Basic Processes in Reading: The Role of Spatial Attention in Visual Word Processing

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The present thesis is concerned with the role of spatial attention in visual word processing. Eleven experiments are reported each of which consists of the combination of a manipulation of spatial attention (i.e., cue validity) with a manipulation of word processing. Five different manipulations of word processing were employed (1) long lag repetition priming, (2) case mixing, (3) inter-letter spacing, (4) the presence/absence of irrelevant features, and (5) set size. The conjoint effects of these factors were used to infer the role of spatial attention in visual word processing. Discussion focuses on integrating the present results into a viable theory and outlining future directions.

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I would also like to thank my family whose unconditional love has been a safety net for me for my entire life. I have never been afraid to fall. I would like to thank specifically my mother, father, Auntie Anne, and grandparents. I would also like to thank my brother for giving me a reason to go to university. All I wanted was to be a good example for him.

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Dedication

To my Sunshine

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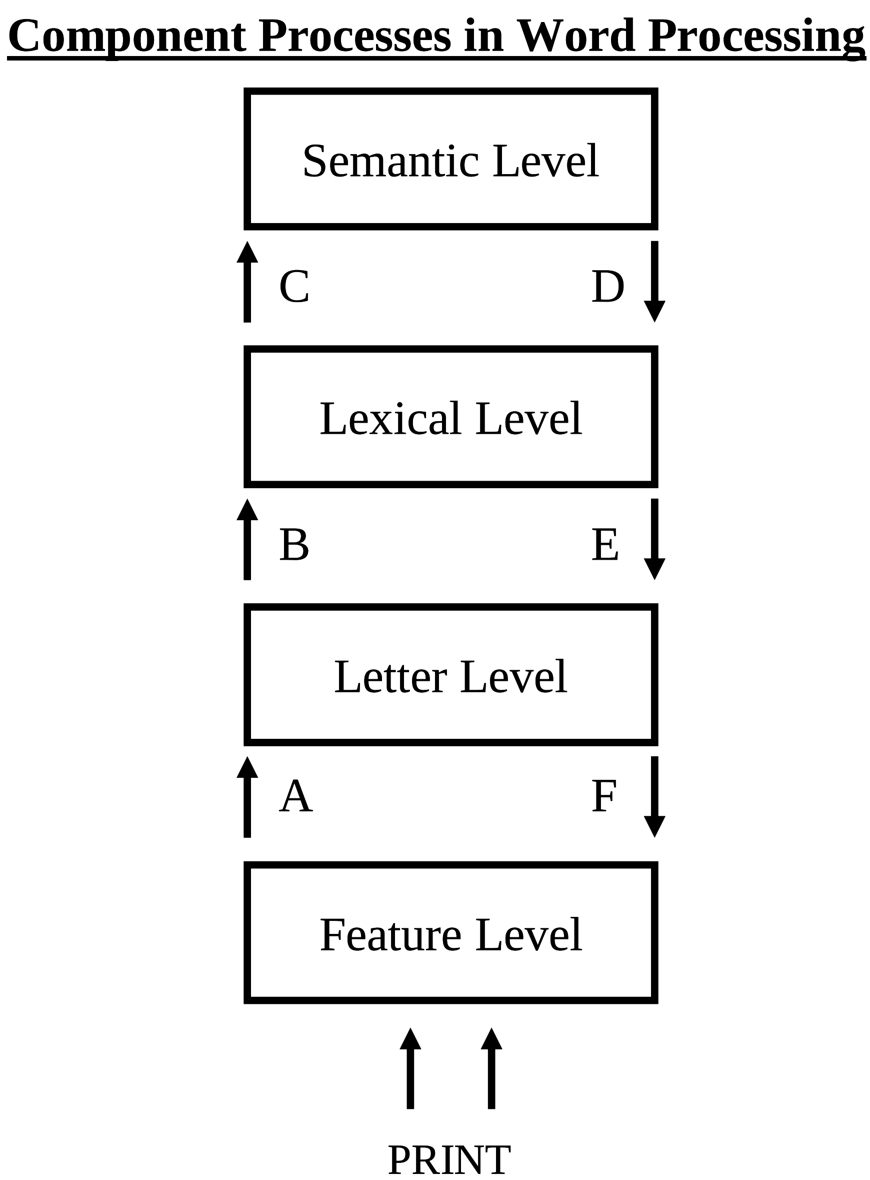
Chapter 1: Introduction and Literature Review

Reading represents one of the most important achievements of the human mind. The journey from the printed page to comprehension consists of the intricate coordination of different cognitive abilities - a kind of cognitive ‘team’ effort. The present investigation is concerned with one of the players on this team, a role player of sorts, but nonetheless a critical part of successful reading. Specifically, the present investigation is concerned with the role of spatial attention in visual word processing. This chapter consists of a brief introduction to the study of both word processing and spatial attention, followed by a broad review of the work that has been done on their interaction. Chapter 2 introduces the methods used in the experiments reported in Chapters 3 through 7. Finally, Chapter 8 summarizes my findings and integrates them into a framework for understanding the role of spatial attention in word processing. Chapter 8 also discusses some caveats and future directions.

A Brief Introduction to Visual Word Processing

A general framework for understanding word processing, adopted from Stolz and Stevanovski (2004), is presented in Figure 1. This framework is consistent with most major theories of word processing (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; McClelland & Rumelhart, 1981; Perry, Zeigler, & Zorzi, 2007) and is presented here for expository purposes more than any particular theoretical statement. The presented model consists of four levels (1) a feature level, (2) a letter level (3) a lexical level and (4) a semantic level. Each of these levels contains representations, specifically, of features at the feature level, letters at the letter level, words at the lexical level, and semantics at the semantic level.

Figure 1. A general model of word processing.



Each representation at a given level is connected to representations at levels both above and below it.

The depicted model is not complete. The assembled phonological route is omitted as is the distinction between orthographic lexical representations (i.e., how each known word is spelled) and phonological lexical representations (i.e., how each known word sounds). The omitted portions of the model are important and are left out only to simplify the diagram (see Coltheart et al., 2001 for a more complete depiction). Nonetheless, the depicted model is sufficient for the present discussion.

Processing of a word unfolds by first detecting the features present at each letter location in the word. These features are typically thought to represent simple line segments (e.g., | \ / -). The activation of a feature leads to the activation of letters that share that feature at the letter level (e.g., the feature **/** would activate the letter A). Activation of a letter activates words that contain that letter. For example, activation of the letter A at the letter level leads to the activation of words with the letter A at the lexical level (e.g., CAT and RAT). Activation from the lexical level feeds forward to semantic representations (i.e., what the word means). Activation from each level also feeds back to previous levels. Thus, activation of a semantic representation would feed back to representations at the lexical level then back to the letter and feature levels. In addition, McClelland and Rumelhart (1981) assume competition between representations *within* each level so that, for example, activation of the letter A will compete with activation of the letter B.

The present investigation is not concerned with adjudicating between competing models of word processing given these theories do not concern themselves with the role of spatial attention (but see Perry et al., 2006). This will have to change in the future but for now the word processing framework is presented as a guide for asking questions about the locus of spatial attention's influence on word processing. In addition, by discussing the role of spatial attention in this framework, future attempts at integrating spatial attention into major theories of word processing will be facilitated.

A Brief Introduction to Spatial Attention

Spatial attention has typically been likened to a spotlight that is moved around the visual field to select relevant information (e.g., words) for preferential processing. The present investigation is concerned with *covert* spatial attention (i.e., shift of the spotlight of attention *without* eye movements) as opposed to overt spatial attention (i.e., shift of the spotlight of attention via an eye movement). Attending to a location (i.e., moving the spotlight to a given location) where a target appears in space has been demonstrated to improve performance across a number of different tasks. This facilitation has been explained via various mechanisms, the most popular of which are signal enhancement (e.g., Carrasco, 2006; Carrasco, Williams & Yeshurun, 2002) and external noise reduction (e.g., Dosher & Lu, 2000; Shiu & Pashler, 1994). According to a signal enhancement view, spatial attention improves the quality of the representation of the attended stimulus (see Carrasco, 2006 for a review). For example, spatial attention increases both contrast sensitivity (Pestilli & Carrasco, 2005) and spatial resolution (e.g., Yeshurun & Carrasco, 1999). Spatial attention also appears to increase the rate of visual processing (Carrasco & McElree, 2001). According to an external noise reduction view, attending to a particular location allows irrelevant information (e.g., distractors) to be excluded (e.g., Dosher & Lu, 2000; Shiu & Pashler, 1994).

Spatial attention has also been associated with feature integration (e.g., Treisman & Gelade, 1980). Feature integration consists of binding individual features together to form a more complex object. For example, in the context of word processing, individual features (e.g., | | -) may need to be "put together" in order to perceive an object that is composed of a conjunction of features (e.g., H). Thus, when feature integration is impaired illusory conjunctions can occur (e.g., a P and Q might be perceived as an R (e.g., Briand & Klein, 1987; Treisman & Schmidt, 1982). In Treisman and Gelade's (1980) feature integration theory spatial attention is required to bind features together. Thus, when spatial attention is unavailable the incidence of illusory conjunctions increases. In Ashby, Prinzmetal, Ivry and Maddox's (1996) locational uncertainty model of feature integration, spatial proximity determines what features get integrated and noise in feature localization leads to illusory conjunctions. Removing spatial attention in this model increases the noise in feature localization and thus increases the likelihood of illusory conjunctions. In this latter model, spatial attention is not required for feature integration but influences it nonetheless.

With a general idea of current views on both word processing and spatial attention, we now move on to a review of the literature on the role of spatial attention in visual word processing. The review will first discuss research on reading problems associated with spatial attentional deficits and finish with a discussion of the role of spatial attention in word processing in skilled readers.

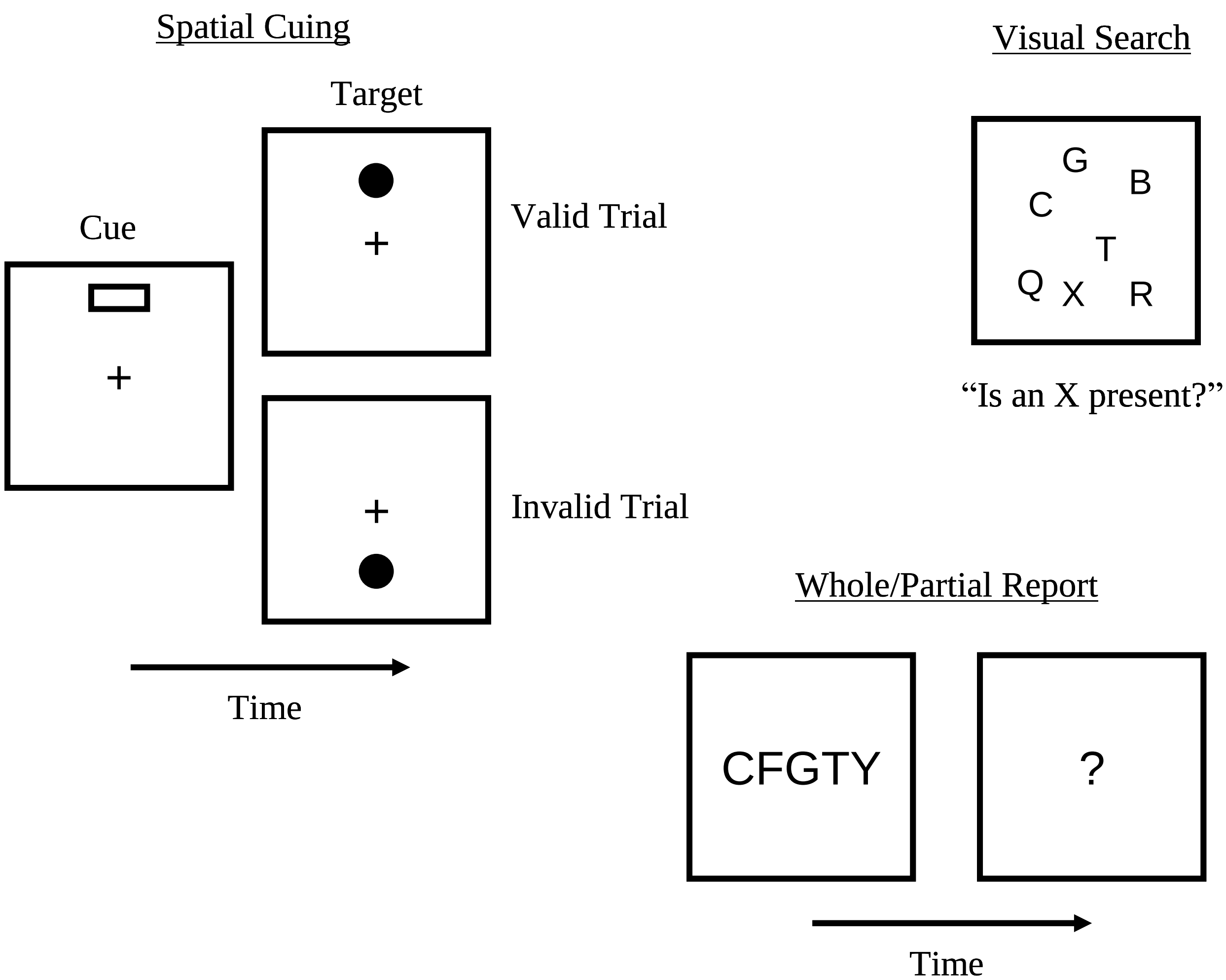
Spatial Attention in Developmental Dyslexia

A significant portion (4-10%) of the general population has difficulty learning to read despite adequate opportunity and intelligence (e.g., Hari, Renvall, & Tanskanen, 2001). Research on developmental dyslexia is dominated by the idea that the core deficit is a phonological impairment. Recently, a large number of researchers have suggested that a deficit in spatial attention may also play a major role in developmental dyslexia (e.g., Valdois, Bosse, & Tainturier, 2004; Vidyasagar, 2004). Indeed, Valdois et al. (2004) suggest that an "attentional deficit appears as a plausible second core deficit in developmental dyslexia" (p. 340). Below, evidence for the association between reading and spatial attentional deficits is discussed.

The most popular means through which to study spatial attention is in the spatial cuing paradigm (Posner, 1980). In this paradigm, participants are asked to fixate on a central fixation (i.e., do not move their eyes) and detect/discriminate a target presented in the periphery. Before the target appears a spatial cue is presented to direct spatial attention to a specific location. If the target appears at the cued location (i.e., a valid trial) performance is superior (e.g., responses are faster) to when the target appears at the uncued location (i.e., an invalid trial; see Figure 2). The resulting cuing effect (i.e., invalid minus valid) is an index of the *benefit* of having spatial attention at the target location when it appears or, alternatively, the *cost* of not having spatial attention at the target location when it appears.

A number of researchers have demonstrated differences between normal and dyslexic readers in the spatial cuing paradigm (Buchholz & Davies, 2005; Facoetti et al., 2006; Roach & Hogben, 2004). For example, Roach and Hogben (2004) demonstrated that dyslexics showed no benefit of a valid spatial cue. Facoetti et al., (2006) also provided evidence that this spatial cuing deficit may be related to an individual's ability to read nonwords. This pattern of results indicates that dyslexics either have an

Figure 2. Example displays from the spatial cuing paradigm, the visual search paradigm and the whole/partial report paradigm.



impairment in orienting spatial attention (i.e., moving the spotlight around the visual field) or in the function of spatial attention (i.e., a dimmer spotlight). Evidence consistent with the idea that dyslexics have a problem orienting spatial attention comes in the form of a deficit in visual search tasks (Buchholz & McKone, 2004; Casco, Tressoldi, & Dellantonio, 1998; Vidyasagar & Pammer, 1999). In a visual search task participants are given a target and asked to find that target amongst a variable set of distractors (e.g., the spotlight moves around the display until the target is found; see Figure 2). Buchholz and McKone (2004) demonstrated that dyslexics performance in a visual search task was more affected by an increase in the number of distractors than controls.

In addition to a problem with orienting spatial attention, dyslexics also appear to have distribute spatial attention assymetrically (Hari et al., 2001; Facoetti & Turatto, 2000; Facoetti, Turatto, Lorusso, & Mascetti, 2001; Sireteanu, Goertz, Bachert, & Wandert, 2005). Specifically, dyslexics demonstrate a shift in the distribution of spatial attention to the right. For example, Facoetti and Turatto (2000) asked controls and dyslexics to identify a central target letter flanked by distractor letters (e.g., HKH; Eriksen & Eriksen, 1974). In the dyslexic group, distractors on the left interfered *less* with identification of the central target relative to controls whereas distracters on the right interfered *more* with identification of the central target relative to controls. They interpreted this pattern as consistent with a "left mini-neglect" and a "right hyperattention."

Lastly, a number of researchers have reported that dyslexics have a smaller attentional span than skilled readers (i.e., the width of the spotlight; (Bosse, Tainturier, & Valdois, 2007; Prado, Dubois, & Valdois, 2007; Valdois, Bosse, Ans, Carbonnel, Zorman, David & Pellat, 2003). These experiments have used both whole and partial report tasks wherein participants are presented with a 5 letter string for a brief duration (e.g., 200 ms) and asked to report the letters presented (see Figure 2). In whole report participants report all of the letters and in partial report a cue is presented that indicates which letter to report. Dyslexic children perform much worse on both whole and partial report than control participants. These results are consistent with a deficit in attentional span such that the spotlight in dyslexics might be smaller than the spotlight in typical readers. This smaller attentional span would limit the amount of information that can benefit from the focus of spatial attention. Consistent with this interpretation, Enns, Bryson and Roes (1995), in a partial report task, reported that dyslexics only differed from controls with larger set sizes (i.e., 4-5 letters) and did not differ with smaller set sizes (i.e., 1-3 letters). This smaller attentional span may also cause dyslexic readers to have to make more eye movements while reading (Prado et al., 2007).

This brief review makes it clear that reading and spatial attentional impairments can go hand in hand. Individuals with developmental dyslexia may have trouble orienting spatial attention, they distribute spatial attention asymmetrically, and they may have a smaller attentional span. While the present thesis does not deal with a dyslexic population, the association between impairments in reading and impairments in spatial attention provides a strong motivation to better understand the role of spatial attention in word processing. The remaining literature review focuses more specifically on the contribution of spatial attention to word processing.

Spatial Attention in Acquired Dyslexia

A number of acquired dyslexias have been associated with spatial attentional impairments and as such have been used extensively to study the role of spatial attention in word processing. In the following, select work on neglect dyslexia, attentional dyslexia, and letter position dyslexia is reviewed. It is important to note that in studying acquired dyslexia the patterns observed in a single patient may not generalize to other patients diagnosed with the same disorder (i.e., acquired brain damage is rarely consistent across individuals). An effort is made here to focus on patterns that tend to be consistent across different patients.

Neglect Dyslexia

Neglect dyslexia is characterized by the misidentification of letters appearing on one side of a word. For example, an individual with left neglect dyslexia might read BARK as “MARK” (substitution error), “ARK” (deletion error), or STARK (addition error; e.g., Haywood & Coltheart, 2000). Neglect dyslexia is thought to be due to a deficit in spatial attention (Andersion, 1999; Brunn & Farah, 1991; Mozer & Behrmann, 1992). Specifically, patients with neglect dyslexia do not attend to the neglected side of the letter string.

One of the most consistent patterns in neglect dyslexia is a lexicality effect such that words are read better than nonwords (e.g., Arguin & Bub, 1997; Arduino, Burani, & Vallar, 2002; Brunn & Farah, 1991; Riddoch, Humphreys, Cleton & Fery, 1990; Sieroff, Pollatsek, & Posner, 1988). For example, reading “FAST” would be easier than “TAST.” Mozer and Behrmann (1992) suggested that the unattended portion of the letter string is “attenuated” which permits partial information to make contact with existing lexical and semantic representations. When present (i.e., when the letter string forms a word) feedback from these representations allows the reader to recover or fill in the neglected information. This partial information may consist of basic letter shape or letter features (i.e., feature level in Figure 1). Arguin and Bub (1997) demonstrated that neglect errors to words *increased* if the target word had orthographic neighbours whose first letter was visually similar to the target word (e.g., BARE-DARE).

Another explanation of the lexicality effect in neglect dyslexia was proposed by Brunn and Farah (1991) in terms of the letter string's influence on spatial attention (rather than spatial attention's influence on the processing of the letter string). Previous work had assumed that neglected letters in words and nonwords were equally neglected (i.e., unattended). Brunn and Farah (1991) demonstrated that this was not the case. Not only were neglect dyslexics better able to read words than nonwords they were also better able to report the colour of initial letters of words than nonwords. This result suggests that spatial attention had been re-oriented to encompass the neglected portion of the letter string when it formed a word. Brunn and Farah (1991) argued that partial processing of the letter string could have led to the initiation of lexical processing which would then lead to the re-distribution of spatial attention to encompass the entire letter string. According to this interpretation spatial attention is not required to initiate lexical processing but might be required to complete it.

Another consistent pattern found in neglect dyslexa is that neglect errors tend to approximate the length of the misread word (e.g., Anderson, 1999; Ellis, Flude, & Young, 1987). For example, FAST might be misread as "LAST" or "BLAST" but not "TELECAST." Thus, there tend to be substitution rather than omission errors. This result suggests, as with the lexicality effect, that partial information from the neglected portion of the letter string is being encoded. In the case of an error, it would appear that enough information is getting through to know "something" is there but not enough to identify "what" is there.

Arduino et al. (2002) related the ratio of substitutions to omissions to the severity of the patient's deficit. They suggested that a predominance of substitution errors constitutes evidence of a relatively minor deficit (e.g., HOUSE – JOUSE) compared to the case in which omissions predominate (e.g., HOUSE – OUSE). Arduino et al. (2002) demonstrated that the presence of lexical effects in the reading of neglect dyslexics was related to the ratio of substitutions to omissions. Specifically, as the ratio of substitution errors to omission errors increased (i.e., as the severity of the patient's deficit decreased), the likelihood of demonstrating lexical effects also increased. For example, patient PP made 91% substitution errors to 9% omissions and demonstrated an effect of target lexicality, word frequency, and nonword neighbour frequency. Patient AA, on the other hand, made 12% substitution errors and 88% omissions and demonstrated no effect of target lexicality, word frequency, or nonword neighbour frequency. These results strongly suggest that the extent of the spatial attentional impairment determines the presence of lexical effects in the reading of neglect patients. As the severity of the spatial attentional impairment increases, the likelihood of lexical effects decreases.

The final pattern to be discussed in the context of neglect dyslexia is the observation that neglect dyslexics are much worse at reading aloud than making lexical decisions (i.e., deciding if a letter string forms a word or not; Arduino et al., 2003; Ladavas, Shallice & Zanella, 1997; Ladavas, Umilta & Mapelli, 1997). Indeed, in lexical decision, neglect dyslexics' performance can approach or even be equal to that of controls (e.g., Arduino et al., 2003). Neglect dyslexics' accuracy in lexical decision is also affected by linguistic variables known to influence normal reader's accuracy in lexical decision (e.g., word frequency; Arduino et al., 2003). Ladavas et al., (1997) suggested that this dissociation between reading aloud and lexical decision results from the use of a sub-lexical reading strategy (e.g., serial grapheme to phoneme conversion) adopted in the reading task as a result of the degraded input to the lexical route. When sub-lexical units (e.g., letters) become the perceptual unit, rather than the whole word, spatial attention may be further biased to the right of the letter string. Whatever the resulting explanation, the dissociation between reading aloud and lexical decision suggests that the assessment of the role of spatial attention in word processing could yield different results depending on the task.

Overall, research on neglect dyslexia suggests that in many cases the impairment in spatial attention influences processing at an early stage (e.g., pre-letter level). In at least some cases, partial information (e.g., basic features, letter shape) from the neglected portion of the letter string activates existing lexical and semantic representations. Feedback from these representations can recover the neglected portion of the letter string (i.e., the lexicality effect; e.g., Arguin & Bub, 1997; Mozer & Behrmann, 1992). Alternatively, this partial information could lead to a re-distribution of spatial attention to encompass the entire letter string thus facilitating further processing (Brunn & Farah, 1991). Lastly, the differential impairment of reading aloud versus lexical decision suggests that the role of spatial attention in these tasks may be different (Arduino et al., 2003; Ladavas, Shallice & Zanella, 1997; Ladavas, Umilta & Mapelli, 1997).

Attentional Dyslexia

The defining characteristic of attentional dyslexia is an inability to recognize visual stimuli when multiple stimuli are present. Thus, identifying isolated letters (e.g., A) or words (e.g., CAT) is superior to identifying letters flanked by letters (e.g., FAH) or words flanked by words (e.g., BOAT CAT TABLE: Humphreys & Mayall, 2001; Mayall & Humphreys, 2002; Price & Humphreys, 1993; Saffran & Coslett, 1996; Shallice & Warrington, 1977; Warrginton, Cipolotti, & McNeil, 1993). In some cases patients are better at identifying a word than the constituent letters of that word. This pattern of results has been interpreted as a kind of selection problem wherein spatial attention cannot focus adequately on individual units (i.e., inability to focus the spotlight; Mozer & Behrmann, 1992; Saffran & Coslett, 1996). When spatial attention cannot be focused irrelevant information gains access to higher levels of processing and interferes with the processing of the relevant stimuli.

One characteristic of attentional dyslexia that has been reported in some but not all cases, is that the decrement in performance associated with the presence of multiple stimuli is category specific (Saffran & Coslett, 1996; Shallice & Warrington, 1977; Warrington et al., 1993). For example, patient FM was worse at identifying letters flanked by other letters than identifying letters flanked by numbers (Shallice & Warrington, 1977). This result suggests that the attentional deficit affects processing after letter identification, in the sense that, the problem is in the selection of relevant *letters* to feed forward to higher levels of processing rather than the selection of relevant stimuli per se. This pattern of results is not observed in all attentional dyslexics (Humphreys & Mayall, 2001; Mayall & Humphreys, 2002).

Another characteristic of attentional dyslexia is that letter and word identification errors often consist of migrations (e.g., FGF = F; DOG TAP = TOP). In words, these migration errors often maintain their original word position (e.g., DOG TAP = TOP rather than GAP; but see Davis and Bowers, 2004). In patient NY (Saffran & Coslett, 1996) and patient FL (Mayall & Humphreys, 2002), migration errors were reduced if the two words were in different cases. Also, in FL, increasing the spacing between the two words decreased the number of migrations. Mayall & Humphreys (2002; see also Humphreys & Mayall, 2001) related these types of errors to a deficit in coding letter location when spatial attention is distributed across a letter string or strings. Mozer and Behrmann (1992) suggested that the inability to focus on individual words in the display would lead to spurious activation of orthographically similar words that may be activated strongly enough to lead to an output (e.g., DOG HOT = DOT). When the spacing between elements is increased it may become easier to focus spatial attention on a prescribed region.

The evidence from attentional dyslexia thus suggests that spatial attention acts to attenuate processing of irrelevant information. When the spotlight is too wide irrelevant information is permitted into the word processing system which can then compete with relevant information. Letter migrations also suggest that spatial attention may be important for the localization of letters.

Letter Position Dyslexia

The notion that spatial attention is important for the localization of letters has been further bolstered by a recent report by Friedmann and Gvion (2001) on letter position dyslexia. The predominant error in letter position dyslexia is letter migrations *within* words. In a reading aloud task these patients were more likely to make an error when reading migratable words or nonwords (i.e., letter strings for which re-arranging the letters can lead to another word; e.g., bread → beard) than non-migratable words or nonwords (i.e., letter strings for which re-arranging the letters will not lead to another word; e.g., butter). Errors in migratable words and nonwords often consisted of reporting a more frequent word that could be made up of the presented letters. This suggests that the letters were processed to a level sufficient to access a lexical representation. These letters, when not "tied" to a location, spuriously activate lexical representations consistent with those letters at the lexical level (i.e., this would be more detrimental for migratable words because they can form multiple words). Friedmann and Gvion (2001) suggested that attention is required to bind letters to specific positions within a string and that these patients had a deficit in this ability. This could be viewed as a feature integration problem wherein the "letter" is considered a feature and the deficit in spatial attention impairs the patient's ability to bind that letter to a location (Treisman & Gelade, 1980; Treisman & Souther, 1985).

Summary

Research on acquired dyslexia has associated spatial attention with a number of different functions. First and foremost, spatial attention has a selective function. In neglect dyslexia, the removal of spatial attention from a portion of a letter string can attenuate or even block access of that visual information to the word processing system depending on the severity of the deficit. In attentional dyslexia, spatial attention cannot be focused on individual items when other items are present leading to the indiscriminate processing of "irrelevant" information. Thus, in both neglect dyslexia and attentional dyslexia, the spotlight of attention controls the flow of information into the word processing system. Where in the word processing system this occurs will be the focus of the present investigation. Letter localization appears as a second potential function for spatial attention in the context of word processing. In letter position dyslexia, a deficit in spatial attention is thought to be associated with difficulty in localizing letters within a letter string (e.g., Friedman & Gvion, 2001). In the next part of the literature review, studies of spatial attention in word processing in skilled readers is considered.

Spatial Attention in Skilled Readers

The question of the role of spatial attention in visual word processing in skilled readers has been addressed in a number of different paradigms. Here, the most popular paradigms are reviewed along with representative results from those paradigms.

Filtering

The most popular paradigm used to study the role of spatial attention in word processing is the filtering paradigm. A filtering task consists of attended and unattended stimuli. For example, participants might be asked to perform a task on a central word flanked by irrelevant distractor words (e.g., CAT JOG CAT). The processing of the unattended stimulus is typically indexed indirectly by its influence on concurrent processing of the attended stimulus. If a word requires spatial attention to be processed, then an unattended word should not influence performance. If a word does not require spatial attention to be processed then an unattended word should influence performance. Thus, the filtering task is designed to address the question of whether or not spatial attention *is required* for visual word processing to occur.

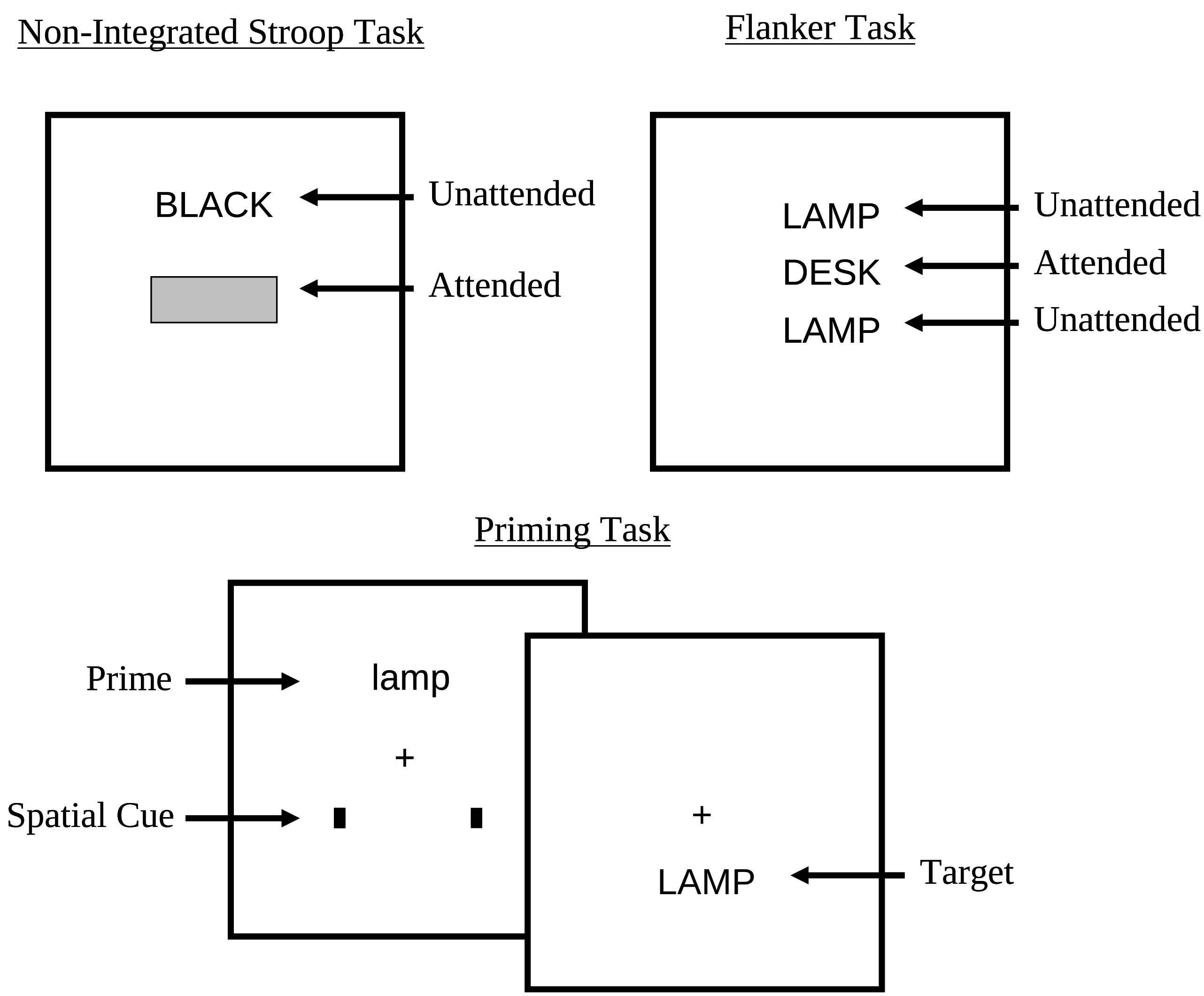
The limiting factor in filtering studies is the assumption that the unattended stimulus is in fact unattended. This can be difficult to prove and makes any strong conclusions from these paradigms difficult to assess (see Besner, Risko, & Sklair, 2005; Lachter, Forster & Ruthruff, 2004; Pashler, 1998; Yantis & Johnston, 1990). A review of three popular variants of the filtering paradigm (the non-integrated Stroop task, the flanker paradigm, and the priming paradigm; see Figure 2) is presented below (for a more extensive review of the filtering paradigm see Lachter et al., 2004).

Non-Integrated Stroop Task

In the non-integrated Stroop task participants are asked to name the colour of a colour bar (i.e., the attended stimulus) and ignore a word that appears in a different location (i.e., the unattended stimulus; see Figure 3). Critically, participants responses are slower and less accurate when an incongruent colour word flanks the colour bar (e.g., red bar flanked by the word GREEN) than when a neutral word (e.g., HOUSE) or a congruent colour word (e.g., RED) flanks the color bar (Gatti & Egeth, 1978; Kahneman & Chajczyk, 1983; Merikle & Gorewich, 1979). This non-integrated Stroop effect is smaller than the integrated Stroop effect (i.e., naming the colour that a colour word is printed in) suggesting that the colour word interferes with naming the ink color less when it is not at the focus of spatial attention. These results are consistent with the idea that spatial attention may influence the processing of the colour word, but is not necessary for word processing to occur.

Brown, Gore and Carr (2002) provided converging evidence for this claim by demonstrating that spatially cuing the location of the colour bar before it appeared reduced but did not eliminate the non-integrated Stroop effect. Thus, even when spatial

Figure 3. Example displays from the non-integrated Stroop task, the flanker task, and the priming task.



attention was focused on the colour bar's location before it appeared, interference from the unattended colour word still influenced performance. It is important to note that, when the colour *word* location was cued it increased interference relative to when the colour *bar* was cued. Again, this is consistent with the idea that removing spatial attention can modulate word processing but cannot stop it from occurring.

Flanker Task

In a paradigm very similar to the non-integrated Stroop task, called the flanker task, participants are asked to attend to a centrally presented word and ignore flanking Words (see Figure 3). Shaffer and LaBerge (1979) used the flanker task and asked participants to semantically categorize a central word (e.g., is the central word a piece of furniture?) and the relation between the target and the flanker category was manipulated. Critically, they demonstrated that responses to targets flanked by same category exemplars (e.g., DESK – lamp) were faster than responses to targets flanked by different category exemplars (e.g., DESK – gold). This result is consistent with the idea that an unattended word can be processed to the semantic level. This general result has been replicated (Dallas & Merikle, 1976; Lambert, Beard, & Thompson, 1988), however, subsequent research has suggested that the flanking words need to be primed in order to be processed to the level of semantics (Broadbent & Gathercole, 1990; White, 1995). Broadbent and Gathercole (1990) demonstrated that Shaffer and LaBerge's (1979) results were largely dependent on the use of a small set of words repeated throughout the experiment. They argued that the use of a small set of words primes the word processing system for these items, so that a very coarse analysis of the flanker word (e.g., features, single letters) could lead to the activation of the word's semantic representation. When a large set of words functioned as the flanker words, no evidence for semantic processing of the flanker word occurred (Broadbent & Gathercole, 1990).

Priming

Another popular variant of the filtering paradigm combines the spatial cuing paradigm with the masked priming paradigm (Besner et al., 2005; Lachter et al., 2004; Underwood & Thwaites, 1982). As discussed previously, the spatial cuing paradigm consists of directing spatial attention to a particular location before presenting the stimulus either at the same or a different location than the cue. In the priming paradigm, a prime word is presented before a target word and its influence on the target word is assessed. Spatial attention to the prime can be manipulated to determine if the prime word needs to be attended to in order to influence target processing (see Figure 3).

Besner et al., (2005) presented participants with a masked prime that had its location cued or not and assessed the influence of that prime on the time to read a word aloud (i.e., the prime was either the same as the target or different; repetition priming). When the spatial cue was uninformative with respect to the target location (i.e., valid on 50% of the trials, invalid on 50% of the trials), participants processed the prime word even on trials in which the prime's location was not cued. This result is consistent with the idea that spatial attention was not required to process the prime word. However, Besner et al. (2005) argued that the participants had no incentive to attend to the cued location because the cue was unpredictive of the target's location. They suggested that in this case spatial attention was distributed across the cued and uncued locations and thus the uncued location was not "unattended." When the cue was 100% informative about the target's location, Besner et al., (2005) observed no priming. This latter result is consistent with the idea that spatial attention is required to process the prime word. Lachter et al., (2004) report similar results. The Besner et al. (2005) study (see also Lachter et al., 2004), in addition to suggesting that spatial attention is required for visual word processing, also highlights the difficulty in interpreting filtering studies. Evidence for processing the "unattended" word can emerge not because the word was processed without spatial attention, but because the word was not actually unattended.

The results from these three filtering paradigms suggest that spatial attention may or may not be required to process a word. In the non-integrated Stroop task, participants appear able to process words outside the focus of spatial attention (Brown et al., 2002; Gatti & Egeth, 1978; Kahneman & Chajczyk, 1983; Merikle & Gorewich, 1979) as they do in the flanker task (Dallas & Merikle, 1976; Lambert et al., 1988; Shaffer & LaBerge, 1979). However, results in the latter paradigm seem dependent on priming the flanker in order to facilitate "unattended" processing (Broadbent & Gathercole, 1990; White, 1995). When a spatial cuing manipulation is combined with a priming manipulation it seems clear that spatial attention is required for visual word processing (e.g., Besner et al., 2005). Thus, results are mixed. The selective review presented here is representative of the literature as a whole (e.g., Lachter et al., 2004). The clear result to emerge from these different filtering paradigms is that spatial attention, while possibly not required, clearly modulates word processing in some manner. If this is the only clear message to emerge from filtering experiments it is certainly enough to motivate, using other paradigms, a concerted effort to understand *how* spatial attention modulates word processing. The present investigation will attempt to provide a better understanding of this modulatory influence.

Spatial Cuing in Word Processing Tasks

Spatial cuing, in addition to being used to control spatial attention in filtering tasks, has been used in conjunction with word processing tasks to more directly assess the role of spatial attention in word processing (Hardyk, Chiarello, Dronkers, & Simpson, 1985; Lindell & Nicholls, 2003; McCann, Folk & Johnston, 1992; Nicholls & Wood, 1998; Nicholls, Wood, Hayes, 2001; Ortells, Tudela, Noguera, & Abad, 1998; Stolz & McCann, 2001; Stolz & Stevanovski, 2004). This paradigm will be used in the experiments reported here. Thus, a brief review of it will suffice (a more in depth discussion of this paradigm appears in Chapter 2). In this paradigm, a spatial cuing manipulation is combined with a traditional word processing task (e.g., lexical decision, reading aloud). After a spatial cue is presented a letter string appears in either the cued or uncued location (i.e., the spotlight is either at that target's location or at a different location). The influence of spatial attention on word processing can be indexed *directly* by the influence of the spatial cue on performance in the word processing task (e.g., how does the location of the cue relative to the target influence the time to read the word aloud?).

In an initial study, Hardyk et al., (1985) failed to find any evidence of a cuing effect (i.e., better performance on valid than invalid trials) in lexical decision. This result is consistent with the view that spatial attention plays no role in word processing. As the review thus far would suggest and later studies using this paradigm would demonstrate, this is not the case. McCann et al. (1992) reported a significant cuing effect in lexical decision as have many others (Ortells et al., 1998; Stolz & McCann, 2001; Stolz & Stevanovski, 2004). Cuing effects have also been found using a reading aloud task

(Lindell & Nicholls, 2003; Nicholls & Wood, 1998; Nicholls et al., 2001). McCann et al. (1992) also demonstrated that this cuing effect was unaffected by the lexicality of the target or the frequency of the target word. They took this result to suggest that the spatial attentional requirements imposed by letter strings was unaffected by their familiarity. This is seemingly inconsistent with observations in acquired dyslexia that demonstrated interactions between spatial attention and lexicality (i.e., the lexicality effect in neglect dyslexia).

The spatial cuing paradigm has also been used to study hemispheric differences. Responses to words are faster when presented in the right visual field (RVF) than when presented in the left visual field (LVF). When words are presented laterally the cuing effect is larger for words presented in the LVF than for words presented in the RVF (Lindell & Nicholls, 2003; Nicholls et al., 2001; Nicholls & Wood, 1998). Nicholls and Wood (1998) explained this effect by suggesting that the right hemisphere processes words in a letter-by-letter fashion that requires the serial application of spatial attention. However, the left hemisphere processes words in a wholistic fashion in which whole words rather than letters function as the perceptual unit. According to Nicholls and Wood (1998), whole word recognition does not require spatial attention. This view seems inconsistent with the fact that there is a spatial cuing effect when words are presented in the RVF (Nicholls et al., 2001), but it certainly appears to be the case that words presented to the left hemisphere are influenced *less* by a manipulation of spatial attention than words presented to the right hemisphere. Thus, spatial attention influences word processing when the word is presented to either the LVF or RVF but the need to apply spatial attention in a letter-by-letter fashion may be specific to LVF presentations. This interpretation suggests the possibility that spatial attention may have multiple roles in word processing.

Spatial Cuing Within Words

The distribution of spatial attention within words has been investigated in another variant of the spatial cuing paradigm (Auclear & Sieroff, 2002; Sieroff & Posner, 1988). In this task spatial attention is cued to the beginning or end of a letter string rather than to a target or non-target location. In this case, the role of spatial attention within the letter string can be assessed. Sieroff and Posner (1988) presented participants with a digit at what would become the left (beginning) or right (end) of a letter string when it was presented. The letter string was presented briefly and the participants had to report the identity of the digit before reporting the word. Sieroff and Posner (1988) found no effect of the cue in the identification of words but did find a cuing effect in the identification of nonwords (i.e., beginning cued nonwords were identified more accurately than end cued nonwords). However, with brief enough presentation durations and long enough words, a cuing effect can be found in words, though this cuing effect is always smaller than it is with nonwords (Auclair & Sieroff, 2002). Auclair and Sieroff (2002) explained the difference in cuing effects between words and nonwords in terms of the facilitated redistribution of spatial attention within words relative to nonwords. For words, the spotlight can be re-distributed to encompass the entire letter string, whereas nonwords require a sequential focus on each letter which is more disrupted by an "end" of letter string cue. This account is similar to Brunn and Farah's (1991) account of lexicality effects in neglect dyslexia. Specifically, there is a benefit for words over nonwords with respect to the distribution of spatial attention within letter strings.

The effect of lexicality reported by Auclair and Sieroff (2002) is inconsistent with the lack of a lexicality effect in McCann et al., (1992). They explained this discrepancy by suggesting that the benefit of lexicality on the re-distribution of spatial attention within words might not show up in experiments that use an on/off cuing procedure like McCann et al.'s (1992). In McCann et al., (1992), spatial attention is either at the letter string's location or not and thus the distribution of spatial attention within the word is not being indexed. Thus, there may be both between word and within word effects of spatial attention on word processing.

Word Processing in Brief Multi-Element Displays

Another way to study the role of spatial attention in word processing is in briefly presented multi-element displays. The idea in these tasks is that spatial attention has to be spread over multiple display locations and, because the presentation is brief, spatial attention cannot be focused on individual elements but must be distributed across the entire array.

A number of researchers have demonstrated that in brief multi-element displays letters can migrate between words (e.g., LINE LACE = "LANE"; Mozer, 1983; McClelland & Mozer, 1986; Treisman & Souther, 1985). A similar phenomenon was reported in attentional dyslexia previously. These migrations were originally thought to preserve letter position (Mozer, 1983) but Davis and Bowers (2004) have demonstrated that position preservation likely reflects participant's reluctance to violate lexical and graphotactic constraints in producing responses (e.g., LINE LACE = "LCNE"). The likelihood of letter migrations are more frequent when a target word and context share letters (e.g., CAPE CONE) than when they do not (e.g., CAPE MONK).

Mozer and Behrmann (1992) explain letter migrations in brief multi-element displays in skilled readers in the same manner as they explain the related phenomenon in attentional dyslexia. Specifically, spatial attention cannot be focused and letter migrations result from spurious activation of migration responses. When spatial attention can be focused on a single word in these displays migration responses are reduced (Mozer, 1983). In attentional dyslexia the unfocused state of spatial attention is part of the disorder, whereas in skilled readers it results from the brief displays. Thus, evidence from multi-element displays suggests that spatial attention is required to selectively process letter strings. When multiple letter strings fall in the spotlight of attention they interfere with each other in the word processing system.

Spatial Attention in Theories of Eye Movements in Reading

The interaction between spatial attention and word processing has been the focus of some debate in models of eye movements in reading. In the EZ reader model (Pollatsek, Reichle, & Rayner, 2006; Reichle, Pollatsek & Rayner, 2003) spatial attention acts as a gatekeeper for lexical processing. According to this model, reading consists of two stages (L_1 and L_2). Completion of L_1 processing (i.e., activation of an orthographic representation) on word n leads to the programming of a saccade to word $n + 1$. Completion of L_2 processing (i.e., activation of a phonological and/or a semantic representation) leads to a shift in spatial attention to word $n + 1$. Lexical processing of word $n + 1$ begins as soon as it is attended but not before. While spatial attention is allocated to word n, basic feature information from word $n + 1$ is available and is used by the saccade generation system. In this model, when spatial attention is not allocated to the word its processing is limited to early levels of processing (e.g., features).

Spatial Attention in Theories of Reading

Perry et al.'s (2007) CDP+ model of reading aloud assumes that spatial attention is responsible for graphemic parsing. Graphemic parsing occurs after letter identification and operates from left to right across the letter string. This process is the basis of sub-lexical processing which suggests that nonwords would place greater demands on spatial attention than words. In Ans, Carbonell, & Valdois' (1998) connectionist multiple-trace memory model of reading, spatial attention plays a similar role. On presentation of the letter string, spatial attention initially encompasses the entire letter string (i.e., global mode). If retrieval of a word fails and a sub-lexical reading strategy has to be adopted then spatial attention is focused on constituent parts of the letter string in order to generate a pronunciation (i.e., analytic mode). Thus, both Perry et al., (2007) and Ans et al., (1998) suggest that spatial attention is specifically involved in controlling information flow during sub-lexical processing. This view is consistent with Facoetti et al.'s (2006) observation that nonword reading was related to the magnitude of the spatial cuing effect.

Summary

The research on the role of spatial attention in word processing has uncovered a number of interesting patterns. As was evident in the research on acquired dyslexia, spatial attention clearly modulates word processing and indeed may be required for word processing to occur (e.g., Besner et al., 2004; Lachter et al., 2004; Pollatsek et al., 2006; Reichle et al., 2005). In filtering paradigms, drawing spatial attention away from a word reduces that word's impact on performance, but in some cases does not entirely eliminate it (e.g., Brown et al., 2002). Cuing spatial attention away from a letter string's location slows word processing and this cuing effect is not affected by the lexicality or frequency of the letter string (e.g., McCann et al., 1992). This latter result is seemingly at odds with research on the role of spatial attention within letter strings (Auclair & Sieroff, 2002; Sieroff & Posner, 1988) and with research on acquired dyslexia (e.g., Arguin & Bub, 1997). Thus, there may be an important distinction to be made between manipulations of spatial attention that influence the distribution of spatial attention within a word and manipulations that influence whether or not a word is spatially attended. Indeed, these different types of spatial attention manipulations may be indexing separate functions of spatial attention in visual word processing (i.e., within object versus between object; Humphreys, 1998). The role of spatial attention within a letter string has begun to appear in models of reading aloud as a means of controlling sub-lexical processing (Ans et al., 1998; Perry et al., 2007).

Conclusion

The above review is a sample of the current state of research on spatial attention in word processing. For the most part a functional gloss has been provided but nonetheless the review is representative of the environment from which the present experiments emerged. If anything is to be taken from the review it is that spatial attention is an important player in the cognitive team effort required to read. The following chapters describe a series of experiments designed with this previous work in mind and with the general goal of understanding the role of spatial attention in word processing.

Chapter 2: Experimental Approach and General Method

The following consists of a description of the experimental approach used in the present investigation along with a general description of the method used in the reported experiments.

Experimental Approach

The research strategy applied here is based on previous work by McCann et al., (1992; and others e.g., Stolz & McCann, 2001; Stolz & Stevanovski, 2004) and belongs to the tradition of mental chronometry (see Meyer et al., 1988). Mental chronometry consists of the use of response time to make inferences about the nature of the information processing architecture and the processing dynamics that underlie human cognition. This general approach has a long and venerable history in cognitive psychology (see Klein, 2003; Meyer et al., 1988; Sternberg, 1969).

To understand the role of spatial attention in visual word processing, McCann et al. (1992) measured response times in a lexical decision task as a function of a spatial cuing manipulation. Participants were asked to fixate at the centre of the display. An abrupt onset peripheral cue appeared in what would become either the target (i.e., a valid trial) or non-target location (i.e., an invalid trial). The cue was intended to capture the participant's spatial attention and draw it to its location. A letter string was then presented and participants made a decision as to the lexical status of the letter string. Thus, on valid trials spatial attention was at the target location before the target word appeared and on invalid trials it was not. The difference in response times as a function of cue validity (i.e., valid vs. invalid trials) was taken as an index of the influence of spatial attention on word processing. Thus, the experimental approach here allows a direct assessment of the role of spatial attention in visual word processing (cf. the filtering paradigm).

In the vast majority of studies combining this type of spatial cuing manipulation with a word processing task a significant cuing effect has been reported. If we take the cuing effect to index spatial attention, we can conclude, as we did in Chapter 1, that spatial attention influences word processing in some fashion. To understand the nature of this influence, the spatial cuing manipulation can be combined with manipulations thought to influence different components of word processing. For example, McCann et al. (1992) combined the spatial cuing manipulation with a manipulation of word frequency which is thought to influence lexical level processing. When two factors (or more) are combined factorially, their joint effects can be used to infer the relation between the processes indexed by each factor. The critical piece of data is the joint influence of both factors on response time (i.e., whether there is an interaction between the two factors or not and if so the nature of that interaction). In the simplest case, the experiment consists of two factors with two levels resulting in three possible outcomes with respect to the joint effects of the two factors - additivity, underadditivity and overadditivity. A discussion of each of these three outcomes and their theoretical interpretation follows.

Before describing the nature of these interactions it is necessary first to note that the following discussion will assume that an increase in a factor level (e.g., A_1 to A_2) is associated with an increase in response time (Sternberg, 1969). This is an arbitrary rather than a theoretical assumption and is made for expository purposes. For example, if participants responded faster on valid than invalids trials, going from valid (i.e., A_1) to invalid (i.e., A_2) would represent an increase in a factor level (i.e., cue validity). Note that describing a given relation between two levels of a factor as an "increase" does not mean a functional increase in any quantity of the factor in any theoretical sense (e.g., going from valid to invalid does not represent an increase in spatial attention).

With this nomenclature in hand, if there is no interaction between the effects of two factors the factor effects are said to be additive (see Figure 4). An increase in the level of one factor does not influence the effect of the other factor. For example, if the two factors are A and B, their effects are additive if the effect of factor A is the same size at both levels of factor B (i.e., B_1 and B_2). Additive effects between two factors are taken as evidence that the two factors do not influence a common process (Sternberg, 1969). If factor A and factor B are additive, for example, factor A could either (1) influence a process that occurs before the process indexed by factor B or (2) influence a process that occurs after the process indexed by factor B.

Underadditivity and overadditivity represent two different types of interactions. An underadditive interaction between two factors occurs when an *increase* in the level of one factor leads to a *decrease in the effect* of another factor (see top panel of Figure 5). Thus, the combined effect of increasing both factors is less than the sum of their separate influences. For example, if factor A and factor B interact in an underadditive fashion, then the effect of factor A would be *larger* on B_1 trials than on B_2 trials. Underadditive interactions are far less common than overadditive interactions but nonetheless have been demonstrated in various contexts (e.g., Besner & Risko, 2005; Johnston, McCann & Remington, 1995; Reynolds & Besner, 2006; Stanovich & Pachella, 1977). The most

Figure 4. Example of additive factor effects. The effect of factor A is the same at both levels of factor B.

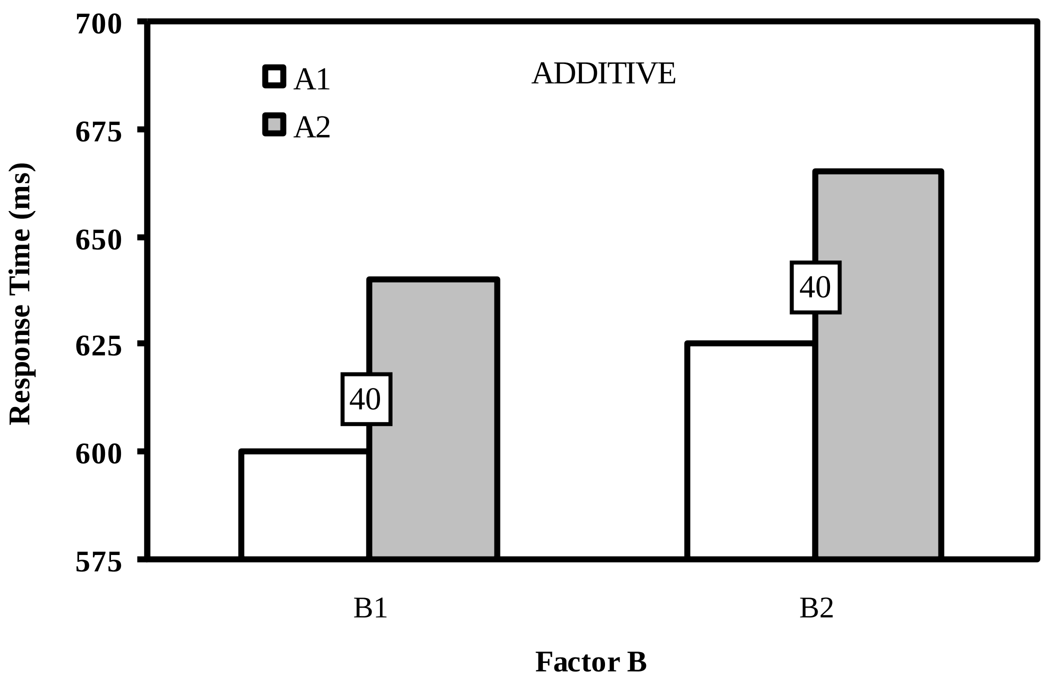
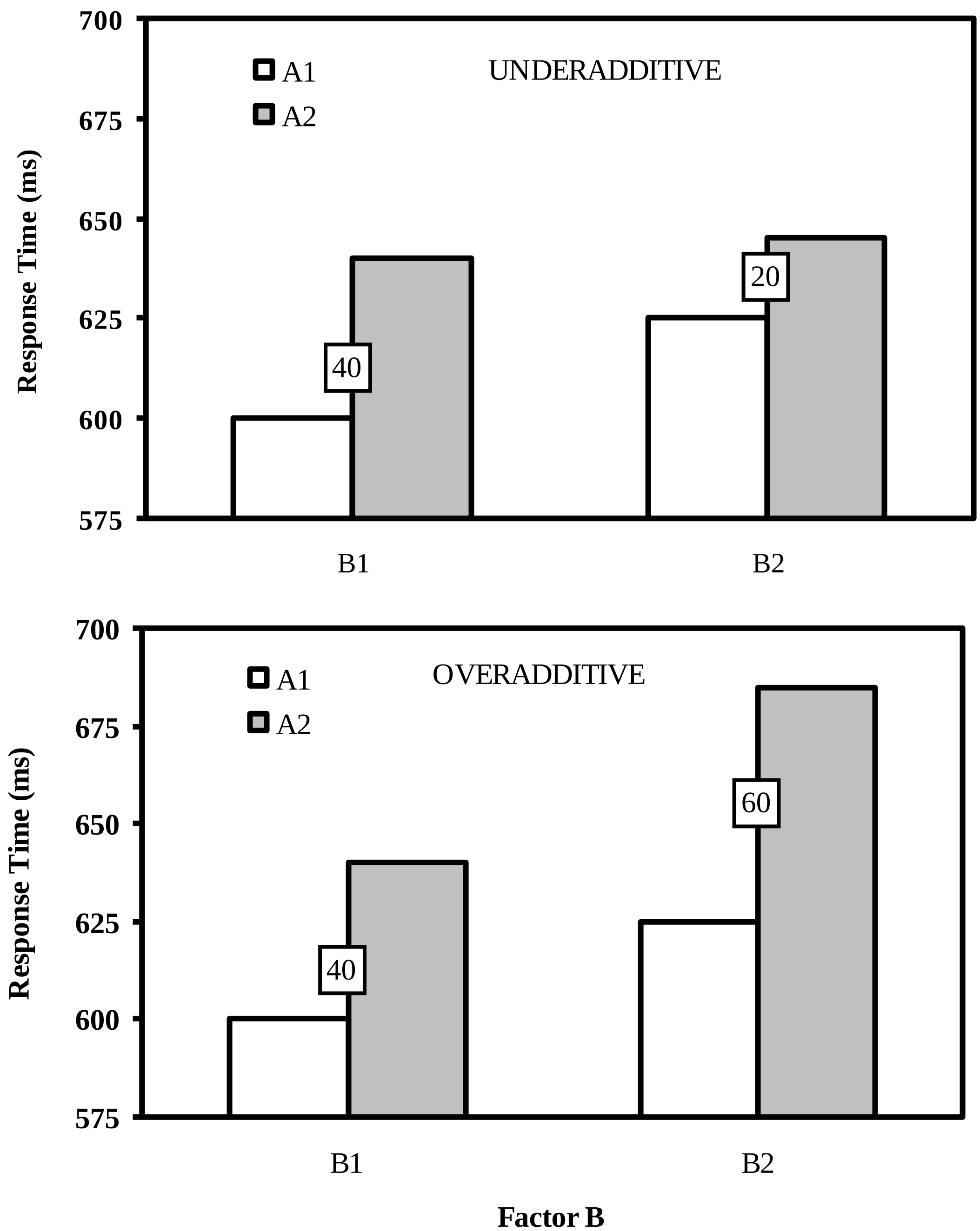


Figure 5. Top panel. Example of underadditive factor effects. The effect of factor A is larger at B1 than at B2. Bottom panel. Example of overadditive factor effects. The effect of factor A is smaller at B1 than at B2.



popular interpretation of an underadditive interaction is that the processes indexed by both factors occur in parallel (e.g., Stanovich & Pachella, 1977). Thus, underadditivity can be taken as indicating that the processes indexed by the two factors overlap in time.

An overadditive interaction between two factors occurs when an *increase* in one factor leads to an *increase in the effect* of another factor (see bottom panel of Figure 5). Thus, the combined effect of increasing both factors is greater than the sum of their separate influences. For example, if factor A and factor B interact in an overadditive fashion, then the effect of factor A would be *smaller* on B_1 trials than on B_2 trials. Overadditive interactions are by far the most common form of interaction in cognitive psychology. An overadditive interaction is interpreted as evidence that the two factors influence a common process (Sternberg, 1969). For example, if factor A and factor B interact in an overadditive fashion then we would conclude that factor A and factor B influence the same process. It is important to note that, if factor A and factor B influence a common process this does not mean that it is the only process either factor may influence. For example, reducing the contrast of a stimulus is thought to influence processing at multiple levels within the word processing system (e.g., Stolz and Stevanovski, 2004).

Within this interpretational framework we can use the joint influence of factor effects to infer the relation between spatial attention and word processing. I next review various benchmark empirical phenomenon generated from this research strategy in the past and discuss how it can be accommodated within a theory of the role of spatial attention in visual word processing.

Previous Work

A selective review of previous experiments combining spatial cuing with a manipulation of word processing is presented in Table 2. A review of the effects of visual field was provided in Chapter 1 but are not relevant to the present studies, so they are omitted from Table 2. As is evident in Table 2, researchers have mainly used lexical decision and only sparingly used reading aloud. In addition, peripheral abrupt onset cues have been used most of the time and central cues have been used sparingly. Most studies used informative cues, though some did not.

In terms of the conjoint effects of cue validity and the various manipulations in Table 2 a number of consistent patterns are apparent. First, the effects of cue validity and word frequency are additive (McCann et al., 1992; Nichols et al., 2001; Nichols & Wood, 1998; Ortells et al., 1998), as are the effects of cue validity and lexicality (McCann et al., 1992; Stolz & McCann, 2001; Stolz & Stevanovski, 2004). Thus, spatial cuing has equivalent effects on high and low frequency words, and has equivalent effects on words and nonwords. These patterns suggest that cue validity does not influence the same process as word frequency or lexicality. Both word frequency and lexicality represent manipulations of "stimulus familiarity" and both are hypothesized to have their effects at a lexical level (McCann et al., 1992). The consistent additivity between cue validity and word frequency and cue validity and lexicality suggests that invalidly cuing spatial attention does not influence lexical level processing. It must then influence word processing at a pre- or post-lexical level. McCann et al. (1992) suggested a pre-lexical locus (see Figure 6 for a schematic). The depiction of the McCann et al. (1992) theory (and subsequent theories) represents my interpretation of their theory.

Table 1. Select results from previous studies using a manipulation of cue validity in a word processing task. A peripheral cue is an abrupt onset in the periphery. A central cue is presented at the center of the screen and typically consists of an arrow. If the cue is informative its location correctly predicts the targets location on the majority of the trials (e.g., 80% valid). If the cue is uninformative its location does not predict the location of the target (e.g., 50% valid).

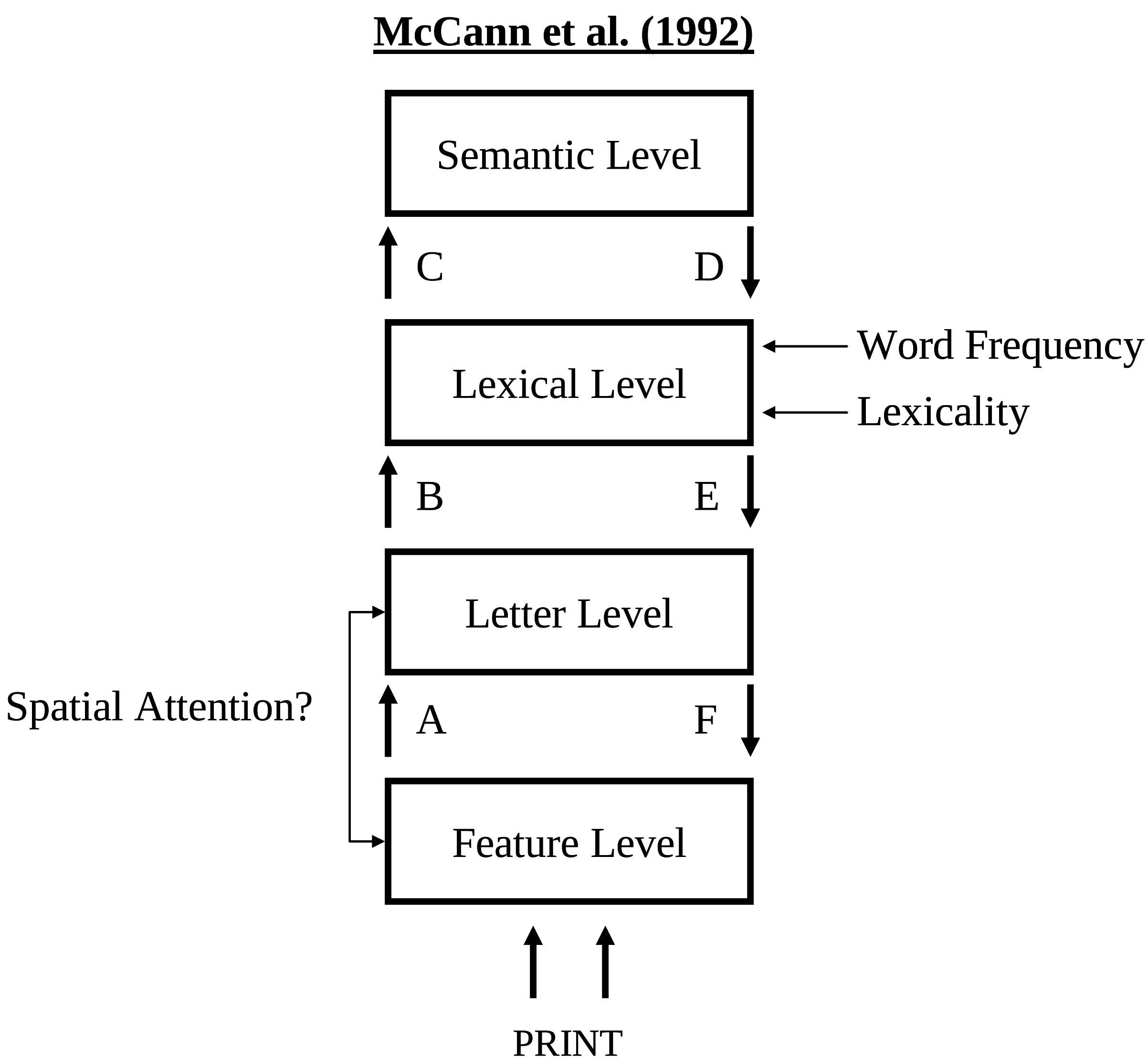
Study		Task	Cue Type	Informative Cue	Factor	Pattern
McCann et al (1992)						
	Experiment 1	Lexical Decision	peripheral	yes	Word Frequency	additive
		Lexical Decision	peripheral	yes	Lexicality	additive
	Experiment 2	Lexical Decision	peripheral	yes	Word Frequency	additive
		Lexical Decision	peripheral	yes	Lexicality	additive
Nichols & Wood (1998)						
	Experiment 1	Reading Aloud	peripheral	yes	Word Frequency	additive
Ortells et al. (1998)						
	Experiment 3	Lexical Decision	peripheral	yes	Word Frequency	additive
	Experiment 4	Lexical Decision	central	yes	Word Frequency	additive
	Experiment 5	Lexical Decision	central	yes	Word Frequency	additive
	Experiment 6	Lexical Decision	peripheral	no	Word Frequency	additive
Nichols et al., (2001)						
	Experiment 1	Reading Aloud	central	yes	Word Frequency	additive
Stolz & McCann (2000)						
	Experiment 1	Lexical Decision	peripheral	yes	Semantic Priming	overadditive
		Lexical Decision	peripheral	yes	Lexicality	additive
	Experiment 2	Lexical Decision	peripheral	yes	Semantic Priming	overadditive
		Lexical Decision	peripheral	yes	Lexicality	additive
	Experiment 3	Lexical Decision	peripheral	no	Semantic Priming	additive
		Lexical Decision	peripheral	no	Lexicality	additive
Stolz & Stevanovski (2004)						
	Experiment 1	Lexical Decision	peripheral	yes	Stimulus Contrast	overadditive
		Lexical Decision	peripheral	yes	Semantic Priming	overadditive
		Lexical Decision	peripheral	yes	Lexicality	overadditive
	Experiment 2	Lexical Decision	peripheral	no	Stimulus Contrast	additive
		Lexical Decision	peripheral	no	Semantic Priming	additive
		Lexical Decision	peripheral	no	Lexicality	additive

In contrast to this relatively clear-cut pattern, Stolz and McCann (2000) and Stolz and Stevanovski (2004) discovered a rather complex relation between cue validity, semantic priming, and the informativenes of the spatial cue. Semantic priming refers to the facilitation observed when a target word is preceded by a semantically related prime (e.g., DOCTOR – nurse) relative to a semantically unrelated prime (e.g., TABLE – nurse; Neely, 1977). There are at least two hypothesized loci for semantic priming effects (1) facilitation of semantic processing within the semantic level and (2) feedback from semantics to earlier levels of processing (via pathway D). Stolz and McCann (2000) and Stolz and Stevanovski (2004) presented a prime word at the centre of the screen followed by an abrupt onset cue. Next, a letter string was presented either in the cue's location or in a different location. The participants made a lexical decision on the letter string.

Stolz and McCann (2000) and Stolz and Stevanovski (2004) demonstrated that when the spatial cue was *informative* with respect to the location of the target (i.e., the cue and target often appeared in the same location), the joint effects of cue validity and semantic priming were *overadditive* suggesting that the two manipulations influenced the *same* process. However, Stolz and McCann (2000) and Stolz and Stevanovski (2004) also demonstrated that when the spatial cue was *uninformative* with respect to the location of the target, the effects of cue validity and semantic priming were *additive* suggesting that the two manipulations influenced *different* processes.

Stolz and Stevanovski (2004) explained this pattern by suggesting that (a) spatial attention influenced processing possibly up to the lexical level and (b) feedback from semantics (via pathway D) was operative when the spatial cue was *informative* but not when the spatial cue was *uninformative* (see Figure 7 for a schematic). They associated

Figure 6. Depiction of the McCann et al. (1992) account of the role of spatial attention in word processing. Spatial attention influences processing before the lexical level.

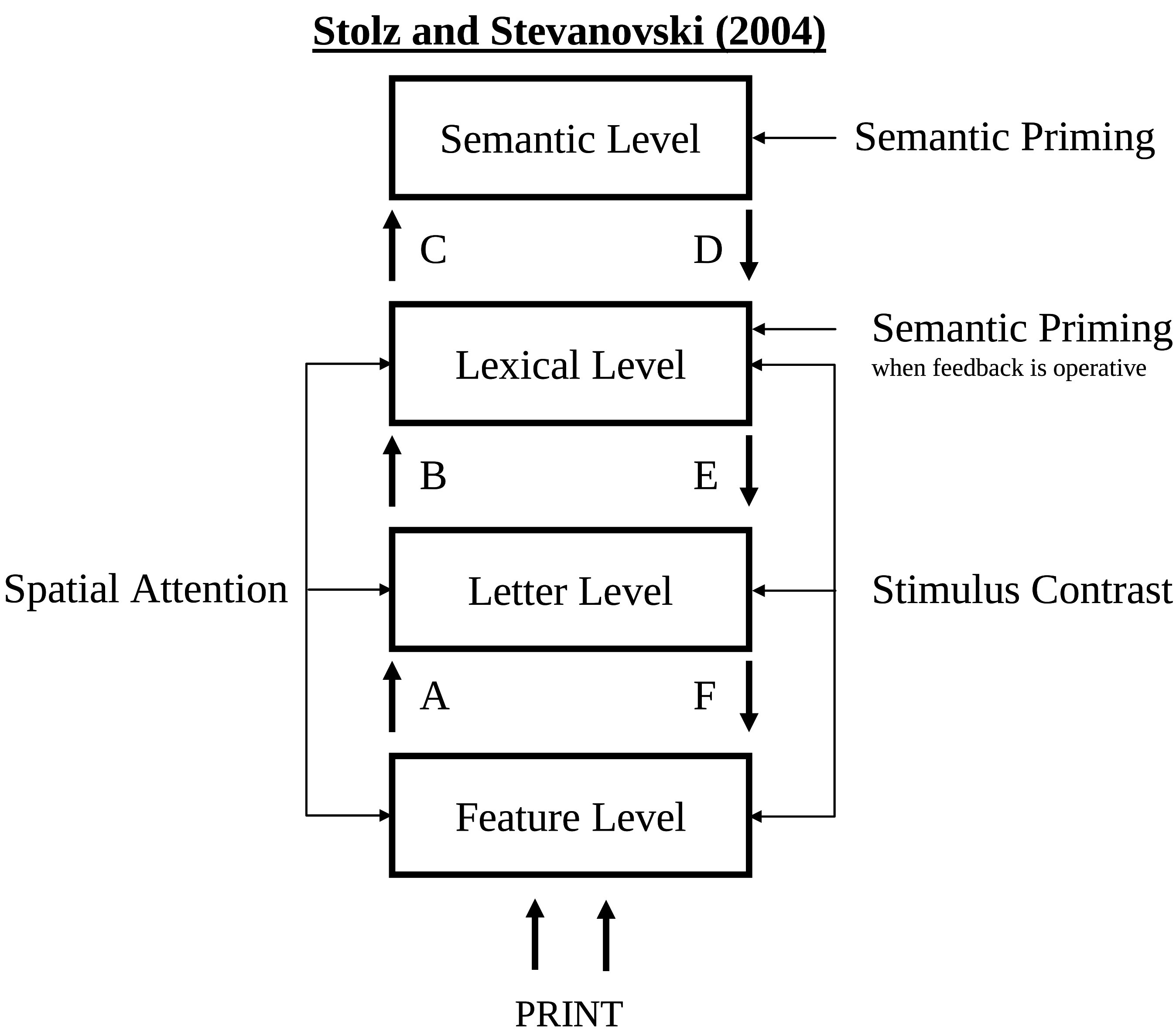


the presence/absence of feedback from semantics with the operation of endogenous spatial attention. Endogenous attention is thought to reflect a more strategic mode of orienting when spatial cues are informative (e.g., spatial attention is moved to the location indicated by an informative cue). Endogenous modes of orienting can be contrasted with exogenous modes of orienting which are thought to be more automatic (e.g., spatial attention is captured by an abrupt onset). Thus, when the cue is informative, both cue validity and semantic priming influence activation at the lexical level leading to an overadditive interaction. When feedback from semantics to the lexical level is not operative, cue validity still influences lexical level processing but semantic priming does not, thus leading to additive effects of the two factors.

This account relies heavily on the notion that the informativenes of the spatial cue modulates feedback from semantics to the lexical level. Stolz and Stevanovski (2004) provided strong evidence for this idea by demonstrating that when the spatial cue was informative, the effects of stimulus contrast (i.e., a bright stimulus versus a dim stimulus) and semantic priming were overadditive. These same factors were additive when the spatial cue was uninformative. The interaction between stimulus contrast and semantic priming is believed to reflect a common influence on the lexical level that occurs *only* when feedback from semantics is operative (Stolz & Neely, 1995). Thus, Stolz and Stevanovski (2004) provided converging evidence for the claim that the presence/absence of feedback from semantics is influenced by the informativenes of the spatial cue.

Whether the spatial cue was informative or not, the effects of cue validity and stimulus contrast interacted in an overadditive fashion. The cuing effect was smaller on bright trials than on dim trials. Stolz and Stevanovski (2004) took this overadditive

Figure 7. Depiction of the Stolz and Stevanovski (2004) account of the role of spatial attention in word processing. Spatial attention influences processing up to the lexical level. Semantic priming influences the semantic level and the lexical level when feedback from semantics (D) is operative. Stimulus contrast influences processing up to the lexical level.

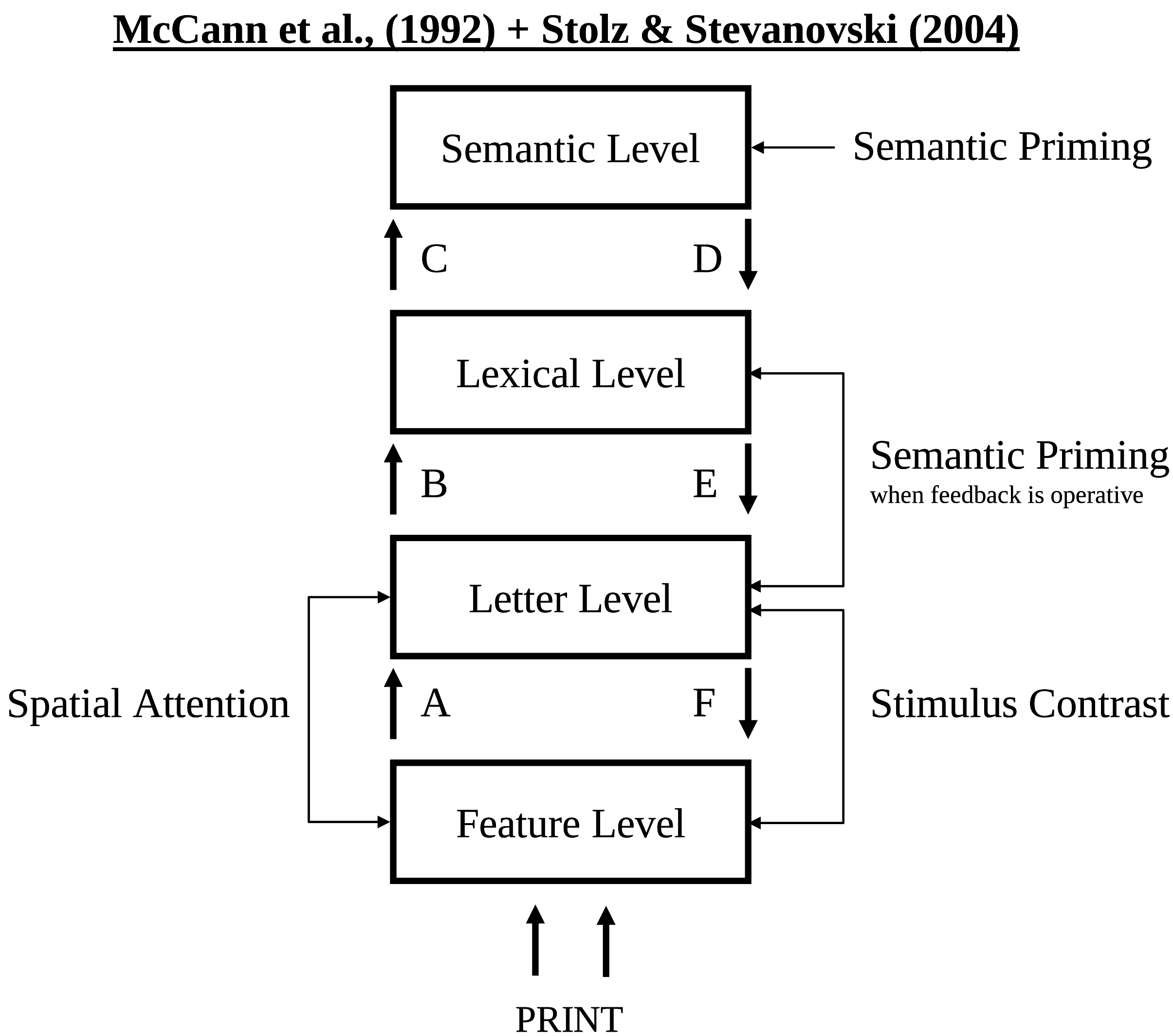


interaction as evidence that cue validity and stimulus contrast influenced the same process, namely, the rate of uptake into the word processing system up to the lexical level. Thus, like spatial attention, stimulus contrast slowed the rate of information processing up to the lexical level.

The account described by Stolz and Stevanovski (2004) is seemingly at odds with McCann et al.'s (1992) experiments using word frequency. To reconcile these two patterns, Stolz and McCann (2000) suggested that the effect of word frequency may not be lexical. Thus the lack of an interaction between the effects of cue validity and word frequency may not constitute evidence against the view that spatial attention influences lexical processing. This juncture represents a good point at which to note that the pattern of factor effects can help elucidate the relation between two factors but does not say anything about what process a given factor influences. This latter piece of information constitutes a conjecture typically made via previous research using that factor or a theoretical analysis. For example, the fact that the effects of cue validity and word frequency are additive suggests that these two factors influence different processes. What those processes are is subject to debate, as is evidenced by the disagreement between McCann et al. (1992) and Stolz and McCann (2000). Note that they disagree on what word frequency is indexing not that cue validity and word frequency index different processes.

Returning to the discussion of the role of spatial attention in word processing, an alternative explanation (see Figure 8 for a schematic) for the Stolz and Stevanovski (2004) results is that feedback from semantics, when operative, flows back to the *letter level* (via pathway D and E). In addition, spatial attention influences the rate of activation

Figure 8. Depiction of a reconciliation between the McCann et al. (1992) and the Stolz and Stevanovski (2004) accounts of the role of spatial attention in word processing. Spatial attention influences processing up to the letter level. Semantic priming influences the semantic level and the lexical and letter levels when feedback from semantics is operative. Stimulus contrast influences processing at least up to the letter level.



up to the letter level but not beyond. This account allows word frequency and lexicality to influence lexical level processing, and would also explain their additive effects with cue validity. In addition, when the spatial cue is *informative* and feedback from semantics to the letter level is operative, an overadditive interaction will emerge between the effects of cue validity and semantic priming. When the spatial cue is *uninformative* and feedback from semantics to the letter level is inoperative, the effects of cue validity and semantic priming will be additive. In addition, this account would explain the overadditive interaction between the effects of cue validity and stimulus contrast in the same manner as Stolz and Stevanovski (2004). This account would appear to explain the benchmark phenomenon listed in Table 1. However, it is clear that more work needs to be done to convincingly determine the influence of spatial attention on word processing. The present investigation represents a step in that direction.

Present Investigation

The present investigation consists of 11 experiments, each combining a manipulation of spatial attention (i.e., cue validity) with another factor thought to influence a component process in visual word processing. The pattern of results across these experiments in conjunction with previous work is then used to develop an account of spatial attention in visual word processing.

In the present experiments the task consisted of reading aloud, rather than the more commonly used lexical decision task. Reading aloud was chosen because the scarcity of research on reading aloud is incommensurate with its position as a major tool to study word processing (e.g., Coltheart et al., 2001; Perry et al., 2007). In addition, an *uninformative* peripheral cue was used in order to isolate the role of *exogenous* spatial attention in word processing. Clearly, there are important differences between exogenous and endogenous forms of spatial attention in word processing (see Stolz & McCann, 2001; Stolz & Stevanovski, 2004). Thus, the present experiments dealt specifically with the role of exogenous spatial attention in reading aloud. As is evident from Table 1, no experiments to date have addressed the role of spatial attention in this particular context and thus the present experiments represent an important extension of the experimental approach.

In all of the reported experiments two factors are manipulated. One factor is always cue validity and the other factor varies between experiments but always functions as a manipulation that influences word processing in some manner. In Experiments 1 and 2, cue validity and long lag repetition priming were manipulated. In Experiments 3 to 5, cue validity and case mixing were manipulated. In Experiments 6 and 7, cue validity and inter-letter spacing were manipulated. In Experiments 8 and 9, cue validity and the presence/absence of irrelevant features were manipulated. Finally, in Experiments 10 and 11, cue validity and word set size were manipulated. The data to be considered is how these different factors operate conjointly. In the following a brief description of the methods used in the present experiments is provided. The experiments are conceptually identical and as such a single method section will, for the most part, suffice. Where relevant, deviations from this approach are described in the experimental methods sections.

General Methods

Participants. Participants were English speaking undergraduates from the University of Waterloo were paid $4 each or received course credit to participate.

Apparatus. Stimulus presentation was controlled using a Pentium IV 2.0 gHz computer running E-prime 1.1 software (Schneider, Eschmann, & Zuccolotto, 2002). Vocal responses were collected using a Plantronics LS1 microphone headset and a voice key assembly. Stimuli were displayed on a 17 inch ADI Microscan monitor.

Stimuli. A silver (RGB: 162, 162, 162) fixation symbol [+] was presented at the center of the screen. Words were presented 1.2 cm above or below the fixation and were preceded by an abrupt onset cue that consisted of a white (RGB: 255, 255, 255) rectangle presented 2.5 cm above or below fixation. The white rectangle was 1.8 cm horizontally and 0.8 cm vertically. Words were always presented in white. The background was always black. A number of different word lists were used and are described with each experiment. The various word lists are presented in Appendices A through G. Each word in a particular word list always appeared across participants in all conditions.

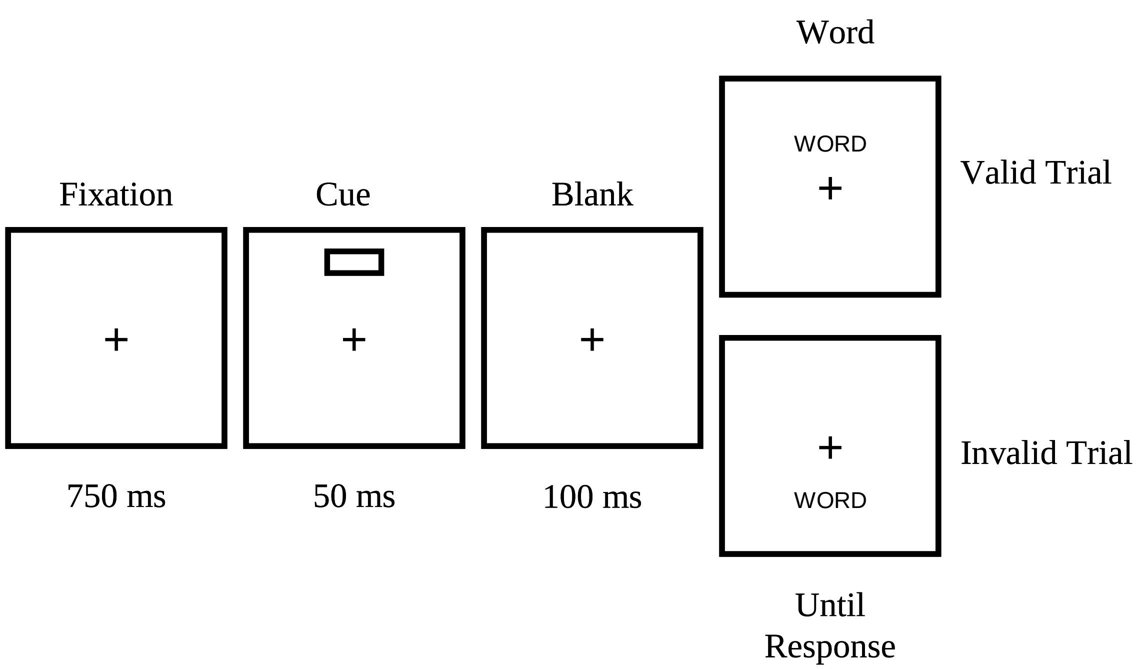
Design. Cue validity was manipulated in all experiments. A valid cue appeared in the same location as the eventual target. An invalid cue appeared in the location opposite the eventual target. Cues were valid on 50% of the trials and invalid on the other 50% of the trials. Thus, cues were uninformative with respect to target location.

Procedure. Participants were tested individually and were seated approximately 50 cm from the screen. Participants were instructed to read aloud the presented word as quickly as possible without making too many errors while remaining fixated on the (+) symbol. Fixation was not monitored but was emphasized by the experimenter. Each trial began with a fixation symbol presented for 750 ms. The spatial cue was then presented for 50 ms. The word appeared 100 ms after the offset of the spatial cue (i.e., SOA = 150 ms). The word was presented until the participant responded. After the participant made her/his response the experimenter recorded her/his accuracy as well as any spoiled trials (e.g., voice key failures). See Figure 9 for a schematic of the trial procedure.

Data Reduction and Analysis

In each experiment correct RT data were subjected to a recursive trimming procedure that removed outliers based on a criterion cut-off set independently for each participant in each condition by reference to the sample size in that condition (Van Selst & Jolicœur, 1994). In each experiment parallel analyses are conducted on mean RT and percentage error data.

Figure 9. Trial procedure.



Chapter 3: Long Lag Repetition Priming

In Experiments 1 and 2, I sought converging evidence for the claim that spatial attention does not influence lexical level processing. As noted in Chapter 2, the results are mixed on this matter. According to Stolz and Stevanovski (2004) spatial attention can influence processing up to the lexical level, whereas according to McCann et al. (1992) spatial attention does not influence the lexical level. In order to test these various accounts, cue validity was combined with a manipulation of long lag repetition priming – another manipulation held to influence lexical processing.

Reading a word aloud is facilitated by a recent encounter with that word (e.g., Blais & Besner, 2007; Bowers, 2000; Forster & Davis, 1984; Morton, 1969; Rueckl, 1990; Scarborough, Cortese, & Scarborough, 1977; Visser & Besner, 2001). This repetition priming effect has both a short term component that lasts only a few trials and a long term component that can last from minutes to days (e.g., Forster & Davis, 1984; Reuckl, 1990; Scarborough et al., 1977). This latter effect, referred to here as long lag repetition priming, is generally thought to reflect a structural change in the lexical-orthographic system (i.e., the lexical level) that facilitates subsequent encounters with that word (Bowers, 2000).

The nature of the change to the lexical-orthographic system indexed by long lag repetition priming has been debated extensively. For example, Morton (1969) argued that the presentation of a word reduces its threshold for response in the lexicon (i.e., lexical level) on subsequent presentations. Rueckl (1990), on the other hand, argued that the presentation of a word leads to changes in the pattern of connection weights between representations that facilitate processing on subsequent presentations of that word.

Whatever the resulting change to the word processing system, most researchers would agree that it reflects lexical level processing and not, for example, feature or letter level processing. Given the number of intervening words between the two presentations in long lag repetition priming experiments, an influence on feature and letter level processing is unlikely. As such, the combination of cue validity with a manipulation of long lag repetition priming provides a strong test of whether spatial attention can influence the lexical level.

There were two main reasons for selecting long lag repetition priming as a manipulation of lexical level processing. First and foremost, it provides a converging operation to test whether spatial attention influences lexical level processing. If the effects of cue validity and long lag repetition priming are additive this would provide strong evidence that spatial attention does not influence lexical level processing.

The second motivation for the use of long lag repetition priming was a recent study by Reynolds and Besner (2006) in the context of the psychological refractory period (PRP) paradigm. The PRP paradigm has long been used as a tool to study *central attention*. Central attention is typically thought to represent a general limited capacity resource (Pashler, 1994). In the PRP paradigm, participants perform two tasks (T1 and T2) in succession and the stimulus onset asynchrony (SOA) between the presentations of the stimulus for each task (S1 and S2) is manipulated. Response time in T2 *increases* as SOA *decreases*. This PRP effect is thought to reflect the delay in T2 central processing caused by T1 central processing. As SOA decreases the overlap in time between central processing in T1 and T2 increases thus leading to an increase in response time on T2 (see Pashler's 1994 review).

Reynolds and Besner (2006) reported an *underadditive* interaction between the effects of long lag repetition priming on T2 and SOA in a PRP paradigm. They took this pattern to indicate that lexical level processing could overlap with central processing in another task and thus does not require central attention. This observation provides a unique opportunity to dissociate spatial and central attention in the context of reading aloud. If the effects of cue validity and long lag repetition priming are additive, this would provide strong evidence for a differential influence of spatial and central attention on reading aloud. Specifically, the same manipulation (i.e., long lag repetition priming) would be shown to behave differently when combined with a manipulation of spatial attention and a manipulation of central attention (see Johnston, McCann & Remington, 1995 for further elucidation of this logic). Thus, the combination of cue validity and long lag repetition priming provides both the opportunity to test whether spatial attention influences lexical level processing and whether spatial attention and central attention have different effects on lexical processing.

Experiment 1

Experiment 1 consisted of two parts. In the first part, participants read aloud a list of words presented at the center of the screen. In the second part, participants again read aloud the words but they appeared in the context of the spatial cuing paradigm described in the General Methods section. Half of the words presented in the second part had also been presented in the first part (i.e., old or repeated words) and half of the words presented in the second part had not been presented in the first part (i.e., new or non-repeated words). The long lag repetition priming effect consists of the difference in performance between new and old words in the second block. Participants were not informed that any words would be repeated between the different parts of the experiment. The average lag between item repetitions was 68 trials. This lag was approximately the same as the lag in Reynolds and Besner (2006).

Methods

Participants. Thirty-two undergraduates participated.

Design. There were two parts to the experiment. In the first part no variables were manipulated. In the second part a 2 (Cue Validity: Valid vs. Invalid) x 2 (Repetition: New vs. Old) within-subject design was used. On half of the trials the target word was new (i.e., not presented in the first part of the experiment) and on half of the trials the target word was old (i.e., presented in the first part of the experiment). Old and new words were presented in a random order.

Stimuli. Stimuli for this experiment were taken mostly from Reynolds and Besner (2006). The word set contained were 96 three to six letter words (see Appendix A). The words were predominantly monosyllabic (i.e., 92/96). Excluding the word "have" the average frequency was approximately six occurrences per million and on average each item had four neighbours (Davis, 2005). Sixteen of these words were used for practice leaving 80 words for the experimental trials. In part 1, eight of the practice words and 40 of the experimental words were presented. In part 2, 16 words were presented in practice (eight new and eight old) and 80 of the experimental words were presented. These 80 words were divided into eight lists of 10 items each. These eight lists were cycled through the eight different conditions formed by the crossing of cue validity, repetition, and target location. Words were always presented in lower case 12 point Arial font. The words ranged from 1.1 to 1.8 cm horizontally and 0.7 cm vertically.

Procedure. In the first part of the experiment participants were instructed to read aloud the word presented at the center of the screen. Each trial began with a fixation symbol (+) presented for 750 ms. The target word was then presented until the participant responded. After the participant's response the experimenter recorded response accuracy and spoiled trials. In the first part of the experiment there were eight practice trials and 40 experimental trials.

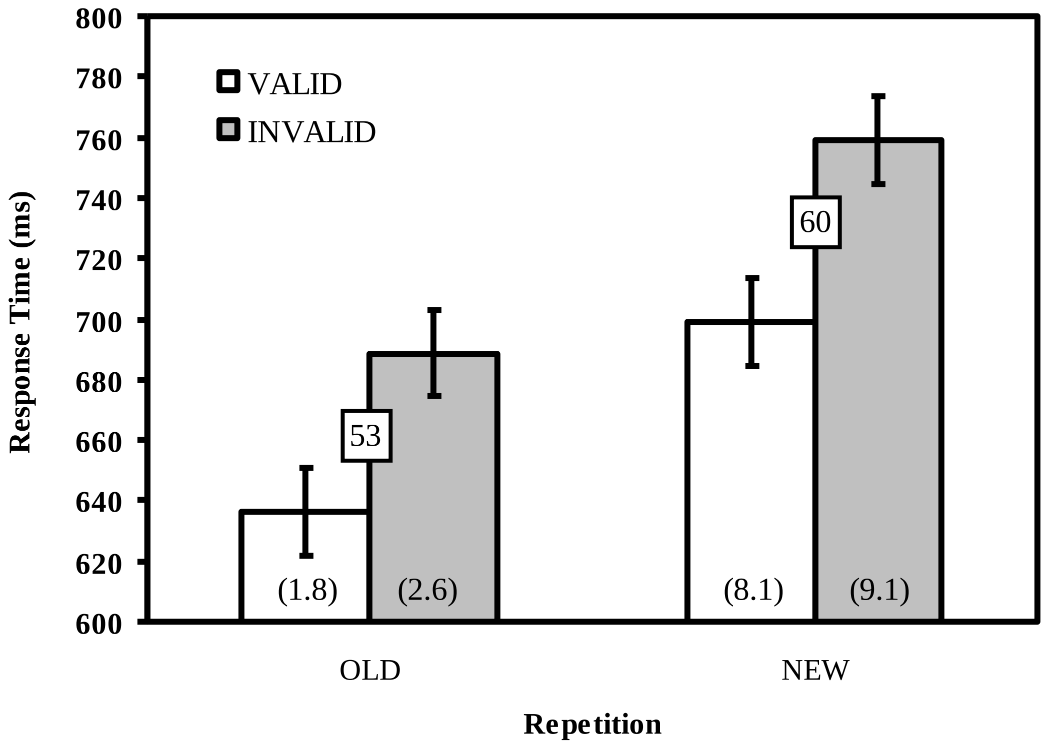
In the second part of the experiment participants were again instructed to read aloud the presented word. In this part of the experiment, the words were presented in the context of the spatial cuing paradigm discussed in the General Method section. There were 16 practice trials and 80 experimental trials. The experiment took approximately 10 minutes to complete.

Results

If a participant made an incorrect response (8.3%) or if there was a spoiled trial (e.g., mic errors; 6.1%) on a given word in the first part of the experiment, that word was removed from the analysis of the second part of the experiment. In addition, spoiled trials in the second part were also removed (3.4%). The outlier procedure led to the removal of 2.7% of the RT data. Data are presented in Figure 10 and Appendix H. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Repetition: Old vs. New) ANOVA was performed on mean RT and percentage error data.

For RTs, the main effects of cue validity and repetition were significant, $F(1, 31) = 49.72$, $MSE = 2039.88$, $p < .05$; $F(1, 31) = 73.96$, $MSE = 1919.75$, $p < .05$, respectively.

Figure 10. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and long lag repetition priming in Experiment 1. Cuing effects (invalid – valid) are presented in boxes.



Participants responded faster on valid trials (668 ms) than on invalid trials (724 ms) and faster on old trials (662 ms) than on new trials (729 ms). Critically, there was no interaction between the effects of cue validity and repetition, $F(1, 31) = 0.42$, $MSE = 1043.92$, $p = .52$. The cuing effect (invalid-valid) on old trials (53 ms) was statistically equivalent to the cuing effect on new trials (60 ms).

For errors, the main effect of repetition was significant, $F(1, 31) = 53.26$, $MSE = 24.32$, $p < .05$, such that participants made fewer errors on old trials (2.2%) than new trials (8.6%). No other effects were significant, (Fs < 1).

Discussion

There was no interaction between the effects of cue validity and long lag repetition priming. Thus, the joint effects of cue validity and long lag repetition priming were additive. This pattern of results suggests that cue validity and long lag repetition priming influence different processes in the course of reading aloud. This result is consistent with the idea that spatial attention does not influence lexical level processing.

The additive joint effects of cue validity and long lag repetition priming also provide strong evidence that spatial attention and central attention have differential effects on word processing. Specifically, the effect of long lag repetition priming was additive with a manipulation of spatial attention whereas Reynolds and Besner (2006) demonstrated that the effect of long lag repetition priming was underadditive with a manipulation of central attention. Thus, spatial and central attention influence word processing in qualitatively different ways.

The additive effects of two factors represents a null (i.e., a failure to detect a significant interaction) and thus should be viewed with caution. Null effects could emerge as a result of a number of factors unrelated to the issues dealt with herein (e.g., lack of statistical power). In order to address this issue, we replicated Experiment 1 with a different word set. The word set used in Experiment 1 consisted of low frequency irregular words and were thus difficult to read. In Experiment 2 a larger list was used that was of higher frequency and consisted of predominantly regular words. The use of a larger list provides more observations and thus more power. The average lag in Experiment 2 was 116 trials.

Experiment 2

Methods

Participants. Forty-eight undergraduates participated.

Design. Identical to Experiment 1.

Stimuli. The word set contained 160 four letter words (see Appendix B). The words were all monosyllabic. The average frequency was approximately 48 occurrences per million and on average each item had nine neighbours (Davis, 2005). Sixteen of these words were used for practice leaving 144 words for experimental trials. These 144 words were divided into eight lists of 18 items each. These eight lists were cycled through the eight different conditions formed by the crossing of cue validity, repetition, and target location. Words were presented in upper case 12 point Arial font. The words were approximately 1.8 cm horizontally and 0.6 cm vertically.

Procedure. Identical to Experiment 1 except that in the first part of the experiment there were 8 practice trials and 72 experimental trials and in the second part of the experiment there were 16 practice trials and 144 experimental trials.

Results

Data reduction was conducted in the same manner as in Experiment 1. Words producing incorrect responses (0.3%) or spoiled trials (e.g., mic errors; 3.0%) in the first part of the experiment were removed from the analysis of the second part, as were spoiled trials in Block 2 (2.5%). The outlier procedure led to the removal of 1.5% of the RT data. Data are presented in Figure 11 and Appendix I. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Repetition: Old vs. New) ANOVA was performed on mean RT and percentage error.

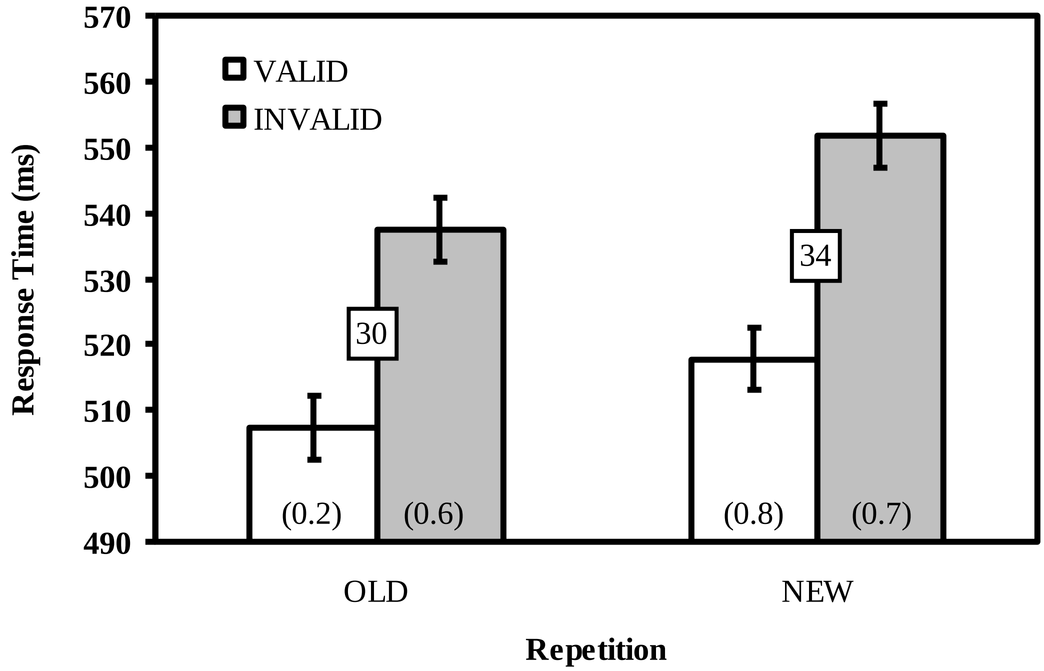
For RTs, the main effects of cue validity and repetition were significant, $F(1, 47) = 103.85$, $MSE = 474.89$, $p < .05$; $F(1, 47) = 28.82$, $MSE = 253.00$, $p < .05$, respectively. Participants responded faster on valid trials (512 ms) than on invalid trials (544 ms) and faster on old trials (522 ms) than on new trials (535 ms). Critically, there was no interaction between the effects of cue validity and repetition, $F(1, 47) = 1.60$, $MSE = 111.26$, $p = .21$. The cuing effect (invalid-valid) on old trials (30 ms) was statistically equivalent to the cuing effect on new trials (34 ms).

For errors, the main effect of repetition was significant, $F(1, 47) = 5.86$, $MSE = 1.17$, $p < .05$, such that participants made fewer errors on old trials (0.4%) than on new trials (0.7%). No other effects were significant, all *F*s < 1.5.

Discussion

As in Experiment 1, the conjoint effects of cue validity and long lag repetition priming were additive. This result replicates Experiment 1 with a new set of items, a longer lag, and a larger sample size. Both are consistent with the idea that spatial attention does not influence lexical processing.

Figure 11. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and long lag repetition priming in Experiment 2. Cuing effects (invalid – valid) are presented in boxes.



Cross Experiment Analysis

As noted previously, additivity of factor effects represents a null. To provide a further test of the additive effects of cue validity and long lag repetition priming the data from Experiments 1 and 2 were analysed together. By combining the data from both experiments a more powerful test can be conducted. This more powerful test yielded no evidence for an interaction between the effects of cue validity and long lag repetition priming, $F(1, 78) = 1.26$, $MSE = 608.99$, $p = .26$. Thus, even with a sample size of 80 participants, there was no evidence that the effects of cue validity and long lag repetition priming interact. Nonetheless, even with a large sample size detecting a very small interaction (i.e., less than 10 ms) would be difficult and the overadditive numerical trend should not be ignored. We will discuss these issues further in Chapter 8.

A couple of potentially interesting results emerged from the cross experiment analysis. First, there was an interaction between the effects of cue validity and experiment, $F(1, 78) = 10.28$, $MSE = 1096.88$, $p < .05$. The cuing effect was larger in Experiment 1 (56 ms) than in Experiment 2 (32 ms). Given the differences between the items used in each experiment (e.g., regularity, length, frequency) and other differences (e.g., case, experiment length, participants, baseline RT), the reason for this difference in cuing effects is at present unclear. In addition, there was an interaction between the effects of repetition and experiment, $F(1, 78) = 61.84$, $MSE = 915.43$, $p < .05$, such that the repetition priming effect was larger in Experiment 1 (67 ms) than Experiment 2 (12 ms). Again there are a number of differences between experiments, but this pattern may reflect the difference in frequency between the item sets. There exist numerous demonstrations that word frequency interacts with long lag repetition priming such that the repetition priming effect is smaller for high frequency words (e.g., Forster & Davis, 1984; Scarborough et al., 1977; Visser & Besner, 2001). Note that this overadditive interaction between the effects of word frequency and long lag repetition priming is consistent with the idea that both influence the same process (i.e., lexical level processing).

Although the supplementary analyses revealed some interesting facts, the critical result from the combined analysis is the observation that a more powerful test still yielded additivity between the effects of cue validity and long lag repetition priming.

Alternatives to a Lexical Account of Long Lag Repetition Priming

The discussion of long lag repetition priming thus far has focused on lexical interpretations of the effect (e.g., the threshold for the lexical representation is lowered; Morton, 1969). A number of researchers have also offered episodic accounts of long lag repetition priming (Forster & Davis, 1984; Tenpenny, 1995). According to an episodic account, each encounter with a word leads to the formation of a new episode trace in memory. Long lag repetition priming occurs because recent episodes are generally more accessible than older episodes (Tenpenny, 1995). According to this account, long lag repetition priming does not reflect a structural change to the word processing system, rather it is a by-product of episodic retrieval. Indeed, strong versions of this episodic account would deny the existence of abstract lexical representations (see Tenpenny, 1995 for a review).

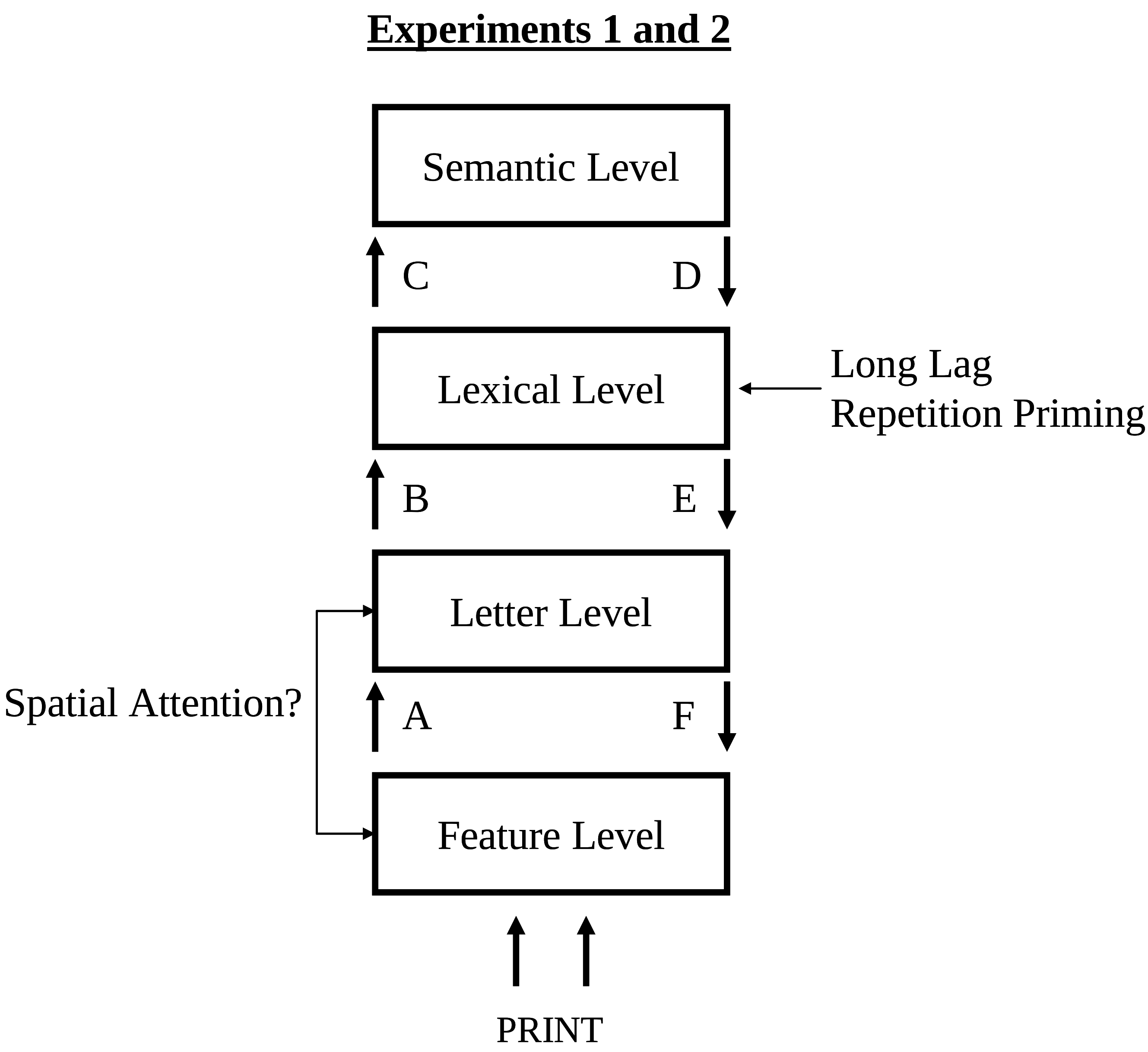
A purely episodic account of word retrieval encounters various difficulties in accounting for all of the relevant data with respect to long lag repetition priming (see Bowers, 2000 for an extensive review). For example, an episodic account has difficulty explaining equivalent long lag repetition priming across different scripts of the same word (e.g., Bowers & Michita, 1998). In addition, if episodic influences do occur they are thought to have less of an influence on reading aloud than on other word processing tasks (e.g., lexical decision; Visser & Besner, 2001). Thus, it is unlikely that the long lag repetition priming effects reported here reflect purely episodic memory.

Critically, whatever the process influenced by long lag repetition priming the lack of an interaction with cue validity demonstrates that spatial attention does not influence the same process.

Conclusion

In conclusion, the combined effects of cue validity and long lag repetition priming are additive. This is interpreted as evidence that spatial attention does not influence lexical processing (see Figure 12). In the following chapters evidence that spatial attention has its influence at a pre-lexical level is sought.

Figure 12. Depiction of conclusion from Experiments 1 and 2. Long lag repetition priming influences lexical level processing. Spatial attention does not influence lexical level processing.



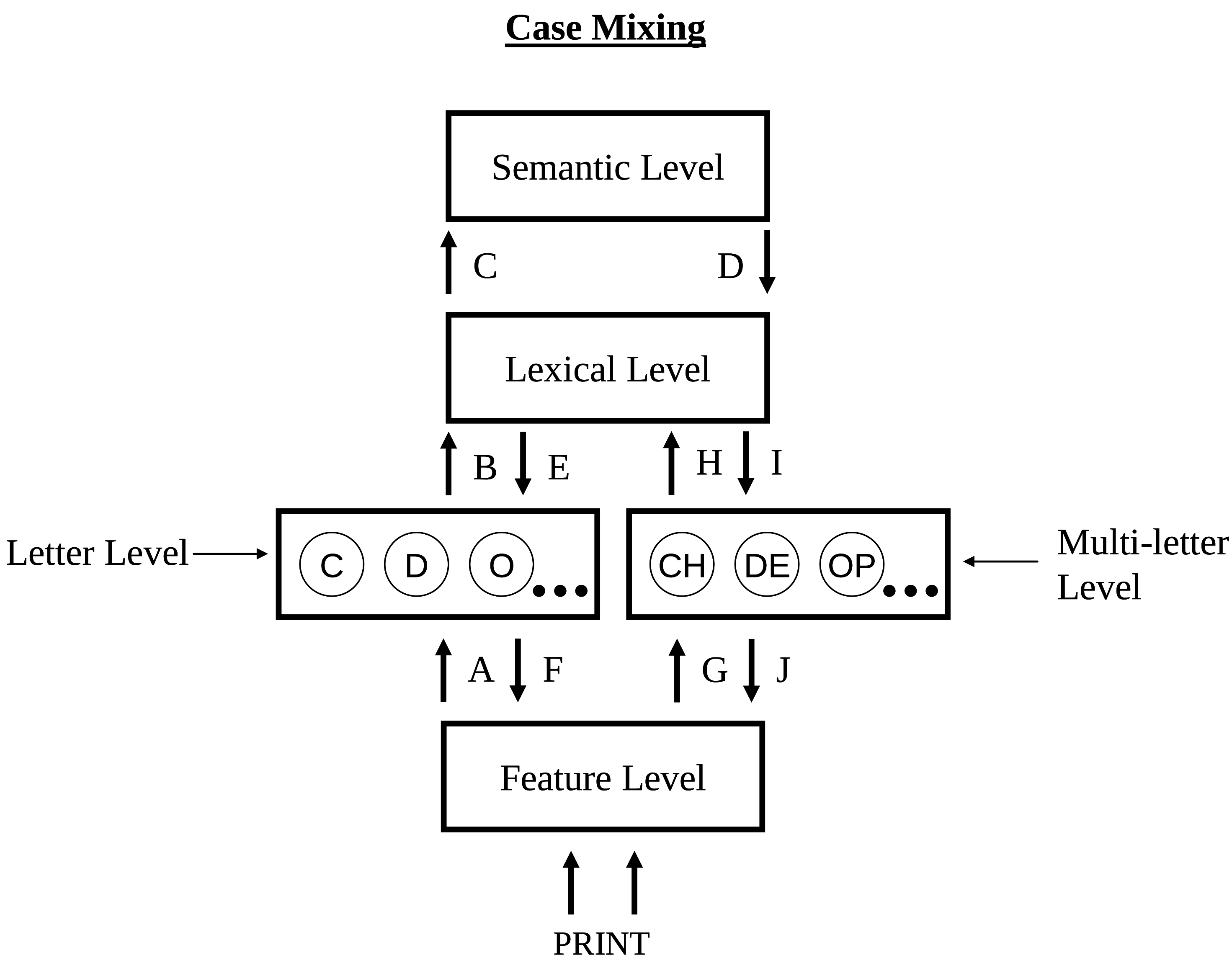
Chapter 4: Case Mixing

The results of Experiments 1 and 2 along with others (McCann et al., 1992; Nichols & Wood, 1998; Ortells et al., 1998; Nichols et al., 2001) suggest that spatial attention does not influence lexical processing. Chapters 3 through 5 begin a search for a pre-lexical locus for spatial attention's influence on word processing. In Chapter 3, cue validity was combined with a manipulation of case mixing.

Presenting words in mixed case (e.g., mIxEd) disrupts reading aloud relative to presenting words in the same case (e.g., SAME or same; Besner, 1989; Besner & Johnston, 1989; Besner & McCann, 1987; Braet & Humphreys, 2006; 2007; Mayall & Humphreys, 1996; Mayall, Humphreys, Mechelli, Olson, & Price, 2001; Mayall, Humphreys, & Olson, 1997). A number of explanations for this case mixing effect have been offered, the most popular of which is that case mixing disrupts the use of multi-letter units (Braet & Humphreys, 2006; 2007; Hall, Humphreys, & Cooper, 2001; Humphreys et al., 2003; Mayall & Humphreys, 1996; 2001; Mayall et al., 1997; Whiteley & Walker, 1994; 1997). Besner and Johnston, (1989) have suggested that case mixing also impairs letter identification (i.e., letter level) but suggest that the effect might be small. A more direct manipulation of letter level processing will be the focus of Chapters 4 and 5.

To facilitate the discussion of multi-letter units, a multi-letter level has been added to the diagram of word processing that has been used thus far (see Figure 13). Multi-letter units, as the name suggests, consists of units representing more than a single letter (e.g., "CH"). Multi-letter units are activated by supraletter features (i.e., features that code

Figure 13. General model of word processing with a multi-letter level included. Representations of letter unit and multi-letter units are depicted.



information beyond a single feature). Case mixing is hypothesized to disrupt the coding of supraletter features and thus disrupt the coding of multi-letter units (Hall et al., 2001; Whiteley & Walker, 1994; 1997). It is important to note that the existence of such a level of processing is a matter of some debate (e.g., Hall et al., 2001; Whiteley & Walker, 1994; 1997). The multi-letter level's placement is in accord with previous work (Besner & McCann, 1987; Besner & Johnston, 1989).

In Experiments 3 through 5, cue validity is combined with a manipulation of case mixing in order to determine if spatial attention influences multi-letter level processing. For example, invalidly cuing spatial attention may slow the rate at which multi-letter units are activated in which case an overadditive interaction between cue validity and case mixing is predicted. Specifically, the spatial cuing effect should be larger for mixed case than same case words.

An alternative mechanism through which an interaction between cue validity and case mixing might be expected has been suggested by a series of studies on case mixing and the parietal lobe (Braet & Humphreys, 2006; 2007; Mayall & Humphreys, 2001). Mayall and Humphreys (2001), for example, suggested that the disruption of multi-letter units may increase the need for spatial attention. For example, spatial attention may need to be allocated to individual letters rather than distributed across the entire word. Consistent with this proposal Mayall and Humphreys (2001) demonstrated that reading mixed case words increased activity in the parietal lobe and Braet and Humphreys (2006; 2007) demonstrated that damage to the parietal lobe or rTMS applied to the parietal lobe increased the disruptive effect of case mixing. The parietal lobe is thought to represent the neural basis of spatial attention (Corbetta & Shulman, 2002). If mixed case words require spatial attention more than same case words then the cuing effect should be larger when participants read aloud mixed case relative to same case words (i.e., an overadditive interaction between the effects of cue validity and case mixing).

Experiment 3

In Experiment 3 participants read aloud words presented in the same case (e.g., fort or FORT) or in mixed case (e.g., FoRt) in the context of the spatial cuing paradigm discussed in the General Methods section.

Methods

Participants. Thirty-two undergraduates participated.

Design. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Case: Same Case vs. Mixed Case) within-subject design was used. On half of the trials the letters of the target word were presented in the same case (e.g., fort or FORT) while on the other half of the trials the target word was printed in mixed case (e.g., FoRt).

Stimuli. The 160 four letter words from Experiment 2 were used (see Appendix B). Eight words were used in practice and the remaining 152 items were divided into eight lists of 19 items each. These eight lists were cycled through the eight different conditions consisting of the crossing of cue validity, case, and target location. Words were presented in 12 point Courier font. The Courier font was used so that the uppercase "I" and lowercase "l" would be less likely to be confused (e.g., in Arial font they are exactly the same form). Words were approximately 1.5 cm horizontally and 0.5 cm vertically. Half of the participants were presented with the same case items in lower case and half of the participants were presented with the same case items in upper case. In case mixing experiments same case words are typically presented in lowercase. We included upper case words in order to control for the possibility that upper case words were better at capturing attention because of their increased size relative to lowercase words.

Procedure. There were eight practice trials and 152 experimental trials. The experiment took approximately 10 minutes to complete.

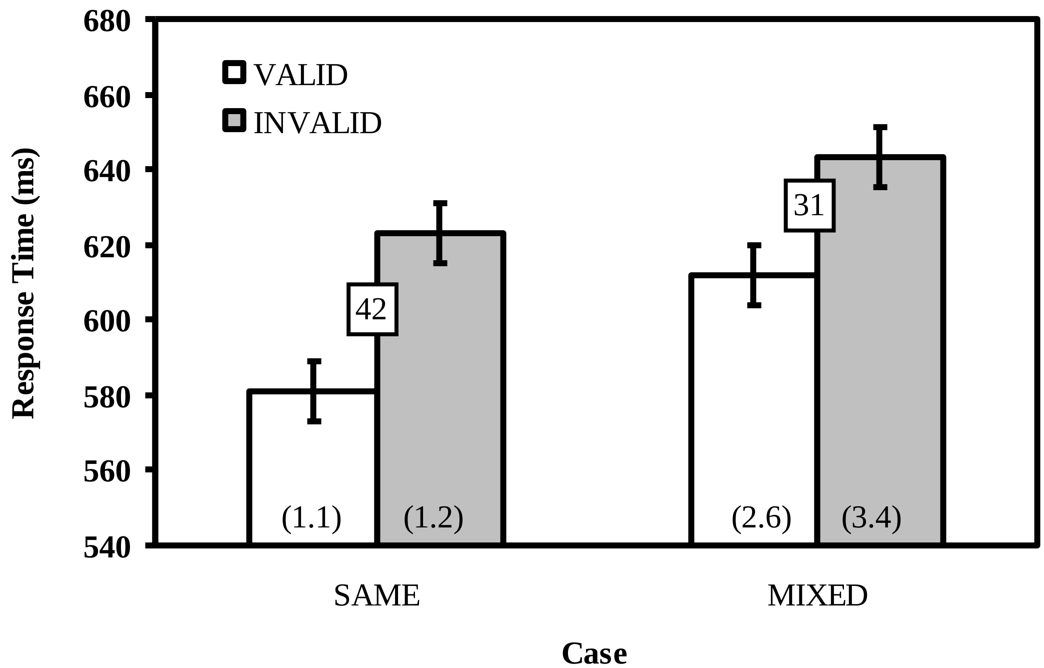
Results

Spoiled trials (3.2%) were removed prior to analysis. The outlier procedure led to the removal of 1.2% of the RT data. Data are presented in Figure 14 and Appendix J. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Case: Same Case vs. Mixed Case) ANOVA was performed on mean RT and percentage error data.

For RTs, the main effects of cue validity and case were significant, $F(1, 31) = 58.33$, $MSE = 745.20$, $p < .05$; $F(1, 31) = 41.63$, $MSE = 500.37$, $p < .05$, respectively. Participants responded faster on valid trials (596 ms) than on invalid trials (633 ms) and faster on same case trials (602 ms) than on mixed case trials (627 ms). There was a marginal underadditive interaction between the effects of cue validity and case mixing, $F(1, 31) = 3.02$, $MSE = 299.34$, $p = .09$. The cuing effect (invalid-valid) on same case trials (42 ms) was larger than the cuing effect on mixed case trials (31 ms).

For errors, the main effect of case mixing was significant, $F(1, 31) = 28.14$, $MSE = 3.93$, $p < .05$, such that participants made fewer errors on same case trials (1.1%) than mixed case trials (3.0%). No other effects were significant, all Fs < 1.

Figure 14. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and case mixing in Experiment 3. Cuing effects (invalid - valid) are presented in boxes.



Discussion

There was a marginal underadditive interaction between the effects of cue validity and case mixing. The cuing effect was smaller when words were presented in mixed case relative to when words were presented in the same case. This underadditive pattern suggests that cue validity and case mixing index processes that may overlap in time. This underadditive interaction was unexpected and as noted in Chapter 2 rarely observed. Before speculating on the mechanism underlying this pattern it is prudent to see whether it replicates. Experiment 4 thus replicates Experiment 3 with a new set of items.

Experiment 4

Methods

Participants. Thirty-two undergraduates participated.

Design. Identical to Experiment 3.

Stimuli. The word set consisted of 104 five letter words (see Appendix C). The words were all monosyllabic. The average frequency was approximately 101 occurrences per million and on average each item had four neighbours (Davis, 2005). Eight of these words were used in practice and the remaining 96 words were divided into eight lists of 12 items. These eight lists were cycled through the eight different conditions consisting of the crossing of cue validity, case, and target location. Across participants, each item appeared equally often in each condition. Half of the same case items were presented in upper case and the other half of the same case items were presented in lower case within subject.

Procedure. There were eight practice trials and 96 experimental trials. The experiment took approximately 10 minutes to complete.

Results

Spoiled trials (3.5%) were removed prior to analysis. The outlier procedure led to the removal of 1.2% of the RT data. Data are presented in Figure 15 and Appendix K. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Case: Same Case vs. Mixed Case) ANOVA was performed on mean RT and percentage error data.

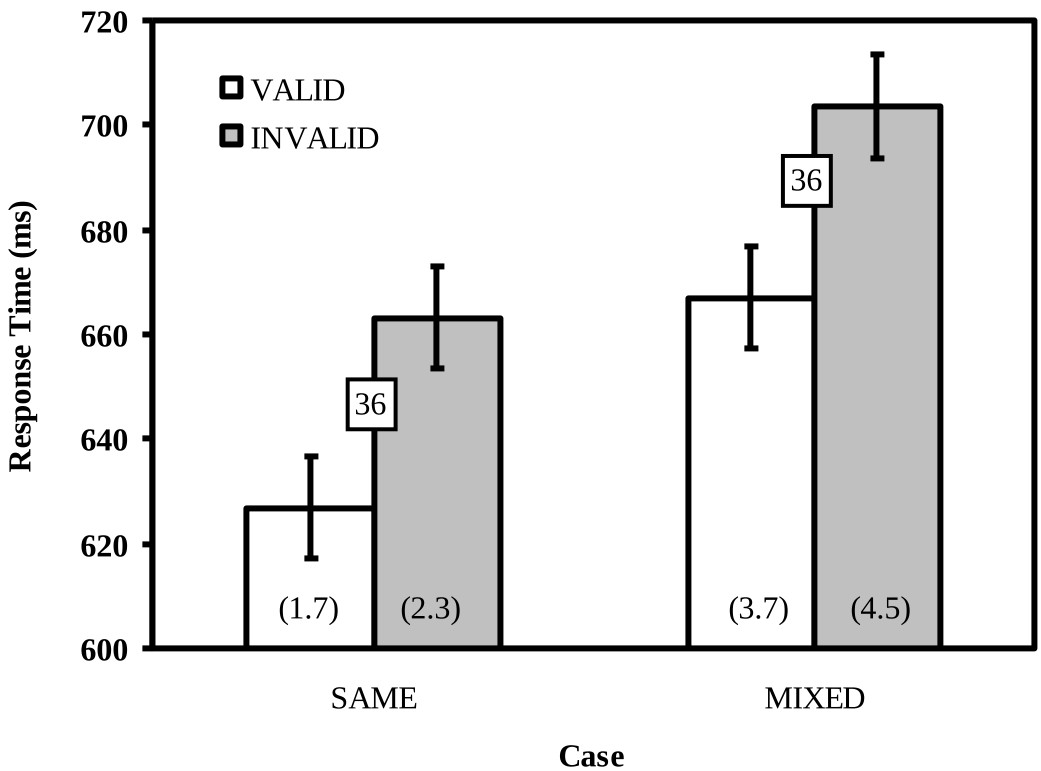
For RTs, the main effects of cue validity and case mixing were significant, $F(1, 31) = 46.31$, $MSE = 914.26$, $p < .05$; $F(1, 31) = 60.54$, $MSE = 853.59$, $p < .05$, respectively. Participants responded faster on valid trials (647 ms) than on invalid trials (683 ms) and faster on same case trials (645 ms) than on mixed case trials (685 ms). Critically, there was no interaction between the effects of cue validity and case mixing, $F(1, 31) = 0.001$, $MSE = 577.85$, $p = .98$. The cuing effect (invalid-valid) on same case trial (36 ms) was statistically equivalent to the cuing effect on mixed case trials (36 ms).

For percentage error, the main effect of case mixing was significant, $F(1, 31) = 17.53$, $MSE = 3.93$, $p < .05$, such that participants made fewer errors on same case trials (2.0%) than on mixed case trials (4.1%). No other effects were significant, all Fs < 1.1.

Discussion

In Experiment 4, there was no interaction between the effects of cue validity and case mixing. The cuing effect was the same size for words presented in mixed case as for words presented in the same case. This pattern suggests that cue validity and case mixing influence different processes. Specifically, spatial attention does not influence multi-letter level processing. The failure to replicate Experiment 3's results suggests that the marginally significant underadditive interaction between the effects of cue validity and case mixing seen in Experiment 3 may not be genuine. We further tested for

Figure 15. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and case mixing in Experiment 4. Cuing effects (invalid – valid) are presented in boxes.



underadditivity in another replication. Experiment 5 was a replication of Experiments 3 and 4 but with a third set of items.

Experiment 5

Methods

Participants. Forty undergraduates participated.

Design. Identical to Experiments 3 and 4.

Stimuli. The stimulus set consisted of 104 three to five letter words (see Appendix D). The words were all monosyllabic. The average frequency was approximately 261 occurrences per million and on average each item had seven neighbours (Davis, 2005). Eight of these words were used in practice and the remaining 96 words were divided into eight lists of 12 items. These eight lists were cycled through the eight different conditions consisting of the crossing of cue validity, case, and target location. Words were presented in upper or lower case 12 point Courier font. Same case items were always in lower case. Words were approximately 1.1 to 1.8 cm horizontally and 0.5 cm vertically.

Procedure. There were 16 practice trials and 80 experimental trials. The experiment took approximately 10 minutes to complete.

Results

Spoiled trials (3.4%) were removed prior to analysis. The outlier procedure led to the removal of 2.0% of the RT data. Data are presented in Figure 16 and Appendix L. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Case: Same Case vs. Mixed Case) ANOVA was performed on mean RT and percentage error data.

For RT, the main effects of cue validity and case were significant, $F(1, 39) = 72.53$, $MSE = 1585.72$, $p < .05$; $F(1, 39) = 50.15$, $MSE = 722.70$, $p < .05$, respectively.

Participants responded faster on valid trials (581 ms) than on invalid trials (635 ms) and faster on same case trials (593 ms) than on mixed case trials (623 ms). Critically, there was no interaction between the effects of cue validity and case, $F(1, 39) = 0.20$, $MSE = 808.83$, $p = .66$. The cuing effect (invalid-valid) on same case trials (56 ms) was statistically equivalent to the cuing effect on mixed case trials (52 ms).

For percentage error, the main effect of case mixing was significant, $F(1, 39) = 15.49$, $MSE = 8.49$, $p < .05$, such that participants made fewer errors on same case trials (1.7%) than on mixed case trials (3.5%). No other effects were significant, all Fs < 1.1.

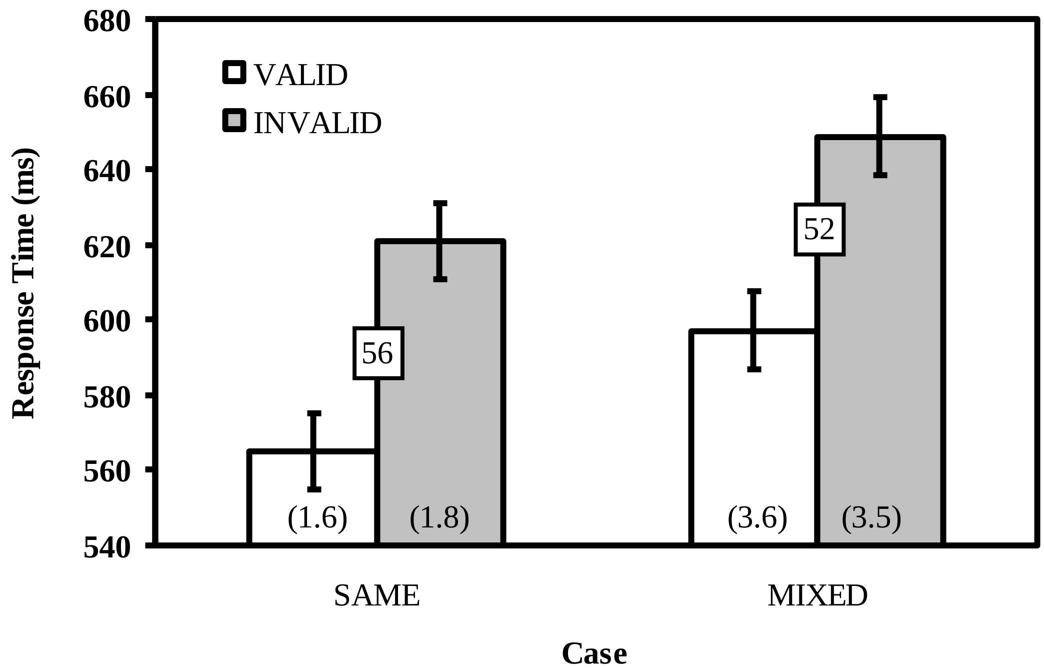
Discussion

In Experiment 5, there was no interaction between the effects of cue validity and case mixing. The cuing effect was statistically equivalent for words presented in mixed case and words presented in the same case. This result again does not replicate the marginally significant underadditive interaction between the effects of cue validity and case mixing in Experiment 3, but does replicate the lack of such an interaction found in Experiment 4. The fact that the underadditive interaction from Experiment 3 does not seem to replicate suggests that either (1) it is a very small effect or (2) it was a type I error. To further explore option (1) a combined analysis was performed.

Combined Analysis

As in Experiments 1 and 2, the critical result in Experiments 3 through 5 relies on a null. To provide a more powerful test of the presence of an interaction between the effects of cue validity and case mixing the data from all three experiments were combined into a single analysis. Critically, this analysis yielded no interaction between the effects of cue validity and case mixing, $F(1, 101) = 1.03$, $MSE = 581.60$, $p = .31$.

Figure 16. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and case mixing in Experiment 5. Cuing effects (invalid – valid) are presented in boxes.



Interestingly, there was an interaction between the effects of cue validity and experiment, $F(1, 101) = 3.17$, $MSE = 1121.65$, $p < .05$, such that the cuing effect was larger in Experiment 5 (54 ms) than in Experiments 3 (37 ms) and 4 (36 ms). There were a number of differences between Experiment 5 and Experiments 3 and 4 that could be responsible for this difference in overall cuing effects (e.g., variable word length).

Spatial Attention and Case Mixing

The effects of cue validity and case mixing are additive on RT. This result is new and suggests that spatial attention does not influence the processing of multi-letter units. This result is inconsistent with the results demonstrating a strong association between case mixing and the neural mechanisms underlying spatial attention. Specifically, an overadditive interaction was predicted based on the suggestion that mixed case stimuli put greater demands on spatial attention than same case words (Braet & Humphreys, 2006; 2007; Mayall & Humphreys, 2001). This clearly was not observed. The inconsistency between the present results and this prediction may lie in the type of spatial attention manipulation used here. Braet and Humphreys (2006; 2007) and Mayall and Humphreys (2001) suggested that the increased demands put on spatial attention by mixed case stimuli may reflect a serial attentional scan within the letter string when the use of multi-letter units breaks down (i.e., when the word is presented in mixed case). If we assume that spatial attention is initially spread across the entire word (see LaBerge, 1983) and then focused on individual letters if need be then the present results would stem from the fact that the serial attentional scan occurs *subsequent to* spatial attention being focused on the word. For example, when the target word appears on an invalid trial spatial attention would be oriented to the word's location and the spotlight set to encompass the entire letter string. The processing of multi-letter units would begin and break down with a mixed case word which would lead to the initiation of a serial attentional scan. Thus, the increased "need" for spatial attention would only occur after spatial attention has been oriented to the word. This would produce additivity between the effects of cue validity and case mixing.

As discussed in Chapter 1, a within word manipulation of spatial attention might be more appropriate to determine if mixed case words in fact make greater demands on spatial attention than same case words (Sieroff & Posner, 1988; Auclair & Sieroff, 2002). In this sense, case mixing may influence how spatial attention is distributed within a word. Alternatively, the association between the parietal lobe and the case mixing effect may be non-attentional (i.e., the parietal lobe is involved with more than just spatial attention). For example, Braet and Humphreys (2006) suggested that it may reflect a spatial transformation of the letters into a common format that would rely on the parietal lobe and may not be modulated by a manipulation of spatial attention.

A different explanation of the case mixing effect is that the impairment is caused by the incorrect grouping of letters of the same case (Mayall, Humphreys, & Cooper, 2000). For example, the mixed case word sPrInG might activate the word "pig" thus slowing the rate of activation of the correct word "spring" at the lexical level. Thus, the case mixing effect may be seen as a *lexical level effect* caused by the incorrect grouping of same case letters prior to the lexical level. Critically, incorrect grouping of letters and the disruption of multi-letter level processing may be seen as different effects. For example, the activation of a multi-letter unit may not be dependent on single letter activation but grouping on the basis of case might be. If spatial attention influences processing before these case specific multi-letter units are formed then additivity between the effects of cue validity and case mixing would be expected.

Critically, whatever the process influenced by case mixing the lack of an interaction with cue validity demonstrates that spatial attention does not influence the same process.

Conclusion

In conclusion, Experiments 3 through 5 demonstrate that the effects of cue validity and case mixing do not interact. These results are interpreted in terms of a spatial attention not influencing either the rate of multi-letter level processing or the formation of case specific letter groups.

Chapter 5: Inter-Letter Spacing

Experiments 1 through 5 have demonstrated that cue validity does not influence the same process as either long lag repetition priming or case mixing. In Experiments 6 and 7 the idea that spatial attention influences letter level processing is tested. Here, cue validity is combined with a manipulation of inter-letter spacing.

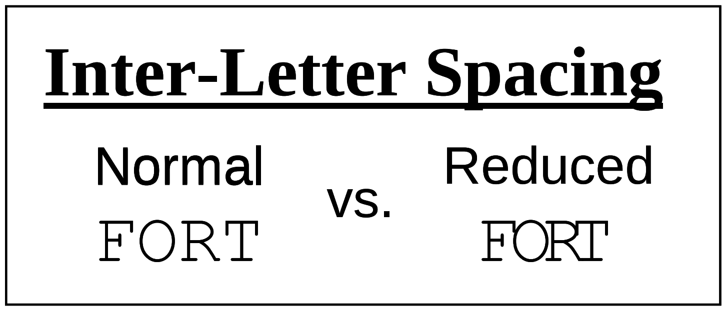
The manipulation of inter-letter spacing used here consisted of comparing performance for words in which inter-letter spacing was normal to words in which inter-letter spacing was reduced (see Figure 17). This manipulation is similar to what has been referred to as lateral masking (e.g., Wolford & Chambers, 1983) and crowding (e.g., Chung, 2002). The term "inter-letter spacing" used here seemed more theory neutral. Reducing inter-letter spacing is known to impair both letter identification (e.g., Bouma, 1970; Wolford, 1975; Wolford & Chambers, 1983) and word reading (Chung, 2002; Yu, Cheung, Legge, & Chung, 2007). Here, reducing inter-letter spacing is hypothesized to impair the input into the letter level thus slowing the activation of letter representations (e.g., Wolford, 1975; Wolford & Chambers, 1983). The disruption of the input into the letter level occurs because reducing inter-letter spacing disrupts accurate feature encoding, which, when activation is feed forward to the letter level, slows letter activation (i.e., a letter level effect) relative to when features are more accurately encoded (i.e., when letters are normally spaced). Reducing inter-letter spacing is not viewed as a feature level effect because it does not influence the rate at which features are activated.

The impairment caused by inter-letter spacing is thus best viewed as the disruption of letter level processing caused a degraded input into the letter level. For example, in the context of Ashby et al.'s (1996) locational uncertainty model of feature integration, features are integrated (i.e., bound together) via their proximity to each other and noise inherent in the encoding of feature location leads to the possibility that incorrect features are conjoined (i.e., an illusory conjunction; Treisman & Schmidt, 1982). By reducing the distance between two objects (here, letters within a word) the potential for an illusory conjunction between features of adjacent letters is increased. If features within a letter are not conjoined accurately the rate of letter activation at the letter level would be slowed.

A similar explanation for inter-letter distance effects is provided by Wolford's (1975) feature perturbation theory of letter recognition. In this theory, letters are activated via matching feature groups corresponding to each letter to stored letter representations. Over time features can "perturb" or migrate to adjacent feature groups. As inter-letter distance is reduced the likelihood increases that a migrating feature will join the feature group of an adjacent letter. The presence of a feature that does not "belong" to a given feature group disrupts the "quality" of the match between the features within that feature group and stored letter representations thus slowing letter identification. Thus, inaccurate encoding of features impairs letter level processing.

In Wolford's (1975) theory, reducing inter-letter spacing also makes it more difficult to segregate letters. Before a feature group can be matched to a stored letter representation, feature groups have to be created. This occurs through the extraction of the spaces between letters. Reducing inter-letter spacing reduces the size of these spaces making it more difficult to extract these spaces from the array. Failure to extract a space between adjacent letters leads to the amalgamation of what would be two separate feature groups into a single feature group. As a result, letter identification would be impaired.

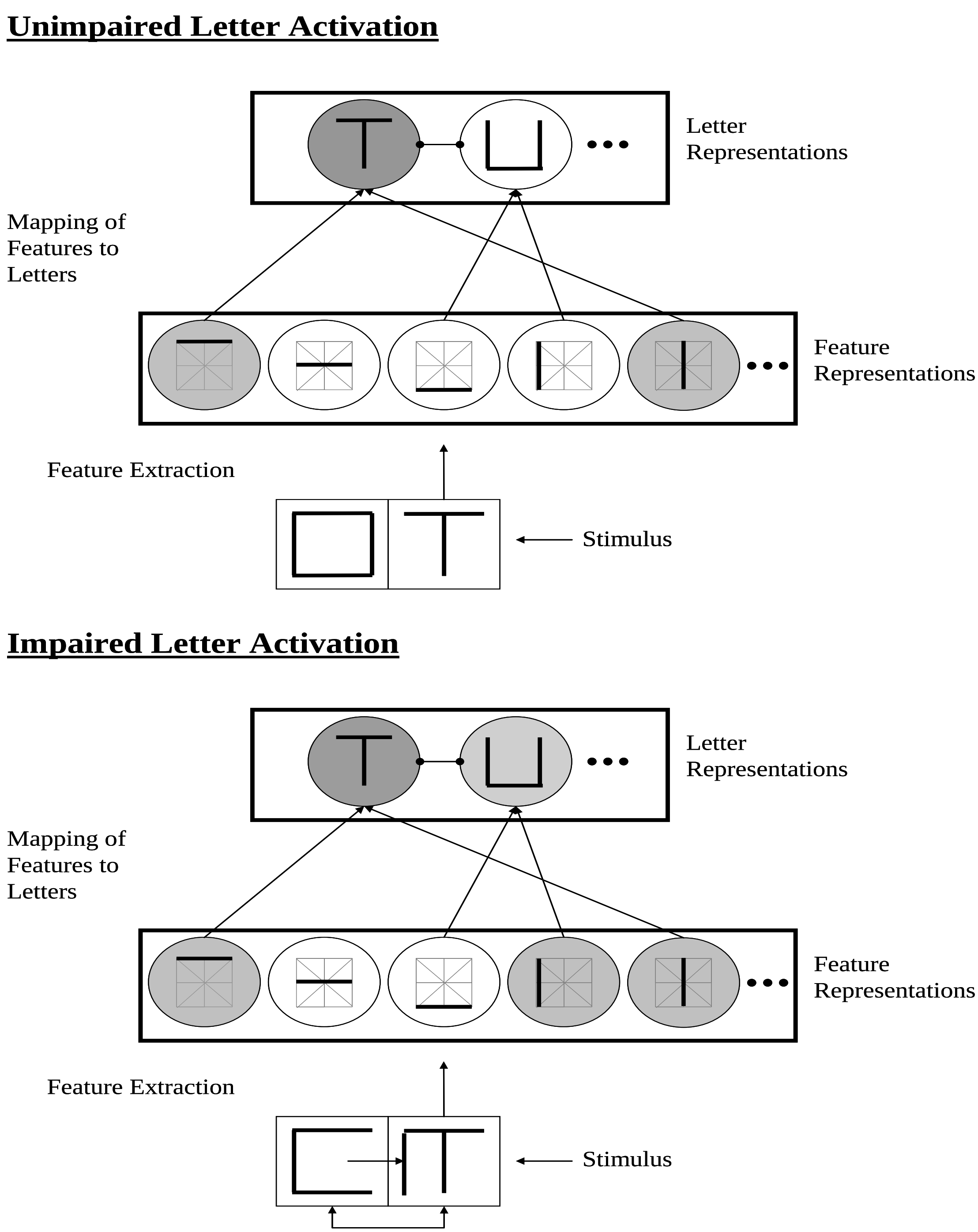
Figure 17. Example of inter-letter spacing manipulation.



To more clearly illustrate how inaccurate encoding of a feature can influence letter level processing an example is provided in Figure 18. In Figure 18, the letters O and T are presented and a condensed version of the feature and letter levels for the right location is displayed. In this type of model, letters will compete with each other, and as a result, the difference in activation between letters will influence how quickly a letter is activated. In the top panel of the figure the correct features are activated leading to the activation of the letter T and no activation of the letter U. This would lead to a higher rate of activation for the letter T relative to the letter T in the lower panel of the figure. In the lower panel of the figure, one of the features belonging to the adjacent letter O has migrated to the letter T's location leading to activation of that feature at the feature level and spurious activation of the letter U at the letter level. This spurious activation will compete with the activation of the correct letter representation (i.e., T) thus slowing down its rate of activation. While Figure 18 is certainly a simplification, it does capture the phenomenon of crowding wherein features of adjacent letters are often perceived as part of the target letter (e.g., Levi, 2008; Nancy & Tjan, 2007).

If spatial attention influences letter level processing, then an overadditive interaction between the effects of cue validity and inter-letter spacing is expected. This prediction is tested in Experiments 6 and 7. There are numerous reasons to expect such an interaction. For example, in Ashby et al.'s (1996) locational uncertainty model, an invalid cue would increase noise in localizing features. When inter-letter spacing is reduced the cost of this noise in localizing features, and thus the cost of an invalid cue, should be increased (i.e., the cuing effect should be larger on trials in which inter-letter spacing has been reduced). Thus, both an invalid cue and a reduction in inter-letter spacing would

Figure 18. Depiction of the letter level effect of a feature migration. Top panel. Features remain in proper location leading to the activation of the letter T only. Bottom panel. A feature from left letter migrates to the right letter leading to the activation of the letter U thus slowing the activation of the letter T.



interfere with the correct assignment of features to letters thus slowing letter identification. A similar prediction can be derived if spatial attention influences the accuracy with which the spaces between letters are extracted. In this case, both an invalid cue and a reduction in inter-letter distance would impair letter segregation. Incorrect letter segregation would impair letter identification.

Experiment 6

In Experiment 6 participants read aloud words presented with normal inter-letter spacing and with reduced inter-letter spacing in the context of the spatial cuing paradigm discussed in the General Methods section.

Methods

Participants. Sixteen undergraduates participated.

Design. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Inter-letter Spacing: Normal vs. Reduced) within-subject design was used. On half of the trials the target word was printed with normal inter-letter spacing and on half of the trials the target word was printed with inter-letter spacing reduced.

Stimuli. The word list from Experiment 2 was used. Eight new items were added to this list to make 168 four letter words in total (see Appendix E). The words were all monosyllabic. The average frequency was approximately 46 occurrences per million and on average each item had nine neighbours (Davis, 2005). In the normal spacing condition letters were separated by 12 pixels horizontally centre-to-centre. In the crowded condition letters were separated by 8 pixels horizontally centre-to-centre. Words were presented in 12 point Courier New font. The normally spaced words were approximately 2 cm horizontally and the words with inter-letter spacing reduced were approximately 1.5 cm horizontally. Both normally spaced words and words with reduced inter-letter spacing were approximately 0.5 cm vertically. The screen resolution was set at 640 x 480.

Procedure. There were eight practice trials and 160 experimental trials. The experiment took approximately 10 minutes to complete.

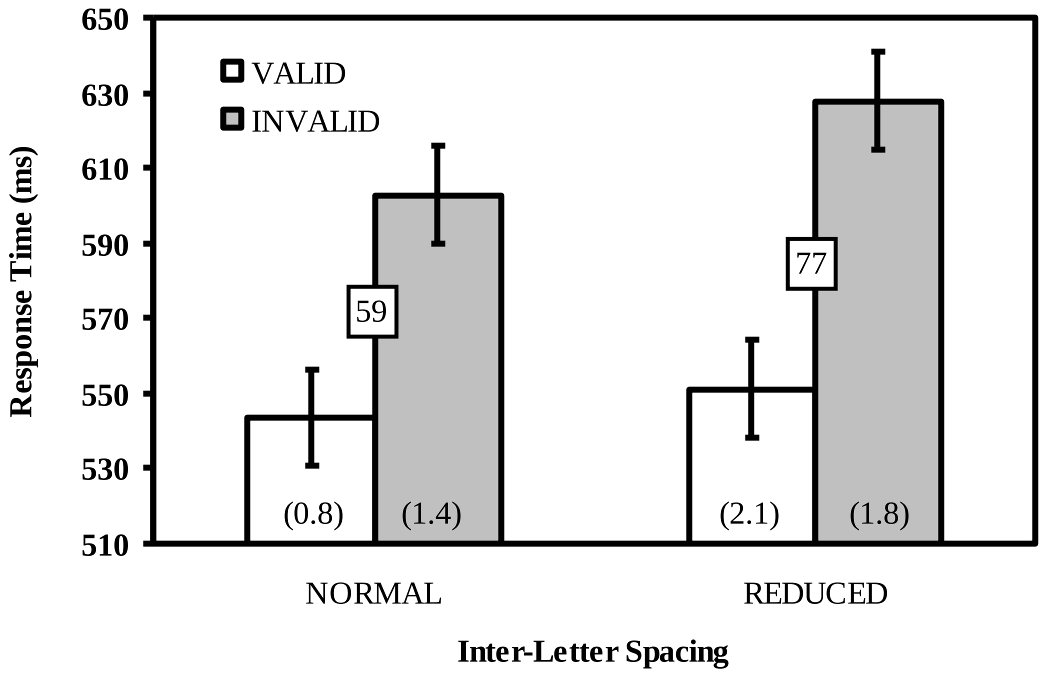
Results

Spoiled trials (2.4%) were removed prior to analysis. The outlier procedure led to the removal of 1.1% of the RT data. Data are presented in Figure 19 and Appendix M. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Inter-Letter Spacing: Normal vs. Reduced) ANOVA was performed on mean RT and percentage error data.

For RTs, the main effects of cue validity and inter-letter spacing were significant, $F(1, 15) = 47.22$, $MSE = 1568.45$, $p < .05$; $F(1, 15) = 18.16$, $MSE = 234.47$, $p < .05$, respectively. Participants responded faster on valid trials (547 ms) than on invalid trials (615 ms) and faster on normally spaced trials (573 ms) than on reduced space trials (589 ms). Critically, there was an interaction between the effects of cue validity and inter-letter spacing, $F(1, 15) = 5.50$, $MSE = 219.34$, $p < .05$. The cuing effect (invalid-valid) on normally spaced trials (59 ms) was smaller than the cuing effect on reduced space trials (77 ms).

For errors, there was a marginal effect of spacing, $F(1, 15) = 3.29$, $MSE = 3.34$, $p = .08$, such that participants made fewer errors on normally spaced trials (1.1%) than on reduced space trials (2.0%). No other effects were significant, (all Fs < 2.3).

Figure 19. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and inter-letter spacing in Experiment 6. Cuing effects (invalid – valid) are presented in boxes.



Discussion

There was a significant overadditive interaction between the effects of cue validity and inter-letter spacing. The cuing effect was smaller when letters were normally spaced than when inter-letter spacing was reduced. This overadditive interaction suggests that cue validity and the reduction of inter-letter spacing influence a common process. This common process is hypothesized to be the activation of letter representations at the letter level.

The inter-letter spacing manipulation is the first to yield clear evidence for a common influence with cue validity and as such represents an important step in identifying the locus of the spatial cuing effect on word processing. Given the theoretical importance of this result, Experiment 7 was conducted using the same design but with a different set of items in order to provide a replication.

Experiment 7

Methods

Participants. Sixteen undergraduates participated.

Design. Same as Experiment 6.

Stimuli. The five letter word list from Experiment 4 was used (see Appendix C). The normally spaced words were approximately 2.4 cm horizontally and the words with inter-letter spacing reduced were approximately 1.8 cm horizontally. Both normally spaced words and words with reduced inter-letter spacing were approximately 0.5 cm vertically.

Procedure. There were eight practice trials and 96 experimental trials. The experiment took approximately 10 minutes to complete.

Results

Spoiled trials (4.4%) were removed prior to analysis. The outlier procedure led to the removal of 1.4% of the RT data. Data are presented in Figure 20 and Appendix N. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Inter-Letter Spacing: Normal vs. Reduced) ANOVA was performed on mean RT and percentage error data.

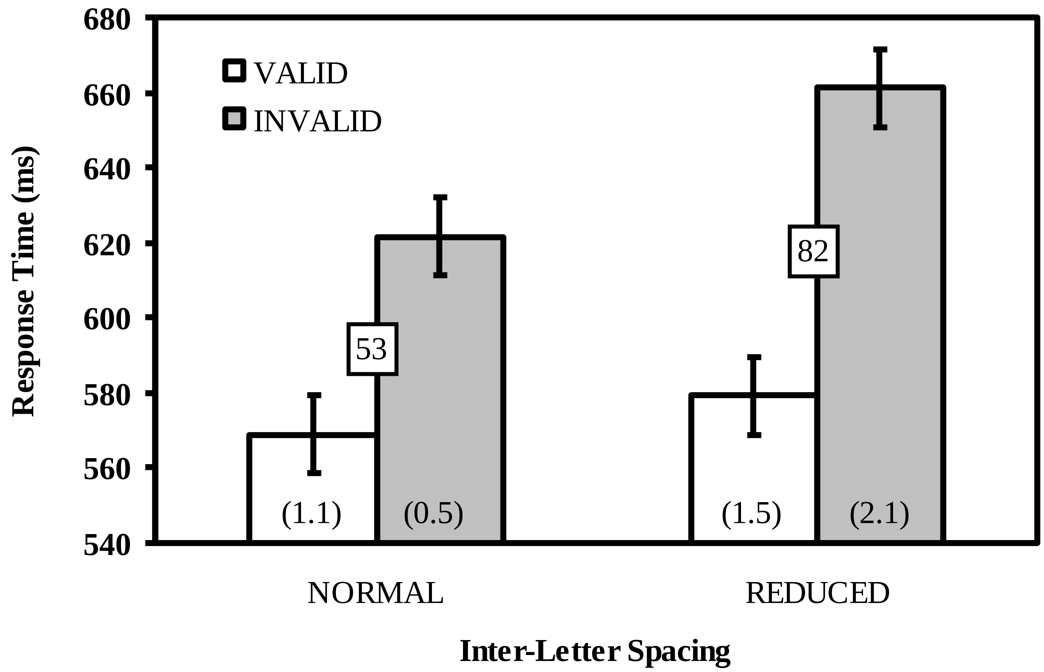
For RTs, the main effects of cue validity and inter-letter spacing were significant, $F(1, 15) = 49.33$, $MSE = 1469.50$, $p < .05$; $F(1, 15) = 12.38$, $MSE = 806.25$, $p < .05$, respectively. Participants responded faster on valid trials (574 ms) than on invalid trials (641 ms) and faster on normally spaced trials (595 ms) than on reduced space trials (620 ms). Critically, there was a significant interaction between the effects of cue validity and inter-letter spacing, $F(1, 31) = 8.76$, $MSE = 393.67$, $p < .05$. The cuing effect (invalid-valid) on normally spaced trials (53 ms) was smaller than the cuing effect on reduced spaced trials (82 ms). No effects were significant in the error analysis, all *F*s < 2.3.

Discussion

As in Experiment 6, there was an overadditive interaction between the effects of cue validity and inter-letter spacing. The cuing effect was smaller when letters were normally spaced than when inter-letter spacing was reduced. This result is again consistent with the idea that spatial attention influences letter level processing.

A number of potential mechanisms were outlined in the introduction that could explain an interaction between cue validity and inter-letter spacing. First, as suggested by Ashby et al. (1996), spatial attention may influence the accuracy of feature localization. In their theory, spatial proximity determines what features are integrated and a reduction in spacing between objects increases the possibility that an illusory conjunction of

Figure 20. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and inter-letter spacing in Experiment 7. Cuing effects (invalid – valid) are presented in boxes.

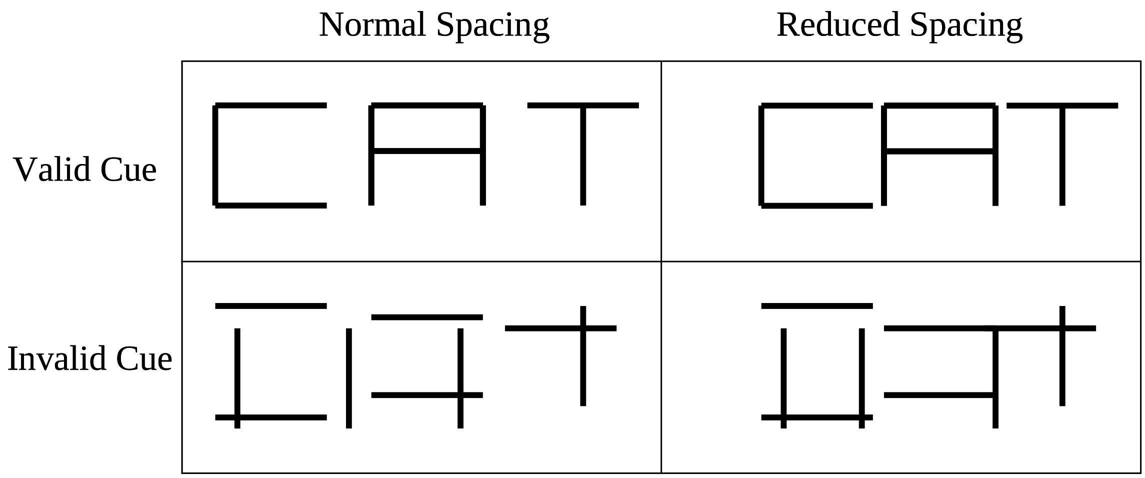


features occurs. Thus, both spatial attention and inter-letter spacing would increase the likelihood of an illusory conjunction thus leading to impairments in letter identification (e.g., spurious letter activations). A schematic of the joint effects of spatial attention and inter-letter spacing is presented in Figure 21. In Figure 21, the same amount of featural mis-localization produces a perceptible difference in identifiability when combined with different levels of inter-letter spacing. This account is not dependent on the occurence of illusory conjunctions. If an invalid cue increases feature localization errors and a feature migrates to a different "letter" this would also slow letter identification (Wolford, 1975) without the need to posit an explicit feature integration process.

In a similar vein, both spatial attention and inter-letter spacing may influence the segregation of letters within the word. In Wolford's (1975) feature perturbation theory the space between letters is extracted and used to delineate feature groups corresponding to letters. By reducing the size of that space it becomes more difficult to delineate feature groups. If an invalid cue impairs the extraction of spaces then both spatial attention and inter-letter spacing could be viewed as impairing the individuation of letters. Failure to segregate letters would slow letter identification. For example, in feature perturbation theory failure to segregate feature groups leads to the amalgamation of adjacent features and the concomitant delay or failure to identify a letter or letters.

A third potential mechanism not discussed in the introduction places spatial attention's influence at an earlier stage than the letter level, but allows its influence to nonetheless propagate to the letter level. Specifically, an invalid cue may slow the rate of uptake of visual information relative to a valid cue (e.g., Stolz & Stevanovski, 2004). This interpretation is consistent with Stolz and Stevanovski's (2004) observation that the

Figure 21. Graphical depiction of the combined effects of cue validity and inter-letter spacing.



effects of cue validity and stimulus contrast interact in an overadditive fashion (i.e., the cuing effect is larger for dim than bright stimuli). Stimulus contrast is thought to influence the rate of information coming into the visual system (e.g., Miller, Ulrich, & Rinkenauer, 1999). Thus, stimulus contrast is a feature level effect in that it would slow the rate of activation of features. If this slow rate of activation is propagated to the letter level it would combine with the slowed activation of letters, induced by the reduction in inter-letter spacing, to yield the observed interaction.

Does Inter-Letter Spacing Influence Feature Extraction?

Rather than concluding that the interaction between cue validity and inter-letter spacing occurs at the letter level, it could be argued that the locus of this interaction is the feature level. In this case, an invalid cue and reducing inter-letter spacing would both be seen as reducing the rate of information uptake into the feature level. While spatial attention's influence on uptake has ample support (e.g., Stolz & Stevanovski, 2004), the idea that reducing inter-letter spacing influences the rate of uptake would be more controversial. In a recent review of crowding effects and their explanation, to which the inter-letter spacing manipulation used here is related, Levi (2008) notes that an "emerging consensus" is an account wherein crowding affects feature integration, but not feature detection (see also Pelli et al., 2004). Nonetheless, Levi (2008) also described crowding as "an enigma wrapped in a paradox and shrouded in a conundrum" (p. 650) so alternative explanations for the present results should not be dismissed out of hand.

Critically, whatever the process influenced by the reduction in inter-letter spacing the interaction with cue validity demonstrates that spatial attention influences the same process.

Conclusion

In conclusion, Experiments 6 and 7 demonstrated that the effects of cue validity interact with inter-letter spacing in an overadditive fashion. These results are interpreted in terms of spatial attention and inter-letter spacing disrupting the input to the letter level (see Figure 30). Experiments 8 and 9 provide a further test of these ideas.

Chapter 6: Irrelevant Features

The results of Experiment 6 and 7 suggest that spatial attention may influence word processing via disrupting the input to the letter level. To test this idea further Experiments 8 and 9 use a different factor that is hypothesized to influence processing in a similar manner to a reduction in inter-letter spacing.

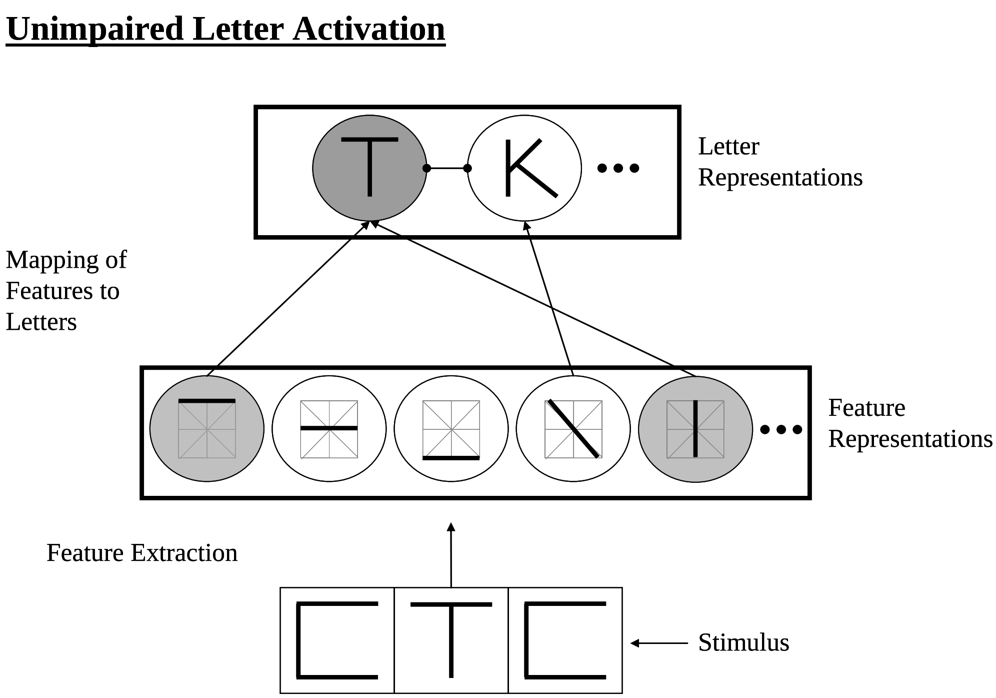
In Experiments 8 and 9, participants were presented with words in a typical format or words with irrelevant features interspersed between each letter (i.e., forward and backward slashes; see Figure 22). These slashes constitute plausible letter features and their extraction is held to slow letter identification. The mechanism through which the presence of irrelevant features should impairs letter identification is similar to how reducing inter-letter spacing impairs letter identification (i.e., the input to the letter level is disrupted leading to a slower rate of letter activation). For example, the irrelevant features could migrate to adjacent letter groups leading to illusory conjunctions and/or the degradation of the match between the features present and stored letter representations. For example, in the top panel of Figure 23, in which irrelevant features are absent, the letter T would be activated faster than the letter T in the bottom panel in which the extraction of the irrelevant feature "\" activates the letter K. In addition, the presence of irrelevant features may impair letter segregation. Given that the irrelevant features are placed in the spaces between letters, the irrelevant features may lead to adjacent feature groups being amalgamated (Wolford, 1975).

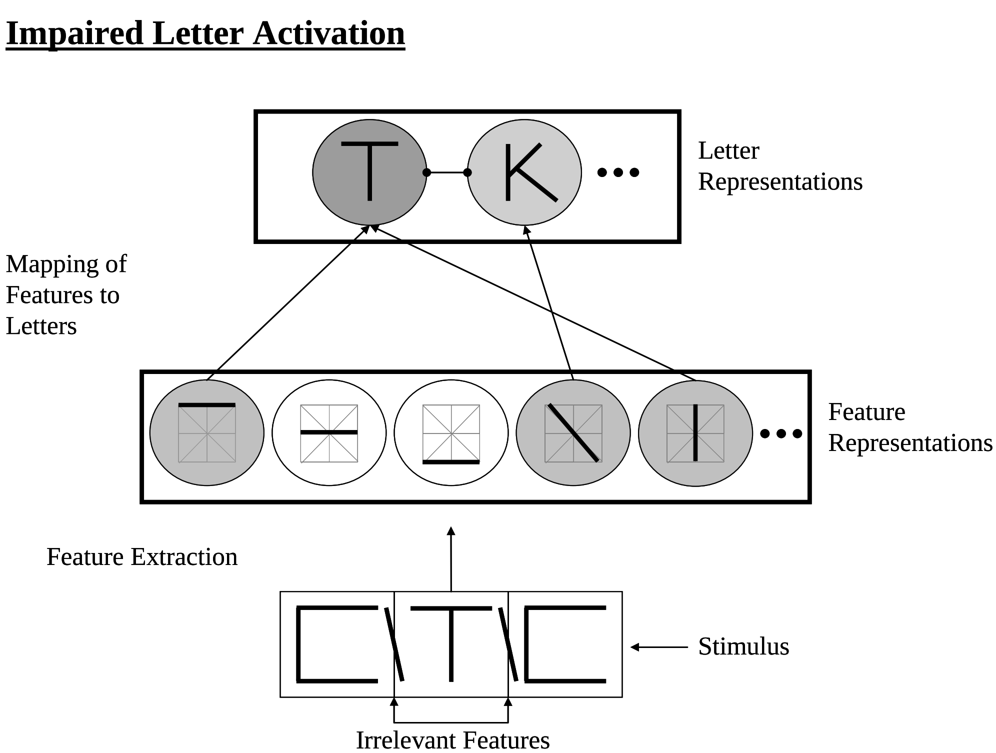
Figure 22. Example of presence/absence of irrelevant features manipulation.

Irrelevant Features

Absent	vs.	Present
F O R T		F/O\R\T

Figure 23. Depiction of the letter level effect of the presence of irrelevant features. Top panel. No irrelevant features are present leading to the activation of the letter T only. Bottom panel. Irrelevant features are present leading to the activation of the letter K thus slowing the activation of the letter T.





If spatial attention influences the same process as the presence/absence of irrelevant features then an overadditive interaction should be found. Specifically, the cuing effect should be larger when irrelevant features are present than when irrelevant features are absent. This prediction is tested in Experiments 8 and 9.

Experiment 8

In Experiment 8 participants read aloud words with irrelevant features absent and irrelevant features present in the context of the spatial cuing paradigm detailed in the General Methods section.

Methods

Participants. Forty-eight undergraduates participated.

Design. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Irrelevant Features: Present vs. Absent) within-subject design was used. On half of the trials the target word was printed normally (e.g., FORT) and half of the trials the target word was printed with forward and backward slashes interspersed between the letters (e.g., F/O\R\T).

Stimuli. The word list from Experiment 6 was used (see Appendix E). In an attempt to control the horizontal extent of the words when irrelevant features were present and absent, a space was inserted between each letter in the irrelevant features absent condition. Words were presented in upper case 12 point Arial font. Words were approximately 2.2 cm horizontally and approximately 0.7 cm vertically. The forward and backward slashes were from the same font as the letters. Whether a given slash was forward or backward was determined randomly for each space within each word.

Procedure. There were eight practice trials and 160 experimental trials. The experiment took approximately 10 minutes to complete.

Results

Spoiled trials (2.7%) were removed prior to analysis. The outlier procedure led to the removal of 1.9% of the RT data. Data are presented in Figure 24 and Appendix O. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Irrelevant Features: Present vs. Absent) ANOVA was performed on mean RT and percentage error data.

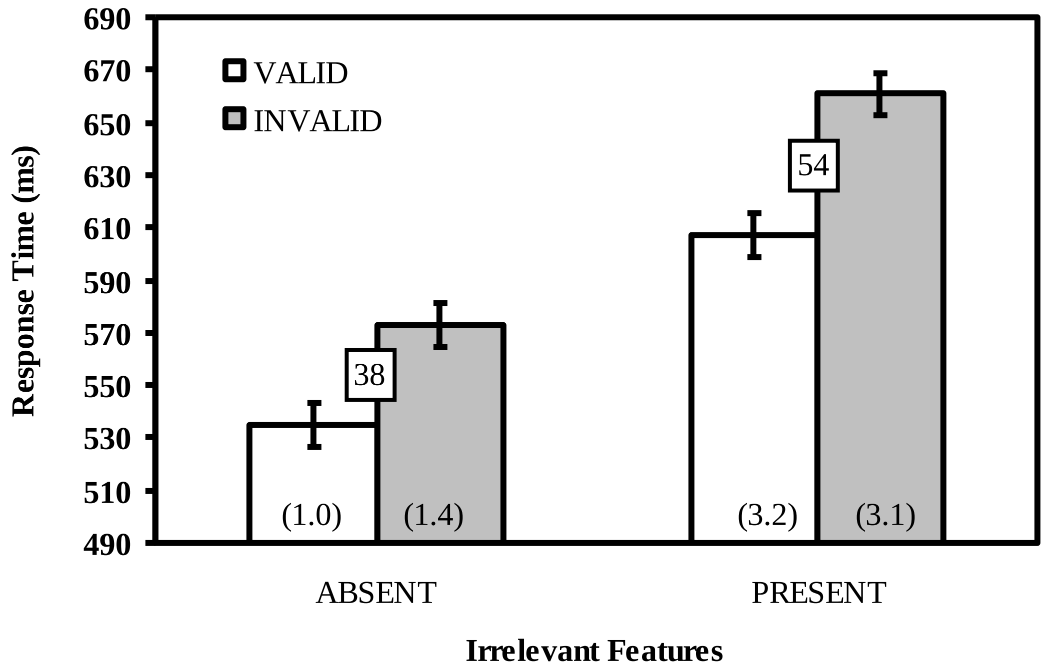
For RT, the main effects of cue validity and the presence/absence of irrelevant features were significant, $F(1, 47) = 95.55$, $MSE = 1059.60$, $p < .05$; $F(1, 47) = 332.90$, $MSE = 926.88$, $p < .05$, respectively. Participants responded faster on valid trials (571 ms) than on invalid trials (617 ms) and faster on irrelevant features absent trials (554 ms) than on irrelevant features present trials (634 ms). Critically, there was an interaction between the effects of cue validity and the presence/absence of irrelevant features, $F(1, 47) = 7.51$, $MSE = 393.09$, $p < .05$. The cuing effect (invalid-valid) on irrelevant features absent trials (38 ms) was smaller than the cuing effect on irrelevant features present trials (54 ms).

For errors, the main effect of the presence/absence of irrelevant features was significant, $F(1, 47) = 20.89$, $MSE = 8.67$, $p < .05$, such that participants made fewer errors on irrelevant features absent trials (1.2%) than on irrelevant features present trials (3.1%). No other effects were significant, all *F*s < 1.

Discussion

There was a significant overadditive interaction between the effects of cue validity and the presence/absence of irrelevant features. The cuing effect was larger when the irrelevant features were present than when the irrelevant features were absent. This overadditive interaction suggests that cue validity and the presence/absence of irrelevant

Figure 24. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and the presence/absence of irrelevant features in Experiment 8. Cuing effects (invalid – valid) are presented in boxes.



features influence a common process. As noted in the introduction this common process is held to be letter identification. Both the inclusion of irrelevant features and an invalid cue is held to disrupt the input to the letter level. Experiment 9 replicates Experiment 8 with a different set of items.

Experiment 9

Methods

Participants. Thirty-two undergraduates participated.

Design. The same as Experiment 8.

Stimuli. The word set from Experiment 7 was used (see Appendix C). Words were presented in upper case 12 point Arial font. Words were approximately 2.7 cm horizontally and approximately 0.7 cm vertically.

Procedure. There were eight practice trials and 96 experimental trials. The experiment took approximately 10 minutes to complete.

Results

Spoiled trials (2.8%) were removed prior to analysis. The outlier procedure led to the removal of 1.6% of the RT data. Data are presented in Figure 25 and Appendix P. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Irrelevant Features: Present vs. Absent) ANOVA was performed on mean RT and percentage error data.

For RTs, the main effects of cue validity and the presence/absence of irrelevant features were significant, $F(1, 31) = 72.03$ $MSE = 758.02$ $p < .05$; $F(1, 31) = 142.89$, $MSE = 1001.32$, $p < .05$, respectively. Participants responded faster on valid trials (539 ms) than on invalid trials (580 ms) and faster on irrelevant features absent trials (526 ms) than on irrelevant features present trials (593 ms). Critically, there was a interaction between the effects of cue validity and the presence/absence of irrelevant features, $F(1, 31) = 11.92$, $MSE = 355.68$, $p < .05$. The cuing effect (invalid-valid) on irrelevant features absent trials (30 ms) was smaller than on irrelevant features present trials (53 ms).

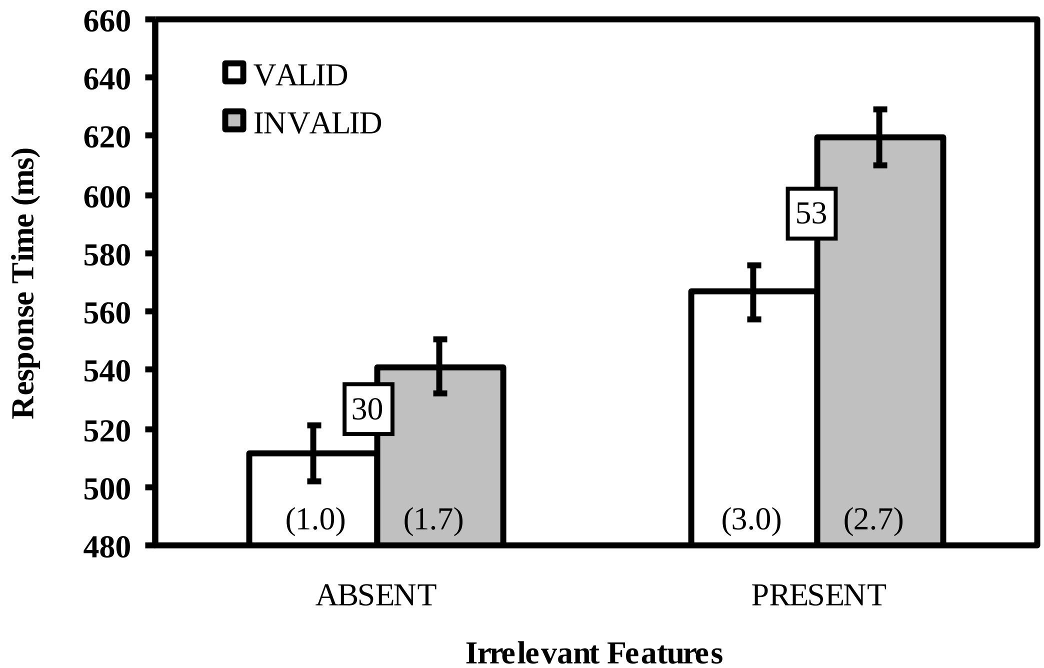
For errors, the main effect of the presence/absence of irrelevant features was significant, $F(1, 47) = 5.54$, $MSE = 12.00$, $p < .05$, such that participants made fewer errors on irrelevant features absent trials (1.3%) than on irrelevant features present trials (2.8%). No other effects were significant, all *F*s < 1.

Discussion

There was a significant overadditive interaction between the effects of cue validity and the presence/absence of irrelevant features. Again, the cuing effect on reading aloud was larger when irrelevant features were present than when irrelevant features were absent. This result replicates Experiment 8 with a different set of items, thus providing converging evidence that spatial attention influences letter level processing via disrupting the input to the letter level. That four experiments all converge on this view, provides strong support for this conclusion.

The interaction between the effects of cue validity and the presence/absence of irrelevant features can be explained in a similar fashion as the interaction between the effects of cue validity and inter-letter spacing. For example, spatial attention may influence the accuracy of feature localization and the addition of irrelevant features to the word may provide a greater likelihood for illusory conjunctions to occur. These illusory conjunctions would impair letter identification, for example, via the activation of spurious letters at the letter level. A schematic of the joint effects of spatial attention and the

Figure 25. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and the presence/absence of irrelevant features in Experiment 9. Cuing effects (invalid – valid) are presented in boxes.



presence/absence of irrelevant features is presented in Figure 26.

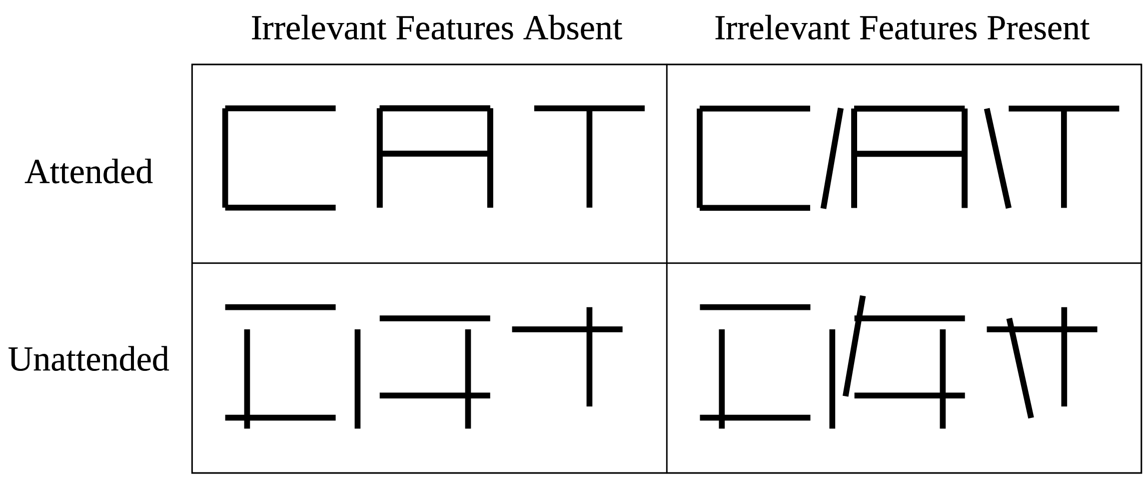
The presence of irrelevant features in the spaces between the letters could also lead to a letter segregation problem. If an invalid cue impairs the extraction of spaces then both spatial attention and the presence of irrelevant features could be viewed as impairing the individuation of letters. Failure to segregate letters would slow letter identification. Lastly, an invalid cue could slow the rate of feature extraction and this slowing is propagated through to the letter level. At the letter level this slowing would combine with the slowing caused by the presence of irrelevant features to produce the overadditive interaction between cue validity and the presence/absence of irrelevant features.

In Chapter 4 the possibility was raised that the manipulation of inter-letter spacing influenced the rate of feature extraction and not the rate of letter level processing. If this were the case spatial attention's influence on word processing could be limited to a feature level effect (i.e.., both cue validity and inter-letter spacing influence the rate of feature activation). It would seem difficult to make the same argument with respect to the manipulation of the presence/absence of irrelevant features. How this manipulation would slow the rate of uptake into the word processing system is unclear.

What About Multi-Letter Units?

The irrelevant features manipulation was introduced as a means to interfere with the input to the letter level and thus to impair letter identification. An alternative suggestion is that the interspersed slashes actually disrupt the use of multi-letter units (Dickerson, 1999; Hall et al., 2001). Hall et al., (2001) used a similar manipulation but interspersed plus signs (e.g., F+O+R+T) in their study of a patient that was particularly reliant on the

Figure 26. Graphical depiction of the combined effects of cue validity and the presence/absence of irrelevant features.



use of multi-letter units. As expected, this manipulation exacerbated this patient's reading difficulty. The patient was also particularly hampered by the presentation of case mixed words as would be expected on the hypothesis that case mixing disrupts the use of multi-letter units (Hall et al., 2001). Critically, as demonstrated in Chapter 4, the effects of cue validity and case mixing were additive, whereas the effects of cue validity and the presence/absence of irrelevant features produced an overadditive interaction. This pattern of results across experiments suggests that the irrelevant features manipulation indexes a process separate from that indexed by case mixing. Note that this does not mean that the irrelevant features manipulation does not disrupt multi-letter units, only that it must also disrupt some other process.

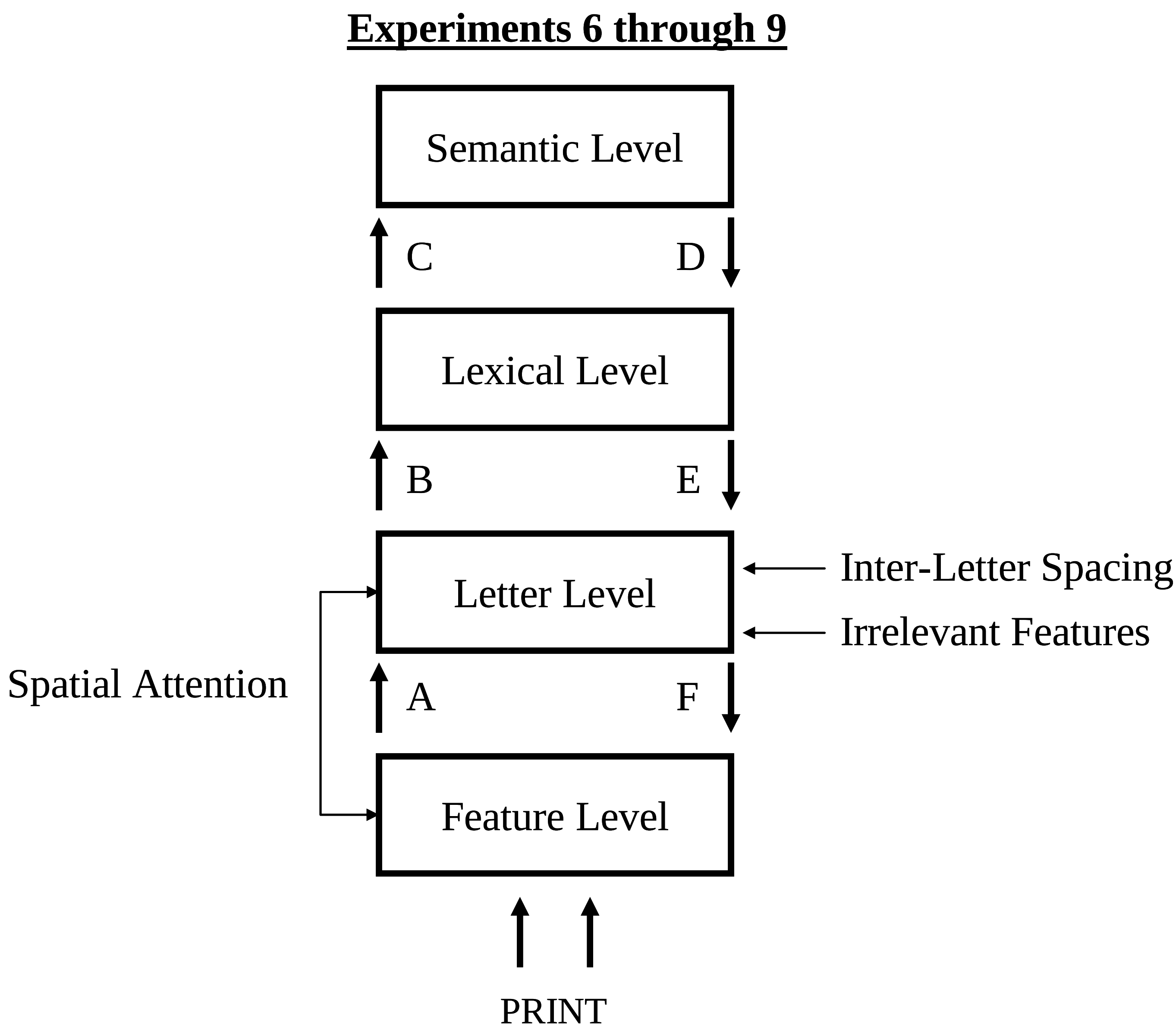
Interestingly, if case mixing is held to influence word processing via spuriously activating lexical representations consistent with case specific letter groups (e.g., activating the PIG in spring) then it is possible to conclude that spatial attention influences both letter activation and multi-letter unit activation. Critically, this claim would rely on the notion that case mixing does not influence the rate at which multi-letter units are formed (otherwise there would have been an interaction between the effects of cue validity and case mixing). Instead, case mixing would be viewed as influencing lexical level processing via the incorrect grouping of case specific letters.

Critically, whatever the process influenced by the presence of irrelevant features the interaction with cue validity demonstrates that spatial attention influences the same process.

Conclusion

In conclusion, Experiments 8 and 9 demonstrate that the effects of cue validity interact with the presence/absence of irrelevant features in an overadditive fashion. These results are interpreted in terms of spatial attention and the presence/absence of irrelevant features disrupting the input to the letter level (see Figure 27).

Figure 27. Depiction of conclusions from Experiments 6 through 9. Inter-letter spacing and the presence/absence of irrelevant features influence the letter level. Spatial attention influences both the feature and letter levels.



Chapter 7: Set Size

In Chapter 7, I return to the possibility that spatial attention may be required more for unfamiliar than familiar words. The results from Experiments 1 and 2 (i.e., long lag repetition priming) and numerous other results using the same paradigm (e.g., McCann et al., 1992) have largely disconfirmed the familiarity sensitive view of the relation between spatial attention and word processing (e.g., LaBerge & Brown, 1989). According to this account, reading “familiar” words requires less spatial attention than reading “unfamiliar” words. In the present investigation, the spatial attentional demands of word processing are indexed by the magnitude of the cuing effect when performing a word processing task. Thus, the familiarity sensitive view of the relation between spatial attention and word processing predicts a smaller cuing effect for “familiar” items than “unfamiliar” items (i.e., an overadditive interaction between the effects of cue validity and familiarity). This prediction would seem to be falsified in light of the fact that familiar letter strings (i.e., words) produce the same size cuing effect as unfamiliar letter strings (i.e., nonwords) and high frequency words produce the same size cuing effect as low frequency words. Indeed, this is exactly what McCann et al. (1992) concluded from their results. In addition, priming would be expected to increase familiarity. Thus the observations that semantically primed words (familiar) produce the same size cuing effect as semantically unprimed words (unfamiliar) when the cue is uninformative and repeated words (familiar) produce the same size cuing effect as non-repeated words (unfamiliar) could also be considered inconsistent with a familiarity sensitive view.

Dismissing the familiarity sensitive view based on results from the spatial cuing paradigm, however, may be hasty given that in other contexts there is evidence for this view (see Chapter 1). For example, individuals with neglect dyslexia demonstrate a lexicality effect such that words are read more accurately than nonwords. Thus, in Experiments 10 and 11, I provide another test of the familiarity sensitive theory using a “strong” manipulation of familiarity in order to have the best chance of finding a familiarity effect on spatial cuing. Specifically, cue validity was combined with a manipulation of word set size.

Set size, in the present context, refers to the number of words from which the target word on each trial is selected. Unless repetition is a variable (as in Experiments 1 and 2), in a typical word processing task the set size is the same as the number of trials so that a novel word is presented on each trial. Thus, *within* a given experiment each word is equally “unfamiliar.” This state of affairs changes when set size is reduced (assuming the number of trials stays the same). For example, if the word on each trial was drawn from a set of 10 different words, each word would become much more familiar than words drawn from a larger set. To provide a strong test of the familiarity sensitive view, in Experiments 10 and 11, cue validity was combined with a manipulation of word set size. Specifically, the magnitude of the cuing effect for words drawn from a small set size (i.e., two words) was compared to the cuing effect for words drawn from a large set size (i.e., the word on each trial was novel within the experiment).

There is ample evidence that set size influences performance in general (e.g., Hyman, 1953) and in word processing (Gellatly & Gregg, 1974; Morton, 1969; Rouder, 2004). Specifically, response times decrease as set size decreases. There is previous evidence that word set size modulates spatial attention’s influence on word processing in the context of the flanker task. As discussed in Chapter 1, Shaffer and LaBerge (1979) provided evidence using a flanker task that participants processed the unattended (i.e., flanker) words to the level of semantics. Thus, focusing spatial attention on the central word did not stop the flanker words from being processed. However, Broadbent and Gathercole (1990) demonstrated that this result was only obtained if a small set of words were used and was not obtained when the words were different on every trial. Taken together, these results suggest that focusing spatial attention on the central word had a greater influence on words from a large set (i.e., new on every trial) than words from a small set.

According to Morton (1969) reduction in word set size reduces the threshold for response within the lexicon for the words in the set (i.e., a lexical level effect). This is similar to how Morton (1969) explains word frequency effects and as such it might be expected that the effects of cue validity and set size would be additive on RT. As noted previously, there are numerous demonstrations that the joint effects of cue validity and word frequency are additive in the spatial cuing paradigm used here (see Table 1). Nonetheless, the large difference in stimulus frequency *within* the current experiments (i.e., two words repeated constantly versus a new word on each trial) may result in a stronger influence at the lexical level. As a result, a more sensitive test of any influence that spatial attention may have on the lexical level is provided.

An alternative possibility is that the set size manipulation actually influences the feature or letter level in addition to the lexical level in the course of word processing. Dykes and Pascal (1981), using a stimulus probability manipulation (i.e., set size also affects stimulus probability) in a letter identification task, provided results consistent with the idea that participants "prepared" for a probable letter and that this preparation also facilitated the processing of visually similar letters. For example, if “C” was the probable stimulus then responses to a visually similar letter like “G” would be faster than a non-visually similar letter like “F” despite the fact that “G” and “F” themselves were equally probable. Thus, preparation for a given letter facilitated the processing of letters with similar features. This result suggests that the expectation that a word will be presented could influence word processing at levels prior to the lexical level (i.e., feature or letter level). Given results already presented (see Chapter 4 and 5), if words from a small set size lead to the facilitation of feature and/or letter level processing, then an overadditive interaction between cue validity and set size is expected. Specifically, the cuing effect for words drawn from a small set should be smaller than the cuing effect for words drawn from a large set.

There is another important motivation for investigating the potential interaction between spatial attention and word set size. Specifically, in the vast majority of filtering studies (some of which are described in Chapter One), the “unattended” words that are presented are from a small set (e.g., Brown et al., 2002; Risko et al., 2005; Shaffer & LaBerge, 1979). As Broadbent and Gathercole (1990) demonstrated in the context of the flanker paradigm, drawing from a small set may reduce the need for spatial attention thus leading to an underestimation of the role of spatial attention in visual word processing. If the cuing effect for words drawn from a small set are indeed smaller than the cuing effect for words drawn from a large set this claim would seemingly be verified. This result would suggest that a “fresh” look at previous studies employing small word sets would be warranted (e.g., Brown et al., 2002; Risko et al., 2005; Shaffer & LaBerge, 1979).

Experiment 10

In Experiment 10 participants read aloud words that were drawn from either a small set (i.e., two words) or a large set (i.e., a novel word on each trial) in the context of the spatial cuing paradigm discussed in the General Methods section.

Methods

Participants. Thirty-two undergraduates participated.

Design. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Set Size: Small vs. Large) mixed design was used. Set size was manipulated between subjects. The small set size group received one out of the same two words on every trial. The large set size group received a different word on every trial.

Stimuli. The 168 four letter words from Experiment 6 were used. Eight additional four letter words were added for a total of 176 words (see Appendix F). The words were all monosyllabic. The average frequency was approximately 46 occurrences per million and on average each item had nine neighbours (Davis, 2005). In the *large set size* condition, 168 of these words were used, 8 words for practice trials and 160 words for experimental trials. In the *small set size* condition, the remaining eight words were used. Each participant was presented with two of the eight words and these two words were used throughout the experiment. There were four sub groups of participants each receiving a different set of two words. Words were presented in upper case 12 point Arial font. Two words were inadvertently repeated in the word list and were removed prior to analysis.

Procedure. There were 16 practice trials and 160 experimental trials. The experiment took approximately 10 minutes to complete.

Results

Spoiled trials (2.8%) were removed prior to analysis. The outlier procedure led to the removal of 2.0% of the RT data. Data are presented in Figure 28 and Appendix Q. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Set Size: Same Small vs. Large) mixed ANOVA was performed on mean RT and percentage error data.

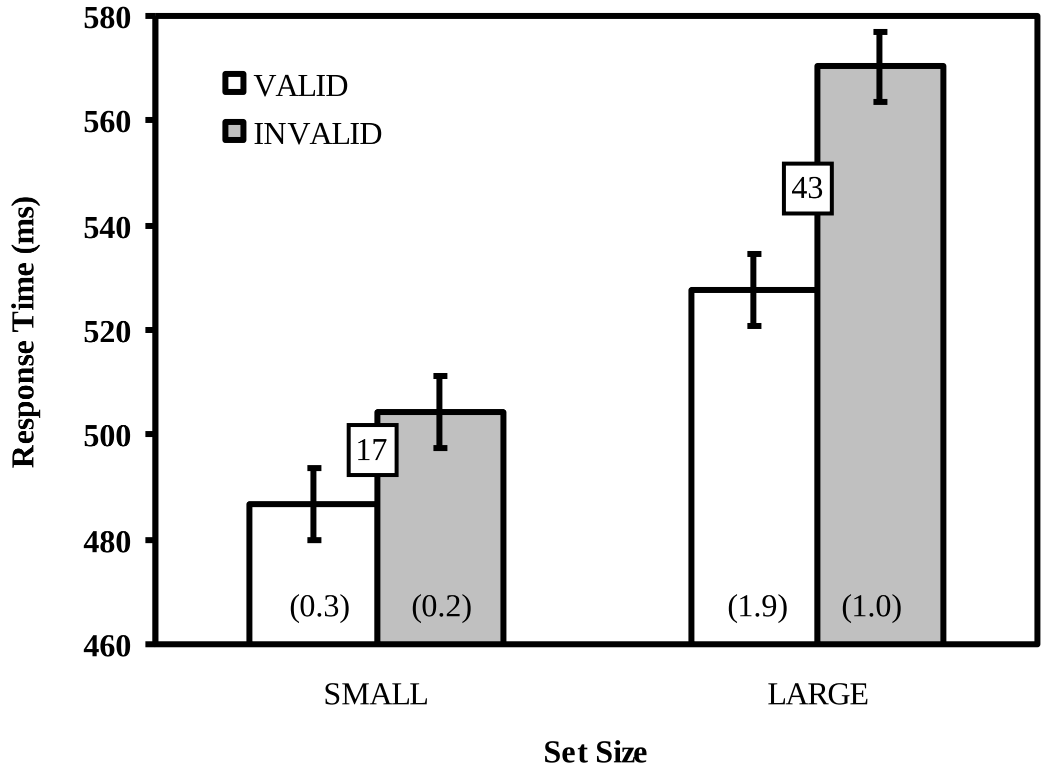
For RTs, the main effect of cue validity was significant but the main effect of set size was not, $F(1, 30) = 77.82$, $MSE = 186.10$, $p < .05$; $F(1, 30) = 2.66$, $MSE = 17214.32$, $p = .11$, respectively. Participants responded faster on valid trials (507 ms) than on invalid trials (537 ms). Critically, there was a significant interaction between the effects of cue validity and set size, $F(1, 30) = 13.62$, $MSE = 186.10$, $p < .05$. The cuing effect (invalid-valid) when on small set size trials (17 ms) was smaller than the cuing effect on large set size trials (43 ms).

For percentage error, the main effect of cue validity was marginal and the main effect of set size was significant, $F(1, 30) = 3.12$, $MSE = 1.19$, $p = .09$; $F(1, 30) = 21.63$, $MSE = 1.07$, $p < .05$, respectively. Participants made fewer errors on invalid trials (0.6%) than valid trials (1.1%) and made fewer errors on small set size trials (0.3%) than on large set size trials (1.5%). The interaction between cue validity and set size was not significant, $F(1, 30) = 2.1$, $MSE = 1.19$, $p = .15$.

Discussion

In Experiment 10 the effects of cue validity and word set size interacted in an overadditive fashion. The cuing effect was smaller when the word was drawn from a small set (i.e., two words) than when it was drawn from a large set (i.e., new word on each trial). This result suggests that a familiarity sensitive view of the relation between

Figure 28. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and the set size in Experiment 10. Cuing effects (invalid – valid) are presented in boxes.



spatial attention and word processing may still be viable. When words are "familiar" within an experiment (i.e., when the same two words are repeated) the cuing effect is smaller than when words are "unfamiliar" within an experiment (i.e., when there are new words on each trial). The results of Experiment 10 are also consistent with Broadbent and Gathercole's (1990) results in the context of the flanker paradigm. Words drawn from a small set appear to "require" less spatial attention than words drawn from a large set. As such, it suggests that filtering experiments using small set sizes are inadvertently reducing the spatial attentional demands of word processing and consequently underestimating those demands.

Experiment 10 suggests that evidence can be found that is consistent with a familiarity sensitive view in the context of the spatial cuing paradigm used here. There is, however, one potentially important difference between Experiment 10 and the previous studies that did not find such evidence. Specifically, set size in Experiment 10 was manipulated *between* subjects whereas manipulations of lexicality, word frequency, semantic priming, and long lag repetition priming were manipulated *within* subjects. This difference makes a direct comparison between studies difficult. Experiment 11 therefore used a within subject manipulation of set size. It is important to note, however, that set size is typically manipulated between subjects or at least blocked within subjects. Thus, the results of Experiment 10 are applicable to typical manipulations of set size.

Experiment 11

Experiment 11 was a replication of Experiment 10 using a *within-subject* manipulation of set size. The word on each trial was selected from either a small set or a large set and these trials were intermixed. Experiment 11 also addresses another potential concern with the design in Experiment 10. In Experiment 10 a different set of items was used in the small and large set size conditions (i.e., a set of words was randomly chosen from a larger set for use in the small set size condition and the remaining were used in the large set size condition). Thus, Experiment 11 addresses the possibility that the randomly selected words happened to be items that produce a smaller cuing effect than the remaining words. This was done by ensuring that the words that appeared in the small set size condition also appeared in the large set size condition. This way an analysis can be conducted that compares the cuing effect for the same items when they were part of a small set and when they were part of a large set.

Methods

Participants. Twenty undergraduates participated.

Design. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Set Size: Small vs. Large) within-subject design was used. Words on each trial were drawn from either a small set (i.e., 2 words) or a large set (i.e., a new word on each trial). The items were drawn from the small set on 50% of the trials and the large set on 50% of the trials.

Stimuli. Ninety words from the 4 letter word list used in Experiment 10 were used (see Appendix G). The average frequency was approximately 45 occurrences per million and on average each item had nine neighbours (Davis, 2005). Twenty of these items were divided into 10 sets of two items to be used in the small set size condition. The remaining 70 words were used in the large set size condition. Eight of these words served as practice stimuli leaving 62 for the experimental trials. Each participant received one of the 10 two-item sets. The remaining 9 sets (i.e., 18 words) were assigned to the large set size condition. Thus, there were a total of 80 items in the large set size condition and two items in the small set size condition for each participant.

Procedure. There were sixteen practice trials and 160 experimental trials. The experiment took approximately 10 minutes to complete.

Results

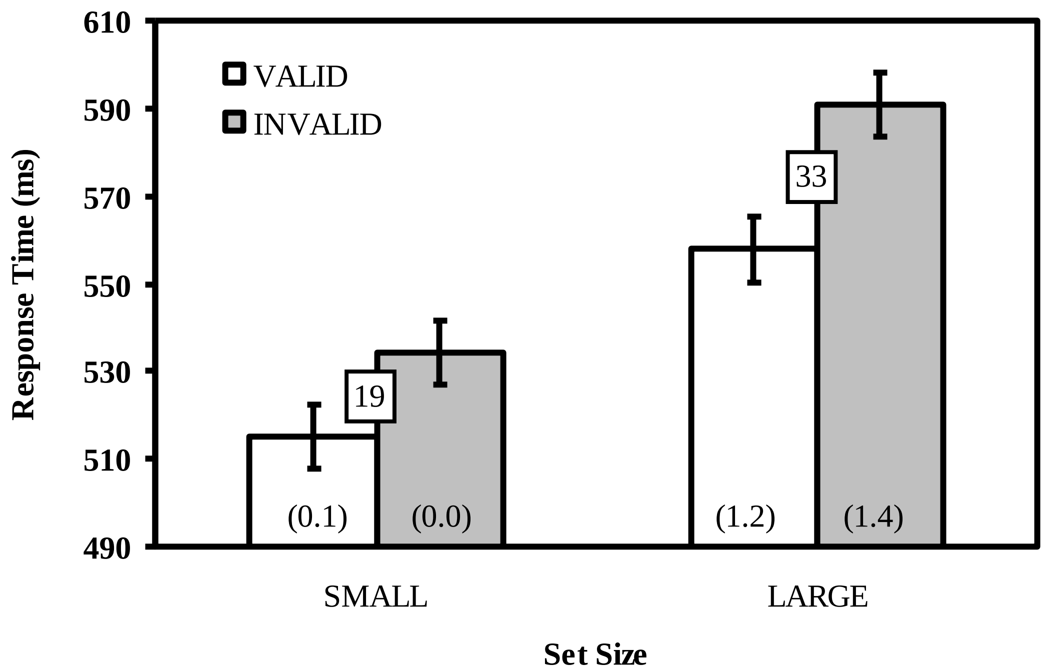
Spoiled trials (2.7%) were removed prior to analysis. The outlier procedure led to the removal of 2.0% of the RT data. Data are presented in Figure 29 and Appendix R. A 2 (Cue Validity: Valid vs. Invalid) x 2 (Set Size: Small vs. Large) ANOVA was performed on mean RT and percentage error data.

In RT, the main effects of cue validity and set size were significant, $F(1, 19) = 29.03$, $MSE = 465.97$, $p < .05$; $F(1, 19) = 47.64$, $MSE = 1033.43$, $p < .05$, respectively. Participants responded faster on valid trials (536 ms) than on invalid trials (562 ms) and faster on small set size trials (525 ms) than on large set size trials (574 ms). Critically, there was a significant interaction between the effects of cue validity and set size, $F(1, 19) = 4.68$, $MSE = 201.86$, $p < .05$. The cuing effect (invalid-valid) on small set size trials (19 ms) was smaller than the cuing effect on large set size trials (32 ms).

When the analysis was confined to words in the large set size condition that also appeared in the small set size condition, the interaction remained significant (marginally), $F(1, 19) = 3.51$, $MSE = 219.39$, $p < .08$. The cuing effect (invalid-valid) on small set size trials (19 ms) was smaller than the cuing effect on large set size trials (46 ms).

In percentage error, the main effect of set size was significant, $F(1, 30) = 13.21$, $MSE = 2.31$, $p < .05$. Participants made fewer errors on small set size trials (0.1%) than on large set size trials (1.3%). No other effects were significant.

Figure 29. Mean response times (in ms) with 95% confidence intervals (Masson & Loftus, 2003) and percentage error (in brackets) as a function of cue validity and set size in Experiment 11. Cuing effects (invalid – valid) are presented in boxes.



Discussion

In Experiment 11 the effects of cue validity and set size interacted in an overadditive fashion. The cuing effect was smaller when the word was drawn from a small set size (i.e., two words) than when it was drawn from a large set size (i.e., new word on each trial). Thus, the results of Experiment 10 generalize to a condition in which set size is manipulated within-subject and to a condition in which the small set size and large set size items are intermixed.

The results of Experiments 10 and 11 are important in a number of respects. First, these results demonstrate that a familiarity sensitive view of the relation between spatial attention and word processing is appropriate in at least one context. Increasing "familiarity" with a word via reducing set size decreases the size of the cuing effect on reading aloud. A word that is familiar within the experiment places less demands on spatial attention then a word that is not familiar within the experiment.

In terms of understanding the role of spatial attention in word processing, the discovery of a manipulation that *reduces* the size of the cuing effect in word processing is also important. The reduction here is relative to the "standard" condition in which the word is presented once in a typical format (e.g., the large set size condition, the normally spaced condition or the irrelevant features absent condition). Thus, the present series of experiments have uncovered manipulations that have no effect on cuing (i.e., long lag repetition priming, case mixing), manipulations that increase the cuing effect (i.e., reducing inter-letter spacing, adding irrelevant features to the word), and a manipulation that decreases the cuing effect on word processing (i.e., reducing set size).

Lastly, the results are also important because they, together with Broadbent and Gathercole (1990), suggest that the use of a small word set in filtering experiments will reduce the estimate of the spatial attentional requirements of word processing. As a result it will increase the likelihood of finding evidence that a word can be processed "without" spatial attention. It may now be important to reconsider the results of previous studies that have used small word sets (e.g., Brown et al., 2002; Risko et al., 2008; Shaffer & Laberge, 1979).

Sequential Effects

The use of small set sizes has a number of auxiliary consequences that researchers ignore at their own peril (e.g., Kornblum, 1969). For example, as set size is reduced the frequency of immediate repetitions will increase (Kornblum, 1969). Immediate repetitions influence response times and thus their frequency in a given context will influence overall performance (Kornblum, 1969). In the present context, the small set size has both immediate word repetitions (trial N: FORT; trial N+1: FORT) and non-repetitions (trial N: FORT; trial N+1: DARE) but in the large set size condition only non-repetitions occur. Thus, it is possible that the reduction in the magnitude of the cuing effect in the small set size condition is a result of immediate repetitions which are absent from the large set size condition.

To determine if the reduction of the cuing effect in the small set size condition was due to the presence of immediate repetitions, the analysis originally reported was performed again with all immediate repetitions removed. This re-analysis was conducted for both experiments. If the reduction in the cuing effect in the small set size conditions was due to the presence of immediate repetitions, then there should no longer be an interaction between the effects of cue validity and set size. In Experiment 10, the interaction between cue validity and set size remained significant, $F(1, 30) = 16.03$, $MSE = 195.57$, $p < .05$. The cuing effect (invalid-valid) on small set size trials (15 ms) was smaller than the cuing effect on large set size trials (43 ms). In Experiment 11, the interaction between cue validity and set size remained significant (marginally), $F(1, 19) = 3.51$, $MSE = 219.39$, $p = .07$. The cuing effect (invalid-valid) was smaller on small set size trials (20 ms) than on large set size trials (33 ms). The preceding analysis suggests that the smaller cuing effects in the small set size condition relative to the large set size condition are not due to the presence of immediate repetitions.

The Locus of Cue Validity by Set Size Interaction

If the reduction in the cuing effect in the small set size condition is not due to the presence of immediate repetitions then what causes it? In the introduction to Experiments 10 and 11 two loci for the set size effect on reading aloud were introduced: a lexical and a pre-lexical locus.

According the to the lexical level account (Morton, 1969), words in the small set size have their recognition thresholds reduced in the lexicon and thus require less input in order to cross that threshold. If set size influences lexical level processing then the interaction with cue validity would indicate that spatial attention also influences lexical processing. The problem with this account is that it would also need to explain why other putative lexical level factors do not interact with cue validity (e.g., long lag repetition priming, word frequency). One strategy here would be to suggest that these manipulations, despite popular opinion, do not actually index lexical level processing. For example, long lag repetition might index retrieval from episodic memory rather than lexical processing. Alternatively, it might be that these other lexical level manipulations were not "strong" enough to detect a lexical influence that was always there (e.g., remember that in Experiments 1 and 2 the trend was always overadditive). For example, in Experiments 1 and 2 a word was repeated once at most whereas in Experiment 10 each word in the small set size condition was repeated 80 times and in Experiment 11 each word in the small set size condition was repeated 40 times. The difficulty with an account in terms of the "strength" of the lexical influence lays in defining "strength." One natural index of strength may be the size of the manipulation's effect on reading aloud. However, the difference in response times between old and new items in Experiment 1, in which no interaction was found, was actually larger than the difference in response times between words in the small and large set size of Experiment 11, in which an interaction was found. Nonetheless, it remains possible that in order to find evidence consistent with a familiarity sensitive view of the relation between spatial attention and word processing a rather extreme manipulation of familiarity is required.

Given the problems with a purely lexical account of the set size effect on reading aloud, an interpretation in terms of a pre-lexical influence in addition to a lexical influence may be preferred. Based on evidence from stimulus probability manipulations in letter identification (Dykes and Pascal, 1981), it was suggested that set size might "prime" processing at levels as early as the feature level. According to this idea, participants "prepare" for the words in the small set size condition and this preparation facilitates feature, letter, and lexical level processing of those words. Given that the previous experiments localized the influence of spatial attention to the feature and letter levels, it would seem parsimonious to now claim that the observed interaction between the effects of cue validity and set size arises because set size facilitates processing at these levels. According to this account, the reason why manipulations like word frequency, lexicality, semantic priming (when the cue is uninformative), and long lag repetition priming do not produce interactions with cue validity is that they do not influence pre-lexical processing (i.e., feature or letter level).

Critically, whatever the process influenced by the reduction in word set size the interaction with cue validity demonstrates that spatial attention influences the same process.

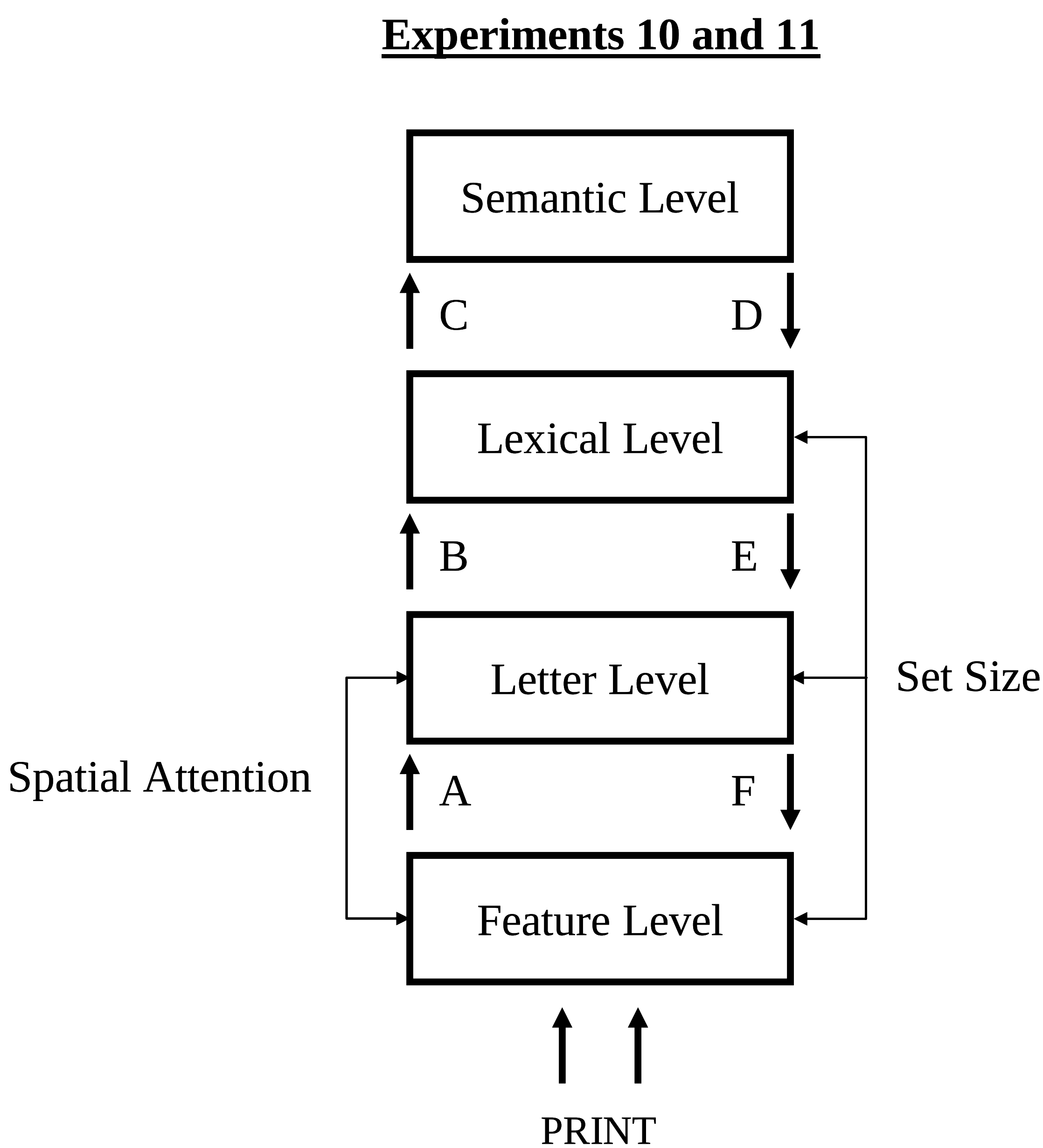
Repetition versus Set Size

The set size manipulation (and most set size and stimulus probability manipulations used elsewhere) confounds set size with number of repetitions. For example, in the present experiments in the small set size condition participants saw the small set size words more than they saw each word in the large set size condition. This need not be the case. A situation could certainly be devised wherein set size was manipulated but the number of repetitions was held constant (e.g., fewer trials in a small set size condition for example). Indeed, this type of experiment might be enlightening with respect to the locus of the set size effect on word processing.

Conclusion

In conclusion, Experiments 10 and 11 demonstrate that the effects of cue validity interact with word set size in an overadditive fashion. These results are interpreted in terms of both spatial attention and word set size influencing the feature and letter level (see Figure 30).

Figure 30. Depiction of conclusions from Experiments 10 and 11. Spatial attention influences feature and letter level processing. Set size influences feature, letter, and lexical level processing.



Chapter 8: General Discussion, Caveats, and Future Directions

General Discussion

The experimental approach adopted here consisted of combining a manipulation of cue validity with various manipulations of word processing in order to better understand the role of spatial attention in visual word processing. Five manipulations were combined with cue validity: (1) long lag repetition priming, (2) case mixing, (3) inter-letter spacing, (4) the presence/absence of irrelevant features, and (5) set size. The joint influence of cue validity and these five factors has substantially increased the empirical base on which theory development can operate (see Table 2 for a summary). In the following sections a rough sketch of the role of spatial attention in visual word processing is proposed, a number of potential caveats are discussed, and some future directions are outlined.

A Rough Sketch of the Role of Spatial Attention in Visual Word Processing

The experimental approach applied here uses the joint effects of two factors to infer the relation between the processes indexed by those factors. When the effects of two factors are additive the inference typically made is that the processes indexed by these factors are separate. When the effects of two factors interact in an overadditive fashion the inference typically made is that the same process is indexed by both factors. Given this framework, at the most basic level the present results indicate that cue validity *does not influence* the same process(es) indexed by long lag repetition priming or case mixing but *does influence* the same process(es) as reducing inter-letter spacing, adding irrelevant features, and reducing word set size. In Chapters 3 through 7, these factors were all hypothesized to influence particular component processes in word processing (e.g., inter-letter spacing influences letter level processing), however, it is important to keep in mind that these are only hypotheses and as such may change with time and may be different across researchers. What will remain is the pattern of factor effects. The fact that cue validity does not influence the same process as long lag repetition priming but does influence the same process as reducing inter-letter spacing is independent of the what the processes indexed by these factors are. As such, the results presented here will constrain theorizing whether or not the particular hypotheses regarding what processes these factors index are correct.

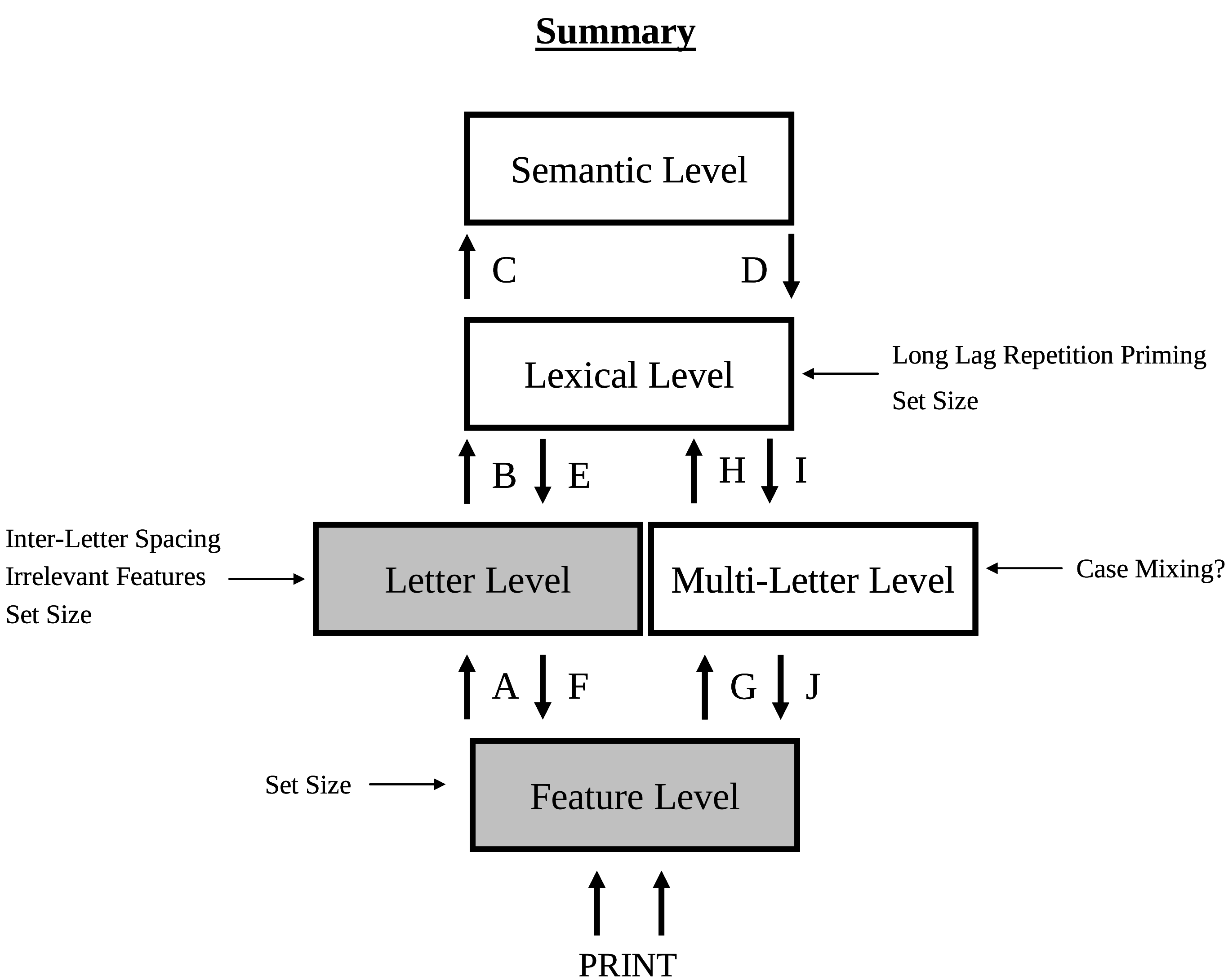
Next, the various hypotheses offered in Chapters 3 through 7 are integrated to form a coherent account of the results reported here and previous results reported using the same paradigm. In Figure 31, the influence of spatial attention on word processing is localized to the feature and letter levels. Evidence from the present experiments to support this view is based on the interactions found between the effects of cue validity and inter-letter spacing, cue validity and the presence/absence of irrelevant features, and cue validity and set size. The interaction between the effects of cue validity and stimulus contrast reported by Stolz and Stevanovski (2004) is also consistent with this claim.

The influence of spatial attention on word processing does not extend to the lexical level. Evidence from the present experiments to support this view is based on the lack of an interaction between the effects of cue validity and long lag repetition priming. The lack of an interaction between the effects of cue validity and word frequency, cue validity and lexicality, and cue validity and semantic priming with a 50% valid cue is also consistent with this claim (see Table 2).

Table 2. Summary of results from Experiments 1 through 11.

Experiment	Factor	Pattern
Experiment 1	Long Lag Repetition Priming	additive
Experiment 2	Long Lag Repetition Priming	additive
Experiment 3	Case Mixing	underadditive?
Experiment 4	Case Mixing	additive
Experiment 5	Case Mixing	additive
Experiment 6	Inter-Letter Spacing	overadditive
Experiment 7	Inter-Letter Spacing	overadditive
Experiment 8	Irrelevant Features	overadditive
Experiment 9	Irrelevant Features	overadditive
Experiment 10	Set Size	overadditive
Experiment 11	Set Size	overadditive

Figure 31. Depiction of conclusions from Experiments 1 through 11. Spatial attention influences feature and letter level processing (depicted in grey). Long lag repetition priming influences the lexical level as does set size. Case mixing may influence the formation of multi-letter groups. Inter-letter spacing, the presence/absence of irrelevant features, and set size in the letter level. Set size may also influence the feature level.



The influence of spatial attention also does not extend to the multi-letter level. This claim is based on the lack of an interaction between the effects of cue validity and case mixing. However, if case mixing influences performance via the formation of incorrect letter groups (i.e., the PIG in spring) then it remains possible that spatial attention influences the processing of multi-letter units.

This rough sketch accounts for a wide range of results in the spatial cuing paradigm. This account should be limited to manipulations of exogenous attention at present as all of the experiments reported here used a manipulation of exogenous spatial attention (as opposed to endogenous spatial attention). In addition, the present findings may also be limited to reading aloud. That said, research to date using what could be considered endogenous manipulations of spatial attention and lexical decision are also accommodated within this framework. The most troublesome finding in this respect is the interaction between the effects of cue validity and semantic priming when the cue is informative (Stolz & McCann, 2001; Stolz and Stevanovski, 2004). As noted in Chapter 2, Stolz and Stevanovski (2004) explained this interaction by suggesting that engaging the endogenous attentional system "turned on" feedback from semantics to the lexical level. It was suggested in Chapter 2 that this feedback from semantics might continue to the letter level. If so, then Stolz and McCann's (2001) and Stolz and Stevanovski's (2004) results are readily explained in the present framework. Specifically, the interaction between the effects of cue validity and semantic priming arises from a mutual influence on letter level processing (or even feature level) when feedback from semantics is operative. This account predicts that priming manipulations which influence letter and feature level processing will interact with spatial attention. In fact, this is how the cue validity by set size interaction is explained in this framework.

How Does Spatial Attention influence Feature and Letter Level Processing?

It is one thing to say that spatial attention influences a hypothetical level of processing and another to describe how it affects that process (Dykes & Pascal, 1981). The hypothesis offered here is that spatial attention influences feature and letter level processing. Two major mechanisms for this influence have been entertained. First, as suggested by Stolz and Stevanovski (2004) spatial attention may influence the rate of feature extraction. Specifically, an invalid cue slows feature activation relative to a valid cue. This proposed mechanism is consistent with a signal enhancement view of spatial attention and draws direct support from psychophysical observations in which removing spatial attention slows the rate of visual processing (Carrasco & McElree, 2001).

A second hypothesized mechanism for the influence of spatial attention on word processing in the disruption of the input into the letter level and the subsequent reduction in the rate of letter activation. For example, in Ashby et al.'s (1996) locational uncertainty model of feature integration, spatial attention is hypothesized to influence the amount of noise in the encoding of feature location. Specifically, an invalid cue would increase the amount of noise in feature encoding relative to a valid trial. The mis-localization of a feature could lead to the formation of illusory conjunctions and/or the degradation of the match between the features present and stored letter representations. In both cases, the activation of letters would be impaired. This proposed mechanism is also consistent with a signal enhancement view of spatial attention and may stem from the fact that removing spatial attention reduces spatial resolution (e.g., Yeshurun & Carrasco, 1999).

According to the arguments above, the role of spatial attention in visual word processing is best thought of as a form of signal enhancement. The extraction of features from the input occurs faster for "attended" words than "unattended" words and the accuracy with which these features are encoded (e.g., their locations) is better for "attended" words than "unattended" words. Thus, the type of processing that is occurring as spatial attention is being re-oriented on invalid trials likely consists of the slow noisy encoding of features and the initiation (though not necessarily the completion) of letter level processing.

Another interesting possibility is that spatial attention influences the segregation of letters within a word. While individuating letters may be included in the letter identification process, as was suggested in Chapters 5 and 6, it may also be possible that letter segregation is a separate process that precedes letter identification (e.g., Wolford, 1975). In this case, if an invalid cue disrupts letter segregation then this disruption would be exacerbated by a reduction in inter-letter spacing and the inclusion of irrelevant features because both make the spaces between adjacent letters less conspicuous. The relation between letter segregation the reduction in set size is less clear.

Accounting for Additivity

While the emphasis here is on identifying how spatial attention influences word processing, it is also important to consider why spatial attention *does not* influence a given level of processing. This challenge arises because most current models of word processing (e.g., Coltheart et al., 2001) assume that processing is both cascaded and interactive. Indeed, the assumption of cascaded and interactive processing has figured in the various explanations for factor effects discussed here. However, accounting for additivity between factors in these models has been difficult (Besner, Wartak & Robidoux, 2008; Borowsky & Besner, 2006). Nonetheless, additivity between factor effects is ubiquitous in both the spatial cuing experiments that have been the focus here and in word processing experiments in general (see Besner, 2006). This issue is unlikely to be resolved without further computational work investigating potential mechanisms to produce additivity between factor effects, but a couple of options are outlined below.

One of the theoretical mechanisms proposed to account for additivity between factor effects involves thresholding or staging processing (e.g., Besner et al., 2008; Sternberg, 1969). Thresholding is achieved by restricting activation flow between levels until processing at a given level is complete. Thus, any effect of a factor on that level will not propagate further into the system. For example, lexical level processing may not begin until letter level processing has finished. Yap and Balota (2007) related this type of thresholding to a kind of perceptual normalization.

In the present context, to explain the additivity between the effects of spatial attention and lexical level variables, a threshold could be introduced between the letter and lexical level (e.g., O'Malley, Reynolds & Besner, 2007). Thus, the effects of an invalid cue would not influence lexical level processing. Here, the effects of the invalid cue can be "normalized" before processing proceeds to later levels (i.e., lexical level).

This account predicts that in the context of a spatial cuing experiment, a manipulation that influences feature or letter level processing will not influence lexical level processing because its effect is being normalized before lexical processing begins. This might be a problematic prediction because in a preliminary experiment in which cue validity, long lag repetition priming, and stimulus contrast were combined, the former two replicated the additivity found here and the latter two produced an overadditive interaction (see Blais & Besner, 2007). This suggests that either (a) there is no threshold or (b) stimulus contrast has two separate influences on performance, one that is pre-lexical and is normalized by the threshold and one that is post-letter and is not normalized. This latter effect of contrast would produce the interaction between stimulus contrast and long lag repetition priming.

As a side note, manipulations of cue validity and stimulus contrast are often thought to have similar effects on visual processing (see Carrasco, 2006 for a review). In the present context, it is interesting to note that the performance decrements caused by an invalid spatial cue and the performance decrements caused by reducing stimulus contrast appear to have different effects in the context of reading aloud. For example, the joint effects of *stimulus contrast* and long lag repetition priming interact but here the effects of *cue validity* and long lag repetition priming do not interact. Also, the joint effects of stimulus contrast and word frequency interact in reading aloud (e.g., O'Malley et al., 2007) but Nichols et al. (1998) found no evidence that the effects of cue validity and word frequency interact in reading aloud. Future experiments combining these manipulations using three factor designs (e.g., cue validity by stimulus contrast by word frequency) will likely shed important light on how spatial attention and stimulus contrast influence the word processing system. One potential difference between invalid spatial cues and reductions in stimulus contrast is that in the former case spatial attention is hypothesized to return to the target location within the trial whereas in the latter case the target is dim for the entire trial.

A threshold between letter level processing and lexical level processing does not explain the additivity between the effects of cue validity and case mixing. One option here is to suggest that multi-letter units are formed only after single letter identification is completed. In this case, the post-letter threshold would yield additivity between the effects of cue validity and case mixing assuming that the threshold occurs after single letter identification but before the identification of multi-letter groups. This account would depart from the view that single and multi-letter units are independent. Case mixing may also prohibit the word processing system from using multi-letter units. For example, route H in Figure 30 may not be functional. This idea is consistent with the suggestion that case mixing might force readers into a letter-by-letter strategy (Braet & Humphreys, 2006; 2007; Mayall & Humphreys, 2001). Thus, even if the invalid cue was influencing the formation of multi-letter units it would not influence performance given case mixing “turns-off” the use of multi-letter units. An alternative view is that case mixing influences same case letter grouping rather than rate of multi-letter unit activation (Humphreys et al., 2003). Case specific grouping may require letter identification to finish thus a threshold following letter level processing may result in the additivity between the effects of cue validity and case mixing.

An alternative strategy to dealing with the challenges posed by explaining additivity is to claim that any observed additivity is actually a type II error and that spatial attention influences all levels of processing. Given the present results it would also have to be argued that, while spatial attention may influence all levels of processing to some extent, it influences some levels more than others. Otherwise, why do some factors produce statistically significant interactions with cue validity and others do not?

To provide stronger evidence for this idea (i.e., that some processes during reading aloud are more influenced by spatial attention than others) a cross-experiment analysis was conducted comparing the magnitude of the interactions across experiments. If, for example, the process indexed by a reduction in inter-letter spacing (i.e., letter level) is more influenced by an invalid spatial cue than the process indexed by long lag repetition priming (i.e., lexical level) then cue validity should yield a statistically larger interaction with the former than with the latter.

Data for this analysis was combined across replications using the same manipulation (e.g., Experiments 1 and 2 would be combined). Experiment 10 was left out of this analysis because in that experiment set size was manipulated between subjects. The size of the interaction is the difference in the magnitude of the cuing effect across the two levels of the factor in question (e.g., cuing effect at A_2 minus the cuing effect at A_1). The critical comparison is between factors that did not interact with cue validity (i.e., long lag repetition priming, case mixing) and factors that did (i.e., inter-letter spacing, presence/absence of irrelevant features, set size). It is important to note that these comparisons are testing the presence of a three way interaction (i.e., cue validity by manipulation by experiment) with a between subjects factor and as such may be difficult to detect.

Long Lag Repetition Priming

The size of the interaction between the effects of cue validity and long lag repetition priming (5 ms) was significantly *smaller* than the interaction between the effects of cue validity and inter-letter spacing (23 ms), $t(110) = 2.10$, $SED = 8.65$, $p < .05$, and between the effects of cue validity and the presence/absence of irrelevant features (19 ms), $t(158) = 2.04$, $SED = 6.53$, $p < .05$. The size of the interaction between the effects of cue validity and long lag repetition priming (5 ms) was not statistically different than the interaction between the effects of cue validity and set size (13 ms), $t(98) = .82$, $SED = 10.30$, $p < .05$.

Case Mixing

The size of the interaction between the effects of cue validity and case mixing (-5 ms) was significantly *smaller* than the interaction between the effects of cue validity and inter-letter spacing (23 ms), $t(134) = 3.07$, $SED = 9.15$, $p < .05$, and between the effects of cue validity and the presence/absence of irrelevant features (19 ms), $t(182) = 3.56$, $SED = 6.58$, $p < .05$. The size of the interaction between the effects of cue validity and case mixing (-5 ms) was not significantly different than the interaction between the effects of cue validity and set size (13 ms), $t(122) = 1.67$, $SED = 11.1$, $p = .10$.

Results of this supplementary analysis provide evidence that spatial attention influences some levels of processing in reading aloud more than others. Thus, to skirt issues associated with accepting null results and explaining additivity, a statistically defensible account of the present results is that spatial attention influences feature and letter level processing *more than* lexical level or multi-letter level processing. According to this account, although interactions with cue validity and lexical, multi-letter, and possibly semantic level manipulations might emerge with more statistically powerful designs (e.g., larger sample size), it nevertheless should remain that these interactions are *smaller* in magnitude than interactions with manipulations that influence feature or letter level processing. Thus, this account makes clear predictions for future research.

Does Word Processing Require Spatial Attention?

In Chapter 1, the issue of whether or not visual word processing requires spatial attention came up in a number of different contexts. The present paradigm is not designed to answer this question (cf. filtering tasks). Nevertheless, it is clear that spatial attention modulates word processing as a significant cuing effect was detected in all of the experiments reported here. In addition, the discovery of factors that interact reliably with cue validity demonstrates that some amount of word processing is occurring as spatial attention is being re-oriented to the word's location. If absolutely no processing was occurring the effects of all manipulated factors would be additive with cue validity. This is clearly not the case. Of course, this conclusion depends on what is considered "word processing." Spatial attention likely has similar effects on other forms of visual recognition.

Caveats

Eye Movements

In studies of covert spatial attention participants are typically instructed to maintain their fixation on the centre of the screen. Rarely in these studies are eye movement's monitored thus leaving the possibility that participants ignore the instructions and move their eyes. Participants might try to move their eyes to the cue and/or move their eyes to the target. An effort is made to make the task "easy" to do without making eye movements (e.g., the words are presented close enough to the fixation that an eye movement is not necessary to resolve the stimulus) but, inadvertent or not, they certainly occur on occasion. This is not a problem unless these undetected eye movements are somehow responsible for the observed results. However, if an alternative account in terms of undetected eye movements were made it would need to be able to account for the entire constellation of results that have been reported here and elsewhere. For example, why would inadvertent eye movements produce no interaction between the effects of cue validity and case mixing but a significant interaction between cue validity and inter-letter spacing? If such an explanation is possible (and it might be) it would strongly suggest that future work with the spatial cuing paradigm in the context of word processing tasks would need to include the tracking of eye movements.

Word Processing versus Attention Orienting

In the spatial cuing paradigm used here the manipulation of cue validity is hypothesized to influence a given level of processing within the word processing system. Thus, the duration of that process is increased on invalid trials relative to valid trials. The length of this duration increase should be related to how long it takes spatial attention to re-orient to the target word's location on invalid trials. Critically, when cue validity is combined with a manipulation of word processing it is assumed that if an interaction emerges it is because they both influence the same process in the *word processing system*. An alternative suggestion is that the manipulation introduced actually influences how long it takes for spatial attention to re-orient to the target word's location. Thus, both cue validity and the manipulation of word processing influence the *attentional orienting system*.

For example, Snowden, Wiley, and Muir (2001) argued that the interaction between cue validity and stimulus contrast (i.e., the cuing effect is larger on dim trials than bright trials) could reflect the fact that dim stimuli are less visually salient and thus on invalid trials participants are slower to initiate the re-orienting of spatial attention.

This delay imposed on re-orienting would not be present on valid trials given there is no need to re-orient and thus an overadditive interaction between the effects of spatial cuing and stimulus contrast would emerge. Critically, this interaction would not be attributable to both cue validity and stimulus contrast influencing the same target processing stage.

This insight is important in the present context because it suggests the possibility that an interaction between cue validity and another factor could emerge outside the word processing system. Indeed, it suggests a rather straightforward manner to produce spurious overadditive or even underadditive interactions. For example, a manipulation that makes the word *harder* to read and *less* visually salient would produce an overadditive interaction (e.g., stimulus contrast) and a manipulation that makes the word *harder* to read but *more* visually salient would produce an underadditive interaction (e.g., FORT vs. XXXFORTXXX).

The issue being raised here is not a particular problem when psycholinguistic variables like long lag repetition priming or word frequency are used because there is no reason to expect that these variables influence visual saliency. The issue becomes more of a problem when perceptual variables (e.g., stimulus contrast, the presence/absence of irrelevant features) are used because there is good reason to expect that these variables influence visual saliency. This will be an important methodological consideration going forward given that it is these perceptual variables that produce meaningful interactions with cue validity.

With respect to the present experiments, an effort was made to use manipulations that should not produce spurious interactions due to the visual saliency of the target. Indeed, the manipulation of the presence/absence of irrelevant features (i.e., Experiments

8 and 9) actually pits a spurious underadditive interaction due to saliency against an overadditive interaction due to the two manipulations influencing the same stage of processing. Specifically, adding irrelevant features to a word makes it more salient (i.e., adding visual information) and thus should have produced a smaller cuing effect. If the effects of cue validity and the presence/absence of irrelevant features influence the same word processing stage, however, then an overadditive interaction is predicted. The latter was the case. A strategy in which saliency and word processing make different predictions is likely a useful way to address such concerns in the future.

More on Overadditive Interactions

An issue that is often raised when an overadditive interaction in response times is reported (e.g., Experiments 6-11) is that the larger effect of one factor at the slower level of the other factor is actually due to overall response time (i.e., effects will always be largest in the slowest condition). This account runs into trouble, however, when an increase in response time from one level of a factor to another is not associated with a concomitant increase in the effect of a jointly manipulated factor (i.e., additivity; see Experiments 1-5; see Visser & Besner, 2001). For example, in Experiment 5 there was a 40 ms main effect of case mixing but the cuing effect at both levels of the case mixing factor was 36 ms. The size of the cuing effect was not largest in the slowest condition.

A similar argument can be made with regard to the fact that in some cases a factor’s effect may be numerically larger in the slower condition but might not be proportionally larger (e.g., a 50 ms effect on a base of 500 ms is equivalent proportionally to an 80 ms effect on a base of 800 ms). Using “proportions” rather than the raw size of the effect would not change the pattern of results *across* experiments assuming that the differences in the mean RTs across conditions are roughly equivalent.

Reading Aloud versus Lexical Decision

The primary motivation for the use of reading aloud, as opposed to lexical decision, was that the latter task had been used almost exclusively in previous work using a spatial cuing manipulation in word processing tasks (see Coltheart et al., 2001). In Chapter 1, it was also suggested that the role of spatial attention in reading aloud tasks and lexical decision tasks might be different (Arduino et al., 2003; Ladavas, Shallice & Zanella, 1997; Ladavas, Umilta & Mapelli, 1997). The present investigation did not provide a direct test of this idea, but the results reported are in no way inconsistent with previous work using lexical decision. That said, a more direct comparison would be required to make any strong claims on this matter.

Future Directions

Exogenous vs. Endogenous Spatial Attention

As already noted, potential differences between exogenous and endogenous spatial attention in the context of word processing is likely a profitable direction for future research. Stolz and McCann (2001) and Stolz and Stevanovski (2004) have already demonstrated that exogenous and endogenous spatial attention may influence word processing in qualitatively different ways. For a complete understanding of the role of spatial attention in word processing both the similarities and the differences need to be explored.

Spatial Attention and Letter Location

In Chapter 1's review of spatial attention and word processing, one idea was that spatial attention may play some role in localizing letters. For example, letter position dyslexia, wherein letters within a letter string migrate, was thought to be caused by an attentional impairment (Freidmann & Gvion, 2001). The letter migrations that occur in brief multi-element displays have also been associated with spatial attention (Treisman & Souther, 1985). This could be viewed as analogous to a feature integration perspective in which letters are considered "features" and spatial attention is required to bind the letters to their appropriate positions. The present experiments do not provide a test of this general idea.

In some preliminary studies, using transposed letter nonwords, I have not found much support for the hypothesis that spatial attention influences the localization of entire letters within words. In these experiments, participants were presented with masked nonwords that would form a word if the letters within it were transposed (e.g., FROT = FORT) and were asked to make a lexical decision. If spatial attention is required to bind letters to locations participants should be more likely to make a transposition error (i.e., call a transposed letter nonword a word) on invalid trials. This does not appear to be the case. In fact, participants appear slightly more likely to make transposition errors on valid trials. Interestingly, if this pattern holds up, it would be consistent with the present idea that spatial attention influences letter level processing in the sense that when spatial attention is withheld the letters would be less likely to be accurately identified and therefore less likely to be transposed. Future work on this issue will use words (rather than nonwords) with transposition neighbours (e.g., silt and slit, marital and martial; Andrews, 1996) to further explore this idea.

Spatial Attention within Words

The manipulation of spatial attention used here provides an index of the differences between word processing when the spotlight of attention is on versus off the word. In Chapter 1, it was suggested that this type of manipulation may not tell us much about the role of spatial attention *within* words (e.g., Auclair & Seiroff, 2002). For example, Ans et al. (1998) and Perry et al. (2007) have assigned spatial attention a role in sub-lexical processing in which the spotlight moves through the letter string as a kind of part based processing mechanism. This idea is certainly intriguing and appears to have some support in the literature (Facoetti et al, 2006). Currently, the differences between within word cuing (Auclair & Seiroff, 2002) and on/off cuing (McCann et al., 1992) are sufficiently large (e.g., the former uses brief displays, masking, and accuracy as the main dependent variable) to preclude any strong conclusions regarding a dissociation between what they index in the context of word processing. A future effort to reduce these differences and directly compare performance as a function of both of these cuing procedures will likely represent an important step in understanding the potential *roles* of spatial attention in visual word processing.

Applications

Understanding the role of spatial attention in word processing has important potential applications. As described in Chapter 1, attentional deficits can lead to impaired reading. Impaired reading, of course, can severely limit an individual’s success in everyday life. Understanding the role of spatial attention in word processing allows us to move toward alleviating the issues encountered by individuals with attentional deficits or even improving reading efficiency in skilled readers.

`The research described here, for example, suggests that spatial attention is important for feature and letter level processing in reading. For example, by simplifying the relation between features and letters we may be able to reduce the spatial attentional requirements of word processing. To this end, using the principles outlined in the present investigation preliminary experiments have been conducted aimed at designing a less attentionally demanding font. Using previous research based on feature distinctiveness in letter recognition (Lockhead & Crist, 1970), the results have been encouraging. Specifically, it appears as though the principles derived from the basic research described herein may lead to the development of a font that would make deficits in spatial attention less cumbersome to readers. The idea that spatial attention and letter segregation are related also suggests that reading text with small spaces between letters or reading handwritten text in which adjacent letters are actually connected would place greater demands on spatial attention. Thus, the present work highlights a number of potential recommendations that could be made to reduce the spatial attentional demands of reading. If this is indeed possible, then it could represent an important step forward in the design of visually based reading aids.

Conclusion

The present investigation has provided a number of new findings that in conjunction with previous work serve to constrain theories regarding the role of spatial attention in visual word processing. In addition, a rough sketch of the role of spatial attention in word processing was provided that can serve as a guide for future research.

Understanding spatial attention in visual word processing is significant both from a basic and applied research perspective. The present work represents a step forward in this important endeavour.

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Appendix A. Word list used in Experiment 1.

aisle	crepe	ghoul	lamb	rogue	sword
aunt	crow	gist	learnt	scent	thumb
beau	deaf	glove	lieu	sewn	tomb
bind	dealt	glow	limb	shoe	tread
bowl	debt	grind	malt	shove	trough
brooch	douche	guild	monk	soot	tsar
broom	dough	guise	mould	sown	wad
chasm	dove	have	naive	sponge	warp
chef	dreamt	hearse	niche	stead	wart
chic	dual	hearth	pear	steak	wasp
choir	dwarf	heir	pearl	stow	weird
chord	feud	hood	pier	suede	wolf
chute	fiend	hoof	pint	suite	womb
comb	flood	isle	plaid	swan	worm
cough	flown	knoll	realm	swap	yacht
coup	geese	knot	reign	swarm	yolk

Appendix B. Word list used in Experiments 2 and 3.

band	cook	fort	loop	pull	stem
barn	cool	fund	luck	push	suit
bath	cope	gear	maid	rain	tail
beam	core	gift	mail	rear	tale
bear	corn	goal	male	rent	tape
beat	crew	gold	meal	rice	task
beef	crop	golf	meat	ring	tent
beer	dawn	grip	mess	risk	text
belt	dean	gulf	milk	rock	tone
bend	dear	hide	mine	roll	tool
bent	desk	hill	mood	roof	trap
bird	dust	horn	moon	rush	tree
boat	ease	host	myth	safe	tube
bomb	edge	hurt	nest	sake	type
bond	fair	inch	nose	sale	vice
bone	fast	jean	pace	salt	vote
bore	fate	join	pack	save	wage
boss	fill	joke	page	seat	ward
bowl	fist	jump	pale	seed	warm
buck	flat	knee	palm	shop	wear
calm	flow	lake	pick	sink	wild
camp	flux	lane	pike	site	wind
cape	foam	lean	pile	snow	wise
card	foil	lift	pink	soap	wood
cash	folk	lime	pipe	soft	yard
cast	fool	load	plug	soil	
chin	foot	loan	pond	song	

Appendix C. Word list used in Experiments 4, 7, and 9.

beach	craft	guilt	reach	speed	theme
bench	crash	judge	right	staff	thick
blame	cream	might	rough	stand	tooth
bound	draft	morse	route	start	touch
bread	drill	paint	scene	state	tough
brief	drink	pause	score	steel	track
burst	earth	peace	share	stern	train
catch	field	phase	sharp	still	treat
chair	fight	phone	sheet	stock	trust
chart	floor	pitch	shell	store	truth
child	frame	point	short	storm	voice
claim	fruit	pound	sight	stuff	wound
class	grace	press	skirt	style	wrong
clean	grain	price	slide	suite	youth
clerk	grant	pride	smart	swift	
close	guard	proof	smell	swing	
cloth	guess	quick	smoke	taste	
cloud	guest	ranch	snake	teeth	

Appendix D. Word list used in Experiment 5.

air	down	gun	name	sign	top
awe	drive	haste	nest	six	torch
ball	dusk	high	paid	skull	tree
bath	each	home	piece	slab	trout
been	eight	house	place	smash	veil
boom	fare	job	plane	sort	view
case	feel	land	plump	sound	wait
cause	feet	large	queen	south	well
chance	find	less	rice	spin	wind
cheer	float	life	rim	spoil	wish
chief	food	like	road	spoon	witch
cold	force	long	roast	spy	world
cut	free	loss	rude	stack	wreck
dame	gas	maid	scratch	stage	zoo
day	gaze	march	scrub	stool	
dense	girl	mask	sea	tape	
desk	goal	mayor	ship	there	
did	gorge	mint	side	thing	

Appendix E. Word list used in Experiments 6 and 8.

band	cool	fool	load	plug	soft
barn	cope	foot	loan	pond	soil
bath	core	fort	loop	port	song
beam	corn	fund	luck	pull	stem
bear	crew	gate	maid	push	suit
beat	crop	gear	mail	rain	tail
beef	dawn	gift	male	rear	tale
beer	dean	goal	meal	rent	tape
belt	dear	gold	meat	rice	task
bend	deck	golf	mess	ring	tent
bent	desk	grip	milk	risk	text
bird	disk	gulf	mine	rock	tone
boat	dive	hide	mood	roll	tool
bomb	dust	hill	moon	roof	trap
bond	ease	horn	myth	rush	tree
bone	edge	host	nest	safe	tube
bore	fail	hurt	nose	sake	type
boss	fair	inch	pace	sale	vice
bowl	fast	jean	pack	salt	vote
buck	fate	join	page	save	wage
calm	fill	joke	pale	seat	ward
camp	fist	jump	palm	seed	warm
cape	flat	knee	pick	self	wear
card	flow	lake	pike	shop	wild
cash	flux	lane	pile	sink	wind
cast	foam	lean	pink	site	wise
chin	foil	lift	pipe	snow	wood
cook	folk	lime	plot	soap	yard

Appendix F. Word list used in Experiment 10. Items with an asterisk (*) were inadvertently repeated within the experiment and not analysed. Superscripts indicate pairs of items used in the small set size condition.

band	cope	gate	meat	risk	till[2]
barn	core	gear	mess	rock	tone
bath	corn	gift	milk	roll	tool
beam	crew	goal	mine	roof	trap
bear	crop	gold	mood	root[3]	tree
beat	dawn	golf	moon	rush	tube
beef	dean	grip	myth	safe	vice
beer	dear	gulf	nest	sake	vote
belt	deck	hide	nose	sale	wage
bend	desk	hill	pace	salt	ward
bent	disk	horn	pack	save	warm
bird	dive	host	page	seat	wash[1]
boat	dust	hurt	pale	seed	wave[4]
bomb	ease	inch	palm	self	wear
bond	edge	jean	pick	shop	wild
bone	fail	join	pike	sink	wind
bore	fair	joke	pile	site	wise
boss	fast	jump	pink	snow	wood
bowl	fate	knee	pipe	soap	yard
buck	fill	lake	plot*	soft	
calm	fist	lane	plug	soil	
camp	flat	lean	pond	song	
cape	flow	lift	port	star[2]	
card	flux	load	pull	stem	
cash	foam	loan	push	suit	
cast	foil	loop*	rain	tail	
cell[3]	folk	luck	rank[4]	tale	
chin	fool	maid	rear	tape	
coat[1]	foot	mail	rent	task	
cook	fort	male	rice	tent	
cool	fund	meal	ring	text	

Appendix G. Word list used in Experiment 11. Superscripts indicate pairs of items used in the small set size condition.

barn	dear[10]	gift[5]	load	pull[1]	snow
beam	dust	goal	loan[8]	push	stem[6]
beef	fair	gold	loop	rain	tale
bend[2]	fast	golf[2]	meal[5]	rice[9]	text
bent	fate	grip	mine	ring[9]	tube
bird	fill	hide	mood	risk	vice[4]
boat[1]	fist	host	myth	rock[8]	vote
boss	flat	hurt[10]	nest	roll[4]	wage[6]
bowl[7]	flow	jean3	nose	roof	ward
calm	flux	join	pace	rush	warm
camp	foam	knee	pack	seat	wear
cape	fool	lake[3]	palm	seed	wild
cool	foot	lane	pink	shop	wise
crop	fort	lean	plot	sink	wood
dean	gear	lime	pond	site[7]	yard

Appendix H. Participant means for Experiment 1 as a function of Cue Validity (Valid vs. Invalid) and Repetition (Old vs. New) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 1							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
OLD	NEW	OLD	NEW	OLD	NEW	OLD	NEW
708	754	802	925	0.0	5.6	6.3	20.0
652	741	675	774	0.0	15.8	13.3	20.0
648	692	740	814	0.0	21.1	0.0	15.8
643	698	752	865	0.0	0.0	0.0	11.1
543	558	585	600	0.0	5.0	0.0	0.0
690	750	753	785	0.0	5.9	0.0	10.5
687	926	738	799	5.9	30.0	6.3	20.0
666	655	706	717	0.0	0.0	0.0	25.0
680	762	743	729	0.0	15.0	0.0	5.0
660	690	743	843	11.8	5.0	0.0	5.9
841	909	855	993	0.0	11.1	0.0	0.0
635	735	732	777	0.0	10.0	10.5	5.0
700	710	767	789	0.0	0.0	0.0	0.0
509	621	577	632	0.0	10.0	0.0	5.3
658	709	786	820	7.1	16.7	0.0	12.5
533	548	563	685	0.0	10.0	0.0	5.3
555	626	594	702	0.0	10.0	0.0	0.0
628	665	624	763	0.0	10.0	0.0	5.6
602	771	663	748	0.0	5.3	0.0	10.0
600	629	659	686	0.0	10.0	0.0	10.5
666	719	785	792	0.0	0.0	0.0	0.0
573	618	642	677	0.0	0.0	0.0	5.3
570	599	600	621	0.0	0.0	5.6	10.5
662	637	715	748	11.8	5.0	5.9	20.0
485	518	485	517	5.9	5.0	0.0	5.3
663	701	762	752	5.9	5.3	7.1	5.6
668	787	624	811	0.0	11.1	0.0	6.3
762	781	738	872	0.0	5.3	17.7	15.0
679	728	710	809	0.0	5.0	5.9	15.0
575	660	554	595	5.6	11.1	0.0	5.0
593	669	693	808	0.0	0.0	0.0	5.6
623	804	675	842	5.3	15.8	5.9	10.0

Appendix I. Participant means for Experiment 2 as a function of Cue Validity (Valid vs. Invalid) and Repetition (Old vs. New) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 2							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
OLD	NEW	OLD	NEW	OLD	NEW	OLD	NEW
507	489	526	509	0.0	0.0	0.0	0.0
458	465	493	516	0.0	0.0	0.0	0.0
489	524	504	518	2.8	5.7	0.0	0.0
507	509	516	541	0.0	2.8	0.0	2.8
433	417	422	422	0.0	0.0	0.0	0.0
556	593	611	635	3.2	0.0	0.0	0.0
479	453	480	494	0.0	0.0	0.0	0.0
428	441	452	440	0.0	0.0	2.8	0.0
500	507	550	580	0.0	0.0	0.0	0.0
530	536	581	607	0.0	0.0	0.0	0.0
418	460	492	504	0.0	0.0	0.0	0.0
485	474	488	492	0.0	0.0	0.0	0.0
647	636	681	672	0.0	0.0	0.0	0.0
399	416	433	426	0.0	0.0	0.0	0.0
508	547	529	557	0.0	0.0	0.0	0.0
481	539	556	578	0.0	0.0	3.0	3.0
492	477	515	535	0.0	0.0	0.0	0.0
495	525	513	518	0.0	0.0	0.0	5.7
518	520	556	548	0.0	2.8	0.0	0.0
578	552	622	604	0.0	0.0	0.0	0.0
452	441	526	505	0.0	0.0	0.0	0.0
567	571	572	596	0.0	0.0	0.0	0.0
484	486	494	485	0.0	2.8	0.0	0.0
525	544	544	587	0.0	0.0	3.3	0.0
644	656	650	708	0.0	0.0	0.0	0.0
595	621	617	645	0.0	0.0	0.0	0.0
590	593	593	615	0.0	2.9	2.9	0.0
568	583	569	602	0.0	0.0	0.0	0.0
448	460	478	473	0.0	2.8	0.0	0.0
469	463	468	494	0.0	0.0	2.8	2.8
469	487	485	495	0.0	0.0	0.0	3.2
510	530	583	617	0.0	0.0	0.0	0.0
523	530	589	600	0.0	0.0	0.0	0.0
425	432	450	462	0.0	0.0	0.0	0.0
498	501	509	528	2.9	2.8	0.0	5.7
431	461	442	468	0.0	2.9	3.0	0.0
490	536	558	588	0.0	3.0	0.0	0.0
462	461	501	521	0.0	0.0	0.0	0.0
452	468	467	451	0.0	0.0	0.0	2.9
606	615	645	635	0.0	0.0	3.3	2.8
443	443	482	496	0.0	0.0	0.0	3.1
595	629	599	636	0.0	2.9	2.9	0.0
476	490	510	517	0.0	2.9	0.0	2.9
552	583	586	612	0.0	0.0	0.0	0.0
614	651	682	723	0.0	0.0	0.0	0.0
526	515	571	563	0.0	0.0	0.0	0.0
510	496	532	576	0.0	2.9	0.0	0.0
525	533	579	592	0.0	0.0	3.0	0.0

Appendix J. Participant means for Experiment 3 as a function of Cue Validity (Valid vs. Invalid) and Case (Same vs. Mixed) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 3							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
SAME	MIXED	SAME	MIXED	SAME	MIXED	SAME	MIXED
533	547	557	572	0.0	2.6	5.4	5.3
690	706	720	778	0.0	0.0	2.6	5.4
574	601	627	607	0.0	0.0	0.0	0.0
554	573	595	626	0.0	0.0	0.0	2.6
498	504	532	525	5.4	8.1	2.7	0.0
541	558	519	566	0.0	0.0	0.0	2.8
815	873	907	919	0.0	5.6	0.0	0.0
601	637	627	647	2.6	2.6	0.0	0.0
689	747	698	731	2.6	0.0	0.0	0.0
586	611	661	628	0.0	5.6	0.0	0.0
540	539	611	607	0.0	0.0	0.0	0.0
590	624	651	633	0.0	0.0	0.0	8.3
571	576	626	605	2.6	2.9	0.0	0.0
691	704	755	764	0.0	7.9	0.0	2.8
639	635	639	588	2.6	5.4	2.6	2.7
730	711	716	767	0.0	0.0	0.0	2.9
513	545	528	547	0.0	0.0	5.3	5.4
534	575	533	548	0.0	2.7	5.3	13.2
544	563	567	583	0.0	2.6	2.7	5.3
549	612	632	638	0.0	0.0	0.0	0.0
519	605	592	626	0.0	0.0	0.0	2.8
533	545	582	620	5.4	14.7	5.3	5.3
549	578	635	687	2.7	5.4	0.0	5.6
541	567	598	639	0.0	0.0	0.0	2.9
584	649	623	693	0.0	0.0	0.0	14.3
493	535	571	548	5.7	7.9	5.3	5.7
589	645	636	670	2.6	2.6	0.0	0.0
557	625	586	662	0.0	0.0	0.0	2.7
531	585	613	675	2.7	0.0	2.9	5.3
476	522	534	537	0.0	2.8	0.0	2.9
486	516	513	526	0.0	0.0	0.0	2.6
749	762	753	822	0.0	5.4	0.0	2.6

Appendix K. Participant means for Experiment 4 as a function of Cue Validity (Valid vs. Invalid) and Case (Same vs. Mixed) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 4							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
SAME	MIXED	SAME	MIXED	SAME	MIXED	SAME	MIXED
594	633	621	630	0.0	12.5	0.0	0.0
597	635	582	778	0.0	8.3	8.7	14.3
594	580	634	676	4.2	8.3	0.0	4.2
882	880	912	914	0.0	8.3	0.0	4.3
654	701	701	698	0.0	0.0	4.2	12.5
539	594	560	542	5.0	4.3	4.2	4.8
595	645	602	663	0.0	0.0	0.0	4.2
609	651	676	700	0.0	0.0	0.0	0.0
595	596	565	642	0.0	12.5	0.0	8.3
627	625	668	668	0.0	0.0	0.0	0.0
662	687	660	726	4.2	0.0	0.0	4.2
562	600	661	676	4.2	0.0	0.0	0.0
637	724	709	792	0.0	0.0	8.3	13.0
654	707	706	734	0.0	0.0	4.2	0.0
583	676	591	622	0.0	8.3	0.0	4.2
587	629	626	658	0.0	4.8	4.2	0.0
689	815	709	822	4.8	0.0	0.0	15.0
765	760	755	794	4.2	4.8	4.2	4.5
558	612	605	687	0.0	0.0	0.0	0.0
666	694	776	774	4.3	4.2	0.0	0.0
556	602	569	602	4.5	8.3	0.0	0.0
647	694	685	734	0.0	0.0	0.0	4.3
666	680	674	695	0.0	0.0	0.0	4.3
713	841	771	805	4.3	4.2	8.7	8.7
509	558	572	596	0.0	8.7	8.3	4.5
627	629	676	742	2.1	4.7	2.2	4.7
476	505	525	525	0.0	4.3	8.7	8.3
688	721	715	761	4.2	0.0	0.0	4.3
649	678	745	743	0.0	4.2	0.0	4.2
613	641	638	677	0.0	0.0	0.0	0.0
676	716	661	741	4.3	4.3	8.7	8.7
592	636	673	694	4.2	4.5	0.0	0.0

Appendix L. Participant means for Experiment 5 as a function of Cue Validity (Valid vs. Invalid) and Case (Same vs. Mixed) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 5							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
SAME	MIXED	SAME	MIXED	SAME	MIXED	SAME	MIXED
604	601	666	680	0.0	4.3	0.0	0.0
516	589	692	598	0.0	4.3	0.0	0.0
561	607	630	612	0.0	8.7	0.0	0.0
608	638	639	636	4.5	0.0	0.0	8.7
543	571	577	666	0.0	0.0	4.2	12.5
531	564	553	561	4.2	9.1	0.0	16.7
581	607	584	674	4.8	4.3	5.3	4.3
526	560	533	582	0.0	0.0	0.0	0.0
515	501	597	626	0.0	0.0	0.0	0.0
502	588	553	545	0.0	4.2	4.2	0.0
529	650	624	649	4.2	9.1	0.0	0.0
470	539	529	589	0.0	4.2	0.0	8.3
550	547	563	544	4.2	4.2	0.0	12.5
508	563	549	616	4.2	12.5	8.7	12.5
515	569	585	628	4.3	0.0	0.0	4.5
537	546	625	647	4.2	0.0	0.0	4.5
500	521	593	635	0.0	0.0	4.2	4.2
576	601	629	667	0.0	4.3	0.0	0.0
530	572	663	670	0.0	0.0	0.0	0.0
456	482	559	608	0.0	0.0	0.0	4.3
577	673	658	681	0.0	0.0	0.0	0.0
504	525	566	602	0.0	0.0	0.0	4.2
555	562	626	721	4.8	8.7	4.2	0.0
700	663	709	746	0.0	9.1	9.5	4.8
710	701	648	671	0.0	8.3	4.3	0.0
582	614	639	635	0.0	4.3	4.2	0.0
497	507	554	606	0.0	4.2	0.0	0.0
531	636	612	649	4.2	0.0	0.0	4.2
616	698	711	773	0.0	4.2	0.0	0.0
518	523	600	627	0.0	4.5	0.0	8.7
535	534	635	720	0.0	4.3	0.0	8.7
585	633	570	708	0.0	0.0	4.2	0.0
654	629	650	660	0.0	0.0	4.2	0.0
683	664	696	658	4.2	8.7	4.2	0.0
513	562	626	609	4.2	4.2	8.3	0.0
707	778	793	803	4.2	0.0	0.0	0.0
740	790	759	767	0.0	0.0	4.3	8.7
513	513	527	563	0.0	8.3	0.0	0.0
597	638	669	639	9.1	4.8	0.0	8.7
627	634	640	685	0.0	0.0	0.0	0.0

Appendix M. Participant means for Experiment 6 as a function of Cue Validity (Valid vs. Invalid) and Inter-Letter Spacing (Normal vs. Reduced) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 6							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
NORMAL	REDUCED	NORMAL	REDUCED	NORMAL	REDUCED	NORMAL	REDUCED
537	565	617	630	0.0	0.0	0.0	0.0
624	630	664	646	2.5	5.0	0.0	0.0
478	461	506	558	0.0	0.0	0.0	0.0
621	650	627	657	0.0	0.0	0.0	0.0
439	484	513	539	0.0	0.0	7.5	5.3
548	551	688	739	0.0	2.5	0.0	8.1
549	539	609	635	7.9	0.0	0.0	5.1
515	525	558	553	0.0	7.5	5.0	0.0
529	519	525	557	0.0	0.0	0.0	0.0
535	553	587	608	0.0	2.7	0.0	0.0
616	633	686	706	0.0	2.6	0.0	2.6
529	525	564	589	2.8	5.7	2.6	2.8
599	635	684	756	0.0	0.0	2.6	0.0
493	466	545	574	0.0	5.0	0.0	2.5
537	532	642	672	0.0	2.7	2.6	0.0
548	550	631	627	0.0	0.0	2.6	2.5

Appendix N. Participant means for Experiment 7 as a function of Cue Validity (Valid vs. Invalid) and Inter-Letter Spacing (Normal vs. Reduced) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 7							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
NORMAL	REDUCED	NORMAL	REDUCED	NORMAL	REDUCED	NORMAL	REDUCED
508	524	541	593	0.0	5.3	0.0	4.2
526	532	599	667	0.0	0.0	0.0	0.0
444	466	503	551	4.2	0.0	0.0	0.0
545	532	591	582	0.0	0.0	0.0	0.0
576	576	530	622	0.0	0.0	0.0	0.0
553	601	672	683	0.0	0.0	0.0	0.0
525	549	580	632	0.0	0.0	0.0	4.2
619	683	744	846	0.0	0.0	0.0	0.0
652	706	736	771	0.0	5.0	8.7	9.1
624	629	719	720	0.0	0.0	0.0	0.0
526	549	575	596	0.0	4.2	0.0	0.0
597	559	652	623	0.0	0.0	0.0	0.0
611	546	612	656	9.1	9.5	0.0	16.7
481	486	585	613	4.2	0.0	0.0	0.0
623	660	650	712	0.0	0.0	0.0	0.0
693	670	657	711	0.0	0.0	0.0	0.0

Appendix O. Participant means for Experiment 8 as a function of Cue Validity (Valid vs. Invalid) and the Presence/Absence of Irrelevant Features (Present vs. Absent) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 8							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT
547	612	573	604	0.0	2.6	0.0	0.0
604	699	617	771	2.6	0.0	0.0	0.0
484	585	493	607	2.6	0.0	5.4	0.0
600	733	630	778	2.6	13.2	2.6	5.0
451	510	474	510	2.6	5.3	2.6	5.6
483	592	555	690	0.0	2.5	0.0	0.0
552	614	598	724	0.0	2.6	0.0	0.0
570	667	666	798	0.0	0.0	0.0	2.5
636	716	643	703	2.5	0.0	0.0	5.0
572	681	647	716	0.0	0.0	0.0	0.0
472	550	494	581	0.0	0.0	2.5	0.0
486	537	503	614	2.5	10.0	0.0	0.0
512	525	529	648	0.0	0.0	0.0	0.0
590	640	585	682	0.0	0.0	0.0	2.9
528	575	550	601	0.0	0.0	0.0	0.0
539	602	585	777	0.0	2.5	0.0	2.6
535	601	583	678	2.6	0.0	2.5	5.0
521	560	534	618	2.5	5.0	0.0	2.6
636	776	689	800	0.0	2.8	0.0	0.0
516	551	523	564	0.0	12.5	0.0	7.5
466	516	568	631	2.5	8.1	2.5	5.0
586	670	614	724	0.0	0.0	0.0	2.5
596	707	688	792	0.0	0.0	2.6	0.0
437	538	523	570	0.0	2.6	0.0	7.9
586	634	648	698	2.5	2.5	0.0	2.5
597	712	616	652	0.0	5.1	2.6	2.7
570	653	616	688	0.0	2.7	0.0	2.6
455	516	466	497	0.0	7.5	0.0	2.5
588	631	679	713	2.5	2.6	0.0	5.4
452	495	453	500	0.0	2.5	0.0	5.0
549	633	589	724	0.0	0.0	2.5	0.0
507	546	537	602	2.5	0.0	7.5	0.0
535	589	562	646	0.0	5.1	5.0	15.4
476	541	489	579	2.5	0.0	5.0	2.5
670	746	698	764	0.0	0.0	0.0	0.0
529	668	629	748	0.0	2.5	2.7	7.5
568	629	630	685	0.0	2.6	0.0	0.0
569	627	591	744	0.0	5.3	5.4	2.5
542	570	546	598	0.0	5.0	0.0	2.5
446	583	517	619	0.0	2.6	0.0	0.0
536	601	615	719	0.0	0.0	0.0	0.0
531	630	578	708	0.0	0.0	0.0	5.3
447	460	456	489	2.6	11.1	10.5	2.8
567	631	602	713	2.5	0.0	0.0	5.0
477	491	472	511	0.0	10.3	5.0	12.8
470	562	481	572	0.0	0.0	0.0	5.1
557	609	587	669	2.5	8.3	0.0	0.0
529	630	579	706	5.6	7.5	2.6	13.5

Appendix P. Participant means for Experiment 9 as a function of Cue Validity (Valid vs. Invalid) and the Presence/Absence of Irrelevant Features (Present vs. Absent) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 9							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT	ABSENT	PRESENT
604	766	649	782	0.0	0.0	0.0	0.0
440	460	459	557	0.0	4.3	0.0	0.0
583	627	624	699	4.2	0.0	0.0	0.0
385	416	462	456	4.2	4.2	8.3	0.0
501	618	602	768	0.0	8.3	0.0	4.3
539	614	574	687	0.0	8.3	8.3	4.3
433	478	471	511	0.0	0.0	4.3	4.2
490	540	484	561	0.0	0.0	0.0	0.0
506	586	538	610	0.0	0.0	4.3	0.0
581	653	596	720	0.0	0.0	0.0	4.2
478	535	513	595	0.0	0.0	0.0	0.0
614	636	685	721	0.0	0.0	4.2	8.3
462	551	512	556	0.0	0.0	0.0	4.3
453	510	519	601	0.0	0.0	4.3	4.2
519	548	585	647	4.2	18.2	0.0	0.0
542	593	534	630	0.0	0.0	4.2	0.0
567	625	572	679	0.0	4.3	0.0	0.0
539	570	539	637	0.0	0.0	4.3	0.0
604	673	620	677	4.2	0.0	0.0	0.0
500	566	514	594	0.0	9.1	0.0	4.3
542	534	534	568	0.0	9.1	4.2	4.3
541	612	551	668	0.0	0.0	0.0	5.0
455	488	478	547	0.0	0.0	0.0	0.0
471	598	507	574	0.0	12.5	0.0	0.0
560	548	558	593	4.2	0.0	0.0	0.0
516	562	535	673	0.0	0.0	0.0	0.0
466	582	492	568	0.0	8.3	0.0	16.7
521	569	580	607	4.2	0.0	0.0	4.3
463	472	444	513	8.3	0.0	8.3	16.7
506	529	523	597	0.0	0.0	0.0	0.0
534	587	602	680	0.0	4.3	0.0	0.0
448	490	462	546	0.0	4.2	0.0	0.0

Appendix Q. Participant means for Experiment 10 as a function of Cue Validity (Valid vs. Invalid) and Set Size (Small vs. Large; arranged vertically because the factor was manipulation between subjects) for both Response Times (RT) and Percentage Error (%Error)

	EXPERIMENT 10			
	RT		%ERROR	
	VALID	INVALID	VALID	INVALID
SMALL	425	461	0.0	0.0
	365	370	0.0	0.0
	621	646	0.0	0.0
	435	457	0.0	0.0
	435	456	0.0	0.0
	510	551	0.0	1.4
	701	678	0.0	0.0
	576	569	0.0	2.5
	431	447	0.0	0.0
	503	543	0.0	0.0
	586	597	1.3	0.0
	514	542	0.0	0.0
	368	382	2.6	0.0
	584	604	0.0	0.0
	362	376	1.3	0.0
	372	389	0.0	0.0
LARGE	456	485	3.9	1.3
	536	555	1.3	0.0
	374	440	2.5	1.4
	448	500	2.5	0.0
	549	624	2.6	0.0
	509	524	2.5	0.0
	515	545	1.3	6.3
	487	523	1.3	1.3
	530	570	0.0	0.0
	499	535	1.4	1.4
	599	635	2.5	0.0
	674	710	2.8	1.4
	552	629	2.5	2.5
	640	719	1.3	1.3
	444	454	1.3	0.0
	630	677	1.3	0.0

Appendix R. Participant means for Experiment 11 as a function of Cue Validity (Valid vs. Invalid) and Set Size (Small vs. Large) for both Response Times (RT) and Percentage Error (%Error)

EXPERIMENT 11							
RT				% ERROR			
VALID		INVALID		VALID		INVALID	
SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE
534	647	551	644	0.0	0.0	0.0	2.7
480	513	490	562	0.0	0.0	0.0	0.0
572	642	616	730	0.0	0.0	0.0	2.5
522	533	538	595	0.0	0.0	0.0	5.0
487	528	498	524	0.0	2.5	0.0	5.0
576	592	585	654	0.0	2.6	0.0	0.0
628	684	649	773	0.0	5.1	0.0	0.0
455	508	484	514	0.0	0.0	0.0	0.0
436	477	450	482	0.0	5.4	0.0	0.0
423	449	436	432	2.5	8.1	0.0	5.4
553	617	583	664	0.0	0.0	0.0	2.6
455	554	471	598	0.0	0.0	0.0	0.0
508	544	509	564	0.0	0.0	0.0	0.0
540	555	554	573	0.0	0.0	0.0	2.5
468	515	528	611	0.0	0.0	0.0	0.0
521	557	559	579	0.0	0.0	0.0	0.0
652	636	646	652	0.0	0.0	0.0	0.0
447	513	476	541	0.0	0.0	0.0	0.0
523	522	523	546	0.0	0.0	0.0	0.0
524	572	539	577	0.0	0.0	0.0	2.5