6 Word Priming and Interference Paradigms

Zeshu Shao and Antje S. Meyer

Abstract

In word priming and interference studies, researchers typically present participants with pairs of words (called primes and targets) and assess how the processing of the targets (e.g., "nurse") is affected by different types of primes (e.g., semantically related and unrelated primes, such as "doctor" and "spoon"). Priming and interference paradigms have been used to study a broad range of issues concerning the structure of the mental lexicon and the ways linguistic representations are accessed during word comprehension and production. In this chapter, we illustrate the use of the paradigms in two exemplary studies, and then discuss the factors researchers need to take into account when selecting their stimuli, designing their experiments, and analyzing the results.

Introduction

In order to talk to each other, people need to have a shared vocabulary. It has long been known that our repository of words, the mental lexicon, is not a random heap of words, but has a complex internal structure. There is plenty of anecdotal evidence illustrating this. For instance, we can easily provide associates ("chicken – hen", "red – fire"), opposites ("tall – short", "good – bad"), or rhymes of words ("cat – mat", "bay – day"). This shows that our memory representations of associates, opposites,

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and rhymes are somehow linked. These links can work against us, for instance when we find ourselves asserting the opposite of the intended meaning ("I hereby declare the meeting closed, eh, opened"), or when we are in a tip-of-the-tongue state, where similar sounding words appear to block access to a target ("it's not Rutherford, Remington, ... Rubicon!"). These observations show that the mental lexicon represents not only properties of individual words but also multiple relationships between them. Describing these relationships and understanding their development and their impact on language production and comprehension have been key issues in psycholinguistics (Gaskell, 2007). Among the most important tools in this research area are word priming and interference paradigms. Their properties are discussed in the following sections.

Assumptions and Rationale

The goal of word priming studies is to observe the effect of a first stimulus, the prime, on the response speed (measured in milliseconds) and/or accuracy (measured as proportion of correct responses) to another stimulus, the target. The prime may, for instance, be the word "cat" and the target the word "mouse." In order to establish the effect of a prime, one needs to include a suitable baseline condition with a neutral or unrelated prime in the experiment (e.g., a row of "xxxx" or an unrelated word, such as "fork," for the target "cat"). The goal of interference studies is exactly the same: To observe the effect of a first stimulus, the distractor, on the speed and/or accuracy of responding to another stimulus, the target. Prototypical priming and interference studies differ in the timing of the stimuli, with primes preceding the targets and distractors co-occurring with the targets; and they also differ in the direction of the effects, with priming studies typically yielding faster and/or more accurate responses in the related relative to the unrelated condition, and interference studies yielding slower and/or less accurate responses in the related condition. However, as neither the timing of the stimuli nor the directions of the observed effects distinguishes clearly between the two types of studies, we consistently refer to *primes* and *priming studies* in this chapter.

The underlying assumptions of word priming studies are straightforward: To affect the response to the target, the prime must have been processed, and the activated mental representation of the prime must be related in some way to the representation of the target. Therefore, priming studies can be used in two ways, namely, first, to study the processing of stimuli and, second, to determine the properties of mental representations and the relationships among them.

Two Exemplary Studies

To illustrate the use of priming paradigms we describe two classic studies, a word recognition study by D.E. Meyer and Schvaneveldt (1971) and a picture naming study by Glaser and Düngelhoff (1984). Meyer and Schvaneveldt were interested in the memory search processes underlying lexical decision, that is, the decision whether or not a written string of letters is a word. The trials of their experiments had the following structure: At trial onset, the participants saw the word "ready" on the

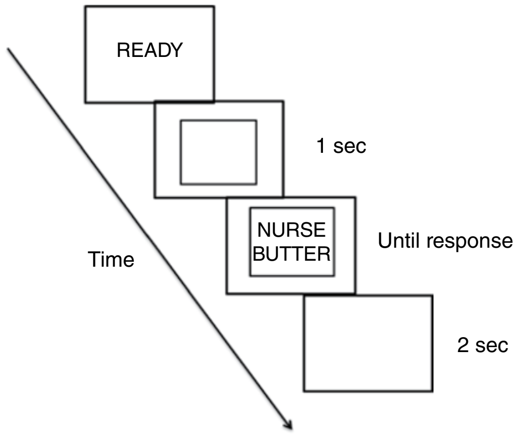

Figure 6.1 An illustration of the trial structure in Meyer and Schvaneveldt (1971). The presentation time for "READY" is described as "brief" in the text.

screen, followed first by a fixation box and then by a pair of stimuli (see Figure 6.1). These stimuli remained on the screen until the participant reacted. After 2 seconds, the next trial began. The stimuli were either two words, two nonwords, or a word and a nonword. Nonwords (for instance MARB) were derived from existing English words, mostly by replacing a single letter. Importantly, the words shown together were either associatively related (as in "bread" – "butter") or unrelated ("nurse" – "butter"). In the first experiment, participants pressed one button on a push-button panel when both stimuli were words and another button when one or both stimuli were nonwords. Twelve participants were tested. The authors recorded the accuracy of their responses, measured as the proportion of correct word and nonword responses, and the response speed for correct responses, measured from the onset of the word pair. The error rates for related and unrelated pairs were 6.3% and 8.7%, respectively; and the corresponding reaction times were 855 ms and 940 ms, respectively. The 85 ms difference between the two conditions was statistically significant. In the second experiment, the participants pressed one button when the two stimuli were both words or both nonwords, and another button when one of them was a word and the other was a nonword. Again, accuracy and response speed for correct responses were recorded. As in the first experiment, responses to word stimuli were more likely to be correct and faster when the words shown together were related than when they were unrelated. To account for these findings, Meyer and Schvanefeldt proposed that there might be passive spread of activation between associated words in the lexicon, so that in the related condition reading the first word facilitated access to the second word, or that the second word might be faster to access from a nearby (associated) location in the lexicon than from a location farther away.

The second classic study to be described was carried out by Glaser and Düngelhoff (1984, Experiment 1). They presented participants with word-picture combinations as shown in Figure 6.2 and asked them either to name the pictures or to read aloud the words. Earlier studies had shown that speakers are slower to name pictures accompanied by semantically related than by unrelated written words. Thus, there is a semantic interference effect for picture naming. By contrast, naming written words (reading aloud) is not hindered by the presence of related compared to unrelated

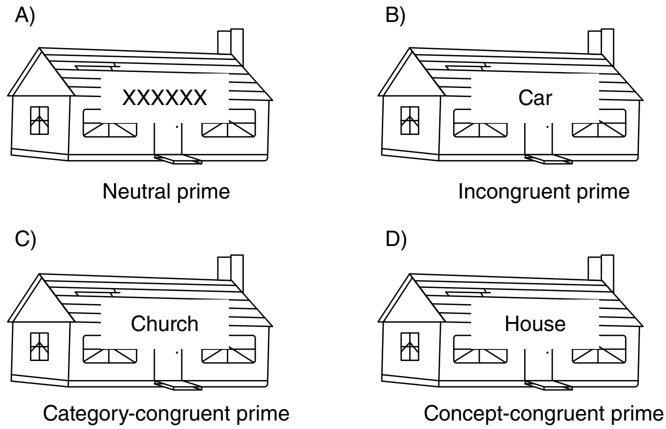

Figure 6.2 An illustration of the prime-target pairs used in Glaser and Düngelhoff (1984).

pictures. This pattern had been linked to the greater speed and automaticity of word naming compared to picture naming. To assess the importance of the speed of access to the meanings of the stimuli for the occurrence of the semantic interference effect in picture naming, Glaser and Düngelhoff varied the time interval between the onsets of the picture and the word (the stimulus onset asynchrony, SOA) giving either the word or the picture a head start. Participants saw four types of prime-target pairs, which the authors called neutral (a row of "xxxxxx" combined with a picture, as in "xxxxxx" – "house"), incongruent ("car" – "house"), category congruent ("church" – "house"), and concept congruent ("house" – "house"). The written stimulus was superimposed upon the picture as shown in Figure 6.2. The presentation of the two stimuli either began at the same time (i.e., with an SOA of 0 ms), or the presentation of the word began 100, 200, 300, or 400 ms before or after picture onset. Both stimuli disappeared 200 ms after the onset of the response. One group of 18 participants had to name the pictures ignoring the words, and another group of 18 participants named the words ignoring the pictures.

Glaser and Düngelhoff recorded the accuracy of the responses, that is, whether or not the participants named the word or picture correctly, and the reaction times for correct responses, measured from the onset of the target. The results obtained for the response latencies are summarized in Figure 6.3. The top panel shows the results for the picture naming task. Compared to the neutral prime baseline, concept-congruent primes speeded up the responses. This was true for primes presented at any time between 400 ms prior to target onset until 200 ms after target onset. In the same broad time window, incongruent primes slowed down target naming relative to neutral ones. Most importantly, in a narrower time window, with primes presented at picture onset or 100 ms later, category-congruent primes interfered with target naming (i.e., slowed it down more) than incongruent primes. Thus, in this time window there was a semantic interference effect. The results obtained for word naming are shown in the bottom panel of the figure. Here, there was little difference in the effects of the different primes, regardless of the SOA. Thus, even when given a head start, semantically related pictures did not interfere with word naming. This shows that other variables than the speed of access to meaning representations must be responsible for the fact that there is a semantic interference effect in picture naming but not in word naming.

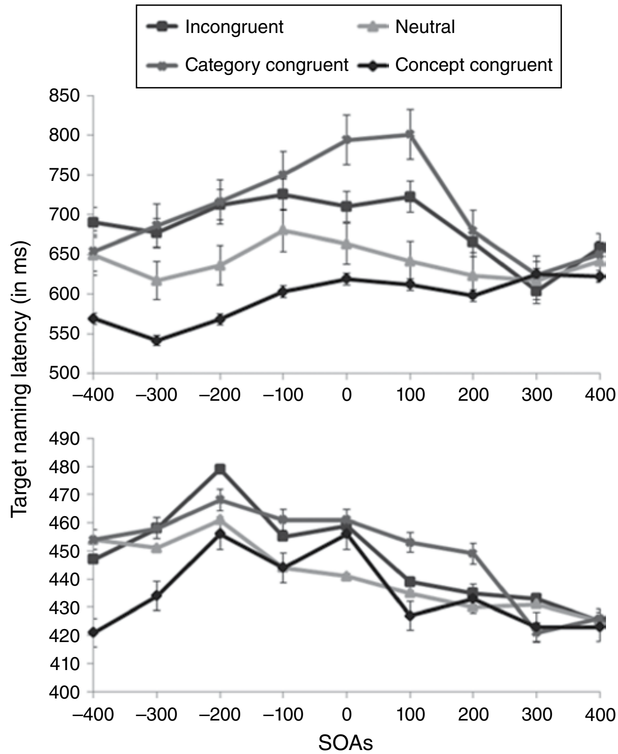

Figure 6.3 Results obtained by Glaser and Düngelhoff (1984).
Average target naming latencies (in milliseconds, error bars represent standard errors of the mean) per SOA (ms) and stimulus type (incongruent, neutral, category congruent, and concept congruent) for picture naming (top panel) and word naming (bottom panel).

In sum, the goal of priming studies is to observe the effects of different types of primes on the processing of targets. As will be further illustrated below, priming experiments can be designed such that specific hypotheses can be tested concerning the representations of words in the mental lexicon and concerning the processes involved in accessing these representations.

Apparatus

For a standard priming experiment, no specialized apparatus is required. The stimuli can be presented using any laptop or desktop computer, and the experiment can be controlled using standard experimental software packages, such as Presentation® software (Version 0.70, www.neurobs.com) or E-prime (Schneider, Eschman, & Zuccolotto, 2012). For masked priming experiments (see below) tight control of ambient lighting in the experimental room and of the timing of the stimuli is required, which needs to be kept in mind when choosing the monitor for stimulus presentation. Speech onset latencies in priming experiments using vocal responses are often measured online using voice keys associated with experimental software packages, which register the onset and offset of speech. However, given the poor accuracy of most voice keys, researchers often record the responses and measure the speech onset latencies off-line, using software packages such as Praat (Boersma, 2001) or Audacity ® software (Version 1.2.2, http://audacity.sourceforge.net/). Specialized equipment is, of course, required for fMRI, MEG, and EEG experiments using priming paradigms.

Designing Priming Experiments

In designing priming experiments, researchers need to decide on the modality of the primes and targets, their properties, the relationships between them, the timing of the events during a trial and in the entire experiment, and the types of responses to the stimuli (e.g., naming or categorization). These decisions depend largely on the hypotheses to be investigated. In this section we describe some of the options to be considered in making each decision.

Modality

A first decision concerns the modalities of primes and targets. The stimuli can be spoken sounds or words, or they can be visual stimuli, that is, strings of letters or written words, signed words, or pictures. Primes and targets can be presented in the same modality or in different modalities. For example, a written prime word may be followed by a written or a spoken target word; or a spoken prime word may be followed by a target picture or a signed word. When prime and target are presented in different modalities, the experiment is a cross-modal priming experiment.

The choice of stimulus modality depends on the goals of the study and on the researcher's theory about the processing of stimuli in different modalities. For instance, studies of lexical access during speaking often use picture naming tasks, whereas reading studies typically use written stimuli. Studies of spoken word recognition often use spoken primes and targets, or spoken primes and written targets (Marslen-Wilson & Zwitserlood, 1989). Presenting primes and targets in different modalities is often useful because the stimuli can then be presented simultaneously without causing mutual sensory masking.

For many research questions, the modality of the stimuli is not critical. For instance, researchers interested in the representation of semantic knowledge that is accessed regardless of the modality of the input may use either written or spoken words. Whereas Glaser and Düngelhoff (1984) used written category-congruent and incongruent primes, other picture naming studies used spoken prime words of the same types and replicated the semantic interference effect observed in the original study (Roelofs, 2005; Schriefers, Meyer, & Levelt, 1990).

Properties of Primes and Targets and Prime-Target Combinations

The properties of primes and targets and their combinations define the experimental conditions of priming experiments (often along with other variables, such as the timing of the stimuli). Obviously, the choice of stimuli depends on the aims of the study. Priming studies have been used in many different research contexts, and consequently many types of primes and targets have been used. To give just a few examples, primes and targets can vary in the language (English, Turkish, American Sign Language), they can be part of the participants' first or second language; they can be words or nonwords; they can be high or low in frequency, long or short, concrete or abstract, emotionally neutral or positive, regular or "tabu" words. Similarly, priming studies have implemented many different types of prime-target relationships. In addition to a substantial body of studies using various types of meaning-related prime-target pairs, there are numerous studies that used morphologically related pairs (e.g., related verb forms as in "fall – fell," Crepaldi, Rastle, Coltheart, & Nickels, 2010; or stems and compounds as in "butter – butter dish," Lüttmann *et al*., 2011), orthographically related pairs (e.g., "castfe – castle," Adelman *et al*., 2014), phonologically related pairs (e.g., "ma – mama," Becker, Schild, & Friedrich, 2014), and identical pairs (Kane *et al*., 2015). In most studies prime and target appear in the same language, but studies of word processing in bilingual speakers often present primes and targets in different languages (Wang, 2013). This allows one to draw conclusions about the relationships between the participants' first and second language lexicon. Primes can also be "novel words," that is, strings that have been associated with novel or existing concepts in a preceding training phase (Gaskell & Dumay, 2003). Comparing the priming effects from novel words and existing words allows researchers to estimate how well the novel lexical items have been learned, and whether they are functionally similar to existing words in the participants' mental lexicon.

Many studies have used several types of related primes with appropriate controls and/or several types of targets and compared the effects obtained for the different prime - target combinations. Such designs can be used to test specific hypotheses about the representations of words. For instance, Lüttmann *et al*. (2011) presented target pictures (e.g., "butter") with primes that were transparent compounds ("butter dish") or opaque compounds ("butterfly"). One of the goals of the study was to determine whether the individual constituents of the compounds became activated only in transparent compounds or in both types of compounds. The results supported the latter hypothesis: The average picture naming latency was 855 ms ($SD = 145$) in the unrelated condition and significantly lower (831 ms, SD = 122) in the transparent prime condition and in the opaque prime condition (831 ms, SD = 134). Thus, both types of related primes equally facilitated target naming, and the difference between the two conditions was not significant.

Designs with multiple prime types have also been used in many studies of visual word recognition. For instance, numerous studies have compared the effects of primes that were both orthographically and phonologically related to the targets to the effects of primes that were related to the targets only in orthographic form or only in sound. Many of these studies aimed to assess the role of the activation of the sound forms of words during reading (for a review see Leineger, 2014).

The large priming literature demonstrates that many types of related primes affect target processing. This indicates that speakers and listeners are sensitive to many different types of relationships between stimuli they perceive together or shortly after each other, which is perhaps not too surprising. However, related primes differ in the strength of their effects. A common finding is that priming effects are stronger for highly similar than for less similar prime target pairs. For instance, Meyer (1991) showed that phonological priming effects increased with the amount of form overlap between words priming each other: Form overlap in the word onset consonant alone, as in "kever – kilo," yielded a facilitatory effect of about 30 ms, compared to an unrelated condition ("hamer – kilo"); whereas overlap in the entire first syllable ("kilo – kiwi") yielded a facilitatory effect of 50 ms. To give another example, several studies have reported mediated priming effects (e.g., "lion" priming "stripes" via the lexical representation of "tiger," Chwilla & Kolk, 2002; Sass *et al.*, 2009), but such effects are generally weaker than direct priming effects ("tiger" priming "stripes"). For instance, in the study by Chwilla and Kolk (2002), the direct priming effect amounted to 82 ms and the mediated effect to 41 ms. Thus, priming paradigms allow researchers to study not only whether or not the representations of words in the mental lexicon are related, but also how tight their links are.

Similarity between prime and target is not necessarily beneficial to target processing. As noted in the above description of the study by Glaser and Düngelhoff (1984), category-congruent primes slow down responses in a picture naming task, compared to unrelated primes. By contrast, associatively related primes tend to facilitate target naming or have no effect. An account of this pattern is that both types of primes facilitate the conceptual processing of the targets, but that category-congruent primes in addition hamper later processes, either the selection of target names from the mental lexicon or the retrieval of the sound form of the target from a response buffer (Mahon *et al.*, 2007; Roelofs, 1992). Thus, comparisons of the effects of different prime types provide insights into the ways different components of the cognitive system cooperate during word processing.

A word priming experiment must feature related and unrelated primes. In most studies each target is combined with each type of prime (e.g., with a semantically related prime, an unrelated prime, and a neutral prime). Thus, each target word appears in each condition. Primes are often also repeated in different conditions. For instance, "dog" might be the related prime for the target "cat" and the unrelated prime for the target "shoe"; and "hat" might be the unrelated prime for "dog" and the related prime for "shoe." Alternatively, one can use different primes and/or different targets in different conditions. However, the words appearing in different conditions then need to be tightly controlled for any properties that may affect their processing, such as their length, frequency, age of acquisition, and so forth. Since perfect matching is often difficult to achieve, and since not all variables that may affect lexical access are known, designs using the same primes and/or targets across conditions are generally preferred.

In some priming studies each participant is presented with all prime–target combinations. This is, for instance, the case for many picture naming studies (e.g., Schriefers *et al.*, 1990). In the picture naming task, items can be repeated because robust priming effects can be obtained even when participants name the same pictures several times. By contrast, in word recognition experiments using word naming or lexical decision, each participant typically sees or hears each target only once, combined with one of the primes for the target; and different groups of participants are presented with different prime-target combinations. Such designs are complex and require many stimuli and participants, but they are often preferred because the priming effects for word recognition are often subtle and can easily be concealed when participants see or hear a target several times.

Priming experiments often include the same number of related and unrelated trials, typically presented in random or pseudo-random order. However, many studies include additional unrelated filler trials. Fillers are used in order to discourage participants from using the primes strategically to predict the targets and to separate trials featuring the same stimuli or conditions, thereby reducing unwanted trial-to-trial priming effects (Kinoshita, Mozer, & Forster, 2011).

Stimulus Timing

In designing priming experiments, researchers need to decide for how long to present the primes and targets and when they should appear relative to each other. When auditory stimuli are used, the duration of the stimuli is determined by the duration of the speech signal, but visual stimuli can be presented for longer or shorter periods. Visual targets can either be presented until the participant responds, or for a fixed duration, typically between 1 and 3 seconds.

The presentation time of the primes is often more critical than that of the targets. When primes are presented for a long time, participants may develop processing strategies that may be quite different from everyday word processing, or they may try to anticipate the targets. Researchers often try to discourage such strategic behavior by using the shortest possible prime presentation times. Numerous studies have used masked primes. Here, primes are presented for very brief periods of time (e.g., for 40 ms in Van den Bussche, Van den Noortgate, & Reynvoet, 2009, and for 56 ms in Gomez, Perea, & Ratcliff, 2013) and are followed and/or preceded by pattern masks suppressing their afterimage. Under these conditions, participants are on most trials unable to consciously identify the primes and to use them strategically. Nevertheless, robust priming effects can be obtained. For instance, Crepaldi, Rastle, Coltheart, and Nickels (2010) found that lexical decision latencies were shorter after masked primes that were morphologically and orthographically related to the targets (*Mean* = 582 ms, *SD* = 51 ms) than after primes that were only orthographically related to the targets (*Mean* = 606 ms, *SD* = 61 ms) or unrelated (*Mean* = 603 ms, *SD* = 60 ms).

Many studies have compared the effects of unmasked and masked primes, for instance to uncover the contributions of early "bottom up" and later "top-down" processes in word recognition (e.g., de Wit & Kinoshita, 2015, see Figure 6.4). However, it should be noted that unconscious prime processing may be modulated

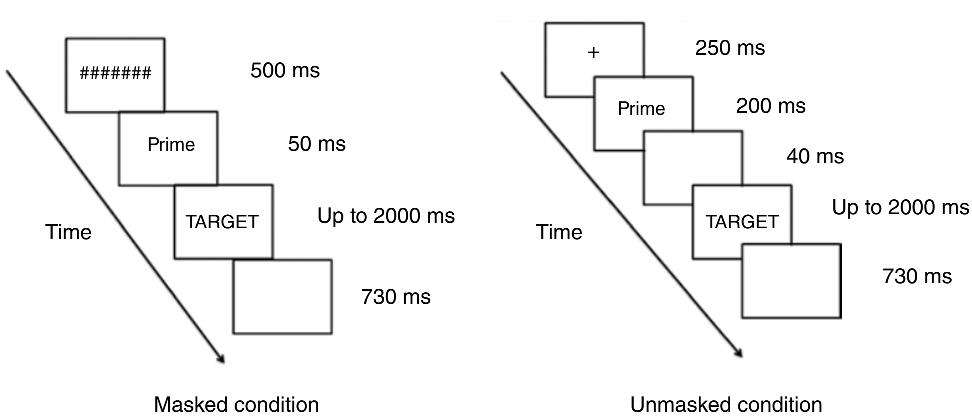

Figure 6.4 Illustration of trial structures in the masked and unmasked conditions in de Wit and Kinoshita (2015). Targets were presented until response, maximally for 2000 ms.

by attentional resources and task requirements (see Kiefer, Adams, & Zovko, 2012, for a review). Moreover, the impact of attentional control on priming may differ across groups of participants (e.g., persons with or without attention deficits). Thus, in interpreting the results of priming studies researchers need to consider possible top-down influences on both prime and target processing.

Finally, the time interval between prime and target onset needs to be determined. In many priming studies, the prime begins at the same time as the target or shortly before or after target onset. The choice of stimulus onset asynchrony (SOA) depends on the theoretical goals of the study and the researchers' assumptions about the time course of the processes they are investigating. It is also possible to link the presentation of the stimuli to the participants' behavior. For instance, a prime word or picture may be replaced by a target as soon as the participant fixates the location of the prime (Morgan & Meyer, 2005). Many studies have included several SOAs, often in conjunction with several types of primes to trace the time course of the activation of different types of information. This was the case for the study by Glaser and Düngelhoff described above. To give another example, in a picture naming study, Schriefers, Meyer, and Levelt (1990) presented target pictures with semantically or phonologically related or unrelated prime words. They observed a semantic interference effect of 20 ms and a phonological facilitation effect of 36 ms; the mean naming latency was 651 ms in the semantically related condition, 595 ms in the phonologically related condition, and 631 ms in the unrelated prime condition. Importantly, the semantic effect peaked at the earliest SOA, namely when the prime was presented 150 ms before target onset; whereas the phonological effect peaked only when the prime was presented 150 ms after target onset. This indicates that the semantic representations of the targets began to be activated before the phonological representations.

In many priming studies, primes and targets appear on separate trials. For instance, in a repetition priming experiment, participants may be asked to name a stream of pictures, and the same picture may come up several times, with the first instance priming the second. Similarly, in a semantic priming experiment, participants may name a picture of an animal and after several intervening trials they may name another animal (Howard *et al.*, 2006). Thus, in this kind of design the distinction between primes and targets is present in the design of the experiment but is not obvious to the participants. Many types of priming effects are robust and can be observed even when several trials intervene between prime and target. For instance, in a picture naming experiment, Zwitserlood, Bölte, and Dohmes (2000) obtained a morphological priming effect of 143 ms (with means of 653 ms in the morphologically related prime condition and 796 ms in the unrelated prime condition) when primes preceded targets by several minutes.

In some priming studies, the stimuli are blocked by condition. In these blocking paradigms, there are homogeneous test blocks where participants repeatedly name small sets of related pictures, for instance members of the same semantic category (as in "duck, mouse, fish, snake, mouse…") or pictures with similar names ("bed, bell, bench, bed…"), and heterogeneous blocks, where the same stimuli are combined into unrelated sets (Belke & Stielow, 2013; O'Seaghdha, Chen, & Chen, 2010). These paradigms allow researchers to study how participants can strategically exploit the similarity between the stimuli; speakers can, for instance, prepare well when all words in a block have the same onset, but not when the words rhyme (Meyer, 1990). More importantly, blocking paradigms can also be used to study the interplay of repetition and competition effects arising when speakers repeatedly access members of the same semantic category.

Task

The choice of task depends, again, on the goals of the study. Researchers using priming paradigms to study word production often ask participants to name target pictures, typically in bare nouns or verbs, occasionally in short phrases. Picture categorization (e.g., with respect to the real-life size of the objects, or as animate or inanimate) has also been used, often in control conditions for naming conditions (Schmitz & Wentura, 2012).

In word recognition studies, a number of different tasks have been used: Participants are sometimes asked to read aloud written targets or repeat or write down spoken ones (Adelman *et al*., 2014; De Bree, Janse, & Van de Zande, 2007). They may also be asked to categorize targets with respect to semantic or phonological properties. A common phonological categorization task is phoneme monitoring, where participants are asked to decide whether or not the target includes a specific phoneme (e.g., /p/). This task is performed faster for words than for nonwords, which indicates that it is suitable to assess lexical knowledge (Dijkstra, Roelofs, & Fieuws, 1995). The most common task used in word recognition studies is probably the lexical decision task, which was already described above. Here, trials featuring target words are mixed with trials featuring nonwords. Both types of targets are preceded by primes. Participants are asked to categorize each target as a word or a nonword by pressing one of two buttons. Lexical decision latencies have been shown to be sensitive to a large number of lexical variables, for instance the length and frequency of the words and characteristics of their phonological neighborhoods (i.e., the words they resemble in their sound forms). These lexical effects demonstrate that the task is suitable for studying how readers and listeners access their mental lexicon. However, lexical decision is a metalinguistic task, as participants are asked to make judgements about the stimuli they see or hear, and is sensitive to various response strategies. This can complicate the interpretation of the results (Ratcliff, Gomez, & McKoon, 2004).

Participants

Most word priming experiments have been conducted with college students. However, priming paradigms can readily be adapted for use with any sample of interest. There are, for instance, recent word priming studies using children as young as 2.5 years (Singh, 2014), and word priming paradigms have been amply used in research on healthy aging (De Bree *et al*., 2007), bilingual speakers (Kroll & Stewart, 1994; van Hell & de Groot, 1998) and in research involving various groups of patients (e.g., patients with Broca's aphasia, Utman, Blumstein, & Sullivan, 2001; with temporal lobe epilepsy, Miozzo & Hamberger, 2015; or semantic dementia, Merck, Jonin, Laisney, Vichard, & Belliard, 2014).

Data Analysis

In this chapter we have focused on the use of priming paradigms in behavioral studies where participants produce individual words or respond to spoken or written stimuli by categorizing them, most commonly as words or nonwords. A priming experiment with a simple design, for instance featuring twenty target pictures that have to be named, each combined with two primes, and thirty participants, who see all prime-target combinations, yields a raw data set of 1,200 naming latencies. Designs with more stimuli, participants, or conditions evidently yield larger data sets. A comprehensive discussion of the statistical analyses of the results of priming experiments including, for instance, exclusion of outliers, appropriate transformations of data, and tests of significance, is beyond the scope of the present paper; we refer the reader to text books (e.g., Baayen, 2008; Field, Miles, & Field, 2012). Here we can only provide a brief sketch of the main steps involved in analyzing the data.

The first step in the analyses serves to decide whether all participants and stimuli should be maintained in the data set, or whether some participants and/or stimuli need to be excluded. Researchers may decide to exclude participants whose overall performance deviates substantially from the remaining sample; these may, for instance, be participants whose average response latencies are exceptionally slow (e.g., more than three standard deviations above the sample mean) or whose error rates are exceptionally high. Similarly, researchers may decide to exclude stimuli that were responded to with exceptionally long latencies or that yielded very high error rates. For instance, in a lexical decision experiment, one might exclude words that the majority of participants categorized as nonwords.

The next step in the analyses concerns the error rates in the remaining data set. In a typical lexical decision experiment, these are the rates of missing responses and the rates of nonword responses for words and of word responses for nonwords. In a picture naming experiment, errors include missing responses, incorrect picture names (e.g., "cat" instead of "dog"), self-repairs ("cat… dog"), and responses that begin with a hesitation or filled pause (e.g. "eh … cat"). Since error rates are rarely normally distributed, many researchers use log-transformed, rather than raw error rates when comparing average error rates. However, in the recent literature analyses of error rates using logit mixed models have often been preferred (Jaeger, 2008).

Even when the hypotheses do not concern the error rates but the response latencies, the error rates in the different conditions are reported and often analyzed. This is to ascertain that the results obtained for the error rates are consistent with those obtained for the latencies. For instance, if related primes are hypothesized to facilitate target processing, the responses should be faster after related than after unrelated primes, and the error rates should be the same or lower, but not higher in the related than in the unrelated prime condition. When related primes are associated with faster responses and higher error rates than unrelated primes, or when related primes are associated with slower responses and lower error rates (i.e., when there is a speed-accuracy trade-off) the interpretation of the results can be challenging. This is because the results obtained for one dependent variable suggest that the related primes facilitate target processing, whereas the results obtained for the other variable suggest that they interfered with target processing.

The following steps in the analyses concern the latencies for correct responses, which are usually the most important dependent variable in priming experiments. In lexical decision experiments, word and nonword responses are often analyzed separately. In addition to incorrect responses, many researchers exclude abnormally fast and/or abnormally slow responses. Such outliers can be defined in different ways (e.g., Ratcliff, 1993). One option is to use fixed deadlines. For instance, picture naming or lexical decision latencies below 200 ms are likely to be due to artifacts or measurement errors since participants cannot process the target and initiate their response so quickly; therefore these latencies are often excluded from the analyses. Another option is to refer to the distribution of latencies in the sample and exclude latencies that deviate from a mean (e.g., the grand mean of the sample, the condition mean, or the participant mean) by a certain amount, for instance by 2.5 or 3 sd. Researchers sometimes use several criteria to exclude outliers, for instance a fixed lower deadline to exclude short latencies and a distribution-based criterion (e.g., three standard deviations above the grand mean) to exclude long latencies. Since parametric comparisons of means (*t*-tests, analyses of variance) require the input data to be normally distributed but raw response latencies typically do not fulfill this criterion but feature a long tail of slow responses, latencies are often log-transformed before analyses (e.g., Baayen, 2008). Contemporary statistical packages (R, R Core Team, 2005, and SPSS, IBM Corp, 2013) offer advanced graphical tools to facilitate the optimal choice of criteria for the exclusion of outliers and the transformation of raw data.

Finally, inferential statistics are used to determine whether or not the primes significantly affected the response latencies to the targets. Analyses typically focus on the condition means, though sometimes it is useful to consider the entire distribution of the latencies (e.g., Roelofs, 2008). Following a proposal by Clark (1973) many researchers carry out separate analyses based on the participant means per condition (i.e., averaging across items) and on item means (averaging across participants) respectively (for an example see Crespaldi *et al.*, 2010). Clark advocated combining the two test statistics into one F-value (min F′), but this is rarely done as min F′ is considered to be overly conservative. An alternative, favored in much of the contemporary literature, is mixed-effects modeling (e.g., Barr, Levy, Scheepers, & Tily, 2013; Baayen, Davidson, & Bates, 2008), which allows researchers to include participants and items as random effects in the same model and, more generally, offers much flexibility in the statistical analyses of the data (for an example, see Shao, Roelofs, Martin, and Meyer, 2015).

Priming paradigms have been used in numerous neurobiological studies using EEG (Jouravlev, Lupker, & Jared, 2014; Llorens *et al.*, 2014; Riès *et al.*, 2015), MEG (Brennan *et al.*, 2014; Whiting, Shtyrov, & Marslen-Wilson, 2014), and fMRI (Almeida & Poeppel, 2013; Massol *et al.*, 2010; Savill & Thierry, 2011). EEG and MEG studies can offer precise information about the time course of prime and target processing. fMRI studies can be used to investigate which brain circuits are implicated when grammatical features, sound forms, or meanings of words are accessed (Koester & Schiller, 2011). How such studies are designed, and how the data are analyzed is described in Chapters 13 and 14 of the current volume.

Evaluation of Word Priming Paradigms

Since their inception in the 1970s, word priming paradigms have been widely used in psycholinguistics. There are many reasons for the popularity of priming paradigms: The underlying theoretical assumptions are straightforward, priming experiments are easy to set up and highly portable, and no specific expertise is required to analyze the data. Most importantly, priming paradigms are extremely versatile and can be used to address a wide range of issues concerning the representation of words in the mental lexicon and the way they are accessed during language production and comprehension.

Word priming paradigms are a research tool and, as is true for any tool, their usefulness depends on the goals of the user. Word priming is an experimental paradigm and is tailored to study how words are represented and accessed. Many issues in psycholinguistics can be studied experimentally and do concern individual words, but evidently there are questions that are not easily studied in experiments and/or do not concern individual words and therefore require other approaches.

When a word-priming paradigm is deemed to be suitable to address a research question, the details of the experimental method, stimuli, and design have to be determined. Many properties of priming experiments are, of course, dictated by the research question. A researcher specifically interested in the processing of morphologically complex forms or in lexical access during speaking will choose the stimuli and task accordingly. Other design properties are not determined in this way. For instance, to study the representation of morphologically complex forms, one might either use a production or a comprehension task, and either masked or unmasked primes. Here choices may to some extent depend on practical considerations (e.g., the ease of finding appropriate stimuli, of setting up the experiment, and of analyzing the responses). In designing experiments, it is often useful to consider published experiments on similar issues and aim to replicate design features (especially those used in many studies) as much as possible. For instance, researchers designing a masked priming experiment might present the stimuli in the same way (same size, luminance, etc.) and with the same timing as reported in a similar recent study in a peer-reviewed journal. This strategy increases the chance that an experiment will actually "work," and it facilitates the comparison of the results to earlier findings.

We are, of course, not advocating blind imitation of existing studies. The most important considerations in designing a word priming experiment (or any other type of study) must stem from the theoretical goals of the research. Researchers need to consider how each design choice may affect how participants approach the task, how the stimuli are processed, and how these influences may affect the conclusions that can be drawn from the results.

Key Terms

Blocking paradigm Experimental paradigm where stimuli are blocked per condition. For instance, four semantically homogeneous blocks may feature pictures of objects from the categories of animals, vehicles, fruits, and items of furniture, respectively; the corresponding four heterogeneous blocks feature pictures of objects from each of the four categories.

Lexical decision task A task that is often used in studies of visual and auditory word recognition. Participants hear or see sound or letter sequences (e.g., BLISS or BLIFF). For each sequence they have to decide as quickly as possible whether or not it is a word. Decision latency and accuracy are measured.

Masked priming paradigm Priming paradigm where primes are presented very briefly (usually 40-50 ms) and followed and/or preceded by visual masks (e.g., %$%$$% or #######). Participants can usually not identify the primes or even reliably report their presence or absence, but the primes may still affect subsequent target processing.

Phoneme monitoring A task that is often used in studies of auditory word recognition. Participants hear strings of words and have to press a button as soon as they detect a specific sound (e.g., /p/).

Picture-word interference paradigm A paradigm often used to study lexical access in speaking. Participants see a stream of pictures, each accompanied by a written or spoken distractor word. They are asked to name the pictures and ignore the distractor words. In spite of these instructions, the distractors may still affect the speed and/or accuracy of the naming responses.

Prime A stimulus that affects the response to a following target; for instance, presentation of the prime word "nurse" may facilitate processing of the following target word "doctor" relative to an unrelated prime word such as "cat."

Stimulus-onset asynchrony Time interval between the onsets of the prime and the target in a priming experiment.

Target A stimulus a participant is asked to react to.

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