a null priming effect and no response bias for the 100% incongruent condition with a short prime-target interval. A longer prime-target interval, in contrast, not only allows more time to suppress that bias it also typically produces an activation pattern that reverses the direction of the initial bias (as documented by Eimer & Schlaghecken, 1998). Therefore, there should be a negative priming effect and a clear bias against the prime's direction with a longer prime-target interval in the 100% incongruent condition. In contrast, in the 100% congruent and unpredictive conditions, there is no need to suppress the response activated by the prime since it does not activate an incorrect response on the majority of the trials. Therefore, responses in both of these conditions should be similar at both prime-target intervals since, in both cases, the responses would be generated by the automatic activation from the masked primes. Specifically, there should be positive priming and positive response biases with a short prime-target interval which would be diminished (potentially turning negative) at longer prime-target intervals.

Concluding Statements

The primary goal of this thesis was to investigate how task instructions and participants' target processing strategies interact to influence the nature of masked priming. A specific emphasis was placed on the role of S-R associations in the priming process (*Chapters 2 and 3*). The framework used in designing this research was based on a prospective view of masked priming. Therefore, a secondary goal was to provide an additional examination of the prospective versus retrospective views of masked priming. The key question of interest was whether one can account for prime validity effects within the framework of a prospective view (*Chapter 4*).

Concerning the origins of masked priming, the results from this thesis indicate that semantic activation plays the dominant role in the priming process. The nature of the task instructions can cause S-R associations to play a more active role once those associations have been sufficiently strengthened (*Chapter 2*), however, S-R associations take a substantial amount of time to develop (*Chapter 3*). These results challenge the notion that S-R associations form rapidly (see Abrams & Greenwald, 2000; Damian, 2001).

Concerning the debate between the prospective versus retrospective views of masked priming, the results of this thesis provide two challenges for a retrospective view (*Chapter 4*). First, the results indicate that the present prime validity effects were due to how the prime was processed when the proportion of incongruent (as opposed to congruent) trials was high. Second, a retrospective view has difficulties explaining the observed negative priming effects. In contrast, a prospective view of masked priming can easily explain the obtained priming effects by assuming that participants invoke a response bias suppression mechanism when the proportion of incongruent trials is high.

In summary, this research contributes to the masked priming literature in two important ways. First, the results from *Chapters 2 and 3* challenge commonly held assumptions concerning the role of S-R associations in masked priming. Specifically, the results suggest that previous research that has been taken as evidence for S-R associations (e.g., Damian, 2001) may have an alternative (possibly, semantically-based) explanation (such as the proposed retrieval/focus account). Second, the results from *Chapter 4* pose a formidable challenge to anyone attempting to explain them within a retrospective view, but could easily be explained within a prospective view of masked priming (such as the proposed response bias suppression mechanism).

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Appendix A : Stimuli Lists

Chapter 2 – Prime and Target Stimuli used in Experiments 1 2.

2 – 1, 3 – 1, 4 – 1, 7 – 1, 8 – 1, 9 – 1, 1 – 2, 3 – 2, 4 – 2, 6 – 2, 8 – 2, 9 – 2, 1 – 3, 2 – 3, 4 – 3, 6 - 3, 7 - 3, 9 – 3, 3 – 4, 2 – 4, 1 – 4, 8 – 4, 7 – 4, 6 – 4, 7 – 6, 8 – 6, 9 – 6, 2 – 6, 3 – 6, 4 – 6, 6 – 7, 8 – 7, 9 – 7, 1 – 7, 3 – 7, 4 – 7, 6 – 8, 7 – 8, 9 – 8, 1 – 8, 2 – 8, 4 – 8, 8 – 9, 7 – 9, 6 – 9, 3 – 9, 2 – 9, 1 – 9.

Chapter 3 – Binary Categorical Structure and Corresponding Target Stimuli.

Four Dimensional Category Set

Category 1		Category 2	
0 0 0 0	WAZY	1 1 1 1	BERO
1 0 0 0	BAZY	0 1 1 1	WERO
0 1 0 0	WEZY	1 0 1 1	BARO
0 0 1 0	WARY	1 1 0 1	BEZO
0 0 0 1	WAZO	1 1 1 0	BERY

Six Dimensional Category Set

Category 1		Category 2	
0 0 0 0 0 0	BANULY	1 1 1 1 1 1	KEPIRO
0 1 0 0 0 0	BENULY	1 1 1 1 0 1	KEPILO
1 0 0 0 0 0	KANULY	1 1 0 1 1 1	KENIRO
0 0 0 1 0 1	BANILO	1 0 1 1 1 0	KAPIRY
1 0 0 0 0 1	KANULO	0 1 1 1 1 0	BEPIRY
0 0 1 0 1 0	BAPURY	1 0 1 0 1 1	KAPURO
0 1 1 0 0 0	BEPULY	0 1 0 1 1 1	BENIRO

Appendix B : Prime Discrimination Data For Number Classifications

Prime discrimination tasks were administered to separate groups of participants to assess prime visibility. Twenty-six participants (age range: 18 - 23, *M* = 21.35) performed the task using single-digit primes and targets.

Each participant performed 24 practice trials followed by 144 experimental trials (three blocks of 48 trials each). Each trial, both practice and experimental, began with a 550 ms pattern mask (i.e.., '###') followed by a prime digit. The target digit '5' (or '55') directly followed the prime. The target '5' was preceded equally often by the prime digits 1 to 9 (excluding 5) and participants had a maximum of two seconds to indicate whether the prime digit was less or greater than 5 before the next trial began.

During the practice trials, the duration of the prime presentation decreased from 165 ms (trials 1 thru 8) to 110 ms (trials 9 thru 16) to 55 ms (trials 17 thru 24). During the experimental trials, the prime digit was always presented for 44 ms. Participants were instructed to make a response even if they were not sure of the identity of the prime or even if there was a prime.

To assess prime discriminability, a sensitivity measure (d') was calculated. A hit was defined as correctly indicating that a prime digit was less than 5 and a false-alarm was defined as incorrectly indicating that a prime digit was less than 5. The hit rate was 55.7% and the false alarm rate was 21.7%. The resulting d' score of 1.01 deviated from zero, $t(25) = 7.14, p < .001$.

Appendix C : Double-Digit Magnitude Judgment Task

Participants. Thirty-six University of Western Ontario undergraduate students received either $10 or course credit for their participation. All had either normal or corrected-to-normal vision.

Materials. Primes were the double-digit numbers ‘11’, ‘22’, ‘33’, ‘44’, ‘66’, ‘77’, ‘88’, and ‘99’. The targets were the digits ‘15’, ‘25’, ‘35’, ‘45’, ‘65’, ‘75’, ‘85’, and ‘95’.

Similar to Experiments 1 and 2 participants completed 1008 trials which were divided into 21 blocks of 48 trials each. Within each block, each target was presented six times, each time paired with a different prime. On half of the trials, the target was preceded by a congruent prime (i.e., both the prime and target were either less or greater than ‘55’) and on the other half of the trials the target was preceded by an incongruent prime (i.e., the prime was less than ‘55’ and the target was greater than ‘55’, or vice-versa).

Procedure. The experiment was identical to Experiments 1 and 2 except that participants were instructed to determine if the target digit was either less than or greater than ‘55’. Participants pressed the right <shift> key if the target was greater than ‘55’ or the left <shift> key if the target was less than ‘55’.

<u>Results.</u> Trials in which no response was given or the response latency was either less than 100 ms or greater than 1500 ms were removed from both the latency and error analyses (1.86% of the trials). In addition, incorrect responses were also removed from the latency analyses (7.25% of the trials).

The category congruence effects for both reaction time and accuracy were analyzed using a 3 (trial segment: early vs. middle vs. late) by 2 (category congruence:

congruent vs. incongruent) ANOVA. The priming distance effect for both reaction time and accuracy was analyzed using a 3 (trial segment: early vs. middle vs. late) by 3 (prime-target distance: one vs. two vs. three) ANOVA. Note that the prime-target distance corresponded to the distance between the digit in the target that was not a ‘5’ and the digit which shared its corresponding position in the prime.

Category Congruence Effect. In the latency analysis, there was no effect of trial segment, $F(2, 70) = 0.51$, *n.s.*, but there was a significant main effect of category congruence, $F(1, 35) = 48.32$, $p < .001$, $MSE = 254.30$. Congruent trials were responded to 15 ms faster than incongruent trials. The interaction was not significant, $F(2, 70) = 0.77$, *n.s.*

In the error analysis, there were significant main effects of trial segment, $F(2, 70) = 11.71$, $p < .001$, $MSE = 0.002$, and category congruence, $F(1, 35) = 16.14$, $p < .001$, $MSE = 0.002$. The error rate was greater for incongruent than congruent trials. The error rate was also significantly greater in the third (9.3%) than in both the first (5.9%), $t(35) = 2.59$, $p < .02$, $SE = 0.009$, and second (7.4%), $t(35) = 2.02$, $p = .05$, $SE = 0.008$, trial segments. The difference in error rates between the first and second trial segments was not significant, $t(35) = 0.99$, *n.s*. The interaction was also significant, $F(2, 70) = 4.27$, $p < .02$, $MSE = 0.001$, due to the fact that the magnitude of the priming effect in the third trial segment was significantly greater than in both the second, $t(26) = 2.79$, $p < .02$, $SE = 0.006$, and first, $t(26) = 2.45$, $p < .03$, $SE = 0.006$, trial segments. There was no significant difference between the magnitudes of the priming effects in the first and second trial segments, $t(26) = 0.42$, *n.s.*

Priming Distance Effect. In the latency analysis, there was no effect of trial segment, $F(2, 70) = 1.36$, *n.s.*, but there was a significant main effect of prime-target distance, $F(2, 70) = 10.48$, $p < .001$, $MSE = 631.04$. Responses were significantly longer when the prime-target distance was three versus one, $t(35) = 4.40$, $p < .001$, $SE = 3.13$, or two, $t(35) = 3.58$, $p < .005$, $SE = 3.61$, units. The difference in response latencies between when the prime-target distance was one versus two units was not significant, $t(35) = 0.24$, *n.s.* The interaction was not significant, $F(4, 140) = 1.97$, *n.s.*

In the error analysis, there was a significant main effect of trial segment, $F(2, 70) = 5.70$, $p < .01$, $MSE = 0.004$, and a marginal effect of prime-target distance, $F(2, 70) = 2.48$, $p < .10$, $MSE = 0.003$. The error rate was significantly greater in the third (8.6%) than in the first (6.2%), $t(35) = 2.67$, $p < .01$, $SE = 0.009$, or second (6.5%), $t(35) = 2.63$, $p < .01$, $SE = 0.008$, trial segments. The difference in error rates between the first and second trial segments was not significant, $t(35) = 0.50$, *n.s*. The error rate was also significantly larger when the prime-target distance was three units versus one unit, $t(35) = 2.50$, $p < .01$, $SE = 0.006$. There was no difference in error rates between when the prime-target distance was two versus one, $t(35) = 1.57$, *n.s.*, or three, $t(35) = 0.57$, *n.s.*, units. The interaction was not significant, $F(4, 140) = 1.56$, *n.s*.

Appendix D : Post-Hoc Analysis for Category Learning Experiments

To further investigate the mechanisms underlying the obtained priming effect pattern an additional analysis was performed in order to determine whether the priming effects vary as a function of the participants' ability to learn the artificial category sets. For each experiment, participants were first divided into three levels of learning achievement based upon overall error rate in the task. The third of the participants with the lowest overall error rates were classified as the "Good" Learners, whereas the third of the participants who had the highest overall error rates were classified as the "Poor" Learners. The middle third were classified as "Fair" Learners. The priming effects for each type of Learner were then calculated both early and late in learning.

The working assumption was that either the "Good" or "Poor" Learners may show an increase in the size of the response priming effect for correct responses across trials. The reason why the "Good" Learners may show this priming effect pattern is that since these Learners more often correctly classified the target stimuli, the response bias for these Learners should have clearly developed by the late trial blocks. Alternatively, the "Poor" Learners may show this priming effect pattern since they may have abandoned the task of learning the category sets in favour of responding on the basis of any response bias.

For both Experiment 1A and 1B the reaction time latencies for correct responses and the errors for the non-prototype targets were submitted to a 3 (learning ability: poor vs. fair vs. good) by 2 (trial segment: early (first half of the trials) vs. late (second half of the trials)) by 2 (prime congruency: congruent vs. incongruent) ANOVA. The results are shown in Table 2. Only the main effect of learning ability and any interactions involving learning ability are reported since the other effects in these analyses are identical to those reported above.

Experiment 1A : Four-Dimension Category Set

Latency analysis. There was the expected significant main effect of learning ability, $F(2, 30) = 9.08$, $p < .002$, $MSE = 20541.19$. “Poor” Learners (448 ms) responded significantly faster than either “Good” (569 ms), $t(20) = 3.96$, $p < .002$, $SE = 30.56$, or “Fair” Learners (550 ms), $t(20) = 3.34$, $p < .008$, $SE = 30.56$. There was no difference in response times between “Good” and “Fair” Learners, $t(20) = 0.62$, *n.s*. None of the interactions involving learning ability were significant (all Fs < 0.52).

Error analysis. There was the expected significant main effect of learning ability, $F(2, 30) = 36.63$, $p < .001$, $MSE = 0.011$. “Poor” Learners (37.8%) made significantly more errors than either “Good” (19.3%), $t(20) = 8.41$, $p < .001$, $SE = 0.022$, or “Fair” Learners (26.3%), $t(20) = 5.23$, $p < .001$, $SE = 0.022$. The difference in error rates between “Good” and “Fair” Learners was also significant, $t(20) = 3.18$, $p < .01$, $SE = 0.022$.

There was also a marginal interaction between learning ability and trial segment, $F(2, 30) = 2.59$, $p < .10$, $MSE = 0.006$. The magnitude of the decrease in error rates between the first and second trial segment for the “Good” Learners (11.2%) was marginally greater than for the “Fair” Learners (6.3%) [$t(20) = 1.80$, $p < .09$, $SE = 0.03$] and significantly greater than for the “Poor” Learners (3.7%) [$t(20) = 2.23$, $p < .04$, $SE = 0.03$]. The magnitude of the decrease in error rates between trial segments did not differ between the “Fair” and “Poor” Learners [$t(20) = 0.66$, *n.s.*]. More importantly, learning

Table 1.

Results for Non-Prototype Targets as a Function of Learning Ability (Reaction Times in Milliseconds, Errors in Percent)

Learning Ability	Incongruent Primes	Congruent Primes	PE
Four-Dimensional Category Set (Experiment 1A)			
“Good” Learners			
Early Trials	565 (23.9)	562 (25.9)	3
Late Trials	580 (14.5)	570 (12.8)	10
“Fair” Learners			
Early Trials	549 (29.5)	536 (29.3)	13
Late Trials	562 (25.5)	554 (20.8)	8
“Poor” Learners			
Early Trials	459 (40.4)	443 (39.0)	16
Late Trials	451 (37.4)	440 (34.5)	11
Six-Dimensional Category Set (Experiment 1B)			
“Good” Learners			
Early Trials	566 (33.0)	558 (33.5)	8
Late Trials	572 (24.0)	562 (22.3)	10
“Fair” Learners			
Early Trials	544 (41.4)	527 (40.5)	17
Late Trials	537 (34.7)	530 (36.1)	7
“Poor” Learners			
Early Trials	461 (48.3)	445 (45.6)	16
Late Trials	452 (49.7)	443 (45.9)	9

Note. Numbers in bracket are the error rates. PE = Priming Effect

ability did not interact with prime congruity, $F(2, 30) = 0.56$, *n.s.*, nor was the 3-way interaction significant, $F(2, 30) = 0.27$, *n.s.*

Experiment 1B : Six-Dimension Category Set

Latency analysis. There was the expected significant main effect of learning ability, $F(2, 42) = 15.46$, $p < .001$, $MSE = 13611.55$. “Poor” Learners (450 ms) responded significantly faster than either “Good” (564 ms), $t(28) = 5.36$, $p < .001$, $SE = 21.30$, or “Fair” Learners (534 ms), $t(28) = 3.95$, $p < .002$, $SE = 21.30$. There was no difference in response times between “Good” and “Fair” Learners, $t(28) = 1.41$, *n.s*. None of the interactions involving learning ability were significant (All *F*s < 0.42).

Error analysis. There was the expected significant main effect of learning ability, $F(2, 42) = 110.04$, $p < .001$, $MSE = 0.005$. “Poor” Learners (47.4%) made significantly more errors than either “Good” (28.2%), $t(28) = 14.77$, $p < .001$, $SE = 0.013$, or “Fair” Learners (38.2%), $t(28) = 7.08$, $p < .001$, $SE = 0.013$. “Fair” Learners also made significantly more errors than “Good” Learners, $t(28) = 7.69$, $p < .001$, $SE = 0.013$.

Learning ability also significantly interacted with trial segment, $F(2, 42) = 12.15$, $p < .001$, $MSE = 0.004$. The magnitude of the decrease in error rates between the first and second trial segment was greater for both “Good” (10.2%) [$t(28) = 5.48$, $p < .001$, $SE = 0.02$] and “Fair” (5.6%) Learners [$t(28) = 2.86$, $p < .009$, $SE = 0.02$] than for “Poor” Learners (-0.01%). The magnitude of the decrease in error rate was also marginally greater for “Good” Learners than for “Fair” Learners [$t(28)= 1.89$, $p < .08$, $SE = 0.02$]. More importantly, learning ability did not interact with prime congruency, $F(2, 42) = 1.58$, *n.s.*, nor was the 3-way interaction significant, $F(2, 42) = 0.57$, *n.s.*

Summary Statement

A post-hoc analysis based on correct performance for the non-prototype targets was run to determine whether the participants' ability to learn the category sets may have obscured any potential support for the S-R association account. The question of interest was whether the S-R association account may receive support when either examining performance for the "Good" Learners since they would have better developed response biases or the "Poor" Learners since they may have abandoned any attempt to learn the category sets in favour of responding on the basis of any formed response bias. The results indicate that neither the "Good" nor "Poor" Learners produced the predicted priming effect pattern.

Appendix E : Prime Discrimination Data For Arrow Classifications

Although no participants in the present experiments reported noticing the primes, a prime discrimination task was administered to a separate group of participants to provide a further investigation of the question of prime visibility. Twenty-two participants (age range: 17 – 35, M = 19.45) performed the task using a 77 ms prime-target interval and 22 participants (age range: 17 – 20, M = 18.36) performed the task using a 165 ms prime-target interval.

Each participant performed 18 practice trials followed by 120 experimental trials (four blocks of 30 trials each). Each trial, both practice and experimental, began with a 550 ms arrow mask (e.g., '><><><><') followed by a double-headed arrow prime (e.g., '<<' or '>>') which was backward masked by a 33 ms arrow mask. A 99 ms stimulus (i.e., '> <') either directly followed the backward mask (Experiment 1 – Prime Discrimination) or followed the backward mask after an 88 ms blank interval (Experiment 2 – Prime Discrimination). For half the trials the prime pointed to the left and for the other half of the trials the prime pointed to the right. The participants had a maximum of 2.5 seconds to respond to indicate the direction of the masked prime before the next trial began.

During the practice trials, the duration of the prime presentation decreased from 165 ms (trials 1 thru 6) to 110 ms (trials 7 thru 12) to 55 ms (trials 13 thru 18). During the experimental trials, the prime was always presented for 44 ms. Participants were instructed to make a response even if they were not sure which direction the prime pointed or even if there was a prime.

To assess prime discriminability, a sensitivity measure (d') was calculated. A hit was defined as correctly indicating that a left-pointing arrow prime pointed to the left and a false-alarm was defined as incorrectly indicating that a right-pointing arrow prime pointed to the left. In Experiment 1 – Prime Discrimination, the hit rate was 47.4% and the false alarm rate was 47.6%. The resulting d' score of -0.001 did not deviate from zero, $t(21) = 0.02$, *n.s.* In Experiment 2 – Prime Discrimination, the hit rate was 52.9% and the false alarm rate was 51.5%. The resulting d' score of 0.072 also did not deviate from zero, $t(21) = 0.26$, *n.s.*

In summary, the prime discrimination results using the parameter settings for both prime-target intervals provide further evidence that, under the experimental display settings used here, participants experienced little, if any, awareness of the prime.

Appendix F: Consent Form

Letter of Information – An Investigation of Masked Priming Mechanisms

In this study you will be presented with stimuli on a computer screen. Depending on the experimental condition which you are in you will be required to either make word/nonword discriminations, number judgments, learn an artificial category set, or determine if an item is a member of a specific category. In the event that these results are published your identity will be kept confidential.

You should also be aware of the following:

1) There are no known risks involved in participation in this study.

2) There are no hidden or deceptive procedures in this study. All instructions should be taken literally as they are described by the experimenter.

3) The experimenter will provide a general written explanation of the studies performed in this lab at the end of the experimental session. If you wish to receive a specific explanation of any study, just let the experimenter know.

4) You will receive one research credit for your participation. Your participation is voluntary and you are **free to withdraw** from this study at any time during the session without loss of credit.

Consent Form – An Investigation of Masked Priming Mechanisms

I have read the Letter of Information and have had the nature of the study explained to me and I agree to participate. All of my questions have been answered to my satisfaction.

____________________	____________________
Signature of Participant	Signature of Experimenter
____________________	____________________
Printed Name	Printed Name
____________________	____________________
Date	Date

Appendix G: Ethics Approval Form

Curriculum Vitae

Jason R. Perry, Ph.D. Candidate
Department of Psychology
University of Western Ontario

Current Research Interests:
Effects of masked stimuli on behaviour.

Education:

2011 (Expected)	PhD	Department of Psychology, University of Western Ontario Thesis Title: An Investigation of Masked Priming Mechanisms in Binary Classification Tasks
2005	MA	Department of Psychology, University of Western Ontario Thesis Title: Lexical Retrieval Processes in the Interactive-Activation Model Evaluated in a Masked Priming Lexical Decision Task
2003	BA	Department of Psychology, University of New Brunswick Thesis Title: An Investigation of the Stroop Effect in a Lexical Decision Task
2001	BA	Department of Computer Science, University of New Brunswick

Honours and Awards:

2005-2006	Ontario Graduate Scholarship	$15 000
2004-2005	Postgraduate Scholarship Master's NSERC	$17 300
2003-2004	Master's Graduate Tuition Scholarship University of Western	$ 6 000

Publications:

Peer-Reviewed Journal Articles

Perry, J.R., & Lupker, S.J. (submitted). An investigation of the effects of masked primes using artificial category sets. *Memory & Cognition.* 35 pp.

Perry, J.R., & Lupker, S.J. (submitted). An investigation of the time course of category congruence and semantic distance effects in number classification tasks. *Canadian Journal of Experimental Psychology.* 44 pp.

Perry, J.R., & Lupker, S.J. (2010). A prospective view of the impact of prime validity on response speed and selection in the arrow classification task with free choice trials. *Attention, Perception, & Psychophysics*, *72*, 528-537.

Perry, J.R., Lupker, S.J., & Davis, C.J. (2008). An evaluation of the interactive-activation model using masked partial-word priming. *Language and Cognitive Processes*, *23*, 36-68.

Conference Presentations:

Perry, J.R., & Lupker, S.J. (November, 2010). Investigating the role of S-R associations in subliminal response priming. Poster presented at the 51st annual meeting of the Psychonomic Society, St. Louis, United States.

Perry, J.R., & Lupker, S.J. (June, 2010). The time course of category congruence effects: Determining the extent to which subliminally presented stimuli are processed. Paper presented at 20th annual meeting of the Canadian Society for Brain, Behaviour, and Cognitive Science, Halifax, Nova Scotia.

Perry, J.R., Lupker, S.J., & Davis, C.J. (November, 2009). The impact of masked primes when learning artificial category sets. Poster presented at the 50th annual meeting of the Psychonomic Society, Boston, United States.

Lupker, S. J., Davis, C. J., & **Perry, J. R.** (November, 2007). Masked priming of orthographic neighbours: An examination of the lexical competition assumption. Paper presented at the 47th annual meeting of the Psychonomic Society, Long Beach, United States.

Perry, J. R., & Lupker, S. J. (2007, June). The impact of shared neighbours in masked form priming. Poster presented at the 17th annual meeting of the Canadian Society for Brain, Behavior, and Cognitive Science, Victoria, Canada.

Lupker, S. J., Davis, C. J., & **Perry, J. R** (2005, November). Masked form priming effects and the interactive-activation model. Paper presented at the 46th annual meeting of the Psychonomic Society, Toronto, Canada.

Lupker, S. J., **Perry, J. R.,** & Davis, C. J. (2005, August). Masked priming effects as a function of prime and target neighbourhoods: An evaluation of the IA model. Paper presented at the 14th meeting of the European Society for Cognitive Psychology, Leiden, Holland.

Perry, J. R., & Lupker, S. J. (2005, July). An evaluation of the ability of the IA model to account for priming effects. Poster presented at the 15th annual meeting of the Canadian Society for Brain, Behavior, and Cognitive Science, Montreal, Canada.

Perry, J. (2003, May). Explorations of the Stroop effect in a lexical decision task. Paper presented at the 27th Annual APICS Undergraduate Honours Psychology Conference.

Teaching Experience:

May 2009 – date	Research Assistant at the University of Western Ontario
2003 – April 2009	Graduate Teaching Assistant at the University of Western Ontario
2002 – 2003	Research Assistant at the University of New Brunswick