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The role of implicit memory in visual word recognition: Principles and processes of long- and short-term repetition priming

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The Role of Implicit Memory in Visual Word Recognition: Principles and Processes of Long- and Short-Term Repetition Priming

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"I declare that this written assignment is my own work and does not include:
(i) material from published sources used without proper acknowledgement; or
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Declaration

I certify that this literature review and research project does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

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Implicit Memory Processes: A Review of Long- and Short-Term Repetition Priming Research

Matthew Merema

Abstract

This review examines the role of long- and short-term repetition priming research in the theoretical debate between episodic and abstractionist accounts of implicit memory. The empirical research and theoretical accounts of priming reviewed indicate that neither episodic or abstractionist theories alone can successfully account for the processes of long- and short-term repetition priming. The major variations between studies in experimental methods used to measure repetition priming are also examined, providing a possible explanation for contrasting results obtained within repetition priming research and a reason for why the episodic versus abstractionist debate persists. Finally, research examining the underlying mechanisms responsible for priming is also discussed, indicating that it still has not been determined whether or not long- and short-term priming rely upon the same underlying mechanism. One method proposed for providing further clarification to this issue is to examine whether fluctuations in long-term priming levels result in changes in the magnitude of short-term priming.

Exploring Implicit Memory Processes: A Critical Review of Long- and Short-Term Repetition Priming Research

Research has demonstrated that people with amnesia are able to become more proficient at completing various word-recognition tasks, despite an inability to remember completing them (Warrington & Weiskrantz, 1974, 1978, 1982). Such a result has lead researchers to the conclusion that memory can operate both "explicitly" (i.e., by means of conscious recollection) and "implicitly" (i.e., in the absence of conscious recollection) (Graf & Schacter, 1987; Tulving & Thompson, 1973). For example, attempting to recall a list of words encountered previously is a conscious process; it requires awareness and the intentional recollection of a previous event and thus draws on explicit memory. Alternatively, the amount of time taken to recognize a particular word decreases with repeated exposure to that word, even in the absence of explicit memory processing (Graf & Schacter, 1985). This suggests that unconscious memory processes are taking place and hence some form of implicit memory system exists.

The phenomenon whereby repeated exposure results in faster and more accurate recognition of an object on subsequent occasions is referred to as "repetition priming" (Cofer, 1967). Repetition priming can be observed in a number of implicit memory tests (see Tenpenny, 1995 for an exhaustive list), including word-stem completion tasks (Chen & Squire, 1990; Forster, Booker, Schacter, & Davis, 1990; Graf & Schacter, 1985) and word-naming tasks (Jacoby & Hayman, 1987; Ostergaard, 1998; Salasoo, Shiffrin, & Feustal, 1985). However, one word-recognition task that has become increasingly prevalent, and thus will form the basis of discussion in this review, is the lexical decision task (Bentin & Moscovitch, 1988; Grant & Logan, 1993; McKone, 1995, 1998). The lexical decision task requires participants to determine as quickly and as accurately as possible whether or not a string of letters, typically presented on a computer screen, constitutes a word (e.g., 'happy') or a non-word (e.g., 'grabe'). Within this task, repetition priming is illustrated by the increased speed at which a participant can make this lexical decision for items that are repeated.

Although items can be identified faster as a result of facilitation brought about by previous presentations, this enhanced ability to process the item deteriorates over time. Whilst initial research pertaining to the lexical decision task has examined the increased speed of processing for repeated stimuli, it is the manner in which repetition priming deteriorates over time in this task that has become the centre of a fundamental theoretical debate in implicit memory research. Research investigating repetition priming suggests that it deteriorates at a rate that is indicative of two distinct processes, a long-term component and a short-term component. An initial study by Morton (1969) introduced the concept of "long-term" repetition priming, suggesting that by observing a word, the required threshold for identifying it was lowered and so less time was required for recognition should the same word be encountered again. This notion was further expanded to suggest that this enhanced capacity to identify previously encountered words remained for days (Sloman, Hayman, Ohta, Law, & Tulving, 1988), even months if it initially involved extensive practice (Grant & Logan, 1993; Salasoo et al., 1985).

More recently, a second component, known as "short-term" repetition priming, has been identified. In comparison to the long-term repetition priming effect, short-term repetition priming is a considerably larger but shorter-lasting priming effect (i.e., lasting up to approximately 10 seconds) that takes place immediately after observing a word (McKone, 1995, 1998). Figure 1 provides a graphical depiction of the repetition priming decay process. The short-term repetition priming component forms a negatively accelerated curve whereby the loss of priming is greatest immediately following the observation of a word. As time passes priming continues to decay, though the rate at which it decays continues to decrease. The short-term component discussed by McKone (1995, 1998) is represented in Figure 1 by the initial substantial loss of priming before leveling out, whereas the plateau represents the long-term component discussed by Grant and Logan (1993) and other studies on long-term repetition priming.

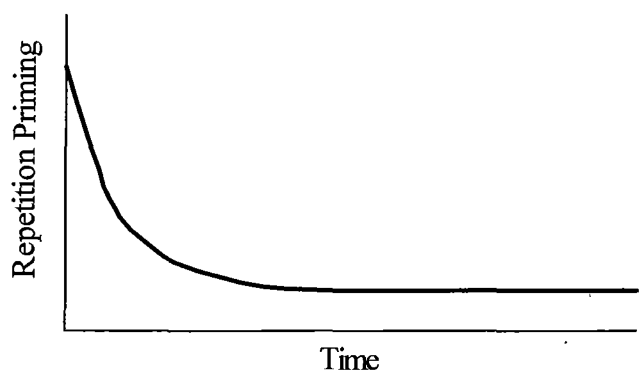

Figure 1. The decay of repetition priming over time.

Theoretical Accounts of Repetition Priming

Whilst research continues to examine the rate at which priming decays, a theoretical debate about the underlying mechanisms responsible for repetition priming continues to develop. Two alternative processes suggested to be responsible for repetition priming have been proposed: (1) the episodic account; and, (2) the abstractionist account. Episodic theories suggest that repetition priming is the result of words being recognized according to a specific moment in which they have been previously encountered (Tulving, 1972). For example, episodic retrieval might include recalling the presentation of the word "happy" only a few seconds prior to it being presented again. Abstractionist theories suggest that repetition priming is the result of words being recalled as general information without reference to a specific event or occasion (Tulving, 1972). For example, abstract retrieval might include recognition of the word "happy" but not necessarily a reference to a specific time when it was last encountered. Whilst previous research has predominantly suggested that repetition priming is the result of either episodic retrieval (Goldinger, 1998; Jacoby & Brooks, 1984; Kolers, 1975, 1976; Logan, 1990) or abstract retrieval (Becker, 1980; Morton, 1969, 1979; Thompson-Schill, Kurtz, & Gabrieli, 1998), more recent evaluations suggest that it may be a combination of both (Bowers, 2000a; McClelland & Rumelhart, 1985).

The processes of long- and short-term repetition priming have played an important role in the theoretical debate between episodic and abstractionist approaches thus far. As Tenpenny (1995) suggests, a successful theoretical account of priming needs to be able to accommodate both the long- and short-term components of priming. Whilst opinions differ widely about which theory is better suited to repetition priming processes, Tenpenny suggests that a purely abstractionist approach is somewhat undermined by the long-term priming component. If a new lexical unit is primed for every new word or group of words encountered, as is suggested by abstractionist theories (Morton, 1979), then the number of primed units would eventually become unfeasibly large. However, Bowers (2000a) challenges this stance, suggesting that no piece of research has indicated that a large number of words cannot be primed simultaneously when the words are presented for sufficient duration or a sufficient number of times for long-term priming to occur. Alternatively, episodic theories are questioned by research that demonstrates that morphologically related words (e.g., "car" and "cars") are primed by each other, though orthographically related words that are not morphologically related (e.g., "car" and "card") are not (Murrell & Morton, 1974; Napps & Fowler, 1987). In essence, both episodic and abstractionist accounts of repetition priming are supported and opposed by the literature and the following section provides an explanation for how such contradictions can occur.

Specific-Visual versus Abstract Meaning of Words

As a seemingly simple resolution to the episodic-abstractionist debate, various tasks have been developed to measure the magnitude of repetition priming under two different conditions. To determine the effect of episodic and abstract retrieval processes, repetition priming has been viewed when the same object is repeated in its original form (e.g., the word “dog” presented twice) and when it is repeated in a different form (e.g., a picture of a dog presented prior to the word “dog”) (Cave & Squire, 1992; Jacoby & Hayman, 1987). If objects repeated in a different form fail to produce priming then one could assume that repetition priming relies upon the object being repeated in its specific original form and that episodic retrieval is responsible. If objects repeated in a different form do produce priming then it indicates that repetition priming is not dependent on the object being presented in its original format and that abstract retrieval processes must be in effect. Also, if objects repeated in a different form produce some priming but this is exceeded by the level of priming produced by objects presented in the same form, then one could assume that both episodic and abstract retrieval processes play a role. However, a seemingly simple dissection of the underlying causes of repetition priming has resulted in a multitude of incompatible conclusions.

Jacoby and Hayman (1987) presented words for a very short period of time (i.e., 35 ms) on a computer screen and investigated the ability of participants to identify them. The study found that when the case in which the word was presented changed between first and second presentations (e.g., “apple” then “APPLE”), the level of priming (i.e., the likelihood of identifying the word) was less than that produced when first and second presentations of a word were shown in the same case (e.g., "apple" then "apple"). However, repeated words presented in a different form were still more likely to be identified than words presented for the first time, suggesting that both episodic and abstract retrieval processes must play a role in repetition priming. Cave and Squire (1992) found that when a picture presented on the second occasion was modified slightly; for example, it was changed in size, brightness, or even the specific example used (e.g., a beagle then a golden retriever), participants responded faster in comparison to first presentations. Such a result also suggests that abstract retrieval processes must at least determine repetition priming to some extent.

Whilst these results seem to reflect a mixture of episodic and abstract retrieval processes, another lexical decision study investigating differences in the amount of priming obtained between words (in word/non-word decisions) and meaningless shapes (in symmetrical/non-symmetrical decisions) indicates that episodic retrieval processes might be solely responsible. Kersteen-Tucker (1991) found that initial levels of priming immediately after repetition and the rate at which the priming decayed was comparable for both words and meaningless shapes. Since abstract accounts of priming discount the importance of the specific occasion in which the word is encountered, processing must involve some form of understanding of what the item represents. As random shapes are meaningless and therefore unlikely to be processed through abstract representations, the result that meaningful words are not processed any faster than meaningless shapes indicates that abstract processing does not contribute to priming.

However, in support of abstract processing, Bentin and Moscovitch (1988) found that although a long-term priming effect was present in a lexical decision task when making word/non-word decisions, it was not present when participants instead attempted to determine whether or not the first and last letters of the word were presented in alphabetical order. Identifying the alphabetical order of individual letters does not involve processing the meaning of the word; therefore it is unlikely that the word is processed through an abstract representation in this example. Since the presence of long-term repetition priming is dependent upon processing the meaning rather than the surface features of the word, the result suggests that an abstract account of recognition is responsible for repetition priming. Using a comparable task, Becker, Moscovitch, Behrmann and Joordens (1997) more recently established that short-term priming is also more durable when the meaning of the word is processed as opposed to only surface features.

Bringing into question episodic retrieval processes and further demonstrating the importance of abstract processing, Buck-Gengler and Healy (2001) found that participants were able to enter digits on a keyboard faster when numbers had previously been observed, regardless of whether the number was previously presented in numeric or word form. However, the application of this task to implicit memory is questionable given that average responses ranged from 3 to over 3.5 s. Though the research reviewed tends to suggest that abstract representations are perhaps the most influential component in priming, it is too early to disregard the influence of specific episodic information in retrieval. It seems likely that retrieval relies on a balance of both episodic and abstract information and that this balance might also fluctuate under different conditions.

Lexicality

Whilst task-type is evidently an important factor when examining repetition priming, whether letters presented form a real word (e.g., 'grape') or a non-word (e.g., 'grabe') also influences repetition priming. The effect of whether or not a string of letters form a real word, referred to as "lexicality", can be observed within the rate at which repetition priming decays to long-term levels. In support of abstractionist theories of retrieval, several lexical decision studies have indicated that whilst priming reaches similarly high levels for both words and non-words following a single repetition, decay of short-term priming occurs at a rate that is much faster for non-words than for words (Bentin & Moscovitch, 1988; McKone, 1995; McKone & Dennis, 2000). For example, McKone (1995) found that priming for non-words decayed to a long-term level after just four seconds if an unrelated word was presented in between repetitions of the target non-word. However, short-term priming for words decayed in a smooth manner over a period of 10 seconds, even if four unrelated words were presented in between repetitions of the target word. The non-words used by McKone (1995) are comparable to the meaningless shapes employed in Kersteen-Tucker's (1991) study; that is, non-words are meaningless and therefore unlikely to be processed through abstract representations. Therefore McKone's (1995) results suggest that processing the meaning of a word is necessary for avoiding instantaneous decay of short-term priming. Further studies have since confirmed the instantaneous decay of priming to long-term levels for non-words over periods less than five seconds when other words are presented between repetitions (Bentin & Moscovitch, 1988; McKone & Dennis, 2000).

However, McKone (1998) has since found that it is not so much the time delay between first and second presentations of a non-word that is responsible for the faster rate of decay but the number of intervening words presented between repetitions of the target item. By decreasing the delay between presentations and keeping the number of intervening items constant and then increasing the number of intervening items and keeping the delay constant, McKone (1998) was able to determine the extent of the effect of both time and number of intervening items. It was found that when the delay between first and second presentations is increased to 10 s but the number of intervening items remains at zero, priming for non-words decays at a rate over time that resembles the rate of decay found for words in other studies (McKone, 1995; McKone & Dennis, 2000). In contrast, it was found that when the delay between the first and second presentations was reduced to 4 s but the number of intervening items was increased to one, priming for non-words decayed to the long-term value immediately. These preliminary results from McKone (1998) suggest that intervening items presented between repetitions of a target item, as opposed to the time delay between repetitions, is primarily responsible for the instantaneous decay of non-words to long-term levels.

This "lag/lexicality" effect identified by McKone (1995) however, has not been observed in all repetition priming studies that manipulate these variables. Mimura, Verfaellie and Milberg (1997) found that when a single intervening item was introduced in a lexical decision task, both words and non-words decayed to long-term priming levels. Furthermore Kersteen-Tucker (1991) suggested that words actually decayed to long-term priming levels faster than non-words over 0, 1, 4 and 8 intervening items. However, these contrasting results serve to demonstrate the importance of task-type on repetition priming. Indeed, the major difference between studies suggesting that repetition priming of non-words decays faster than words (Bentin & Moscovitch, 1988; McKone, 1995, 1998; McKone & Dennis, 2000) and those that dispute this effect (Mimura et al., 1997; Kersteen-Tucker, 1991) is the manner in which the words are presented. That is, studies supporting the lag/lexicality effect each gave participants approximately two seconds to respond to the lexical decision task, for which the word or non-word remained present for the entire time. However, Mimura et al. (1997) and Kersteen-Tucker (1991) also gave participants approximately two seconds to respond but the word or non-word was only presented for 500 ms or 150 ms respectively. Apart from this, the studies remained the same, suggesting that the lag/lexicality effect is subject to the items remaining visible until the participant has completed the lexical decision.

Task-Related Issues Affecting Priming

Discrepancies between studies that are used to develop theoretical accounts of repetition priming is partly a product of the sensitivity of repetition priming to small experimental variations. Whilst the process of repetition priming has proved to be a reliably quantifiable phenomenon across various implicit memory tests (see Roediger, 1990 for a review), the magnitude of priming and the pattern in which it manifests itself is often dependent upon a particular task, word type, method of presentation or other specific factor that is incorporated into the task. The following section reviews various issues in the literature that have resulted in considerable differences in the level of repetition priming obtained. Whilst an in-depth discussion of the underlying causes of the effect of slight changes in experimental designs on repetition priming is beyond the scope of this paper, it does provide some explanation for discrepancies in the research and justification for why the episodic-abstractionist debate is yet to be resolved.

Task Type

The type of task used to measure the extent of repetition priming is perhaps the most influential and obvious factor within the research. As research on the construct of repetition priming is quite a recent phenomenon, most studies have chosen to examine priming by using only a single task and investigating other variables, such as level of word abstractness or specificity (Buck-Gengler & Healy, 2001), presentation rate of words (McLennan & Luce, 2005), length of delay between word repetitions (Sloman et al., 1988) or the effects of amnesia on implicit memory (Haist, Musen, & Squire, 1991). As a result, little effort has been made to directly investigate the effects of using different types of tasks. However, studies that have compared different tasks have shown that they can produce considerably different results on measurements of repetition priming (Bowers, 2000a; McKone, 1995).

Bowers (2000a) compared levels of repetition priming between the lexical decision task and a perceptual identification task, which determined the minimum duration a word was required to be presented for in order to be identified at least 50% of the time. The study investigated the effect of word frequency (i.e., how common a word is prior to the task) and found that the lexical decision task was more sensitive to word-frequency than the perceptual identification task. That is, the difference between the levels of priming obtained for high-frequency words (more common) and low-frequency words (less common) in the lexical decision task was greater than in the perceptual identification task. Thus, the study indicates that the lexical decision task is more sensitive to pre-experimental practice than the perceptual identification task and that generalizing between the tasks should be done with caution. A distinction between these tasks, despite the high degree of similarity between them certainly brings into question comparisons being made between other tasks used to measure repetition priming that are less alike, such as lexical decision (Grant & Logan, 1993; McKone, 1995, 1998) and word-stem completion tasks (Chen & Squire, 1990; Forster et al., 1990).

Despite these apparent differences, it has been demonstrated that although task type influences initial levels of priming, it does not necessarily impinge on the rate at which it decays (Roediger, Weldon, Stadler, & Riegler, 1992). Word-stem completion tasks involve deciphering a word from which only a section is presented (e.g., deciphering "growth" from "gro___?"). Similarly, word-fragment completion tasks involve deciphering a word from which only segmented letters are presented (e.g., deciphering "growth" from "g_o_t_?"). In both tasks, repetition priming is illustrated by the increased likelihood of completing the word-stem or word-fragment with items that the participant has previously been exposed to rather than with some other possible solution. When comparing a word-stem completion task with a word-fragment completion task, Roediger et al. found that whilst initial levels of priming were greater for word-fragment completion than for word-stem completion, priming decayed at the same rate over periods up to two hours and 48 hours. Whilst Ostergaard (1998) has suggested that differences in initial levels of priming for different implicit memory tasks may be due to differences in task difficulty, comparable rates of decay suggest that the two tasks presumably draw on similar cognitive processes (Roediger et al., 1992). Although the notion of various implicit memory tasks drawing on the same processes is quite probable, research has indicated clear differences between initial levels of priming in the lexical decision task, a semantic decision task (Becker et al., 1997) and in a perceptual identification task (Bowers, 2000a), and these differences also warrant further investigation.

Number of Repetitions

A second factor that has been identified as influencing levels of priming is the number of repetitions of a word or object over the course of a task. Several studies have indicated that levels of priming continue to increase with increasing presentations of a stimulus (Chen & Squire, 1990; Salasoo, Shiffrin, & Feustal, 1985). For example, Chen and Squire investigated the effect of number of repetitions of a word (1, 2, 4, 16 and 32 repetitions) and found that when participants were exposed four or more times to a particular word (e.g., "fishing"), the likelihood of completing the associated word-stem test (e.g., "fis___?") 3 minutes and 22 minutes later increased significantly from words repeated only once. Grant and Logan (1993) further clarified this effect, revealing that priming increases with repetition in a negatively accelerated manner. That is, priming builds up quickest in initial repetitions of a word then increases less with continued repetitions. These studies indicate the importance of standardizing the number of word or object presentations when investigating repetition priming and present another factor that may have contributed to contradictions in the literature.

Despite suggestions of the importance of number of stimulus presentations, many studies continue to investigate the decay of repetition priming without also considering number of stimulus presentations as a variable (Kersteen-Tucker, 1991; McKone, 1998; McKone & Dennis, 2000; McKone & Trynes, 1999). This lack of consideration for the effects of varied number of word repetitions prior to testing is important to note, particularly when established concepts such as long- and short-term decay of repetition priming are potentially influenced by changes in this variable. This is not to say that such an omission has produced inaccuracies in what has been revealed insofar about the concept of repetition priming and the rate at which it decays; though it is possible that important effects that are dependent on the number of stimulus presentations may have been overlooked.

Word-Frequency

Where stimulus repetition refers to practice throughout a task, word-frequency refers to practice prior to the task. As previously stated, word-frequency refers to how common a word is; for example, how many times the word is encountered per one million words of text (e.g., Coltheart, 1981; Kucera & Francis, 1967). It is suggested that high-frequency or more common words (e.g., "cat") are identified much faster than low frequency words (e.g., "vindicate") in a lexical decision task (Kinoshita, 1995; McKone, 1995). For example, Kinoshita found that when presented with a string of five letters that formed a low-frequency word (averaging 2.6 occurrences per one million words of text), participants' reaction times for identifying whether or not the letters formed a word took significantly longer than when the string of letters formed a high-frequency word (averaging 188 occurrences per one million words of text). Similarly, high-frequency words require a shorter presentation time to be identified in a word-naming task than low-frequency words (Jacoby & Hayman, 1987). Jacoby and Hayman found that high-frequency words were identified 83.50% of the time when presented for only 30-35ms, though low-frequency words were only identified 71.25% of the time under the same conditions.

In addition to differences in the time taken to identify high- and low-frequency words, it has also been found that word-frequency has an effect on the magnitude of repetition priming. Whilst some lexical decision studies central to the concepts of long- and short-term priming have not considered the effect of word-frequency (Grant & Logan, 1993; McKone, 1998), it has since been found that prior exposure to low-frequency words produces greater levels of priming than prior exposure to high-frequency words in a lexical decision task (Balota & Spieler, 1999; Bowers, 2000b). That is, the initial presentation of a low-frequency word (e.g., "vindicate") leads to a greater magnitude of priming in a lexical decision task than the initial presentation of a high-frequency word (e.g., "cat"); though this effect is not present in all implicit memory tasks (Bodner & Masson, 1997; Graf & Mandler, 1984; Rajaram & Neely, 1992; Schwartz & Hashtroudi, 1991). This indicates that short-term priming is influenced by word frequency in a lexical decision task; an effect that is fundamental to the discussion concerning the underlying mechanisms of long- and short-term priming.

Underlying Mechanisms for Long- and Short-term Priming

The sensitivity of short-term priming to word frequency is particularly important in light of repetition priming literature which suggests that long- and short-term priming effects are instigated by different underlying mechanisms (Bowers, 2000a; McKone, 1995). Whilst the magnitude of short-term priming reduces with increasing word-frequency (Balota & Spieler, 1999; Bowers, 2000a, 2000b; McKone, 1995), Grant and Logan (1993) have demonstrated that increased repetition of words within a lexical decision task results in greater levels of long-term priming. Therefore, if it is the case that "experimental practice" (i.e., how often words are encountered within the experiment) and "pre-experimental practice" (i.e., how often words are encountered prior to the experiment) constitute the same learning process, then previous research would indicate that one factor (i.e., practice) influences long- and short-term priming in different ways. That is, the magnitude of short-term priming decreases with increasing pre-experimental practice, though the magnitude of long-term priming increases with increasing experimental practice. Such a result would provide support to the notion that the two forms of priming rely on different underlying mechanisms. However, a study by Kirsner and Speelman (1996) undermines this reasoning, indicating that priming attributable to repetition within a task (experimental practice) does not emulate priming resulting from word-frequency effects (pre-experimental practice).

Kirsner and Speelman (1996) effectively demonstrated that the manner in which experimental practice effects and pre-experimental practice effects manifest within a lexical decision task are considerably different. It was found that experimental practice or repetition of items throughout the task had a considerably greater effect on task performance than did the influence of increased frequency of words. Thus, it was suggested that learning within a task does not precisely reflect the process of learning prior to a task, despite the possibility of both processes being generated by the same mechanism. Consequently, comparisons made between studies investigating word-frequency effects on short-term priming (Balota & Spieler, 1999; Bowers, 2000a, 2000b; McKone, 1995) and Grant and Logan's (1993) study investigating the effect of item repetition on long-term priming are questionable. As a result, it is difficult to determine at this time whether or not long- and short-term priming are produced by the same underlying mechanism.

It is suggested by Bowers (2000a) that long-term priming results from episodic retrieval, whilst short-term priming is the result of a temporary arousal of an abstract representation of a word group. This differentiation between the underlying mechanisms responsible for the two components of repetition priming is based upon research that has indicated that long-term priming is influenced by word-frequency but that short-term priming is not (Bodner & Masson, 1997; Rajaram & Neely, 1992). It is important to note, however, that there is research that contests this suggestion, indicating that short-term priming is in fact sensitive to word-frequency (Balota & Spieler, 1999; Bowers, 2000b). The factor responsible for this contradiction between the research is most likely due to whether or not the words being presented in a lexical decision task are masked (i.e., concealed shortly after being presented) or not. As short-term priming is sensitive to word-frequency in unmasked priming studies but not in masked priming studies, it is possible that masking the presentation of an item reduces the level of sensitivity required to detect differences in the magnitude of priming between high- and low-frequency words. Bowers (2000a) provides no explanation of this discrepancy between masked and unmasked priming studies and to disregard unmasked priming studies altogether brings into question Bowers' suggestions that long- and short-term priming rely on different mechanisms.

However, in support of Bowers (2000a), McKone (1995) found that short-term priming was not influenced by word frequency in an unmasked lexical decision task. McKone found that regardless of whether high-frequency or low-frequency words were used in a lexical decision task, repetition priming decayed to long-term levels after just four subsequent intervening words. However, as noted by McKone, the decay rates of low- and high-frequency words were tested in different experiments. More importantly, the lexical decision task for low-frequency words used low-frequency words as intervening items presented between repetitions of the target word, whereas the task for high-frequency words used high-frequency words as intervening items. Thus, results in support of the dissociation between long- and short-term priming are again questionable. In spite of these limitations however, it is difficult for the dissociation between the underlying mechanisms of long- and short-term priming to be demonstrated because results indicating a different effect of a particular factor on the two components can often be blamed on a lack of sensitivity in the test, which does not allow an effect in both components of priming to be ascertained (e.g., Grant & Logan, 1993).

In contrast to Bowers (2000a) and McKone (1995), Tenpenny (1995) suggests that both long- and short-term priming are produced by the same underlying mechanism. It is maintained by Tenpenny that both components of priming can be attributed to episodic retrieval processes and that short-term priming only decays faster than long-term priming because it is sustained by less durable episodic representations. Tenpenny's reasoning is based upon the use of masked presentations for short-term priming (see Humphreys, Besner, & Quinlan, 1988) and unmasked presentations for long-term priming (see Jacoby & Dallas, 1981; Jacoby, 1983), suggesting that whether an item is presented masked or unmasked influences the strength of the episodic representation that is used for later retrieval. However, Tenpenny's explanation is unable to accommodate for short-term priming that is obtained in studies that do not use masked presentations. That is, if long- and short-term priming are the result of differences in the method of item presentation, how can both components result from a single presentation of an unmasked item?

Whilst theoretical accounts of the underlying mechanisms for long- and short-term priming are only vaguely supported by the literature, more recent research has attempted to investigate the mechanisms underlying priming using neurological imaging techniques (Naccache & Dehaene, 2001; Poldrack & Gabrieli, 2001). Using magnetic resonance imaging (MRI), Poldrack and Gabrieli effectively measured the locations of brain activity in participants undertaking a lexical decision task. The study found that when participants were asked to identify whether mirror-reversed items formed a word or a non-word, both long- and short-term priming resulted in decreased neural activity in the same specific regions of the brain. Poldrack and Gabrieli suggest that this result indicates that long- and short-term priming rely on the same underlying neural mechanisms. It is tempting to assume that MRI methods could provide a more observable technique for measuring repetition priming and the mechanisms that instigate it in the future; however its application to behavioural phenomena should be approached with caution given the extent of incoherency in repetition priming studies.

Given the research reviewed on long- and short-term repetition priming, it seems difficult to determine at the present time whether the same or distinctly different underlying mechanisms are responsible for both components of priming. Whilst there is some research to support both of these perspectives, it appears that there is not yet any research that has demonstrated robust support for either point of view that is resilient to changes in task type, word-frequency or that can not be manipulated to support both viewpoints. A simple research technique that could settle the debate is to investigate the influence of one priming component on the other. That is, to measure short-term priming at varying levels of long-term priming. If short-term priming is sensitive to changes in long-term priming when all other conditions are held constant then it would suggest that the components rely on the same underlying mechanism. Should short-term priming be unchanged by variation in long-term priming, it would not demonstrate that the two processes rely on different mechanisms (because the absence of an effect might be due to a lack of design sensitivity) but it would provide some support towards this suggestion that does not depend on manipulating additional factors, such as varying word-frequency or masking items.

In addition to resolving the long- and short-term priming issue, there is considerable need within the repetition priming literature for a conceptual framework to clarify the effects of differences in the type of task used to measure the magnitude and subsequent decay of repetition priming. A detailed framework within the literature would go a long way to revealing the precise nature of priming effects and would provide an indication of the areas within the research that need to be further developed or re-examined. Such a structure might initially include making a distinction between studies using different tasks for measuring repetition priming, such as lexical decision, word-stem completion and word-fragment completion tasks. The next step might then involve standardizing methods of measuring repetition priming within the different tasks (e.g., making distinctions between tasks that repeat items once or thirty times) so that effects of factors that are manipulated can be seen more clearly. At present there are too many factors that vary between studies and thus it is somewhat difficult to see whether particular outcomes are the result of changes in the variables that are manipulated intentionally or due to slight differences in experimental technique.

In summary, it has been established that neither episodic nor abstract retrieval processes can account for all results in repetition priming research. Whilst there is research to support and contest both episodic and abstractionist accounts of priming, many of the studies are contradictory of one another and this can partly be attributed to the high level of experimental sensitivity of implicit memory tasks that are used to measure priming. The type of implicit memory task used, as well as word-frequency and the number of repetitions of items throughout a task are all factors that have been shown to influence priming and contribute to the complex nature of repetition priming research. It is suggested that the results of repetition priming studies should be observed with careful consideration given to the type of implicit memory task used as well as to other experimental manipulations, such as word-frequency and word repetition throughout a task.

In reference to the investigation of the underlying mechanisms of long- and short-term repetition priming, the current review found little support to suggest that the two components are a function of the same or of different underlying mechanisms. More recent alternatives to behavioural research have indicated that using brain imaging techniques to measure repetition priming may be a method worth pursuing.

However, this technique has only recently emerged and the research is still in its early stages of development. It has been proposed that a seemingly simple resolution to the debate concerning the underlying mechanisms responsible for long- and short-term priming would be to measure the effect of one component on the other. If one component has an effect on the other, the result would provide strong support to the notion that long- and short-term priming rely upon the same mechanism. If the components are not affected by each other then it would provide some support to the idea that long- and short-term priming do not rely upon the same mechanism. Also, as with research relating to how repetition priming is generated, studies on long- and short-term priming are often contradictory and would benefit equally as well from a re-evaluation of the repetition priming research and its sensitivity to small experimental manipulations.

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The Effect of Long-Term Priming Levels on Short-Term Repetition Priming: Support for Existing Single-Process Models

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Abstract

Previous models of word recognition assume the presence of only a single underlying mechanism in repetition priming. Recent research has, however, suggested that priming may be generated by two distinct processes; namely a long-term priming component and a short-term priming component. An experiment was conducted in order to examine the relationship between long- and short-term priming in order to determine whether or not these two processes can be attributed to a single underlying process. A total of 60 people (45 females, 15 males) participated in a computer-based lexical decision task designed to measure levels of short-term priming at varying levels of long-term priming. It was anticipated that if the priming components represented two distinctly different processes, a change in the level of long-term priming should not influence the obtainable level of short-term priming when other factors are held constant. The results demonstrated that changes in long-term priming were typically accompanied by changes in short-term priming ($p < .05$). Results were interpreted as support for existing single-process models of priming.

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October, 2006

The Effect of Long-Term Priming Levels on Short-Term Repetition Priming: Support for Existing Single-Process Models

Introduction

Although suggestions of an unconscious form of memory are thought to have first emerged in the 17th century (see Schacter, 1987), empirical research confirming this concept was not carried out until around the 1970s. In a series of studies investigating memory functioning in people with amnesia, Warrington and Weiskrantz (1968, 1970, 1974, 1978, 1982) were able to establish that, despite an inability to consciously recall participating in a word recognition task, improvements in performance still occurred. This result has lead to investigations into two distinctly different memory systems, referred to as explicit memory (i.e., memory operating through deliberate conscious recollection) and implicit memory (i.e., memory operating in the absence of deliberate conscious recollection). As a result, several word recognition tasks have since been established to examine implicit memory functioning. One such task, known as the lexical decision task, is often employed to observe implicit memory functioning in word identification processes. In the lexical decision task, participants observe a number of letter-strings (usually presented via a computer screen) and are required to identify whether these letter-strings form a word (e.g., "jump") or a non-word (e.g., "jemp").

Lexical decision studies have consistently found that words can be identified with greater efficiency upon subsequent presentations. When observing an item (a word in this case), the brain appears to be prepared or primed to recognize the word more efficiently should the same item appear again (Cofer, 1967). This process is referred to as repetition priming. It is argued by some researchers that repetition priming is generated unconsciously from within the implicit memory system and that this process is dissociable from that of explicit memory recall (Graf & Schacter, 1985; Kinoshita, 1995; Schott, Richardson-Klavehn, Heinze, & Duzel, 2002). Several studies have indicated that repetition of a word in the lexical decision task results in faster (Morton, 1969; Scarborough, Cortese, & Scarborough, 1977; Sloman, Hayman, Ohta, Law, & Tulving, 1988) and more accurate (Jacoby & Dallas, 1981; Kinoshita, 1995) recognition of that word. For example, it may initially take 700 ms to identify that a string of letters forms a word. However, if the same word is presented subsequently, the time required for recognizing the word may decrease to 500 ms; indicating a priming effect of 200 ms.

Studies examining changes in levels of repetition priming over time in the past have shown it to be particularly durable. Implicit memory research has indicated that the enhanced capacity to identify previously encountered words can endure many months (Sloman et al., 1988). Furthermore, Grant and Logan (1993) have established that over such an extended period of time, priming in a lexical decision task decays slowly and steadily. It was illustrated that priming for words observed only once initially decayed to approximately 15 ms following a five minute delay and deteriorated completely within eight hours. Grant and Logan also demonstrated that priming for words accumulates with increasing repetitions in a negatively accelerated manner (see also Salasoo, Shiffrin, & Feustal, 1985). That is, the overall priming effect is increased with each presentation of a word, though the amount contributed by each subsequent presentation decreases. This pattern is often referred to as a power function, as the magnitude of priming obtained is a power function of the number of word repetitions (e.g., Kirsner & Speelman, 1996). Given this negatively accelerated build-up of repetition priming, Grant and Logan also found that priming was still present after a two month interval if items were initially observed 16 times. Thus, it was demonstrated that multiple repetitions of the same word throughout a task results in greater levels of priming at various delay intervals.

The Decay of Priming

More recent research into the decay of repetition priming has suggested that, in addition to the long-lasting effect of priming, an initial distinctly different priming event may also be taking place (McKone, 1995, 1998). It was found that a substantially larger but shorter-lived priming effect occurs immediately (within 10 seconds) after the presentation of a word. McKone referred to this shorter-lived effect that presents initially as "short-term" priming (e.g., McKone, 1995, 1998); suggesting that the smaller but more persistent priming effect found by Grant and Logan (1993) represents the "long-term" priming component. Figure 1 illustrates these long- and short-term priming components.

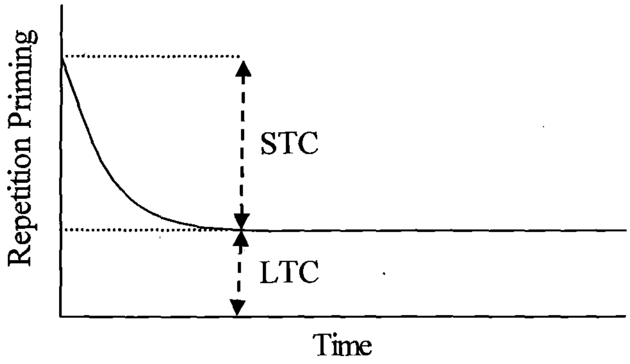

Figure 1. The decay of repetition priming over time, which according to McKone (1995), consists of a short-term component (STC) and a long-term component (LTC).

McKone (1995) suggests that the short-term component of priming is an implicit memory function comparable with short-term explicit memory. McKone found that, in addition to a long-term effect (such as that demonstrated by Grant and Logan, 1993), a word presented twice within two seconds in a lexical decision task could be identified as much as 170 ms faster on the second presentation than on the first (McKone, 1998, Experiment 2). This was found to decay to around 90 ms within 6 to 8 seconds and to around 60 ms within 16 seconds. This deterioration of priming from 170 ms to around 80 ms over a period of approximately 16 seconds is clearly different from the long-term component demonstrated in Grant and Logan's (1993) research, which demonstrated a reduction in priming of approximately 15 ms between 5 minutes and 8 hours following the presentation of a word.

The decay rate of priming found by McKone (1995) in Experiment 1 was suggested to be most appropriately represented by an exponential function; indicating that one mathematical formula could account for 98% of the variance found in the rate at which priming decayed. It was claimed that the decay of priming was most accurately predicted by an exponential function in the form of, $P = 93.5\ e^{-0.63\ L} + 49.1$, where P equals the amount of priming in milliseconds and L represents the number of intervening items. Therefore, the equation suggests that McKone's data is most effectively represented by a curve that decays to 63% of its value for every intervening item that is presented (i.e., every two seconds). This decay occurs above a constant minimum priming value of 49.1 ms. Given this exponential function, McKone contended that an initial short-term priming effect was superimposed on a long-term priming effect of around 49.1 ms.

Theoretical accounts of priming

Whilst empirical research has revealed much about the nature of repetition priming, theoretical accounts have continually suggested that priming is produced through the use of a single underlying mechanism. Examples of such models include

McClelland and Rumelhart's (1985) Interactive Activation model and Parallel Distributed Processing model and Morton's (1969, 1978, 1979) Logogen model.

The Interactive Activation and Parallel Distributed Processing Models

According to McClelland and Rumelhart (1985), repetition priming is generated by a single underlying mechanism. It is maintained by the Interactive Activation model that within the implicit memory system, every known word is represented by a distinctive unit. McClelland and Rumelhart suggest that when sufficient visual information of a word is presented, the associated lexical unit for that word (referred to as a node) is activated, allowing for recognition of the word to take place. However, in much the same way that the sound created by plucking a guitar string fades over time, this activation exists only momentarily and over time also decays back to its pre-activation level. The Interactive Activation model also states that the pre-activation level for nodes is not static; rather that they vary as a function of the number of previous encounters with the words or items that they represent.

McClelland and Rumelhart (1986; see also Plaut & Booth, 2000) later extended this concept with the word recognition model of Parallel Distributed Processing. The Parallel Distributed Processing model proposes much the same processes in word recognition as those found in the Interactive Activation model; however the Parallel Distributed Processing model predicts that a new unit is created with every presentation of a word. Contributing to this modification was the introduction of research suggesting that word recognition is influenced by context. For example, several studies have identified differences in word recognition outcomes for written versus spoken presentations (Jacoby, 1983a, 1983b) as well as between voices of different people in aural presentation experiments (McLennan, 2003). The Parallel Distributed Processing model predicts that several closely-related word detectors (which represent information from different sources such as spoken and visually presented words) form interconnected groups, which work in partnership and enable word recognition (as well as recognition of other objects) to take place. For example, the Interactive Activation model (McClelland & Rumelhart, 1985) proposes that a picture of a chair would not aid in the recognition of the word "chair" because the model only takes into account the relationships between nodes for written stimuli. The Parallel Distributed Processing model, however, suggests that the unit responsible for recognising a picture of a chair is grouped together with the word-detector unit responsible for recognising the word "chair". Consequently, these separate traces are able to influence each other in a manner that allows one to prime the other; an effect which is supported by the literature (Jacoby, 1983a, 1983b; McLennan, 2003; Roelofs, 2004; Tree & Hirsh, 2003; Vitkovitch, Rutter, Begum, & Thompson, 2002).

According to both the Interactive Activation model (McClelland & Rumelhart, 1985) and Parallel Distributed Processing model (McClelland & Rumelhart, 1986), the phenomenon of repetition priming is said to occur as a result of a word or item being presented on a subsequent occasion when a word-detector unit's level of activation generated from a previous presentation has not yet decayed to its pre-activation level. That is, if the unit is still active on account of any remaining effect from a previous activation, it is combined with the new activation value. Since a smaller value is now needed to reach the required activation value for word recognition to occur, the word is distinguished faster; thus producing a priming effect. Given that priming levels are not limitless (i.e., it is not possible to obtain a negative reaction time when making a lexical decision), the models propose that there is a maximum level of activation for units and that the increase in priming with repeated presentations is limited by how much priming is able to be obtained.

The Logogen Model

As with McClelland and Rumelhart's (1985) Interactive Activation model, Morton's (1969, 1978, 1979) Logogen model also proposes that words are represented as a single individual unit within the word recognition system. The lexical units (which in this case are referred to as logogens) respond in much the same way that nodes in the Interactive Activation model do. That is, a logogen gathers information relevant to the word it represents as it becomes available (by matching the shapes of letters with the representation provided by the logogen). When the amount of information accumulated reaches a certain level (the threshold), the item being presented is able to be recognised. Morton predicts that once the threshold for identifying a word has been reached; the accumulated information in the logogen deteriorates immediately, supposedly lasting only around one second.

Given that the activation of a logogen lasts only around one second, Morton's (1969, 1978, 1979) model proposes that repetition priming is generated in a different manner to that suggested by McClelland and Rumelhart (1985). As opposed to a slow decay of activation in a node, Morton suggests that the threshold level of a logogen (which is required to be reached in order for recognition of a word to occur) decreases with each presentation of a word. Rather than priming being the result of leftover activation in a logogen, Morton proposes that with each presentation of a word, the threshold of the logogen required to be reached for word recognition to occur is decreased. That is, as opposed to a change in the lexical units level of activation (as is predicted by McClelland and Rumelhart); Morton suggests it is the change in the threshold of the lexical unit that produces priming. It should be noted at this point that the Logogen model has received criticism for its inability to account for context effects in word recognition (e.g., Jacoby, 1983a, 1983b). Nevertheless, it is included in the current study for the purpose of examining, in general, the integrity of single-process models of priming given McKone's (1995) suggestions of the presence of two distinct priming components.

Mechanisms Underlying Long- and Short-Term Priming

Given McKone's (1995, 1998) suggestions of a distinct short-term priming effect, research has attempted to discern whether or not long- and short-term priming are generated by the same underlying mechanism. In the past, research has attempted to resolve this issue by observing whether differences can be found in the manner in which long- and short-term priming respond to word-frequency (i.e., how common a word is). A number of lexical decision studies have demonstrated that greater levels of short-term priming can be generated through repetition of low-frequency (i.e., less common) words than through repetition of high-frequency (i.e, more common) words (Balota & Spieler, 1999; Bowers, 2000a, 2000b). That is, the maximum obtainable level of short-term priming for a repeated word is reduced when using words that are more familiar. Bearing in mind this effect of word-frequency on short-term priming, Grant and Logan (1993) have also established that increased repetition of words throughout a lexical decision task generates greater levels of long-term priming. Therefore, if it were the case that repetition of words throughout the task (i.e., experimental practice) and word familiarity prior to the task (i.e., word-frequency) conformed to the same learning process, then this would demonstrate that one factor (i.e., practice) influences long- and short-term priming in a distinctly different manner. That is, as the degree of practice or familiarity increases, the level of long-term priming increases, whilst the level of short-term priming decreases. Such a result would provide strong support to the notion that long- and short-term priming constitute different processes.

However, the results of Kirsner and Speelman (1996) add obscurity to this rationalization. There is little, if any, research to suggest that the effect of compressing word repetitions throughout an experiment conforms to the same learning processes as those found in word-frequency effects. Indeed, Kirsner and Speelman have indicated that the manner in which these processes manifest themselves within a lexical decision task are considerably different. Kirsner and Speelman found that experimental practice or repetition of items throughout the task had a considerably greater effect on task performance than did the influence of increased frequency of words. Thus, it was suggested that learning within a task does not precisely reflect the process of learning prior to a task, despite the possibility of being generated by the same mechanism. Given this result, it seems dubious to consider studies assessing the effects of word-frequency on short-term priming (Balota & Spieler, 1999; Bowers, 2000a, 2000b; McKone, 1995) together with Grant and Logan's (1993) study investigating the effect of item repetition on long-term priming in order to settle this issue.

In addition to Kirsner and Speelman's (1996) findings, there is ambiguity in the research at this point as to whether or not short-term priming is in fact sensitive to word-frequency, given that some studies have suggested it is (Balota & Spieler, 1999; Bowers, 2000b) and some have suggested it is not (Bodner & Masson, 1997; Rajaram & Neely, 1992). The source of discrepancy between these studies is possibly the result of differences in the manner in which words in the lexical decision task are presented. When words in the task are masked (i.e., concealed shortly after being presented), as they are in Bodner and Masson's (1997) and Rajaram and Neely's (1992) research, the effect of word-frequency on short-term priming disappears (for an explanation, see Forster & Davis, 1984). Hence, the rationale of using this research as a basis for supporting the assumption that different mechanisms are responsible for long- and short-term priming is undermined by its inability to account for unmasked repetition priming research that has found short-term priming to be sensitive to word-frequency.

However, McKone (1995) provides some support to the notion that short-term priming is not influenced by word-frequency using an unmasked lexical decision task. It was found that regardless of whether high-frequency or low-frequency words were used in a lexical decision task, repetition priming decayed to long-term levels after just four intervening words. However, as noted by McKone, the rate at which priming deteriorated for high- and low-frequency words were measured in separate tasks. Furthermore, the lexical decision task for low-frequency words used low-frequency words as intervening items, whereas the task for high-frequency words used high-frequency words as intervening items. Given the sensitivity of priming to small experimental manipulations (for a review, see Tenpenny, 1995), the lack of effect of word-frequency on short-term priming may have resulted from changes in the frequency of intervening words. Thus, it appears difficult at this point in time to determine whether or not long- and short-term priming are generated by the same underlying mechanism.

The Current Study

Despite several recent attempts to resolve the issue, at present there is seemingly little or no robust support for whether or not long- and short-term priming are generated by the same underlying mechanism. Previous research has typically attempted to resolve the issue by observing long- and short-term priming under one condition (e.g., word-frequency) and assessing whether or not the two components respond in the same manner. Different outcomes for long- and short-term priming under the influence of one condition have been interpreted as support for the notion that they rely on different mechanisms. On the contrary, comparable outcomes for long- and short-term priming have been interpreted as support for the notion that they rely on the same mechanism. However, no study to date appears to have examined whether or not changes in one component produce changes in the other. That is, do obtainable levels of short-term priming vary under different levels of long-term priming? An effect of one component on the other when all other conditions are held constant would provide robust support to the notion that long-and short-term priming rely upon the same underlying mechanism. The current study aims to address this question by examining short-term priming at various levels of long-term priming.

A lexical decision task was used in the current experiment, with sets of words being presented 1, 4, 8 or 16 times. Given that research has indicated that long-term priming increases as a function of number of presentations of a word (Grant & Logan, 1993), it was expected that an increase in long-term priming would occur at some point as the number of presentations increases. Short-term priming was measured within each of these presentation conditions to assess the effect of long-term priming on short-term priming. If both long- and short-term priming are generated by the same underlying mechanism, as is suggested by single-process models of priming (e.g., McClelland & Rumelhart, 1985; Morton, 1969, 1978, 1979), it would be expected that as the level of long-term priming increases, a change in the obtainable level of short-term priming should also take place. If the two priming components are independent of one another, as is suggested by McKone (1995), it would be expected that a change in the level of long-term priming when all other conditions are held constant should not influence short-term priming. If this is the case, then the obtainable level of short-term priming should not vary between the different presentation conditions.

Method

Participants

A total of 60 people participated in the study (45 females, 15 males), including 41 undergraduate students from Edith Cowan University, Joondalup (35 females and 8 males) and 19 members of the general public (10 females and 7 males). All participants spoke fluent English and had normal or corrected-to-normal vision. Participants were entered into a raffle to win $50 and received a certificate of participation for taking part in the study. All participants were exposed to each of the four levels of the independent variable.

Materials

The stimuli used in the task included 410 four-to-seven letter words and 480 four-to-seven letter non-words. All words had a word-frequency count of one per million, as ranked by Kucera and Francis (1967). Of the 410 words, 10 were allocated to each of four presentation conditions (40), 10 were allocated to each of three control conditions created (30) and 20 were allocated to an initial practice block and to each of the 16 blocks throughout the task to be presented as new words (340). The 480 non-words were generated by changing one letter of real words to create a pronounceable and orthographically legal letter-string. None of the non-words were generated from stimuli presented as words in the task. The words and non-words used are presented in Appendix A. The task was performed on a Macintosh computer with SuperLab software installed, which recorded the participants' responses.

Procedure

Participants were tested individually in a single session lasting approximately 30-40 minutes. Each participant was presented with 1430 trials. On each trial, a string of letters was presented on the computer screen. The participant was required to decide whether the letter-string was a word or a non-word and each letter-string remained on the screen until the participant responded. Participants responded by indicating that each stimulus presented was either a word (by pressing the "m" key on the keyboard marked "word" with their right hand) or a non-word (by pressing the "c" key marked "non-word" with their left hand). Handedness was not taken into account as no comparison in the analysis was made between words and non-words. Participants were instructed to respond as quickly and as accurately as possible. Accuracy and reaction time (ms) for each stimulus presentation were recorded by SuperLab software. No feedback was provided to the participant in reference to accuracy or speed throughout the task.

The first block of trials were practice trials and included a total of 30 stimuli (20 words and 10 non-words), allowing the participants to settle into the task and to minimize the effect of practice on reaction times. The 16 experimental blocks included words presented in the four presentation conditions and in three control conditions, as well as new words and non-words. The precise manner in which the stimuli were presented to participants is depicted in Appendix B.

Design

A one-way repeated measures design was used to determine the effect of varying levels of word presentation on short-term priming. Words were presented under four different conditions (1, 4, 8 and 16 presentations) in order to produce different levels of long-term priming. Long-term priming was measured as the decrease in time taken (in milliseconds) to make the lexical decision for words in the 1, 4, 8 and 16 presentation conditions on the first presentation within the final block in comparison to new words presented in the final block. Short-term priming was measured as the decrease in reaction time (milliseconds) to identify the lexicality of words in the 1, 4, 8 and 16 presentations conditions on the second presentation in the final block in comparison to the first presentation in the final block. The four sets of words allocated to each of the four presentation conditions were rotated through each condition across participants in order to control for possible effects related to individual words.

To prevent participants from assuming that all words repeated throughout the task would be immediately repeated twice in succession in the final block, three control conditions were included in the design. For the first 16 blocks of the task, words in the three control conditions were presented in the same manner as the words in the 4, 8 and 16 presentations conditions (see Appendix B). That is, the words in each of the control conditions were presented the same number of times and in the same blocks as one of each of the 4, 8 and 16 presentation conditions. Words from all presentation and control conditions were retrieved from the same source and were not noticeably distinguishable in any manner. In the 16th (final) block, words in the 4, 8 and 16 presentations conditions were presented twice in succession in order to measure short-term priming. However, although words in the three control conditions were presented in the 16th block, they were only presented once as opposed to being repeated. No control condition was required for the 1 presentation condition because words in this condition were presented for the first time in the 16th block.

Results

Accuracy and Valid Response Percentages

McKone (1995) omitted from the analysis all incorrect responses as well as correct responses not between 300 ms and 1200 ms. To maintain consistency, only correct responses between these values were included in the analysis in the current study. Measures of response accuracy (i.e., percentage of correct responses) and percentage of valid responses (i.e., correct responses between 300 and 1200 ms) were obtained for each participant. The average response accuracy for all participants was 91.28% (*SD* = 5.66). The average percentage of valid responses (i.e., correct responses between 300 ms and 1200 ms) for all participants was 78.82% (*SD* = 10.53). Data from two participants was omitted from the analysis because the total number of valid responses was less than 20% (i.e., fewer than one in five responses could be used). Data from all participants used in the analysis had a percentage of valid responses greater than 50%. The data for each participant upon which the analysis is based is included in Appendix C.

Long-Term Priming

A one-way repeated measures Analysis of Variance (ANOVA) was carried out to determine the effect of number of presentations on long-term priming. Words in the one presentation condition were not included in this analysis because they were not presented in the first 15 blocks and so could not contribute to a measure of long-term priming. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 21.74, p < .05$). Therefore, the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .76$). The results indicated that the obtained level of long-term priming was significantly influenced by the number of presentations throughout the task, $F(1.52, 89.89) = 12.60, p < .05$. Upon more detailed analysis, Bonferroni-adjusted post-hocs revealed that long-term priming was significantly greater for words presented 16 times (*M* = 71.93 ms, *SD* = 65.10) than for words presented 4 (*M* = 29.90 ms, *SD* = 84.12) and 8 (*M* = 42.50 ms, *SD* = 61.16) times. However, long-term priming in words presented 8 times was not significantly greater than in words presented 4 times. Figure 2 provides a graphical depiction of long-term priming patterns for words under different numbers of presentations. This result, which suggests that an increase in the number of word presentations results in greater levels of long-term priming is consistent with the findings of Grant and Logan's (1993) research.

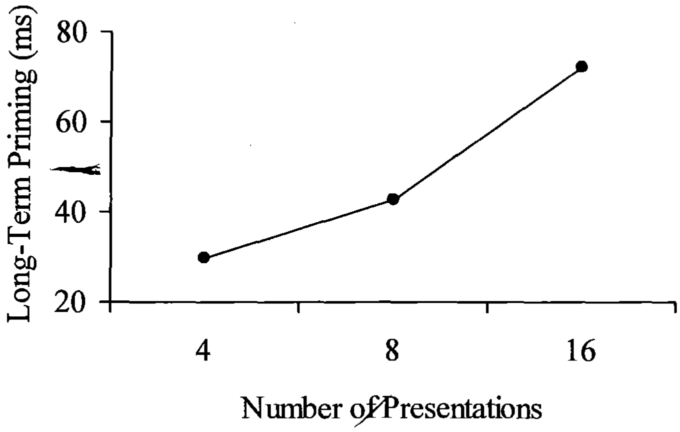

Figure 2. Long-term priming levels for words presented 4, 8 and 16 times.

Short-Term Priming

A second one-way repeated measures ANOVA was performed to determine the effect of number of presentations on short-term priming. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 26.14, p < .05$). Therefore, the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .73$). The results indicated that the obtained level of short-term priming was significantly influenced by the number of presentations throughout the task, $F(1.47, 86.58) = 4.98, p < .05$. Bonferroni-adjusted post-hocs revealed that short-term priming was significantly larger for words presented 4 times (M = 143.86 ms, SD = 90.92) than for words presented 16 times (M = 111.02 ms, SD = 68.36). However, short-term priming for words presented 8 times (M = 127.90 ms, SD = 79.84) was not significantly different to short-term priming for words presented 4 times; nor was it significantly different to words presented 16 times. The patterns of short-term priming in the 4, 8 and 16 presentation conditions are depicted in Figure 3.

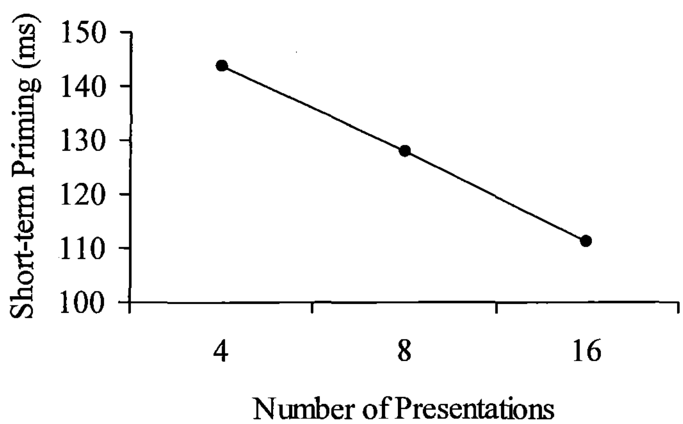

Figure 3. Short-term priming levels for words presented 4, 8 and 16 times.

Dealing with Outliers

Words within each block were presented in a random order for each participant and thus distances between presentations within each condition used to measure long-term priming were not held constant. Given that several studies have indicated that repetition priming deteriorates over time (e.g., Grant & Logan, 1993; McKone, 1995, 1998), it is probable that within each presentation condition different levels of long-term priming would have emerged for different words. It was expected that this variation in the manner in which words were presented would result in greater variability of scores for long- and, perhaps also, short-term priming within each condition. McKone (1995) used presentation templates to ensure stimuli were presented in the same order for each participant. Whilst using such presentation templates can potentially lead to biases related to non-random presentation order, it is highly probable that the priming levels obtained by McKone showed less variation than priming levels obtained in the current experiment.

To maintain utmost consistency with McKone's (1995) research, the analysis was repeated with all outlying scores (i.e., scores greater than two standard deviations from the mean of each condition) removed from each presentation condition within the sets of scores for both long- and short-term priming. This would supposedly reduce the amount of variance within each condition, resulting in priming scores more representative of those found by McKone (1995). If the removal of outlying scores resulted in more outliers, these scores were also removed (this process was repeated until no score within each presentation condition was greater than two standard deviations from the mean). A more stringent measure of two standard deviations was used to identify outlying scores (as opposed to 2.5 or 3 standard deviations) because high levels of variability within groups meant a score had to be situated considerably further from the mean than what would normally be required in order to be identified as an outlier.

Long-Term Priming (Outliers Removed)

A one-way repeated measures ANOVA was repeated on the long-term priming data with all outlying scores from the 4, 8 and 16 presentation conditions removed (two removed in total). Mauchly's test of sphericity revealed that the assumption of sphericity had been violated ($\chi^2(5) = 20.76, p < .05$). The degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .76$). The ANOVA indicated that long-term priming was influenced significantly by number of presentations, $F(1.52, 85.21) = 10.90, p < .05$. Bonferroni-adjusted post-hocs indicated that long-term priming was significantly greater for words presented 16 times ($M = 62.99$ ms, $SD = 53.10$) than for words presented 4 ($M = 22.16$ ms, $SD = 78.02$) and 8 ($M = 34.92$ ms, $SD = 52.63$) times. However, no difference in long-term priming was found between words presented 8 times and words presented 4 times.

Thus, analysis of this long-term priming data provided the same result as the analysis with outlying scores included.

Short-Term Priming (Outliers Removed)

A one-way repeated measures ANOVA was also repeated on the short-term priming data with all outlying scores from each condition removed (16 removed in total). Again, Mauchly's test revealed that the assumption of sphericity had been violated ($\chi^2(5) = 7.96, p < .05$) and consequently the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .85$). The ANOVA revealed that the number of presentations of words had a significant effect on short-term repetition priming, $F(1.70, 73.33) = 4.94, p < .05$. Bonferroni-adjusted post-hocs indicated that short-term priming was significantly less for words presented 16 times (M = 104.14 ms, SD = 50.28) than for words presented 4 (M = 130.13 ms, SD = 44.63) and 8 (M = 130.24 ms, SD = 61.20) times. However, no significant difference in short-term priming was found between words presented 4 and 8 times. Thus, by removing outlying scores, a significant difference is now obtained in short-term priming between the 8 and 16 presentation conditions.

Discussion

Overview of Results

Contrary to the views of McKone (1995), the current set of results demonstrate support for the notion that long- and short-term priming are generated by the same underlying mechanism(s) and that they do not constitute distinctly different processes. The results effectively demonstrate that in a lexical decision task, an adjustment in the magnitude of long-term priming (achieved by varying the number of word presentations throughout the task) results in a change in the obtainable level of short-term priming when all other factors are held constant. Whilst an analysis of long- and short-term priming with outlying scores included indicates that it is not always the case that a change in long-term priming will inevitably result in a change in short-term priming, there is undoubtedly an inverse relationship that exists between them (see Figures 2 and 3). In support of this notion, the relationship between long- and short-term priming became more evident when outlying scores were removed from the data of each of the four presentation conditions within long- and short priming.

If it were the case that the long- and short-term components of priming constituted two distinctly different processes generated by different underlying mechanisms, as is proposed by McKone (1995), one would expect short-term priming to remain unchanged given a shift in long-term priming. However, this is clearly not the case for the current set of results. By increasing the number of presentations of a word throughout the task from 4 to 16, the obtainable level of short-term priming decreased, whilst the level of long-term priming increased. When outlying scores were removed from the analysis (thus reducing variability and adding power to the analysis), the relationship between long- and short-term priming becomes more obvious. By increasing the number of word presentations from 4 to 16, the same outcome for long- and short-term priming was observed as in the initial analysis with outliers included (i.e., a significant increase in long-term priming and a significant decrease in short-term priming). Furthermore, both priming components were found to respond in the same manner when increasing the number of word presentations from 4 to 8 to 16. That is, neither long- nor short-term priming changed significantly when the number of word presentations was increased from 4 to 8. However, by increasing word presentations from 8 to 16, a significant increase occurred in long-term priming and a significant decrease occurred in short-term priming. The results show strong support for the notion that the processes of generating long- and short-term priming are dependent upon the same underlying mechanism(s).

The non-significant reduction in short-term priming between 8 and 16 presentations in the initial analysis (which included outliers), despite a significant increase in long-term priming between these conditions is, in all probability, attributable to a lack of statistical power resulting from high levels of variability in data within each presentation condition. Given that letter-strings in the current experiment were presented randomly within each block, the length of delay between the first presentation of a word in the 16th block (from which long-term priming was measured) and its preceding presentation could have varied considerably. For example, a word in the 16 presentations condition could have appeared at the beginning of block 15 but at the end of block 16, which would have allowed more time for decay to take place compared to another word presented at the end of the block 15 but at the beginning of block 16. Whilst it was expected that this flexibility would occur evenly across conditions given the large number of words presented, the resulting high levels of variability within each of the presentation conditions perhaps contributed to the initial non-significant difference in short-term priming between the 4 and 8, and 8 and 16 presentations conditions. If templates had been used in the current experiment to specify the order in which words were presented, as were used by McKone (1995), a significant difference in short-term priming between the 4 and 8 presentations conditions and/or the 8 and 16 presentation conditions may have been obtained prior to removing the outlying scores.

Reconsidering Suggestions of Distinct Priming Processes

Although there is much support for the idea that priming is generated by a single underlying mechanism, the current study does not dispute that the data obtained in

McKone's (1995) Experiment 1 indicates the presence of two distinct priming events. Clearly the exponential function that best represents McKone's data supports the argument that both a long- and short-term priming effect exists. However, McKone's data and the exponential function fitted to it (upon which reasoning for two distinct components is partly based), is not an accurate reflection of the entire decay of priming process. In the exponential function provided by McKone, it is suggested that short-term priming is superimposed on top of a constant long-term priming effect of 49.1 ms. McKone insinuates that the two components are clearly different because the equation suggests that short-term priming decays rapidly and long-term priming does not decay at all (as indicated by the 49.1 ms constant). The problem with employing this equation to support the notion of two distinct priming processes is that the equation assumes that the long-term priming component of 49.1 ms is present regardless of how long priming is given to decay. However, Grant and Logan (1993) have clearly demonstrated that priming for words presented once decays completely within eight hours. In essence, McKone's experiment measures only the first 48 seconds of a decay process that Grant and Logan have demonstrated to last somewhere between five minutes and eight hours.

A second source of support provided by McKone (1995) for the presence of two distinctly different repetition priming components is that long-term priming disappears when using high-frequency words (i.e., a mean frequency of 275 per million), despite the short-term effect remaining unchanged. McKone illustrated that regardless of whether high- or low-frequency words are used, the maximum obtainable short-term priming effect remains the same (around 85 ms). However, it was also demonstrated that a long-term priming effect (around 50 ms) remains after a 10 second delay with low-frequency words, though it has decayed completely by this time when using high-frequency words. As with the exponential function fitted to the low-frequency word data, this interpretation assumes that long-term priming is an everlasting effect. Hence, if long term priming levels were measured after an eight hour delay (as opposed to a 10 second delay), it is plausible to assume that no long-term effect would be present for low-frequency words either. One could assume then that the presence of a long-term priming effect in low-frequency words at a delay of 10 seconds simply exists because sufficient time has not passed to allow for the initially much higher level of overall priming to deteriorate to the extent that high-frequency words have by this time.

Given the results obtained in the current experiment, there appears to be little support for two distinct priming components generated by different underlying mechanisms. At this point, several question marks have been raised concerning research supporting the existence of two distinctly different priming components and their contribution to an overall priming effect. Whilst an exponential function effectively summarises McKone's (1995) priming data in a statistical manner, its application to the actual cognitive processes inherent within repetition priming are questionable given that it insinuates an everlasting long-term priming effect. Previous studies examining long-term priming decay have demonstrated that decay is best represented by a power function (Grant & Logan, 1993; Wixted & Ebbesen, 1991). Given that the current study has effectively demonstrated that long- and short-term priming rely upon the same underlying mechanism(s), it seems reasonable to assume that the short-term component discussed by McKone might also correspond to a power function that is able to account for most of the variance in long-term priming. Consequently, priming could perhaps more accurately be interpreted as a single and continuous process, as opposed to an additive integration of long- and short-term components.

Theoretical Implications

Given that it has been demonstrated that long-term priming influences obtainable levels of short-term priming, the result suggests that the two priming components are merely different stages of the same process. Thus, the result provides support for McClelland and Rumelhart's (1985) Interactive Activation model and Parallel Distributed Processing model as well as some support for Morton's (1969, 1978, 1979) Logogen model. According to McClelland and Rumelhart's models, the observed increase in long-term priming brought about by an increase in the number of word presentations can be attributed to the associated node (or group of word-detectors) for each stimuli being activated on a number of occasions. On each occasion, the level of activation is not given time to decay to its pre-activation resting level and thus, priming accumulates with each presentation. The models are also able to account for the inverse relationship between long- and short-term priming. Given McClelland and Rumelharts' prediction that priming has a stable maximum value; an increase in long-term priming should limit the amount of short-term priming able to be obtained, which indeed appears to be the case.

Morton's (1969, 1978, 1979) Logogen model of word recognition is able to account to some extent for the data, though not to the extent that McClelland and Rumelharts' (1985) models do. According to Morton's model, long-term priming has risen with increasing word repetitions as a result of a decrease in the threshold of each logogen associated with each word that was presented multiple times. The model is, however, unable to account for why short-term priming decreases as long-term priming increases. Given that it is predicted that each presentation of a word decreases the threshold for recognition, it would be expected that increasing presentations of word would also increase the level of short-term priming. Since this is not the case for the data obtained in the current study, Morton's Logogen model needs to be adjusted to account for this effect. The most reasonable adjustment in the model would be to adopt a position similar to that of McClelland and Rumelhart, whereby it is suggested that there is a limited overall amount of priming that can be obtained.

Given McClelland and Rumelhart's (1985) suggestion of a limited overall effect of priming, future studies could further explore the inverse relationship between the long- and short-term components identified in the current study in order to determine whether a substitution-like association actually exists between the two components. The current study was not able to investigate this matter on account of differences in the manner in which long- and short-term priming were measured. Given that practice effects were taken into account for long-term priming (i.e., reaction times for target words were measured against new words within the same block) but not for short-term priming, combining the data to give an overall priming score seems questionable. Future studies could deal with this problem by measuring short-term priming against new words within the same block to avoid the possibility of practice effects. If a limited overall effect of priming was able to be identified, it would provide further support for the use of McClelland and Rumelhart's Interactive Activation (1985) and Parallel Distributed Processing (1986) models in portraying repetition priming processes in visual word recognition.

In conclusion, McKone's (1995) suggestion of the presence of two distinct underlying mechanisms in repetition priming processes has been examined and disputed. It was found that the magnitude of the short-term priming component identified by McKone (1995) is influenced by levels of long-term priming illustrated by Grant and Logan (1993). This result suggests that the two components are not independent of one another. Thus, in combination with previous research indicating that the decay of priming conforms to a power function (Grant & Logan, 1993), the current study suggests that long- and short-term priming may in fact make up different stages of a single decay process. Furthermore, alternative explanations were provided for both of McKone's claims suggesting the presence of separate long- and short-term priming components. The result supports the notion of a single underlying mechanism in repetition priming, therefore providing support to existing single-process models of priming.

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Appendix A

Presentation Condition Words

Set 1		Set 2		Set 3		Set 4	
anagram	brazen	atypical	wreak	restock	precept	rogue	perch
icicle	corsage	sadist	rattler	mutter	invert	migrate	liqueur
rubble	wallow	pendant	leakage	gnome	fallacy	gymnast	flora
tycoon	seismic	forgery	chorale	dazzle	canine	dune	caress
retina	pallet	benign	adrift	beckon	agitate	booted	allure

Control Presentation Condition Words

Control Set 1		Control Set 2		Control Set 3	
closure	toffee	wield	replica	sequel	remorse
scald	rejoice	pout	mains	paging	malign
ponder	gorge	harp	gabble	hybrid	gleeful
fret	calorie	flatter	caddy	expend	concise
bubbly	allege	broach	askew	broker	augment

New Words

			Practice Block			
almond	bead	compile	deem	expire	knead	ladle
fatten	graced	hyena	infect	joust	peddle	query
oblige	refute	shrub	truant	midwife	nullify	
			Block 1			
unravel	vocally	walrus	yoga	zoned	affix	binge
dented	elapse	frilly	gutter	fare	indigo	jovial
lute	mayhem	nuance	outcast	ketchup	caviar	
			Block 2			
pagoda	quartz	riddle	smuggle	typify	untidy	vaccine
yodel	zombie	acidity	bunny	coax	deviate	eagerly
gurgle	hearse	idolize	jewel	wand	faucet	
			Block 3			
kiosk	livid	mauve	neuron	omit	primate	quirk
shun	trawler	unbound	varnish	wrongly	yolk	zipper
blubber	copious	defence	enchant	repress	antic	
			Block 4			
fickle	grapple	halter	irate	jittery	kite	lament
mentor	noun	orphan	paddle	quicken	roofing	silky

tricky	unpack	vacate	wicket	yearn	zebra	
			Block 5			
abstain	breezy	cavern	duct	embody	flake	groan
humid	implant	joyful	licking	mascara	natured	outwit
perk	quits	reducer	skit	tint	unsure	
			Block 6			
vortex	woeful	yonder	ascend	boar	clotted	dinghy
exclaim	fielded	gauze	hoist	inflame	jostle	lawsuit
mumble	nibble	onward	partook	quench	regain	
			Block 7			
seclude	tandem	uphill	vibrato	whimper	atone	booming
carver	drowsy	evasion	ferret	grovel	heiress	inhabit
jumper	lava	mould	nigh	octopus	paddock	
			Block 8			
remarry	sizzle	toil	upbeat	vendor	whack	adapter
booklet	canter	draught	envious	finicky	gander	hinge
inflate	jeans	lobster	metre	numeral	overran	
			Block 9			
overeat	pelvis	rift	sewn	taint	unpaved	veal
weed	anvil	bonding	charmer	deceive	excel	fancier
gratify	helmet	imperil	lower	mammal	netting	
			Block 10			
parsley	radiate	sling	topple	unstuck	voyager	wiggle
animate	bracket	cube	diesel	exalt	fauna	glacier
harden	infest	looped	malt	nether	panther	
			Block 11			
rodeo	shack	ticking	uplift	waltz	allergy	brawl
citrus	detach	empower	feud	graze	hexagon	imprint
lurk	majesty	nostril	parcel	racquet	sibling	
			Block 12			
touchy	upshot	wilder	asthma	barrack	clench	dilute
empathy	flee	grading	hefty	infer	loader	meaty
perplex	rash	silo	trauma	unequal	weasel	
			Block 13			
archery	brewing	camel	divert	embryo	femur	gash
hobble	intrude	lottery	magpie	pageant	rampage	scuffle
toxin	unscrew	womanly	astound	bran	caramel	
			Block 14			
digit	enamel	fodder	gloss	haggle	invader	logger
mellow	pebble	rascal	snout	triplet	wastage	aura
bribe	cedar	degrade	enrage	felony	giggle	

Block 15						
humour	insipid	lodged	mash	pamper	rudder	seizing
thimble	whoosh	anchovy	baffle	cardiac	duress	eave
fern	glum	hospice	inmate	labile	manikin	

Block 16						
anthem	froth	catchy	brainy	amplify	prank	raisin
shopper	tongs	bred	fuming	prolong	candle	solicit
avert	funnel	prune	refresh	fusing	runt	

Non-Words

Practice Block						
anumaly	hamour	inicle	quib	rebuce	toiret	suvken
ulable	whote	zipler				

Block 1						
atricot	badle	chaw	dault	heena	inbense	levul
mive	nert	ornan	pammer	reth	seanch	taixor
tranel	unarted	vogica	weat	yope	zome	

Block 2						
appian	ballus	chank	duvty	elezent	futume	glape
hute	ioch	juviper	knat	lume	mesican	naul
oviforg	pirnic	quibbie	roding	sagety	tubban	upbeal
voleble	woten	yows	boll	dwinkle	enlange	inhulan
jurce	quom					

Block 3						
biss	corpete	daled	edenly	faddle	gool	harb
inotial	jopian	kala	lind	mutial	nolody	rever
snofy	thackly	ustal	vose	wrose	zealet	

Block 4						
anching	beseine	colbat	dunleon	emil	fupy	guggle
harkful	itjelf	jorial	kandly	lins	madren	nurging
ovive	panks	quilk	rulled	snabbed	trop	uncifil
vulgal	wheck	yorder	bandare	crynt	dosk	forring
gekius	ipland	jewal	kaowing	leart	mourd	norve
rikual	scanny	tixic	unboind	viazzle		

Block 5						
arpenic	balarce	cunical	dotor	esjort	feseral	gumnast
healta	inlat	jistle	kread	libetal	nomph	onse
pock	quilote	reng	shink	tacket	unalare	

Block 6						
armury	balnoon	boron	curcass	diol	edumate	feves
gadgat	hanor	ibory	jeamous	klack	lamer	murtard

nopinee	oblitue	prace	queet	rustuc	sifing	thew
urterly	voval	whola	xyleg	yellof	zesh	beke
cortail	doscent					

Block 7

bawtism	calera	drunten	embrake	fengal	grawe	haloc
imland	jerist	katchen	lurg	meare	naturi	outlome
poysics	quarify	rinning	seck	tubi	usem	

Block 8

akthem	bael	basaful	binch	climp	claft	defict
elaptic	encure	forave	gronny	goilt	hecraic	inper
jomble	kadney	koys	lapie	marstro	morvow	nightry
okoy	optose	paxagon	praving	quinck	reack	ribbish
spuce	subsoal	tonor	tirsue	umper	unward	wrected
xynon	yowth	zorbie	zonc	wrone		

Block 9

avip	befind	copsult	dinit	endirg	frawe	grimble
helt	istue	jodge	knawn	lurkily	mayle	nutreg
ozelet	petly	quiltus	rabine	shabing	tren	

Block 10

bartism	barbud	bigging	cirvus	deverse	ekade	foat
golmen	hirkory	imrart	jawl	kees	luzgage	molur
negite	odinion	pierred	quips	rame	socken	thern
unaiked	badued	wodded	yomel	choer	duil	exfort
lebical	krew					

Block 11

aponess	biffle	colcede	dwaif	eropt	fakial	gitter
hergelf	illebal	jeply	mecus	nevesis	nuglet	oope
poliby	quint	reyalty	sapred	thomb	upriar	

Block 12

adrict	badon	bicups	carcium	diffel	elipe	facey
gommy	hefry	imirate	jatters	kneckle	louth	memu
nuck	occuny	poter	quona	roister	serrant	tyrang
uppift	veltor	witrout	xenua	yiell	zeafous	astote
barkuni	cemint	deup	eleftor	fael	geswure	hote
imagevy	jongle	kassing	leasy	midel		

Block 13

advern	banfing	cancol	driad	eterkal	fuil	guiss
hounj	impehil	janta	kosmer	lodie	medday	neted
offsut	plases	queep	rufal	sharlow	terch	

Block 14

atylum	battegy	curt	deceipe	elact	fleak	gream
hanzed	iller	jumfer	knipe	luft	mepodic	nunge
ontical	polu	quark	reeny	stirk	thoory	urgect

vilious	whisty	yarl	votek	wedwock	yerp	zote
blekish	drast					
			Block 15			
awesh	banina	clase	dyeng	epivode	foend	granify
hoos	ipem	jount	koit	locag	mutic	nakal
ozto	peloem	trapic	usacle	vewel	weafe	
			Block 16			
anound	bary	biar	cewtify	custoly	dearlo	danamo
eare	elvy	frake	fiam	garsic	gaft	haubage
hert	influde	indute	jurtly	jery	kack	kright
lacad	lumky	mackine	mouthud	noan	novej	odtave
osmoxic	pulace	purfy	quirf	rish	rudar	sacting
sequoya	tasi	tacoon	utirize	urter	vertimo	volame
whurf	wrouget	yacut	yiddisk	zeac	barriet	cascase
dimpen	egotasm	floir	gane	herejic	idolipe	justity
kond	lapent	molify	narion	onscure	pire	ruxt
speater	taftar	ugsy	viltaic	wrettle	zeera	blart

Appendix B

Number of letter-strings in each condition presented in each block of the task (including practice block).

	Block Number																	
Stimulus Condition	P	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
16 Presentations	-	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10[r]	160
8 Presentations	-	-	10	-	10	-	10	-	10	-	10	-	10	-	10	-	10[r]	80
4 Presentations	-	-	-	-	10	-	-	-	10	-	-	-	10	-	-	-	10[r]	40
1 Presentations	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10[r]	10
16 Control	-	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	160
8 Control	-	-	10	-	10	-	10	-	10	-	10	-	10	-	10	-	10	80
4 Control	-	-	-	-	10	-	-	-	10	-	-	-	10	-	-	-	10	40
New Words	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	340
Non-Words	10	20	30	20	40	20	30	20	40	20	30	20	40	20	30	20	70	480
Total	30	60	90	60	120	60	90	60	120	60	90	60	120	60	90	60	160	1390

[r] Denotes that stimuli were presented twice in succession in order to measure short-term priming.

Appendix C

Data Set Included in Analysis

ID	Accuracy (%)	Valid Responses (%)	Long-Term Priming			Short-Term Priming		
			4	8	16	4	8	16
1	96.64	94.76	60.83	16.83	81.73	69.20	91.14	78.36
2	92.52	83.01	91.83	14.96	102.81	60.42	70.00	64.05
3	93.08	82.80	29.45	77.25	47.58	169.50	96.20	162.11
4	90.91	66.99	89.21	75.36	111.36	173.77	168.38	184.00
5	94.41	69.79	104.83	189.39	216.33	3.56	29.11	-44.75
6	97.55	89.16	-35.71	2.96	60.99	229.80	108.96	32.30
7	95.52	83.92	-88.91	-98.56	-20.46	213.06	222.30	154.50
8	92.94	85.03	83.83	38.56	85.50	75.47	105.39	91.36
9	96.15	82.73	4.07	-31.26	4.56	129.29	166.50	133.8
10	83.43	79.86	-27.71	-33.21	13.79	119.89	145.30	51.10
11	94.20	89.23	2.79	62.03	95.73	157.43	151.40	125.90
12	97.13	85.38	125.13	60.80	-1.30	25.00	-85.42	-19.47
13	86.64	70.91	197.45	184.95	254.08	107.00	150.25	37.88
14	87.83	75.52	71.79	-28.43	51.02	102.48	217.88	69.81
15	94.48	86.43	-51.42	5.58	37.90	157.90	34.53	-26.03
16	86.08	82.66	105.18	83.75	133.18	107.13	59.80	98.30
17	90.56	70.35	-64.91	104.64	96.16	265.70	28.37	119.29
18	93.08	85.59	-43.85	-49.35	-49.58	208.40	146.00	176.67
19	96.43	62.59	44.07	167.44	132.64	169.37	14.83	56.10
20	87.06	76.36	-1.05	63.40	57.95	263.70	285.14	315.30
21	96.99	90.84	-14.45	-1.68	56.85	104.70	80.03	70.20
22	89.16	54.13	-122.47	21.91	-10.84	98.04	64.50	67.75
23	95.31	81.96	-6.63	5.25	24.19	123.60	129.67	104.70
24	92.03	87.55	0.33	81.77	99.47	153.03	75.80	63.50
25	91.47	87.13	-5.33	85.59	79.99	134.72	91.19	72.68

26	96.64	73.50	201.30	20.13	12.08	159.21	329.17	255.96
27	96.85	92.45	6.82	14.27	78.82	138.30	135.16	68.80
28	94.55	82.66	79.34	20.94	68.44	-118.51	30.00	-0.40
29	95.73	94.90	31.95	-13.35	-6.35	59.58	109.10	96.60
30	85.87	72.87	85.07	86.48	45.39	69.07	116.28	139.14
31	92.66	84.90	31.22	98.74	151.99	166.52	171.60	104.94
32	92.31	78.46	-27.58	-9.89	-21.83	100.45	1.06	60.28
33	94.83	54.48	97.24	9.09	147.37	266.33	311.91	218.43
34	94.83	91.12	32.32	55.42	73.20	209.33	152.34	117.01
35	93.50	73.22	228.67	185.27	255.04	114.70	177.00	114.74
36	91.22	78.78	85.29	31.38	13.44	143.81	156.63	215.68
37	67.83	65.73	162.07	141.32	190.40	146.00	81.42	78.07
38	95.31	85.59	3.17	70.61	36.43	116.79	80.94	90.43
39	84.20	66.22	-54.12	87.88	109.97	417.25	189.14	178.29
40	78.95	77.34	27.33	-20.26	75.07	111.46	94.00	113.90
41	93.29	78.04	-8.21	86.90	84.90	164.01	95.00	77.90
42	86.71	68.81	180.58	111.76	117.05	109.80	236.40	145.89
43	91.96	78.11	13.89	-66.12	40.86	173.99	262.19	200.80
44	89.32	55.10	-10.60	24.31	128.80	60.68	247.44	168.70
45	96.01	90.70	-68.92	37.02	131.36	255.90	41.44	41.32
46	97.13	90.28	76.36	67.36	79.88	7.72	119.72	81.08
47	89.44	84.69	-69.21	-39.31	3.37	121.13	87.30	48.56
48	96.22	95.45	-0.68	3.72	68.32	164.88	165.60	67.00
49	91.96	76.85	118.03	39.33	80.96	68.90	109.50	117.44
50	91.96	81.33	85.38	57.27	67.28	147.80	173.21	166.80
51	91.77	84.63	85.54	14.07	58.5	129.90	157.21	89.00
52	76.64	63.71	-80.14	-4.31	39.64	278.13	132.38	171.21
53	92.31	75.94	169.97	31.80	120.47	45.39	251.33	133.00
54	84.83	74.20	-157.07	-23.20	-32.29	290.63	90.83	180.22
55	84.97	51.90	110.93	77.14	137.18	-59.90	1.29	83.50

56	80.28	74.83	-54.41	131.73	60.30	255.64	61.63	98.65
57	92.10	83.50	3.46	56.79	110.03	298.44	177.27	226.29
58	92.87	70.63	-127.17	30.90	50.70	296.72	201.3	173.90
59	94.97	90.49	-1.53	-3.84	-32.01	135.56	167.58	178.08
60	95.38	83.64	-10.74	38.69	9.39	163.63	112.40	120.33

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