Explaining the spacing effect

*Study-phase retrieval, contextual-variability, and priming accounts*

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# Explaining the spacing effect
*Study-phase retrieval, contextual-variability, and priming accounts*

# Het spreidingseffect
*Verklaringen in termen van studiefaseherinnering, contextuele variatie en preactivatie*

**PROEFSCHRIFT**

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| Copromotor: | R.M.J.P. Rikers |

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# Voorwoord

Het is alweer bijna vier jaar geleden dat ik, na langdurig wikken en wegen, besloot om het knusse provinciestadje Maastricht te verruilen voor de bruisende metropool Rotterdam. Ik kwam er terecht in een kleine, overwegend jonge en onervaren, maar zeer enthousiaste groep mensen die tot taak had om aan de Erasmus Universiteit een start te maken met een nieuwe psychologieopleiding. Het pioneerswerk dat ik samen met deze mensen verrichtte, heeft de Rotterdamse jaren een bijzondere status in mijn leven gegeven. Ik zal me de afgelopen jaren daarom ook blijven herinneren als een fantastische periode waarin ik bovendien gevormd werd tot een academische *allrounder*. Hiervoor ben ik Henk Schmidt veel dank verschuldigd: hij had namelijk de moed om mij als groentje naar Rotterdam te halen.

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Peter
Rotterdam, januari 2005

*Chapter 1*

# The spacing effect in memory:
## *An introduction*

Repeated practice is, in itself, hardly a reliable method to achieve long-term learning, let alone understanding. For instance, how many adult Dutch-men, despite of regular practice in primary school, can reproduce all of the 12 Dutch provinces and their associated capitals? Furthermore, mere repetition of the statistical theory underlying analysis of variance will generally not suffice to induce conceptual understanding in the modal psychology student. Having said that, the fact remains that repetition is a powerful technique to aid memory performance. If there is anything general to the field of learning it is that repetition of an experience improves memory over a single experience. This beneficial effect of repetition on memory is mediated by a number of factors, one of the most important being the interval between the first occurrence of a stimulus and its second occurrence.

A reference experiment for the influence of the inter-repetition interval on memory has been conducted by Melton (1967). In this study, forty-eight different words were presented individually at a rate of 1.3s per word. Some of the words occurred once, whereas other words were shown twice. For the latter category, the number of interpolating items between both occurrences was manipulated. Specifically, items were repeated with *lags* of 0, 2, 4, 8, 20, or 40 intervening items. Participants studied the words by means of performing a so-called continuous recognition task: for each word in the list they had to indicate if the word had been previously presented. Thus, participants had to determine for each word whether it was a repetition or not. After the study phase, participants were given a free recall task that required them to write down as many words of the studied list as they could remember. The free recall data demonstrated that the probability of remembering a repeated item increased with the length of the inter-repetition lag. This phenomenon has been dubbed *the spacing effect,* and it has proven to be a highly robust phenomenon that has been obtained in a variety of memory tasks and with a variety of stimulus materials following the initial findings of Melton (for reviews see Crowder, 1976; Dempster, 1996; Hintzman, 1974, 1976). Over the years, several theoretical frameworks have been proposed to explain the spacing effect. In the next paragraphs of this chapter, these theoretical frameworks will be described in an order chronological to their first occurrence in the literature. Further, the empirical evidence supporting each of these theories will be assessed based on the studies that have sought to test the assumptions incorporated in the particular theory. The goals of the studies presented in the next chapters of this thesis will follow directly from the historical overview.

## Deficient processing theories

Deficient processing theories attribute the spacing effect to a less than optimal processing of a repeated item if the lag between an item's first occurrence (p1) and second occurrence (p2) is short. Deficient processing theories can be categorized depending on (a) whether deficient processing takes place during the inter-repetition interval or during the presentation of the second occurrence, and (b) whether deficient processing is a result of voluntary (i.e., under the participant's control) or an involuntary mechanism. Combining these two dimensions yields a 2 x 2 classification in which each of the cells corresponds with a different deficient processing theory. In Table 1, the 2 x 2 classification is depicted. Based on the terminology used by Hintzman (1974), these theories are termed consolidation, rehearsal, habituation, and attention.

**Table 1**
*Classification of the deficient processing theories of the spacing effect.*

| | **Control of processing** | |
|---|---|---|
| Deficient processing | Involuntary | Voluntary |
| Between p1 and p2 | Consolidation | Rehearsal |
| During p2 | Habituation | Attention |

## Consolidation

Peterson (1966) and Landauer (1969) have put forward a consolidation mechanism to explain the spacing effect. Consolidation can be conceptualized as an autonomous and gradual, time-dependent increase of retrievability of an item's memory trace that takes place independent of the item's physical presence. As a result of consolidation an instable memory trace in short-term store is transferred to a permanent retrievable state in long-term store. In explaining the spacing effect it is further assumed that the same consolidation mechanism operates on both occurrences of a repeated item, and that both occurrences compete for its use. This assumption implies that the presentation of the second occurrence before the consolidation of the first occurrence has reached completion will disrupt the consolidation process of the first occurrence. However, the negative influence of the second occurrence on the consolidation of the first will dissipate as the inter-repetition interval increases. Consequently, the memory strength of a repeated item increases as a function of the inter-repetition interval, giving rise to the spacing effect in memory performance.

However, the consolidation account of the spacing effect has difficulties explaining some findings reported in the spacing effect literature. First, Baddeley (1976) estimated that the time course of consolidation ranged from 15s to 1 hour. According to this estimate, the consolidation account cannot accommodate the findings of studies in which spacing effects were observed for inter-repetition lags longer than 15s (e.g., Toppino & Bloom, 2002).

Second, the consolidation theory states that the spacing effect is located at the first occurrence of a repeated item. That is, spacing effects are assumed to emerge due to a deficient processing of a repeated item's first occurrence at short inter-repetition intervals. However, the findings of a study by Hintzman, Block, and Summers (1973) are at variance with this assumption. The aim of this study was to identify the locus of the spacing effect by using the *modality tagging* procedure. This procedure can be defined as a process in which participants have to report not only whether or not a particular item had been shown during a study phase, but also in which modality the item was presented. In the first experiment, participants were instructed to learn a list consisting of once-presented and twice-presented words. Once-presented words occurred either in a visual or an auditory modality, and repeated words occurred either twice in the same modality or twice in different modalities. Following the study phase, participants had to indicate for each word in the list how often it had been presented and in which modality or modalities it had occurred. The results demonstrated that people were good at remembering the modality or modalities in which words had been presented. In the different-modality conditions (i.e., auditory-visual or visual-auditory), participants reproduced the appropriate modality order in about 36% of the words. Hintzman et al., (1973) used this displayed proficiency of participants as a methodological tool to determine which of a repeated item's occurrences was negatively affected at short inter-repetition intervals.

In a second experiment, participants were required to study a list containing once-presented items and twice-presented items repeated at inter-repetition intervals (lags) of 0, 1, 5, and 15 intervening words. Once-presented items occurred either in a visual or auditory modality, and repetitions in each lag condition occurred in one of four modality arrangements: visual-visual, auditory-auditory, visual-auditory, or auditory-visual. Comparable to the procedure used in their first experiment, Hintzman et al., (1973) instructed participants to provide a frequency-of-occurrence judgment and a modality judgment for each word from a previously studied list. Although the data analysis for this experiment is complex, the line of reasoning used by the researchers can be explained without going into detail about the analysis. Consider one of the mixed modality arrangements, for example auditory-visual. In this condition, participants will correctly reproduce the modality order for some of the repeated words. However, for other repeated words participants will erroneously report that the word occurred once, or that the word occurred in one of three other modality arrangements. The interpretation of these errors constitutes the crux of the line of reasoning followed by Hintzman et al., (1973). If a participant indicates that an auditory-visual repetition was presented once or twice in a visual modality then this means that the second occurrence of this item was more salient in memory than the first. Alternatively, if a participant reports an auditory-visual repetition as being presented once or twice in an auditory modality then this implies that that the first occurrence was more salient in memory than the second. Thus, by examining participants' error responses on mixed modality repetitions one can assess the memory strength of repeated items' first occurrences and second occurrences.

The results of the second experiment revealed that frequency judgments for repeated items became more accurate in all modality arrangements with the length of the inter-repetition interval. Moreover, for repetitions in our example, (i.e., the auditory-visual condition) the error responses suggested that, with an increasing inter-repetition interval, participants became more certain that the words had occurred in a visual modality, but that they did not became more certain that the words had occurred in an auditory modality. The reversed pattern was obtained for repetitions in the visual-auditory condition. These findings suggest that the strength of repeated items' *second* occurrences is negatively affected by factors operating under short inter-repetition intervals. These findings are inconsistent with the assumption made by the consolidation hypothesis that the spacing effect is due to a less than optimal processing of repeated items' *first* occurrences at short inter-repetition intervals.

### Rehearsal

Similar to the consolidation account, the rehearsal hypothesis (Atkinson & Shiffrin, 1968) proposes that the spacing effect can be traced back to a deficient registration of a repeated item's first occurrence, taking place in the absence of the physical stimulus that represents the first occurrence. Contrary to the consolidation theory, however, the rehearsal hypothesis postulates that the deficient registration of the first occurrence is due to a voluntary rehearsal mechanism rather than to a non-voluntary, automatic consolidation process. For the present purposes, rehearsal may be defined as an activity under a participant's control that is characterized by the retrieval and reprocessing of an item's memory trace when the item is no longer physically present. In Atkinson and Shiffrin's (1968) general memory model rehearsal is considered to be a control process that plays a critical role in the transfer of information from short-term store to long-term store. It is assumed that a participant rehearses a limited number of items (i.e., the rehearsal set) in short-term store. By rehearsing the items, the stay of these items in short-term store is prolonged, and this increases the amount of information about the items that is transferred to long-term store. The explanation of the spacing effect requires two additional assumptions (1) the probability that a repeated item's first occurrence is included in the rehearsal set decreases with time, and (2) it is not permitted to hold two copies of the same items (i.e., both occurrences of a repeated item) concurrently in the rehearsal set. If now, the inter-repetition interval is short, rehearsal of a repeated item's first occurrence and therefore it's long-term memory trace, will suffer from the presentation of the second occurrence. On the other hand, if the second occurrence is presented after the first occurrence has been rehearsed, the second occurrence will not exert a negative influence on the first occurrence's long-term memory trace. It follows that the total memory strength of a repetition becomes stronger as the inter-repetition interval increases. The positive correlation between memory strength of a repetition and the inter-repetition interval produces the spacing effect in memory performance.

Rundus (1971) has provided evidence for the rehearsal hypothesis by asking participants to rehearse aloud while studying a word list prior to a free recall task. The list entailed words repeated in immediate succession (i.e., massed repetitions), and words repeated with a number of intervening items (i.e., spaced repetitions). The results showed that free recall of spaced items was superior to free recall of massed items. In addition, and in line with the rehearsal hypothesis, spaced items had received more rehearsal than massed items. Although the findings reported by Rundus (1971) are in favour of the rehearsal hypothesis, other studies have produced results that are clearly at variance with it.

The rehearsal hypothesis predicts that experimental interventions designed to avert participants from rehearsing should eliminate the spacing effect. Studies using different manipulations to prevent participants from rehearsing, such as presenting an interpolated test during the inter-repetition interval (Bjork & Allen, 1970), or complex difficult to rehearse visual stimuli (Hintzman & Rogers, 1973) have failed to corroborate this prediction. Further, congruent with the consolidation theory, the rehearsal hypothesis places the locus of the spacing effect at a repeated item's first occurrence. This notion is contradicted by the findings of Hintzman et al., (1973) discussed previously, which suggest that the locus of the spacing effect is situated at a repeated item's second occurrence.

## Voluntary attention

The voluntary attention hypothesis mimics the rehearsal hypothesis in the sense that it attributes the spacing effect to a voluntary, non-automatic process. However, in contrast to both the rehearsal hypothesis and the consolidation account, the voluntary attention hypothesis states that the spacing effect should be explained by a deficient processing mechanism that operates during the presentation of a repeated item's second occurrence. Specifically, the voluntary attention hypothesis assumes that the spacing effect emerges because participants choose to allocate less attention to a repeated item's second occurrence when the inter-repetition interval is short than when the interval is long. Overall, therefore, less attention will be devoted to items that are repeated at short intervals than to items repeated at long intervals, and this will give rise to the spacing effect in memory performance. A question that has to be dealt with by a voluntary attention approach is why participants decide to devote less attention to the second occurrences of repetitions presented in immediate succession (i.e., massed repetitions) than to second occurrences of repetitions presented at a longer inter-repetition intervals (i.e., spaced repetitions). To this question different answers have been put forward.

For instance, in a study by Dempster (1986) college students read a text twice, either with an inter-repetition interval of 5 minutes (massed practice) or 30 minutes (spaced practice). Subsequently, they performed a free-recall task on the studied text. Following the free-recall task, they filled out a questionnaire that contained questions directed at obtaining information about the participants' cognitive and emotional states during reading and testing. Amongst others, questions were included that prompted participants to report how interested they were during the second reading of the text, and how much attention they had paid to the second presentation of the text. The results demonstrated that students considered the second reading of the text to be less interesting than the first, and that they had allocated less attention to the second reading. Further, in line with the voluntary attention hypothesis, analysis of the obtained data revealed that free recall of the text was positively related to the amount of attention directed at the second reading. This correlation between attention to the second presentation of a repeated stimulus and memory performance is predicted by the voluntary attention hypothesis. On the basis of his findings, Dempster (1986) concluded that participants pay less attention to the second occurrence of a massed repetition than to the second occurrence of a spaced repetition because the second occurrence of a massed repetition is thought to be less interesting. Arguably, this might be the result of the perceived abundance of the second occurrence in case of short inter-repetition intervals. However, Zechmeister and Shaughnessy (1980) offered an alternative explanation. In their study, participants were given a word list, and for each word they had to indicate how confident they were that they would remember that particular word at a later free recall test. The data showed that participants were more confident in remembering massed repetitions than spaced repetitions, although the free recall performance revealed exactly the opposite pattern (i.e., a spacing effect). Therefore, Zechmeister and Shaughnessy (1980) argued that a false sense of knowing underlies the deficient allocation of attention to the second occurrences of massed repetitions

Although the studies of Dempster (1986) and Zechmeister and Shaughnessy (1980) primarily aimed at the identification of the mechanism underlying the allocation of attention to massed repetitions and spaced repetitions, they also provide empirical evidence for the voluntary attention hypothesis of the spacing effect. Additional support for the voluntary attention hypothesis has been obtained in other studies. For example, in the third experiment of a study by Shaughnessy, Zimmerman, and Underwood (1972), participants learned a word list including massed repetitions and spaced repetitions. During study, participants could determine themselves how much study time they wanted to direct at each word. The free recall data demonstrated a clear spacing effect, indicating that memory of spaced repetitions was better than that of massed repetitions. More important, however, was the finding that participants spent less time studying the second occurrences of massed repetitions than the second occurrences of spaced repetitions. The demonstrated spacing effect in combination with the displayed pattern of study time allocation is consistent with he voluntary attention hypothesis.

Furthermore, Elmes, Greener, and Wilkinson (1972) obtained results in favour of the voluntary attention hypothesis. In their study, participants learned a list of once-presented words and words repeated at inter-repetition intervals of either, 0, 3, or 10 intervening items. Subsequently, free recall of the repeated words as well as free recall of once-presented words was tested. With respect to once-presented words, Elmes et al., (1972) were particularly interested in free recall of once-presented words occurring adjacent to repeated items. According to the voluntary attention hypothesis, the amount of attention allocated to a repeated item's second occurrence increases with the inter-repetition interval. Elmes et al., (1972) reasoned that the proposed expenditure of attention on a repeated item's second occurrence might influence the effort directed at once-presented items directly following repeated items. Specifically, they hypothesized that the attention devoted to such a once-presented item is an inverse function of the amount of attention spent on the preceding item. Reasoning from this hypothesis, once-presented words following the second occurrence of a massed repetition should receive more attention than once-presented words following the second occurrence of a spaced repetition. This in turn, should provide the once-presented words from the former category with a memory advantage. The results of Elmes et al., (1972) confirmed this prediction. First, a spacing effect was demonstrated for repeated words. Second, and congruent with the voluntary attention hypothesis, free recall of once-presented words was higher for words following the second occurrences of massed repetitions than for words following the second occurrences of spaced repetitions.

Despite the aforementioned confirmatory evidence for the voluntary attention hypothesis of spacing effects, several studies have failed to support a prediction that is crucial to the voluntary attention hypothesis. On the basis of the voluntary attention hypothesis, spacing effects are expected to disappear if the experimental manipulation ensures that participants keep their attention fully sustained to both occurrences of a repeated item. This notion has been repeatedly tested under different experimental conditions. For instance, D'Agostino and DeRemer (1973) required participants to study a list of repeated sentences for a memory test. In order to control processing of each sentence's first and second occurrence, participants had to read the sentence aloud, form a visual image of the sentence, and describe the contents of the visual image to the experiment leader. After the study phase, a free recall or a cued recall test on the previously shown sentences was administered. The results were dependent on the kind of memory test: the free recall data demonstrated a spacing effect, whereas the cued recall data failed to reveal a spacing effect. These findings indicate that, at least for free recall, spacing effects cannot be explained by a voluntary attention mechanism. The free recall data reported in the study by D'Agostino and DeRemer (1973) were replicated in other studies (e.g., Hintzman and Summers, reported by Hintzman, 1974, p.88; Elmes, Sanders, and Dovel, 1973), thereby strengthening the idea that the voluntary attention hypothesis falls short in providing a complete account of the spacing effect.

## Habituation

The habituation account of the spacing effect (Hintzman, 1974; Hintzman, Summers, and Block, 1975) resembles the voluntary attention hypothesis in the sense that it attributes the spacing effect to a deficient processing of a repeated item's second occurrence. However, dissimilar to the voluntary attention hypothesis, the habituation account proposes that the deficient registration of a repeated item's second occurrence should be attributed to an automatic, non-voluntary habituation mechanism rather than a voluntary process. Habituation refers to a neurologically determined temporary increase of an item's response threshold following registration of that item. Furthermore, it is assumed that recovery from habituation takes approximately 2.2s. Consequently; if a repeated item's second occurrence is presented within the recovery period it will not be fully encoded. Regarding memory performance, the habituation account predicts that memory performance for repeated items will increase as a function of the length of the inter-repetition interval until the recovery from habituation has reached completion (i.e., after 2.2s). Hence, for repeated items with inter-repetition intervals greater than 2.2s, spacing effects are not expected. This prediction is at variance with some of the results in literature that demonstrate spacing effects beyond inter-repetition intervals of 2.2s (e.g., Glanzer & Duarte, 1971; Madigan, 1969). Given these contradictory findings it is difficult to accept that a habituation mechanism is underlying the spacing effect.

## Contextual-variability theory

Deficient processing theories as a class propose that the spacing effect in memory performance arises as a result of depression in item processing at massed inter-repetition intervals relative to item processing at spaced inter-repetition intervals. Contrary to the deficient processing approach, the contextual-variability theory (e.g., Glenberg, 1979; Madigan, 1969; Melton, 1970), explains the spacing effect in terms of enhancement of item processing at spaced inter-repetition intervals in comparison to item processing at massed inter-repetition intervals. According to the contextual-variability theory, a repeated item's representation in memory (i.e., its memory trace) includes, in addition to the item itself, references to the context in which the item occurred. Because variation in context can be assumed to be greater for massed inter-repetition intervals than for spaced inter-repetition intervals, the memory trace of spaced repetitions will entail more contextual elements than the memory trace of massed repetitions. At the time of the memory test, participants will use these contextual elements in order to access, and subsequently retrieve information from memory. Given that the number of encoded contextual elements is larger for spaced than for massed repetitions, it follows that the probability of retrieving a spaced repetition will be higher than the probability of retrieving a massed repetition.

Madigan (1969) conducted the first series of experiments designed to validate the contextual-variability theory by manipulating the elements of semantic context encoded in a repeated item's memory trace. In a crucial second experiment, participants studied word pairs, each consisting of a target noun in combination with another noun serving as a cue. The cue noun determined the semantic interpretation of the target noun. The cue-target pairs were presented once or twice. Twice-presented pairs were repeated at inter-repetition intervals of 0, 4, 8, or 16 intervening pairs. Most important, however, was that there were two conditions of repetitions, occurring at each of the four inter-repetition intervals. In the experimental condition, the target nouns were presented twice with two different cues. For instance, the word *bank* might occur twice in the study phase, once in combination with the cue *money,* and once in combination with the cue *river.* In the control condition, target nouns occurred twice with the same cue; in our example *bank* would occur twice with the cue *money.* Reasoning from the contextual-variability account of the spacing effect, the effect of experimentally induced context variation on memory performance should be highest for massed repetitions. The rationale underlying this prediction is that the number of encoded contextual elements is smaller for massed than for spaced repetitions. Therefore, the proportional increase in encoded contextual elements, and thus the increase in memory performance as a result of the experimental context manipulation should be greater for massed repetitions than for spaced repetitions. The results reported by Madigan (1969) confirmed this prediction. First, it was shown that the variation of semantic context increased memory of the target items. Moreover, and consistent with the contextual-variability account, the beneficial effect of context variation was located primarily at short inter-repetition intervals. Thios (1972), Gartman and Johnson (1972), and D'Agostino and DeRemer (1973), using experimental procedures similar to those of Madigan (1969), have demonstrated comparable findings. These results have also been obtained in other studies under context manipulations directed at the orthographic level, rather than at the semantic level of to-be-remembered stimuli.

For instance, in a study of Glanzer and Duarte (1971) bilingual participants studied once-presented words and twice-presented words repeated at different inter-repetition intervals. Furthermore, twice-presented words were repeated in the same language (i.e., English-English, or Spanish-Spanish) or in a different language (English-Spanish, or Spanish-English). In the latter condition, the semantic information activated at a repeated item's first presentation (house) is identical to the semantic information activated at its second occurrence (casa). However, the physical characteristics of the first presentation (i.e., the item's orthography) are different from the physical characteristics of the item's second occurrence. The free recall data revealed a pattern consistent with the findings of Madigan (1969). That is, words repeated in a different language were better recalled than words repeated in the same language, and the beneficial effect of different-language repetition was largest for short inter-repetition intervals. Findings similar to those of Glanzer and Duarte (1971) have been demonstrated in a study of Delarosa and Bourne (1985). In this study, participants were instructed to learn once-presented sentences, as well as twice-presented sentences repeated at different inter-repetition intervals. Twice-presented sentences were either repeated verbatim or with meaning-preserving changes in their wording. For instance, in the meaning-preserving condition the following sentence might be presented first: "*he was fired from his job as director due to his inadequacies*". The second occurrence of this sentence would then be: "*due to his inadequacies, his appointment as director was terminated*". In the verbatim condition, one of these two sentences would be presented twice. The free recall data of the studied sentences demonstrated an interaction effect between the surface structure of the sentence (i.e., verbatim versus meaning-preserving change) and inter-repetition interval. It was shown that repeating sentences in a different surface structure improved free recall performance most at short inter-repetition intervals.

Although the findings of the above-described studies are in support of the contextual-variability theory, some empirical data present a problem to a contextual-variability explanation of the spacing effect. Johnston and Uhl (1976) in their second experiment required participants to perform a continuous recognition task on a series of once-presented words, and repeated words occurring at spacing intervals of 1, 6 or 13 intervening items. Thus, for each word, participants had to decide whether it was new or whether it had been presented before (i.e., whether the word was a repetition). The free recall data demonstrated a spacing effect for repeated words that had been correctly identified as repetitions during the continuous recognition task. However, no spacing effect was revealed for repeated words that had not been identified as repetitions, suggesting that the retrieval of an item's first presentation at its second occurrence is a condition for the spacing effect to arise. Similar results have been obtained in a study of Thios and D'Agostino (1976) under a somewhat different experimental design. These findings are clearly at variance with the contextual-variability theory that predicts a positive relationship between memory of repeated items and the length of the inter-repetition interval.

## Two-process account

Thus far, theories have been discussed that attribute the spacing effect in memory performance to a single mechanism. However, two objections can be raised against these unitary approaches to the spacing effect. First, although each of the described theories (with exception perhaps of the consolidation theory) can account for a subset of the empirical data on the spacing effect, none of the theories can cover all of the data reported in the spacing effect literature. Second, unitary theories assume that spacing effects in explicit cued-memory tasks, such as word stem completion, and recognition, and spacing effects in free recall memory tasks can be traced back to the same mechanism. This assumption, however, is most probably incorrect given the existing fundamental difference between cued-memory tasks and free recall tasks. In cued-memory tasks, the experimenter provides cues (either cues associated with the target, or the incomplete target, as in word stem completion, or a copy of the target, as in recognition) on the basis of which participants have to retrieve a particular target from memory. In free recall tasks, however, no experimenter cues are given, and participants have to rely on self-generated sets of retrieval cues to access a particular target in memory.

Taking into consideration the distinction between cued-memory tasks and free recall tasks, Greene (1989) argued that two categories of mechanisms are required in order to accommodate the findings reported in the spacing effect literature. According to Greene's *two-process account* spacing effects in cued-memory tasks arise as a result of a voluntary, and therefore, non-automatic deficient processing mechanism. It was suggested that learners employ a strategy in which the rehearsal processing effort allocated to a particular item depends on a judgement about how well the item has been learned. As the second occurrence of a repeated item is assumed to be more familiar for massed repetitions than for spaced repetitions, a massed repetition is mistakenly thought to be better learned, and thus receives less rehearsal processing than a spaced repetition. Consequently, at test, memory of spaced items is superior to that of spaced items.

Based on the assumption that free recall is particularly sensitive to contextual associations, Greene (1989) put forward a specific version of the contextual-variability theory (e.g., Glenberg, 1979; Madigan, 1969; Melton, 1970), the study-phase retrieval theory, to account for the spacing effects demonstrated in free recall tasks. Similar to the contextual-variability account, the study-phase retrieval theory assumes that contextual change occurring between the first occurrence and the second occurrence of a repeated item is stored automatically (i.e., without deliberate intent) with a repeated item's memory trace. These contextual elements may be used as cues to facilitate the retrieval of information in free recall tests. Because the number of stored contextual elements increases as a function of the length of the inter-repetition interval, memory performance for repeated items is expected to improve with spacing. However, in contrast to the contextual-variability theory, the study-phase retrieval theory suggests that elements of contextual change are incorporated in a repeated item's memory trace only if the first occurrence of a repeated item is actually retrieved from long-term store at it's second occurrence. Consequently, spacing effects in free recall tasks will only emerge for repeated items that have undergone successful study-phase retrieval. The auxiliary assumption that the incorporation of contextual elements into a repeated item's memory trace is conditional on study-phase retrieval, allows the study-phase retrieval theory to explain empirical data on the spacing effect that were hard to accommodate by the contextual-variability theory alone. As previously mentioned, Johnston and Uhl (1976) as well as Thios and D'Agostino (1976) observed that spacing effects did not appear for words that were not recognized as repetitions. These results cannot be explained by an automatic contextual-variability mechanism, but they do make sense from a study-phase retrieval point of view.

To collect empirical evidence for the two-process account of spacing effects, Greene (1989) designed a series of experiments that focussed on the dissociation between the automatic nature of the study-phase retrieval mechanism on one hand, and the non-automatic nature of the deficient processing mechanism on the other. The dissociation between the automatic mechanism and the non-automatic mechanism was investigated by manipulating the intentionality of learning. Specifically, in each of the six conducted experiments, half of the participants were instructed to study a list of words, containing repetitions at different spacing intervals, for a later unspecified memory test (i.e., intentional instruction). The other half of the participants received the same word list without being informed about the following memory test. Instead, they were told that they had to determine the order in which the words were presented (i.e., incidental learning instruction). According to the two-process account, the automatic study-phase retrieval mechanism will operate independently of the intentionality of learning. Therefore, spacing effects in free recall should be found both for intentionally and incidentally learned materials. In contrast, spacing effects in cued-memory tasks are thought to be the result of a voluntary deficient processing mechanism that leads participants to allot less rehearsal effort to massed items than to spaced items. Under intentional learning instructions, participants are likely to use this differential rehearsal strategy. However, under incidental learning instructions, the use of such a rehearsal strategy becomes very unlikely. Consequently, spacing effects in cued-memory tasks should be revealed for intentionally learned materials, but not for incidentally learned materials. The results of the Greene's (1989) experiments consistently supported these predictions. Spacing effects in free recall were demonstrated following intentionally learned word lists and incidentally learned word lists, whereas spacing effects in cued-memory tasks were only shown for word lists studied under intentional learning instructions. The latter finding was replicated in another series of experiments (Greene, 1990) using a variety of cued-memory tasks. The studies of Greene (1989, 1990) provided some empirical evidence for the two-process account of spacing effects. Since the initial studies of Greene, the study-phase retrieval mechanism has remained largely undisputed as an explanation for spacing effects in free recall tasks. In contrast, the voluntary deficient processing explanation of spacing effects in cued-memory tasks has been submitted to a critical evaluation in subsequent studies.

## Priming accounts of the spacing effect in cued-memory tasks

As previously indicated, the voluntary deficient processing explanation of spacing effects in cued-memory tasks predicts that spacing effects are absent under incidental learning conditions. Thus, if reliable spacing effects would be obtained under incidental learning conditions, then this would argue against the voluntary deficient processing account. This notion was tested by Challis (1993) in two experiments in which participants studied once-presented words as well as massed repetitions and spaced repetitions under intentional learning instructions, incidental-semantic learning instructions, or incidental-graphemic learning instructions. Similar to the study of Greene (1989), participants in the intentional learning condition were informed about the following memory test, whereas participants in the incidental conditions were not informed about this test. Participants in the incidental-semantic study condition had to rate each word in terms of its pleasantness (a typical semantic processing task) or on its abstractness. Alternatively, participants in the incidental-graphemic condition counted for each word in the list the number of ascending and descending letters in the word (such as the *t* or *g*) or the letters with enclosed parts (such as *b* or *d*). Further, it was assumed that providing participants with intentional learning instructions would induce semantic analysis of the words. After the study-phase, participants in all conditions performed a frequency-judgement task (Experiment 1) or a cued recall test

(Experiment 2) on the studied words. The results on both the cued-recall test and a frequency-judgment task, demonstrated spacing effects only when the instructions encouraged participants to employ an orienting task, which involved the semantic analysis of target words. That is, spacing effects were revealed in both the intentional condition and the incidental-semantic condition. On the other hand, no spacing effect emerged when the encoding task was directed at the analysis of structural features of the target words (i.e., in the incidental-graphemic condition). Results similar to those demonstrated by Challis (1993) were also reported in other studies (e.g., Greene & Stillwell, 1995; Russo & Mammarella, 2002).

To account for his findings, Challis (1993) suggested that the spacing effect in cued-memory tasks emerges on the basis of the process of semantic priming, automatically elicited by the semantic analysis of the target items. It was proposed that the first occurrence of a target item primes its second occurrence, thus reducing the semantic processing of the second occurrence. Moreover, because the semantic-priming effect decreases as a function of the time elapsed between the first occurrence and the second occurrence of a target item, less semantic processing should be allocated to the second occurrence of a repeated item when presented under massed repetition than when presented under spaced repetition. As a result of the proposed mechanism, spaced items receive on average more semantic processing than massed items, and consequently, the spacing effect in cued-memory tasks arises. According to Challis (1993), the experiments reported by Greene (1989, 1990) may have failed to show a spacing effect in cued-memory tasks because a non-semantic orienting task was used during incidental learning that might have disrupted the semantic processing of target items.

Russo, Parkin, Taylor, and Wilks (1998) noticed that Challis' (1993) semantic priming account of spacing effects in cued-memory tasks did not allow for the emergence of spacing effects if either the experimental manipulation or the nature of the used item materials prevented semantic priming during learning. However, inconsistent with the semantic priming account, Russo et al., (1998) found reliable spacing effects in the recognition of unfamiliar faces learned incidentally under orienting tasks focussing on the structural (i.e., non-semantic) features of the target items. Furthermore, in another study, Russo and Mammarella (2002), using incidental learning tasks promoting structural-perceptual processing, obtained a spacing effect in the yes/no recognition of non-words, whereas no spacing effect was revealed for words. Given that the semantic analysis of the target stimuli was largely prevented or even impossible under the learning conditions offered in the studies of Russo et al., (1998) and of Russo and Mammarella (2002), the reported spacing effects strongly suggest that the semantic priming account cannot completely explain spacing effects observed in cued-memory tasks.

To accommodate the spacing effects demonstrated for target stimuli that are unlikely to be processed semantically, Russo et al., (1998; see also Russo & Mammarella, 2002; Mammarella, Russo, & Avons, 2002) embedded the semantic priming account (Challis, 1993) in a transfer-appropriate processing approach to memory (e.g., Kolers & Roediger, 1984). They argued that the mode of processing on target items during study should be congruent with the mode of processing on targets during the memory test. Under the assumption that most cued-memory tasks involve mainly semantic processing, spacing effects should be revealed whenever learning instructions direct participants at the semantic analysis of targets during study. In that case, spacing effects are assumed to be the result of the semantic priming mechanism proposed by Challis (1993). However, if processing at study and at test is based on non-semantic features of target items, for instance because unfamiliar faces or non-words are used, spacing effects should be explained in terms of a short-term perceptual priming mechanism. Russo and colleagues (1998, 2002) suggested that cued-memory task performance on non-semantically processed targets is dependent on the mobilization of structural-perceptual information of that particular target. They argued that the structural-perceptual analysis of the first occurrence of a target serves as a prime for its second occurrence, hence facilitating the structural-perceptual processing of the second occurrence. However, the effect of short-term repetition priming for non-words decays rapidly as the number of intervening items between the first and the second occurrence increases (e.g., McKone, 1995; Mckone & Dennis, 2000). Thus, as a result of the short-term perceptual priming mechanism, spaced repetitions receive more structural-perceptual processing than massed repetitions, leading to the spacing effect in subsequent non-semantic cued-memory tasks.

Empirical evidence for the short-term perceptual priming mechanism, in addition to the results of the studies already mentioned (Russo et al., 1998, Russo & Mammarella, 2002), was provided by a series of experiments in which the effect of changing the font types between the targets' repeated occurrences on the magnitude of the spacing effect was assessed (Russo, Mammarella & Avons, 2002). Russo et al., (2002) hypothesized that changing the font between targets' repeated occurrences would inhibit the short-term perceptual priming for massed repetitions of non-words. In their first experiment, participants incidentally learned a list of non-words under orienting tasks focussing on the orthographic characteristics of the targets. The results showed that changing the font removed the spacing effect for non-words and that this effect could entirely be attributed to the superior recognition memory of massed items presented in different fonts relative to the condition in which massed items were presented in the same font. Moreover, the experimental manipulation did not affect recognition memory of spaced items. However, the transfer-appropriate processing approach predicts that changing the font between repeated occurrences influences the spacing effect in cued-memory tasks only if the mode of processing during study and test is non-semantic in nature. To test this prediction, a second experiment was conducted using semantic orienting tasks to promote incidental learning of a list comprising English words. As predicted, recognition performance on the studied targets was not hindered by the experimental manipulation of font. The results revealed spacing effects both for repeated items presented in the same font and for repeated items presented in different fonts.

## Conclusion

On the basis of the described historical overview, it can be inferred that spacing effects in memory are explained in terms of a two-process framework that proposes different mechanisms to account for spacing effects in free recall tasks and in cued-memory tasks. First, with respect to free recall, spacing effects are assumed to emerge as a result of a study-phase retrieval mechanism (Greene, 1989). According to the study-phase retrieval mechanism, elements of contextual change are encoded in a repeated item's memory trace if an item's first occurrence is retrieved from long-term store at its second presentation. The spacing effect in free recall is obtained because the number of encoded contextual elements, and therefore the number of retrieval cues, increases with the inter-repetition interval. However, successful study-phase retrieval is thought to be a necessary condition for the storage of contextual elements. Consequently, spacing effects in free recall will be demonstrated exclusively for repeated items that have been identified as repetitions.

Second, spacing effects in cued-memory tasks are attributed to two qualitatively different priming mechanisms. If repeated items are semantically processed during study and test, a semantic priming mechanism (Challis, 1993) is thought to cause the spacing effect in cued-memory tasks. The semantic priming mechanism presents an automatic, deficient processing explanation of the spacing effect. The first occurrence of a repeated item primes its second presentation, thereby facilitating the semantic analysis of the second occurrence. As the semantic priming effect dissipates rapidly over time, the total amount of semantic processing directed at a both occurrences of a repeated item increases with the length of the inter-repetition interval. Therefore, the probability of remembering a repeated item at a cued-memory task also increases with the length of the inter-repetition interval. Alternatively, if, for some reason, semantic analysis of repeated items is made impossible during study and test, a structural-perceptual priming mechanism (e.g., Russo et al., 1998, 2002; Mammarella et al., 2002) is assumed to underlie the spacing effect in cued-memory tasks. The structural priming explanation of spacing effects is conceptually analogous to the semantic priming mechanism, with the exception that the structural-perceptual mechanism operates at a repetition's orthographic, rather than at its semantic level of representation.

## The present studies

Although the described two-process explanation of spacing effects has received some empirical support, the framework still entails ill-specified components. For instance, the study-phase retrieval account of the spacing effects in free recall tasks provides little, if any, information on the determining factors of the study-phase retrieval mechanism itself. Given that successful study-phase retrieval is assumed to be a necessary condition for the spacing effect in free recall to occur, research at factors affecting the study-phase retrieval mechanism would be very useful in terms of identifying the boundaries of the spacing effect. The studies presented in Chapters 2 through 4 of this thesis were conducted with the purpose of unearthing some of the determining factors of the study-phase retrieval mechanism.

In the study presented in **Chapter 2**, variation in repetition background was used to investigate the role of study-phase retrieval and contextual-variability in spacing effects in free recall. Two experiments were conducted in which free recall was measured for massed and spaced repetitions following intentional learning. The most important manipulation, however, was directed at establishing a difference between the presentation context at a repeated item's first occurrence and the presentation context at its second occurrence. In both experiments, half of the repetitions were presented twice on the same background, whereas the other half was presented twice on different backgrounds. According to the encoding specificity principle, the probability of retrieving a particular memory event is positively related to the degree of overlap between information in the retrieval cue and the context information stored in the event's memory trace (Tulving, 1983; Tulving & Thomson, 1973; see also Smith & Vela, 2001, for information on context-dependent memory). The encoding specificity principle has an important implication for the operation of the study-phase retrieval mechanism. If a spaced item is repeated on different backgrounds, rather than on the same background, the study-phase retrieval of that item will be impaired. Hence, spaced repetitions presented on the same background are expected be recalled better than spaced repetitions presented on different backgrounds. Moreover, according to the study-phase retrieval point of view, context variation is expected to have no effect on free recall of massed repetitions because the first presentation can be expected to be still in the short-term buffer at its second occurrence and therefore it has not to be retrieved from long-term store. Interestingly, the *contextual-variability account* (Glenberg, 1979; Madigan, 1969; Melton, 1970) of spacing effects in free recall predicts exactly the reversed pattern. Remember that the contextual-variability account states that the number of encoded contextual elements (i.e., retrieval cues) increases with the spacing interval, and that the probability of recalling a repeated item is positively related to the number of retrieval cues. If items are repeated on different backgrounds, the increase of contextual elements, relative to the situation in which items are repeated on the same background, will be larger for massed repetitions than for spaced repetitions. Therefore, recall of massed items should be greater when repeated on different backgrounds, whereas recall of spaced items will be unaffected by the background variation. However, it might also be possible that *both* the study-phase retrieval and the contextual-variability mechanism are needed to explain the spacing effect in free recall. In case of this combined model, the two aforementioned predictions should be integrated. That is, the contextual-variability mechanism is expected to provide massed items repeated on different backgrounds with a recall advantage over massed items repeated on the same background. On the basis of the study-phase retrieval mechanism, free recall of spaced items repeated on the same background will be higher than free recall of spaced items repeated on different backgrounds.

The study in **Chapter 3** investigates how the study-phase retrieval mechanism, and therefore, free recall performance is influenced by the interaction between intentionality of learning and the length of the inter-repetition interval. The study is an extension of a series experiments reported by Toppino and Bloom (2002; for comparable results see Toppino, Hara, and Hackman, 2002). In their first experiment, Toppino and Bloom (2002) attempted to replicate the findings obtained by Greene (1989). Specifically, participants had to study a word list containing once-presented items and spaced repetitions with respectively 0 (massed repetition), 4, and 8 intervening items under either intentional or incidental learning instructions. Each word in the list was shown for 10s. Consistent with Greene's procedure, participants in the intentional condition were informed about the following free recall test. Participants in the incidental condition were not informed about the test. Instead, they were told to find a rule that determined the order in which the words in the test were presented. Contrary to the findings in Greene's (1989) study, in which spacing effects in free recall were obtained after intentional and incidental learning instructions, the free recall data of Toppino and Bloom (2002) revealed an interaction-effect between type of instruction and level of spacing. That is, a spacing effect was demonstrated in the intentional learning condition, whereas in the incidental learning condition memory performance remained constant for each of the three spacing levels. Toppino and Bloom (2002) interpreted their findings in terms of the study-phase retrieval mechanism. They argued that, in comparison to the intentional learning condition, depth of word processing was shallow in the incidental learning condition. If a repeated item's first occurrence is shallowly processed, then study-phase retrieval at its second presentation will suffer even at relatively short inter-repetition intervals. Because a presentation rate of 10s per word was used in Toppino and Bloom's (2002) first experiment, spaced repetitions were presented at intervals of approximately 40s (4 intervening items) and 80s (8 intervening items). Toppino and Bloom (2002) hypothesized that the length of the inter-repetition intervals might have hindered study-phase retrieval for spaced items in the incidental learning condition, but not for spaced items in the intentional learning condition. Hence, the spacing effect disappeared following incidental learning. According to this hypothesis, spacing effects should be demonstrated under incidental learning conditions if shorter presentation rates were to be used. This prediction was tested in their second experiment in which participants incidentally studied the same word list as in the first experiment with either a presentation rate of 3s per word or a presentation rate of 10s per word. The free recall data revealed a spacing effect in the 3s condition, whereas no spacing effect was demonstrated in the 10s condition. In a post-hoc elaboration on these results, inter-repetition intervals were expressed in seconds rather than in the number of intervening items. Subsequently, the free recall data from both experimental conditions were combined and displayed as a function of six levels of temporal spacing between the repetitions. Interestingly, the resultant pattern suggested that an inverted u-shaped relationship exists between free recall and the length of the inter-repetition interval. The inverted u-shaped function can be readily explained by the study-phase retrieval account. Free recall performance increases with the inter-repetition interval as long as study-phase retrieval is successful for the majority of the repeated items. However, at a certain length of the inter-repetition interval, study-phase retrieval will fail for most of the repeated items. As a result, a reversed spacing effect will be demonstrated from this spacing interval onwards.

Problematic for the interpretation of the inverted u-shaped function between free recall and the length of the inter-repetition interval reported by Toppino and Bloom (2002), is that the function was obtained through a post-hoc combination of the free recall data from two different experimental conditions. The study presented in Chapter 3 was conducted to reveal the inverted u-shaped function without having to revert to post-hoc manipulations of the free recall data. In the first experiment, participants learned a list of words under incidental or intentional learning instructions identical to those used by Toppino and Bloom (2002). The word list contained once-presented items, massed repetitions, and spaced repetitions, presented at spacing intervals 0 (i.e., massed repetition), 2 (i.e., lag 2) and 8 intervening items (i.e., lag 8). Each word was presented for 10s. After participants had studied the list, a free recall task was administered. Under the assumption that the level of processing is deeper in the intentional learning condition than in the incidental learning condition, study-phase retrieval for spaced repetitions was predicted to be successful at lag 2 and at lag 8. Therefore, a spacing effect in free recall was expected for intentionally learned repetitions. Alternatively, for incidentally learned repetitions, the post-hoc analysis of Toppino and Bloom (2002) suggested that free recall rises with the length of the inter-repetition interval until the maximum is reached at an interval of approximately 20s. From this point onwards, free recall performance decreases as a function of the length of the inter-repetition interval. At a spacing interval of about 80s, free recall has dropped to the level of performance for massed repetitions. Thus, with respect to incidentally learned repetitions, free recall of lag 2 repetitions (corresponding with a spacing interval of 20s) was expected to be better than free recall of both massed repetitions, *and* of lag 8 repetitions (corresponding with a spacing interval of 20s). In the second experiment of the study presented in Chapter 3, the procedure and the materials were identical to those used in the first experiment. However, instead of presenting repetitions at three spacing intervals (i.e., spacing intervals of 0, 2, and 8 intervening items), repetitions were presented at six spacing intervals (i.e., spacing intervals of 0, 2, 5, 8, 14 and 20 intervening items). By this means, the relationship between free recall performance and the length of the inter-repetition interval could be further specified.

The starting point of the study presented in **Chapter 4** was the question to what extent study-phase retrieval is affected by the degree of overlap between linguistic representation levels of repeated items. Theories of language processing make a distinction between an orthographic and a semantic level of representation (e.g., Gollan & Kroll, 2001; Potter, So, Von Eckhart, & Feldman, 1984). The orthographic level represents the physical appearance of a word whereas the semantic level represents the meaning of a word. It could be argued that overlap at the semantic level of representation is sufficient to ensure successful study-phase retrieval. On the other hand, it might be possible that study-phase retrieval will only occur for repetitions that overlap at the semantic level of representation and the orthographic level of representation. Three experiments were conducted to investigate which of these alternatives is correct. Bilingual participants studied massed and spaced items repeated either in the same language (i.e., Dutch-Dutch, or English-English) or in a different language (i.e., Dutch-English or English-Dutch), before being tested on the repeated items in a free recall memory task. In Experiment 1A and in Experiment 1B, participants received learning instructions, directed at the semantic analysis of the repeated items. The only difference between these two experiments was that learning occurred intentionally in Experiment 1A, whereas it occurred incidentally in Experiment 1B. If study-phase retrieval requires an overlap solely at the semantic level of representation, then the spacing effect in free recall should emerge for both same-language repetitions and different-language repetitions under learning instructions that encourage semantic processing of repeated items. Alternatively, if study-phase retrieval depends on an overlap at the semantic level of representation and the orthographic level of representation, then the spacing effect should be revealed for same-language repetitions, but not for different-language repetitions. With respect to Experiment 1A and Experiment 1B, it was proposed that study-phase retrieval requires repeated items to share at least the semantic level of representation. However, it could be argued that merely sharing the same semantic level of representation is not sufficient to trigger study-phase retrieval. Instead, it is reasonable to assume that the shared level of semantic representation should be activated in memory on both occurrences of a repeated item to induce study-phase retrieval. If this assumption holds true, the spacing effect should neither emerge for same-language repetitions nor for different-language repetitions if participants are averted form activating a repeated item's semantic level of representation. To test this hypothesis, a third experiment was performed, in which the learning instructions stressed the orthographic processing of repeated items rather than the semantic processing of repeated items.

Contrary to the studies described in Chapters 2 through 4, which are directed at the study-phase retrieval mechanism, the study presented in **Chapter 5** focuses on the semantic priming explanation of spacing effects in cued-memory tasks. The semantic priming explanation suggests that the semantic analysis of a repeated item's first occurrences facilitates semantic processing of the second presentation in case of short inter-repetition intervals. Hence, the total amount semantic processing directed at both occurrences of a repeated item will be smaller for massed repetitions than for spaced repetitions. As a result, the chances of remembering a repetition are lower for massed than for spaced repetitions, giving rise to the spacing effect. However, despite the plausibility of this line of reasoning, empirical data on the relationship between semantic priming and cued-memory performance is scarce. Therefore, the aim of the study presented in Chapter 5 was to investigate the relationship between semantic priming and cued-memory performance as proposed by the semantic priming explanation. In the first experiment, participants learned a word list under intentional instructions for a subsequent yes/no recognition test. The word list comprised massed and spaced repetitions as well as massed and spaced semantically related word pairs. These pairs consisted of semantically associated words, such as *sleep* and *bed*. Because the words in a pair are semantically related, the presentation of the first word (sleep) enhances the semantic processing of the second word (bed). Thus, if the semantic priming explanation of spacing effect in cued-memory tasks holds true, then spacing effects in recognition performance should be obtained for repetitions, but also for semantically related pairs. The second experiment was identical to the first, with the exception that incidental-semantic learning instructions, instead of intentional learning instructions were used.

**Chapter 6** includes a summary of the findings reported in the studies presented in the thesis and a general discussion.

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# *Chapter 2*

# Detrimental influence of contextual change on spacing effects in free recall[1]

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*Two experiments were conducted to determine the mechanism underlying the spacing effect in free recall tasks. Participants were required to study a list containing once-presented words as well as massed repetitions and spaced repetitions. In both experiments, presentation background at repetition was manipulated. The results of Experiment 1 demonstrated that free recall was higher for massed items repeated in a different context than for massed items repeated in the same context, whereas free recall for spaced items was higher when repeated in the same context. Furthermore, a spacing effect was shown for words repeated in the same context, whereas an attenuated spacing effect was revealed for words repeated in a different context. These findings were replicated in Experiment 2 under a different presentation background manipulation. Both experiments seem to be most consistent with a model that combines the contextual-variability and the study-phase retrieval mechanism to account for the spacing effect in free recall tasks.*

The *spacing effect* refers to the phenomenon that repeated items induce better recollection if both occurrences are separated by time and/or other targets (i.e., spaced presentation), compared to a situation in which repetitions occur in immediate succession (i.e., massed presentation). Although the spacing has been demonstrated in a vast number of studies (e.g., Challis, 1993; Greene, 1989, 1990; Greene, & Stillwell, 1995; Hintzmann & Block, 1973; Hintzmann, Summers, & Block, 1975; Mammarella, Russo, & Avons, 2002; Russo & Mammarella, 2002; Russo, Mammarella, & Avons, 2002; Russo, Parkin, Taylor, & Wilks, 1998) it has largely defied a unitary explanation. (For reviews on proposed theoretical mechanisms see: Crowder, 1976; Dempster, 1996; Hintzman, 1974, 1976, and Kintsch, 1970). For instance, different mechanisms are proposed to account for spacing effects in cued-memory tasks and in free recall.

Regarding the spacing effect in free recall, two important theoretical explanations can be distinguished. The *contextual-variability account* (e.g., Melton, 1967, 1970) suggests that the number of encoded retrieval cues increases with repetition spacing, and that the chance that an item is recalled is positively related to the number of retrieval cues. Evidence for the contextual-variability account has been obtained in a number of studies using different operationalizations of contextual-variability (e.g., Delarosa & Bourne, 1985; Durgunoglu & Roediger III, 1987; Glenberg, 1979; Krug, Davis, & Glover, 1990; Madigan, 1969).

Alternatively, the *study-phase retrieval account* states that the storage of contextual features in a repeated item's memory trace will only take place if a prior presentation is retrieved from long-term store during study (Greene, 1989). This account predicts that spacing will be positively related to free recall performance under the condition of successful study-phase retrieval: For items that are not retrieved at their second occurrence the spacing effect will disappear. Moreover, according to the study-phased retrieval point of view, context variation is expected to have no effect on free recall of massed repetitions because the first presentation can be expected to be still in the short-term buffer at its second occurrence and therefore has not to be retrieved from long-term store. Empirical support for the study-phase retrieval account has been demonstrated in several studies (e.g., Braun & Rubin, 1998; Johnston & Uhl, 1976; Thios & D'Agostino, 1976; Toppino & Bloom, 2002; Toppino, Hara, & Hackman, 2002).

Although in literature the spacing effect in free recall is attributed to either a contextual-variability or a study-phase retrieval mechanism, it might be possible that *both* mechanisms are required to explain the spacing effect in free recall tasks. It should be noted that such a combined model predicts different effects of context manipulation for massed and for spaced repetitions. Based on the contextual-variability component of the model, it can be inferred that repetitions in different environmental contexts should benefit massed items more than spaced items, relative to same context repetitions, and consequently recall of massed items should be greater when repeated in a different context.

However, on the basis of the study-phase retrieval component of such model, the *reversed* pattern is expected for spaced items. The encoding specificity principle states that the probability of retrieving a particular memory event is positively related to the degree of overlap between information in the retrieval cue and the context information stored in the event's memory trace (Tulving, 1983; Tulving & Thomson, 1973; see also Smith & Vela, 2001, for information on context-dependent memory). An important implication of the encoding specificity principle is that repetitions in different contexts should impair performance in the spaced condition because prior occurrences in a different context will be relatively difficult to retrieve. This implication has been repeatedly demonstrated not only in free recall memory (e.g., Godden & Baddeley, 1975; Sahakyan & Kelley, 2002; Smith, Glenberg, & Bjork, 1978), but also in recognition memory (e.g., Murnane, Phelps, & Malmberg, 1999). Thus, spaced repetitions presented in the same context are expected be recalled better than spaced repetitions presented in different contexts.

The aim of the present study was to provide evidence for the idea that both contextual-variability and study-phase retrieval underlie the spacing effect in free recall. To that end, two experiments were conducted in which free recall for words repeated in a massed or spaced fashion was measured. The most important manipulation was directed at establishing a difference between the presentation context at an item's first and the presentation context at its second occurrence. In Experiment 1, the manipulation of the presentation context was subtle as we varied the color of the presentation background between repetitions. Alternatively, the context variation in Experiment 2 was larger than in Experiment 1. Repetitions in the experimental condition were presented on backgrounds that did not only differ at a perceptual but also at a semantic level. More specifically, repetitions were presented once on the background of a city-skyline and once on the background of a forest landscape.

## Experiment 1

In Experiment 1, the main manipulation entailed contextual modifications occurring between massed and spaced target repetitions during learning. In the control condition, both occurrences of the repeated items were presented on the same background (on either a white or an olive-green screen), whereas in the experimental condition both occurrences were presented, in a counterbalanced fashion, on different backgrounds.

## Method

### Participants

Thirty-six first-year psychology students from Erasmus University Rotterdam, the Netherlands, took part in the experiment in order to fulfill a course requirement.

### Materials

One list template comprising 120 serial positions was created. Slots 11-110 were reserved for 20 once-presented filler items and for 40 twice-presented targets representing both the spacing and the context conditions of the experiment. Twenty targets were presented at lag 0 (massed presentation) and 20 were presented at lag 6 (spaced presentation). Furthermore, of the 20 targets in each spacing condition, 10 were assigned to the same context (SC) condition: Five targets in the SC condition were presented twice on a white background and 5 on an olive-green background. The remaining 10 targets in each spacing condition were assigned to the different context (DC) condition. In this condition, 5 targets were presented for the first time on a white background and were repeated on an olive-green background. For the other 5 targets, the sequence of presentation-background was reversed. Because the second presentations of repeated items, on average, tend to occur near the end of the study list as the inter-repetition interval increases, an observed spacing effect in free recall might in fact be the result of an extended recency effect (e.g., Underwood, 1969). To avoid confounding by this extended recency factor, we controlled for serial position effects in several ways. First, a mean serial position was calculated for all targets and the average of the mean serial positions was equated for each of the two context conditions and for each of the two lag conditions. In addition, for both context conditions, the average of the mean serial positions did not differ between targets repeated at lag 0 and at lag 6. To control for further serial position effects, the list structure began and ended with slots for 10 primacy and 10 recency buffers, respectively. Half of the primacy and recency buffers as well as half of the filler items were presented on a white background. The other half was presented on an olive-green background.

Stimuli consisted of 30 adjectives and 30 nouns that were three to eleven letters in length and were high frequency words according to Dutch word frequency standards (Uit den Bogaart, 1975). During the selection of the stimuli, it was made sure that no obvious semantic relationship existed between the included words.

The stimuli were divided into three sets (A, B, and C) consisting of an equal number of nouns and adjectives. Subsequently, three study lists were created from the list template. To create the first study list, the stimulus sets A and B were assigned to the lag 0 and the lag 6 conditions respectively. Within each spacing condition, the words in the stimulus set were randomly distributed across the two context conditions. The words in stimulus set C were used as filler items. In order to generate the second and the third study list, the stimulus sets were rotated through the spacing conditions. Consequently, the stimulus sets corresponding to lag 0, lag 6 and the filler items were CAB in the second and BCA in the third study list. The procedure used to distribute the words in the stimulus sets across the context conditions was identical to the one used in the construction of the first study list. Each study list was presented to twelve participants.

### Procedure

Participants were informed that they were to be presented with a list of 120 words and that they had to try to remember as many words of the list as possible for a later unspecified memory task. Furthermore, they were told that each word would be shown once for 3 seconds in the center of a computer screen with an inter-stimulus interval of 500 milliseconds. During the inter-stimulus interval a row, consisting of four asterisks was displayed in the center of the screen. The background color used in the inter-stimulus interval was identical to the background color of the preceding word. After they had studied all the words in the list, the participants had to engage in a distraction task for two minutes. The distraction task involved writing down as many cities of the United States as they could think of. Following the distraction task, the experiment leader handed out a sheet and asked the participants to write down as many of the 120 words of the experimental list as they could remember. For this free recall task, participants were allowed a maximum of 15 minutes. Participants were tested individually or in groups. In case of the latter situation, participants were seated in separate cubicles.

### Analysis

Context with two levels (i.e., SC vs. DC) and lag with two levels (i.e., lag 0 vs. lag 6) were manipulated within subjects. For each combination of the context and lag levels, a percentage of accurate free recall was determined and this percentage of free recall was included as the dependent variable in a 2 (context) x 2 (lag) within-subject analysis of variance. Planned paired t-tests were conducted for individual comparisons in case of a significant interaction term. For the analysis of variance and the paired t-tests a cut-off value of $p = .05$ was used as a criterion of significance.

## Results and discussion

Because frequency of occurrence (i.e., once versus twice-presented items) and spacing (i.e., massed versus spaced repetitions) are two conceptually distinct variables, two separate analyses were conducted to determine their effects on free recall performance.

Two paired t-tests demonstrated that twice-presented items were recalled better than once-presented items both for items repeated on a same background [$t$ (35) = 4.05, $p < .001$; $M_{twice}$ = 25.42% versus $M_{once}$ = 17.22%] and for items repeated on a different background [$t$ (35) = 6.18, $p < .001$; $M_{twice}$ = 26.39% versus $M_{once}$ = 17.22%]. Remarkably, massed repetition in the same context did not enhance recall performance relative to once-presented items.

Table 1 depicts mean free recall performance as a function of lag and context. Analysis revealed a significant effect of lag [$F$ (1, 35) = 29.42, $MSE$ = 162.59, $p < .001$] without a significant effect of context [$F < 1$]. These results imply, in combination with the descriptive statistics displayed in Table 1, that, irrespective of context, mean percent recall performance for words presented at lag 6 was superior to mean recall performance for words presented at lag 0. Furthermore, on average, words presented on the same background were reproduced equally often as words presented on different backgrounds. Most interestingly, however, was a significant lag x context interaction [$F$ (1, 35) = 10.87, $MSE$ = 141.17, $p < .01$], suggesting that the effect of context manipulation differed between the two levels of the lag factor. For lag 0, a paired t-test showed that mean recall performance was *lower* for words presented twice on the same background than for words repeated on a different background [$t$ (35) = 2.26, $p < .05$]. For lag 6, mean recall performance was *higher* for words presented twice on the same background than for words repeated on a different background [$t$(35) = 2.22, $p < .05$]. In addition, a clear spacing effect was demonstrated for words repeated on the same background [$t$ (35) = 6.01, $p < .001$], whereas an attenuated spacing effect was present for words repeated on a different backgrounds [$t$ (35) = 1.78, $p < .05$].

**Table 1**

*Mean percentage of accurate free recall and standard errors in Experiment 1 as a function of the spacing between repetitions and the presentation context at repetition.*

| | **Spacing between repetitions** | | | |
|---|---|---|---|---|
| | Zero (Lag 0) | | Six (Lag 6) | |
| Repetition context | *M* | *SE* | *M* | *SE* |
| Same context | 16.39 | 2.26 | 34.44 | 3.29 |
| Different context | 23.61 | 2.29 | 28.61 | 2.56 |

The results of Experiment 1 seem to provide support for the proposed combined model of spacing effects in free recall. In line with the prediction derived from the contextual-variability component of this model, free recall for massed repetitions presented on different backgrounds was more elaborate than free recall for massed repetitions presented on the same background. This suggests that, for massed repetitions presented in different contexts, the experimentally induced background variation had resulted in a substantial increase of encoded contextual elements relative to the same context condition. Moreover, reasoning from the study-phase retrieval component of the model, we expected the probability of successful study-phase retrieval to be lower for spaced repetitions presented in different contexts in comparison to spaced repetitions presented in the same context. As a consequence, free recall of spaced repetitions presented in different contexts was expected to be less elaborate than free recall of spaced repetitions presented in the same context. The free recall performance for spaced repetitions in Experiment 1 confirmed this prediction.

Although the results obtained in Experiment 1 are consistent with the predictions derived from the combined model of spacing effects, it might be possible that they were simply due to the specific context manipulation used in Experiment 1. To demonstrate the general nature of the findings in Experiment 1, we conducted a second experiment in which a different context manipulation was used.

## Experiment 2

Similar to Experiment 1, the main manipulation in Experiment 2 consisted of contextual change occurring between massed and spaced target repetitions during learning. However, the nature of the context manipulation in Experiment 2 was different from the one used in Experiment 1. In the control condition both occurrences of the repeated targets were presented on a background depicting either a forest landscape or the skyline of the city of Chicago. For the repeated targets in the experimental condition, both occurrences were presented on different backgrounds (forest and skyline) in a counterbalanced way. This context manipulation was expected to produce the same pattern of results as in Experiment 1. Thus, we expected a beneficial effect of variation in presentation context on free recall of massed repetitions, and a detrimental effect of presentation context on free recall of spaced repetitions.

## Method

### Participants

Eighteen first-year psychology students from Erasmus University Rotterdam, the Netherlands, took part in the experiment in order to fulfill a course requirement. Only students, who had not participated in Experiment 1, were allowed to participate in Experiment 2.

### Materials and procedure

Materials and procedure were identical to those used in Experiment 1, except for the context modifications. In the same context (SC) condition, half of the targets were presented twice on the forest background and the other half on the city background. In the different context (DC) condition, half of the targets were presented for the first time on the forest background and were repeated on the city background. For the remaining targets, the sequence of presentation-background was reversed.

### Analysis

Context with two levels (i.e., SC vs. DC) and lag with two levels (i.e., lag 0 vs. lag 6) were manipulated within subjects. For each combination of the context and lag levels, a percentage of correct free recall was determined and this percentage of free recall was included as the dependent variable in a 2 (context) x 2 (lag) within-subject analysis of variance. Planned paired t-tests were conducted for individual comparisons in case of a significant interaction term. For the analysis of variance and the paired t-tests a cut-off value of $p = .05$ was used as a criterion of significance.

## Results and discussion

Two paired t-tests demonstrated that twice-presented items were recalled better than once-presented items both for items repeated on a same background [$t$ (17) = 3.84, $p < .001$; $M_{twice} = 31.67\%$ versus $M_{once} = 18.33\%$] and for items repeated on a different background [$t$ (17) = 4.89, $p < .001$; $M_{twice} = 29.44\%$ versus $M_{once} = 18.33\%$].

Table 2 demonstrates mean free recall performance as a function of context and lag. The within-subject analysis of variance showed a main effect of lag [$F$ (1, 17) = 17.18, $MSE = 156.54$, $p < .001$] indicating that, independent of context level, the mean percentage of correctly reproduced targets was higher for spaced than for massed words. The main effect of context manipulation turned out to be non-significant [$F < 1$]. Apparently, independent of lag level, mean free recall performance did not differ between words presented on different backgrounds and words presented on the same background. Moreover, the lag x context interaction was significant [$F$ (1, 17) = 10.51, $MSE = 103.59$, $p < .01$], suggesting that the effect of the context manipulation differed between the levels of lag. In line with our predictions, it was demonstrated that mean percentage of free recall was higher for lag-0 words presented on different background than for lag-0 words presented on the same backgrounds [$t$ (17) = 1.96, $p < .05$]. For lag-6 words, this pattern was reversed; mean percentage of free recall was highest for words presented on the same background [$t$ (17) = 1.93, $p < .05$]. Finally, a spacing effect was obtained in case repeated words were shown on the same background [$t$ (17) = 2.49, $p < .05$], whereas a spacing effect was absent when words were presented on different backgrounds [$t$ (17) = 1.29, $p = .11$].

**Table 2**

*Mean percentage of accurate free recall and standard errors in Experiment 1 as a function of the spacing between repetitions and the presentation context at repetition.*

| | **Spacing between repetitions** | | | |
|---|---|---|---|---|
| | Zero (Lag 0) | | Six (Lag 6) | |
| Repetition context | *M* | *SE* | *M* | *SE* |
| Same context | 21.67 | 3.45 | 41.67 | 6.12 |
| Different context | 27.22 | 2.89 | 31.67 | 3.81 |

The results of Experiment 2 replicated the findings obtained in Experiment 1, thereby strengthening the support for an explanation of spacing effects that entails *both* the contextual-variability and the study-phase retrieval mechanism. Again, it was shown that massed words repeated on the same background suffered from a recall disadvantage relative to massed words repeated on a different background. For spaced repetitions the reversed pattern was found: Spaced repetitions in the same context condition were recalled better than spaced repetitions in the different context condition.

## General discussion

Although a vast amount of research has focused on the spacing effect in free recall tasks it has been difficult to arrive at a unitary explanation for the phenomenon. Some theorists have attributed the spacing effect in free recall to a contextual-variability mechanism (e.g., Glenberg, 1979; Madigan, 1969, Melton, 1967, 1970), while others have proposed a study-phase retrieval mechanism (e.g., Braun & Rubin, 1998; Johnston & Uhl, 1976; Greene, 1989; Thios & D'Agostino, 1976; Toppino & Bloom, 2002; Toppino, et al., 2002). However, it might also be possible that the best explanatory model for the spacing effect in free recall is a model that combines the contextual-variability and the study-phase retrieval mechanism.

In the present study, we tested this hypothesis by conducting two experiments in which participants were required to learn a word list containing both massed and spaced items that were repeated either in the same or in a different context. Based on the contextual-variability component of the combined model, we predicted the variation in presentation background to have a beneficial effect on free recall of massed repetitions. On the other hand, based on the study-phase retrieval component of the model, variation in repetition context was expected to have a detrimental effect on free recall of spaced repetitions. The results in both Experiment 1 and Experiment 2 were consistent with the predictions derived from the combined model as they demonstrated a significant cross-over interaction effect between spacing and presentation background. In both experiments, the interaction effect could be attributed to the fact that massed repetitions were recalled better when presented in different contexts, whereas spaced repetitions were recalled better when presented in the same context. These findings suggest that an adequate explanation of the spacing in free recall task should incorporate the contextual-variability and the study-phase retrieval mechanism. Furthermore, the results of the present study seem to point at a boundary condition of the spacing effect. In most of the studies aimed at investigating the spacing effect, a monotonically increasing relationship between the inter-repetition spacing interval and free recall performance was demonstrated (e.g., Greene, 1989; Madigan, 1969; Melton, 1967). However, our findings suggest that the facilitative effect of inter-repetition spacing on free recall will only occur if the first presentation is retrieved at its second occurrence.

Interestingly, the results of the present study are consistent with a new model for spacing effects based on the Search of Associative Memory (SAM) model (Raaijmakers & Shiffrin, 1980, 1981), which was recently proposed by Raaijmakers (2003). This model is a formalized explanation of the spacing effect, and it also integrates the contextual-variability and the study-phase retrieval mechanism. However, further studies, using a more quantitative modeling-based approach, are needed to test implications that can be derived from the SAM model. The aim of such a class of studies should be to systematically vary the factors of contextual-variability and retrievability and subsequently to determine whether the SAM model can be adequately fitted to the data.

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*Chapter 3*

# Limitations to the spacing effect in free recall:

## *Demonstration of an inverted u-shaped relationship between inter-repetition spacing and free recall*[1]

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*The spacing effect refers to finding that memory for repeated items improves when the inter-repetition interval increases. To explain the spacing effect in free recall tasks a two-factor model has been put forward that combines mechanisms of contextual-variability and study-phase retrieval. An important, yet untested, implication of this model is that free recall of repetitions follows in inverted u-shaped with inter-repetition spacing. Two experiments were conducted to demonstrate this relationship. In both experiments, participants studied a word list, consisting of items repeated at different inter-repetition intervals, under incidental or under intentional learning instructions. Subsequently, participants received a free recall test. The results of Experiment 1 showed a spacing effect in free recall in both the incidental learning condition and the intentional learning condition. However, no decrease of the effect as a function of inter-repetition interval was demonstrated. Experiment 2 was identical to Experiment 1 with the only exception that the word list contained a greater variety of inter-repetition intervals. The results of Experiment 2 demonstrated an inverted u-shaped relationship between free recall and inter-repetition spacing in both the incidental learning condition and the intentional learning condition. Moreover, for intentionally learned repetitions, the maximum free recall performance was located at a longer inter-repetition interval than for incidentally learned repetitions. The findings in the present study were interpreted in terms of the two-factor model of spacing effects in free recall tasks.*

Memory for stimulus materials improves with repeated exposure. However, the beneficial effect of repetition is greater when items are separated by other stimulus materials (i.e., spaced repetitions) than when items occur in immediate succession (i.e., massed repetition). This phenomenon has been known as the *spacing effect*. The spacing effect is a remarkably robust phenomenon that has been demonstrated in a vast number of studies using a variety of explicit-memory tasks, such as free recall, recognition, and frequency estimation (e.g., Challis, 1993; Glenberg, 1979; Greene, 1989, 1990; Hintzman & Block, 1973; Hintzman, Summers & Block, 1975; Mammarella, Russo & Avons, 2002; Mammarella, Russo & Avons, 2004; Melton, 1967; Russo & Mammarella, 2002, Russo, Mammarella & Avons, 2002; Russo, Parkin, Taylor & Willks, 1998; for a review see Dempster, 1996). Despite the apparent simplicity of the spacing effect, two different theoretical frameworks have been invoked to account for the spacing effect in free recall tasks on one hand and in cued-memory tasks on the other hand.

Recently, a two-factor model that incorporates mechanisms of contextual-variability and study-phase retrieval has been put forward to account for the spacing effect in free recall tasks (e.g., Raaijmakers, 2003; Verkoeijen, Rikers, & Schmidt, 2004). The contextual-variability component of this model states that contextual change occurring between the first occurrence and the second occurrence of a repeated item is stored automatically (i.e., without deliberate intent) with a repeated item's memory trace. These contextual elements may be used as cues to facilitate the retrieval of information in free recall tests. Because the number of stored contextual elements increases as a function of the length of the inter-repetition interval, memory performance for repeated items is expected to improve with spacing. Empirical evidence for the proposed influence of contextual-variability on memory of repeated items has been provided in a number of studies (e.g., Delarosa & Bourne, 1985; Krug, Davis, & Glover, 1990; Verkoeijen et al., 2004). However, the study-phase retrieval component of the two-factor model dictates that elements of contextual change are incorporated in a repeated item's memory trace only if the first occurrence of a repeated item is retrieved from long-term store at it's second occurrence. Consequently, spacing effects in free recall tasks will only emerge for repeated items that have undergone successful study-phase retrieval. Empirical evidence has been obtained for important assumptions of the two-factor model. For instance, Greene (1989) provided support for the proposed automatic nature of the encoding of contextual elements by demonstrating spacing effects in free recall for words learned under both incidental and intentional instructions. Russo et al., (1998; experiment 1A) obtained results similar to those reported by Greene (1989). In their study, spacing effects in free recall emerged both after divided attention and focused attention during learning. Furthermore, studies of Johnston and Uhl (1976) as well as Thios and D'Agostino (1976) corroborated the notion that the incorporation of contextual elements into a repeated item's memory trace is conditional on study-phase retrieval. These studies demonstrated spacing effects in free recall for repeated items that were identified as repetitions during study, but not for repeated items not identified as such.

Although the above two-factor model (Raaijmakers, 2003; Verkoeijen et al., 2004) has received some empirical support, it has been difficult to confirm a straightforward prediction of this model. Consider the situation, presented in a typical spacing effect experiment, in which free recall is measured as a function of the inter-repetition interval. According to the combined model, two opposing processes govern memory performance in this situation. First, the probability of successfully retrieving a repeated item's first presentation at its second occurrence decreases as the length of the inter-repetition interval increases. Second, the amount of contextual change, and therefore the number of contextual elements encoded with a repeated item's memory trace upon study-phase retrieval, becomes larger with the length of the inter-repetition interval. Initially, the potentially negative effect of the first process on free recall performance, will be cancelled out by the second process, thereby giving rise to the spacing effect (i.e., an improvement of memory performance with increased inter-repetition spacing). However, at a certain spacing interval, the balance must reverse, and the first process must start to outweigh the second. From this spacing interval onwards, free recall performance must decline as a function of the length of the inter-repetition interval. Thus, the combined model predicts an inverted u-shaped relationship between the length of the inter-repetition interval and free recall performance.

Contrary to this prediction however, studies on the spacing effect generally show that free recall increases as a function of inter-repetition spacing. To our knowledge, there is only one study that has reported an inverted u-shaped relationship between free recall performance and inter-repetition spacing (i.e., Toppino & Bloom, 2002) and only indirectly[2].

In their first experiment, Toppino and Bloom (2002) instructed participants to study a word list, each word being presented for 10s. The word list contained once-presented items and repetitions with respectively 0 (massed repetition), 4, and 8 intervening items. The most important manipulation, however, was directed at the learning instruction given to the participants. In the intentional learning condition participants were informed about the free recall test that would be administered following the study-phase. Alternatively, participants in the incidental learning condition were not informed about the test. Instead, they were told to find a rule that determined the order in which the words in the list were presented. The free recall data revealed an interaction-effect between type of instruction and level of spacing. That is, a spacing effect was demonstrated in the intentional learning condition, whereas in the incidental learning condition memory performance did not differ between massed repetitions and spaced repetitions. Toppino and Bloom (2002) interpreted their findings in terms of the study-phase retrieval mechanism. They argued that, relative to the intentional learning condition, depth of word processing was shallow in the incidental learning condition. If a repeated item's first occurrence is shallowly processed, then study-phase retrieval at its second presentation will suffer even at relatively short inter-repetition intervals. Because a presentation rate of 10s per word was used in their first experiment, spaced repetitions were presented at intervals of approximately 40s (4 intervening items) and 80s (8 intervening items). Toppino and Bloom (2002) hypothesized that the length of the inter-repetition intervals might have hindered study-phase retrieval for spaced items in the incidental learning condition, but not for spaced items in the intentional learning condition. Hence, the spacing effect disappeared following incidental learning.

2 *In a similar vein, Toppino, Hara, and Hackman (2002) obtained an inverted u-shaped function. However, in this study, the used materials (i.e., words from a single semantic category) can be considered somewhat a-typical in the spacing effect literature. Furthermore, it should be noted that inverted u-shaped functions between memory and length of the inter-repetition interval have been occasionally demonstrated in studies in which participants learned paired associates for a subsequent cued-memory test (e.g., Madigan, 1969; Peterson, Wampler, Kirckpatrick, & Saltzman, 1963; Young, 1971). However, these inverted u-shaped functions were revealed under extremely short retention intervals (for instance, an interval of 8s between the study-phase and the test-phase). Increasing the length of the retention interval typically resulted into regular spacing effects. It is assumed that the inverted u-shaped functions do not reflect the mechanism underlying the spacing effect (Hintzman, 1974, 1976), and therefore, these findings are beyond the scope of the present chapter.*

Based on their hypothesis, Toppino and Bloom (2002) reasoned that spacing effects should be demonstrated under incidental learning conditions if shorter presentation rates were to be used. To test this prediction, the incidental learning condition from the first experiment was repeated in a second experiment using two different word presentation rates. One group of participants studied the word list at a presentation rate of 3s per word, whereas the other group studied the word list at a presentation rate of 10s per word. Similar to the results in the first experiment, no spacing effect was demonstrated in the 10s condition. However, in the 3s condition a clear spacing effect was found. In a post-hoc elaboration on the results, inter-repetition intervals were expressed in seconds rather than in the number of intervening items. Subsequently, the free recall data from both experimental conditions were combined and displayed as a function of temporal spacing between the repetitions. Free recall increased with spacing until a maximum was reached at an inter-repetition interval of 24.8s. From this spacing level onwards, memory performance declined as a function of spacing. Free recall at the longest inter-repetition interval (i.e., an interval of 87.8s) was significantly lower than maximum free recall performance. In sum, the resultant pattern suggested an inverted u-shaped relationship between free recall and the length of the inter-repetition interval.

Problematic for the interpretation of the inverted u-shaped function reported in Toppino and Bloom's (2002) second experiment, is that it was obtained through a post-hoc combination of the free recall data from two different experimental conditions. The first experiment of the present study, therefore, was conducted to demonstrate the inverted u-shaped relationship between free recall and the length of the inter-repetition interval without having to revert to post-hoc manipulations of the free recall data. To this aim, participants studied a word list under incidental or intentional learning instructions, that were identical to those used by Toppino and Bloom (2002). The word list contained once-presented items, massed and spaced repetitions. The spaced items were repeated with intervals of two (i.e., lag 2) or eight (i.e., lag 8) intervening words, corresponding with time lags of 21.5s and 84.5s. Thus, the time-intervals of lag-2 and lag-8 repetitions coincided almost completely with, respectively, (1) the inter-repetition interval at which Toppino and Bloom (2002) suggested the maximum free recall performance following the incidental learning instruction to be, and (2) their longest inter-repetition interval. After participants had studied the words in the list, a free recall task was administered.

Assuming, in line with Toppino and Bloom (2002), that an incidental learning instruction promotes a less elaborate level of item processing than an intentional instruction, the probability of successful study-phase retrieval is expected to start to decline at a shorter inter-repetition interval for the incidental-instruction than for the intentional-instruction group. From the perspective of the combined model of spacing effects in free recall this implies that the maximum level of free-recall performance for the incidental-instruction group should occur at a shorter inter-repetition interval than for the intentional-instruction group. Furthermore, in line with the suggestion made by Toppino and Bloom (2002) based on the data in their second experiment, free recall in the incidental learning condition was predicted to follow an inverted u-shaped function with inter-repetition spacing. Free recall of words repeated at lag 2 was expected to be higher than free recall of massed repetitions and words repeated at lag 8. With respect to the intentional learning condition, earlier studies (e.g., Toppino & Bloom, 2002; Experiment 1) seem to suggest that the maximum free recall performance occurs at an inter-repetition interval that is longer than the length of the largest inter-repetition interval in the present experiment (i.e., lag 8). Therefore, free recall was expected to increase as a function of spacing in the intentional learning condition.

# Experiment 1

## Method

### Participants and design

Forty first-year psychology students participated in the experiment in order to fulfill a course requirement. They were randomly assigned to one of two between-participant conditions (incidental versus intentional learning instruction) of a 2 x 4 mixed factorial design with the second factor (once-presented items and twice-presented items repeated after lags of zero, two or eight intervening items) varied within participants.

### Materials

A list template containing 160 slots was created. In the list template, the first ten and the last ten positions were reserved to primacy and recency buffers, respectively. The positions 11-150 contained slots for 20 once-presented items and 60 twice-presented items (20 each, representing inter-repetition lags of zero, two and eight intervening items). To prevent confounding by an extended recency effect, which has occasionally been reported to affect free recall performance (e.g., Underwood, 1969), the list template was constructed in such a way that the mean serial position of the final occurrences of the twice-presented items was equated for each of the spacing conditions and with the mean serial position of the once-presented items.

Stimuli consisted of 80 high-frequency nouns (in accordance with Dutch word association norms; Uit den Bogaart, 1975), which were randomly divided into four equally sized sets. Further, 20 high frequency nouns were used as primacy and recency buffers. All words were nominally unrelated. Four study lists were created based on the list template. To create the first study list, each of the four word sets was randomly assigned to either the slots reserved to the once-presented items or to the slots reserved to the three repetition-spacing conditions. In order to generate the remaining three study-lists, the word sets were rotated among the once-presented condition and the repetition-spacing conditions according to the Latin-square principle. Thus, across the four study lists each word was presented equally often at each of the four levels of the within-participant factor. In each between-participant condition, each of the four lists was administered to an equal number of participants.

### Procedure

There were 1-4 participants in each experimental session and participants were tested individually. In line with the procedure used by Toppino and Bloom (2002), participants in the incidental instruction condition were told that they were about to take part in an experiment, set up to investigate inductive reasoning skills of psychology students. Their task was to view a list of 160 words and to discover the rule that determined the order in which the words were presented. (Of course there was no rule). Participants in the intentional instruction condition were told to memorize the 160 words for a subsequent, unspecified memory task. Words were presented one at a time in the center of the computer screen at a 10s rate. Successive word presentations were separated by a 0.5s interval. During the interval, four asterisks (* * * *) were shown in the center of the screen as a fixation point. Following the presentation of the list, participants were asked to state the rule if they could. Then the experimenter handed them an answer sheet along with the request to write down as many words of the study list as they could remember. Participants were allowed a maximum of 10 minutes for the free recall task.

## Results and discussion

Because frequency of occurrence (i.e., once versus twice-presented items) and spacing (i.e., massed versus spaced repetitions) are two conceptually distinct variables, two separate analyses were conducted to determine their effects on free recall performance. For all tests, a $p$-value of .05 was used as a criterion of significance.

Table 1 shows free recall performance as a function of intentionality of learning and frequency of occurrence. To assess the effects of intentionality of learning and frequency, two paired t-tests were performed. Analysis revealed that twice-presented words were recalled better than once-presented words following intentional learning $t$ (19) = 5.74, $p < .001$, and following incidental learning $t$ (19) = 5.63, $p < .001$.

**Table 1**
*Mean percentage of accurate free recall and standard errors as a function of frequency of occurrence and intentionality of learning.*

| | **Frequency of occurrence** | | | |
|---|---|---|---|---|
| | Once-presented | | Twice-presented | |
| Intentionality of learning | *M* | *SE* | *M* | *SE* |
| Incidental | 16.00 | 3.28 | 26.67 | 2.83 |
| Intentional | 30.50 | 4.09 | 46.84 | 3.15 |

Table 2 (on the next page) depicts free recall performance as a function of intentionality of learning and level of spacing. The data were analyzed with a 2 (intentionality) x 3 (levels of spacing) mixed ANOVA with repeated measures on the second factor. Analysis revealed a significant effect of intentionality $F$ (1, 38) = 23.12, $MSE$ = 532.14, $p < .001$, indicating that the mean percentage of accurate free recall was higher in the intentional-instruction than in the incidental-instruction group. This finding corroborates the assumption that level of item processing was shallower in the incidental learning condition than in the intentional learning condition. In addition, mean free recall performance improved with increased spacing $F$ (2, 76) = 16.56, $MSE$ = 160.32, $p < .001$. However, the intentionality x spacing interaction was also significant $F$ (2, 76) = 3.13, $MSE$ = 106.32, $p < .05$. Analysis of simple main effects showed a spacing effect in the intentional learning condition $F$ (2, 38) = 13.11, $MSE$ = 107.96, $p < .001$, that could be attributed to a superior free recall of lag-8 repetitions in comparison to the free recall of massed (i.e., lag-0) repetitions and lag-2 repetitions. By contrast, the spacing effect demonstrated in the incidental learning condition $F$ (2, 38) = 6.48, $MSE$ = 104.67, $p < .01$, could be attributed to superior free recall of lag-2 repetitions and lag-8 repetitions relative to lag-0 repetitions.

**Table 2**

*Mean percentage of accurate free recall and standard errors as a function of the spacing between repetitions and intentionality of learning.*

| | **Spacing between repetitions** | | | | | |
|---|---|---|---|---|---|---|
| | Zero (Massed) | | Two (Lag 2) | | Eight (Lag 8) | |
| Intentionality of learning | *M* | *SE* | *M* | *SE* | *M* | *SE* |
| Incidental | 20.00 | 2.59 | 29.25 | 3.52 | 30.75 | 3.91 |
| Intentional | 40.75 | 3.84 | 43.50 | 3.25 | 56.50 | 3.84 |

The results of Experiment 1 in part support our hypotheses. On the basis of the proposed two-factor model of spacing effects in free recall (Raaijmakers, 2003; Verkoeijen et al., 2004), we hypothesized the maximum level of free recall performance to occur at a lower level of spacing in the incidental than in the intentional learning condition. The findings obtained in Experiment 1 are in agreement with this hypothesis. Furthermore, reasoning from the free recall data suggested in the second experiment of Toppino and Bloom (2002), but not actually tested, we expected to find an inverted u-shaped relationship between free recall and inter-repetition spacing in the incidental learning condition. Contrary to this prediction, the results obtained in the incidental learning condition revealed that free recall of words repeated at lag 2 was better than of massed repetitions, and that memory performance remained stable beyond an inter-repetition interval of 2 items. Clearly, the demonstrated asymptotic level of memory performance is incongruent with both the proposed influence of a study-phase retrieval mechanism on the spacing effect in free recall, and the suggestion made by Toppino & Bloom (2002) based on this mechanism.

The absence of the predicted inverted u-shaped relationship between free recall and inter-repetition spacing in the incidental learning condition can be interpreted in two different ways. First, it may be possible that, rather than following an inverted u-shaped function, the relationship between free recall performance and inter-repetition spacing follows a monotonically increasing function reaching asymptote at a certain level of spacing. If this is true, a valid explanatory framework for spacing effects in free recall tasks should not entail a study-phase mechanism. However, this interpretation of the findings in Experiment 1 seems implausible given the existing empirical evidence in favor of a study-phase retrieval mechanism (e.g., Braun & Rubin, 1998; Johnston & Uhl, 1976; Thios & D'Agostino, 1976).

Second, it could be argued that Experiment 1 failed to demonstrate the expected inverted u-shaped function between level of free recall and spacing interval because only a limited number of spacing intervals (i.e., lag 2 and lag 8) was used. Perhaps, an inverted u-shaped function would have been demonstrated if a greater variety of spacing intervals had been used. To test this hypothesis we conducted a second experiment.

## Experiment 2

The second experiment was identical to the first in terms of the to-be-studied word list, the presentation rate of each word in the list (i.e., 10s), and the learning instructions. The only difference with respect to Experiment 1 was the number of spacing intervals occurring in the word list. In the first experiment, the word list contained, in addition to once-presented items and massed repetitions, spaced items repeated at inter-repetition intervals of two or eight intervening items. However, in the second experiment spaced items were repeated at intervals of two, five, eight, fourteen, or twenty intervening items. Regarding the relationship between free recall performance and inter-repetition spacing the predictions were similar to those formulated prior to the first experiment. In the incidental learning condition, we expected to demonstrate the inverted u-shaped function between free recall and the length of the spacing interval similar to the one suggested by Toppino and Bloom (2002).

The two-factor model (Raaijmakers, 2003; Verkoeijen et al., 2004) also predicts an inverted u-shaped relationship between free recall and inter-repetition spacing in the intentional learning condition. Furthermore, under the intentional learning instructions, level of item processing can be assumed to be deeper than under incidental learning instructions. Therefore, the two-factor model predicts that the maximum point of performance in the inverted u-shaped function between free recall and spacing occurs at a longer inter-repetition interval for intentionally learned repetitions than for incidentally learned repetitions. However, it might be possible that the maximum point of performance falls beyond the longest inter-repetition interval used in Experiment 2 (i.e., lag 20). In that case, free recall will show an increase with spacing.

# Method

## Participants and design

Forty-eight first-year psychology students participated in the experiment in order to fulfill a course requirement. None of the participants in Experiment 2 had taken part in Experiment 1. Participants were randomly assigned to one of two between-participant conditions (incidental versus intentional learning instruction) of a 2 x 7 mixed factorial design with the second factor (once-presented items and twice-presented items repeated after lags of two, five, eight, fourteen, or twenty intervening items) varied within participants.

## Materials and procedure

A list template containing 160 slots was created. In the list template, the first ten and the last ten positions were reserved to primacy and recency buffers, respectively. The positions 11-150 contained slots for 10 once-presented filler items, 10 once-presented experimental items and 60 twice-presented items (10 each, representing inter-repetition lags of zero, two, five, eight, fourteen, and twenty intervening items). To prevent confounding by an extended recency effect, the list template was constructed in such a way that the mean serial position of the final occurrences of the twice-presented items was equated for each of the spacing conditions and with the mean serial position of the once-presented experimental items.

In Experiment 2, the primacy and recency buffers as well as the experimental stimuli from Experiment 1 were used. The experimental stimuli consisted of 80 high-frequency nouns that were randomly divided into eight equally sized sets. Subsequently, eight study lists were made from the list template. To create the first study list, each of the eight word sets was randomly assigned to either the slots reserved to the once-presented filler items, the once-presented experimental items, or to the slots reserved to the six repetition-spacing conditions. Rotating the word sets among the once-presented conditions and the repetition-spacing conditions according to the Latin-square principle generated the remaining seven study-lists. In each between-participant condition, each of the eight lists was administered to an equal number of participants.

The procedure in Experiment 2 was identical to the procedure in Experiment 1, both for participants in the intentional learning condition and for participants in the incidental learning condition.

## Results and discussion

Table 3 shows free recall performance as a function of intentionality of learning and frequency of occurrence. Two paired t-tests demonstrated that mean free recall performance was better for twice-presented items (collapsed across spacing levels) than for once-presented items following intentional learning $t$ (23) = 3.78, $p < .001$, as well as following incidental learning $t$ (23) = 6.09, $p < .001$.

**Table 3**

*Mean percentage of accurate free recall and standard errors as a function of frequency of occurrence and intentionality of learning.*

| | Frequency of occurrence | | | |
|---|---|---|---|---|
| | Once-presented | | Twice-presented | |
| Intentionality of learning | *M* | *SE* | *M* | *SE* |
| Incidental | 9.58 | 2.85 | 22.01 | 2.98 |
| Intentional | 37.50 | 4.27 | 47.57 | 3.75 |

Table 4 (on the next page) depicts free recall performance as a function of intentionality of learning and level of spacing. The data were analyzed using a 2 (intentionality) x 6 (levels of spacing) mixed ANOVA with repeated measures on the second factor. Analysis revealed a significant effect of intentionality $F$ (1, 46) = 28.18, $MSE$ = 1668.81, $p < .001$, suggesting that the mean percentage of free recall was higher following intentional learning than following incidental learning. This finding provides evidence for the assumption that, in comparison to the incidental learning condition, items were more deeply processed in the intentional learning condition. In addition, it was demonstrated that, across learning instructions, free recall varied with inter-repetition spacing $F$ (5, 230) = 5.44, $MSE$ = 170.91, $p < .001$. The intentionality x spacing interaction turned out to be significant $F$ (5, 230) = 2.62, $MSE$ = 170.91, $p < .05$, indicating that the effect of inter-repetition spacing on free recall performance differed between the intentional learning and the incidental learning condition.

Analysis of the simple main effect in the incidental learning condition showed, consistent with the suggestion made by Toppino and Bloom (2002), an inverted-u-shaped function between free recall and inter-repetition spacing. It was demonstrated that free recall increased with spacing until a maximum was reached at an inter-repetition interval of eight intervening items $F$ (3, 69) = 7.23, $MSE$ = 126.53,

$p < .001$. Furthermore, free recall of lag-14 repetitions was worse than free recall of lag-8 repetitions $F(1, 23) = 4.56$, $MSE = 165.13$, $p < .05$. In the intentional learning condition, free recall also displayed an inverted u-shaped function with inter-repetition spacing. Consistent with the predictions formulated on the basis of the two-factor model of spacing effects in free recall (Raaijmakers, 2003; Verkoeijen et al., 2004), the maximum point of performance occurred at a longer inter-repetition interval in the intentional learning condition than in the incidental learning condition. Namely, analysis in the intentional learning condition revealed that free recall performance initially improved with spacing, reaching a maximum at a inter-repetition interval of fourteen intervening items $F(4, 92) = 5.20$, $MSE = 198.93$, $p < .001$. As the inter-repetition interval increased from fourteen to twenty intervening items, free recall performance decreased significantly $F(1, 23) = 6.90$, $MSE = 173.91$, $p < .05$. The implications of the results obtained in Experiment 2 will be discussed in the General discussion.

**Table 4**

*Mean percentage of accurate free recall and standard errors as a function of the spacing between repetitions and intentionality of learning.*

| | **Intentionality of learning** | | | |
|---|---|---|---|---|
| | Incidental | | Intentional | |
| Spacing between repetitions | *M* | *SE* | *M* | *SE* |
| Zero (Massed) | 18.75 | 3.09 | 39.17 | 4.12 |
| Two (Lag 2) | 15.83 | 3.24 | 46.67 | 4.57 |
| Five (Lag 5) | 23.33 | 3.79 | 45.42 | 4.66 |
| Eight (Lag 8) | 30.00 | 3.95 | 50.00 | 4.50 |
| Fourteen (Lag 14) | 22.08 | 4.58 | 57.08 | 4.83 |
| Twenty (Lag 20) | 22.08 | 4.04 | 47.08 | 4.44 |

## General discussion

The results of the present study demonstrate two novel findings. First, in Experiment 2, it was shown that the relationship between free recall and inter-repetition spacing follows an inverted u-shaped function. Second, the form of the relationship between free recall and spacing is dependent on the learning instructions provided to the participants, and hence, the level of item processing. In Experiment 2, the maximum free recall performance of the inverted u-shaped function in the incidental learning condition occurred at a shorter inter-repetition interval than the maximum free recall performance in the intentional learning condition. The free recall data in Experiment 1 revealed a similar interaction effect between inter-repetition spacing and the provided learning instructions. In the intentional learning condition, free recall performance reached a maximum at the largest inter-repetition interval, i.e., an interval of eight intervening items. By contrast, following incidental learning, free recall improved with spacing as the inter-repetition interval increased from zero (i.e., massed repetition) to two intervening items. From the latter inter-repetition level onwards, free recall performance remained stable. Collectively, the findings of Experiment 1 and Experiment 2 can be explained in terms of a two-factor model of spacing effects in free recall (Raaijmakers, 2003; Verkoeijen et al., 2004).

According to this model, two opposing processes influence free recall of repeated items as inter-repetition spacing increases. On one hand, inter-repetition spacing will exert a positive effect on free recall performance through the variation in context between a repeated item's first and the second occurrence. It is assumed that changed elements of context are automatically encoded in a repeated item's memory trace. Because contextual change is positively related to the length of the inter-repetition interval, the number of encoded contextual elements will become greater with increasing inter-repetition spacing. Therefore, in free recall that depends on encoded contextual elements as retrieval cues, the probability of remembering a repeated item will increase as a function of inter-repetition spacing. On the other hand, the encoding of contextual element will only take place if a repeated item's first presentation is retrieved at its second occurrence, and the probability of this study-phase retrieval decreases with inter-repetition spacing. With respect to the relationship between free recall and inter-repetition spacing, the study-phase retrieval theory states that memory for repeated items will initially improve with inter-repetition spacing because of the first process (i.e., context variation) overruling the second process (i.e., study-phase retrieval). However, there must be an inter-repetition interval at which the balance begins to reverse, and at which the second process starts to outweigh the first. From this interval onwards, free recall will decline with inter-repetition spacing. Thus, the two-factor model predicts that free recall of repeated items will follow an inverted u-shaped function with inter-repetition spacing. The expected free recall pattern was observed in the incidental learning condition and the intentional learning condition of Experiment 2.

Furthermore, the two-factor model (Raaijmakers, 2003; Verkoeijen et al., 2004) makes predictions about how the level of item processing influences the relationship between free recall of repeated items and inter-repetition spacing. In the present study it was assumed that, relative to the intentional learning instructions, the incidental learning instructions induce a shallower level of word processing. Hence, the probability of successful study-phase retrieval must start to decrease at a shorter inter-repetition interval for incidentally studied words than for intentionally studied words. This implies that the maximum level of free recall performance for incidentally studied words must be reached at a shorter inter-repetition interval than for intentionally studied words. The interaction effects between inter-repetition spacing and the provided learning instructions that were observed in Experiment 1, and in Experiment 2 provide evidence for this hypothesis.

All in all, it seems that the data in the present study are consistent with a two-factor model of spacing effects in free recall that incorporates a study-phase retrieval mechanism and a contextual-variability mechanism. However, an alternative explanation of the data might exist. Occasionally, the spacing effect has been attributed exclusively to a study-phase retrieval mechanism (e.g., Braun & Rubin, 1998; Thios & D'Agostino, 1976). In this view, the presentation of repeated item's second occurrence during study triggers a retrieval operation aimed at reinstating the repeated item's first occurrence. Moreover, it is assumed that the spacing effect is only obtained in case of successful study-phase retrieval. If the inter-repetition interval increases, the study-phase retrieval operation becomes more and more similar to the retrieval operation performed at memory test. Consequently, free recall of repeated items improves with increases of inter-repetition spacing. However, at the same time, the probability of successful study-phase retrieval decreases with increased spacing. At a certain inter-repetition interval, the balance between these two processes will shift, and from this interval onwards, free recall declines with further spacing. In addition, the inter-repetition interval at which the point of maximum performance occurs is dependent on whether learning conditions promote study-phase retrieval. If learning conditions induce a relatively deep level of item processing, the point of maximum performance will occur at a longer inter-repetition interval than if learning condition induce a shallow level of item processing. Thus, it seems that a theoretical framework encompassing only a study-phase retrieval mechanism can accommodate the data obtained in the present study equally well as the proposed two-factor model (Raaijmakers, 2003; Verkoeijen et al., 2004). Further research must be conducted to competitively evaluate these two approaches.

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*Chapter 4*

# Different-language repetitions and the spacing effect in free recall:

## *The role of orthographic and semantic similarity in study-phase retrieval*[1]

[1] *This chapter is submitted for publication as: Verkoeijen, P. P. J. L., Rikers, R. M. J. P., & Schmidt, H. G. (submitted). Different-language Repetitions and the Spacing Effect in Free Recall: The Role of Orthographic and Semantic Similarity in Study-phase Retrieval. The study in this chapter was also presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis, November 18-21, 2004.*

*Previous studies have demonstrated that free recall of repeated items increases with the length of the inter-repetition interval. However, this spacing effect only occurs if a repeated item's first presentation is successfully retrieved at its second occurrence. The aim of the present study was to determine how much overlap, in terms of linguistic representation, is required between repetitions for successful study-phase retrieval. To this aim three experiments were conducted. In Experiment 1A, participants studied under intentional learning instructions a word list containing same-language repetitions and different-language repetitions presented in a massed or in a spaced fashion. Subsequently, they were given a free recall test for words in the list. Experiment 1B was identical to Experiment 1A with the only exception that participants received incidental-semantic learning instructions. The free recall data demonstrated a spacing effect for same-language repetitions, but not for different-language repetitions. This finding could be attributed to a free recall advantage of different-language repetitions over same-language repetitions in the massed condition. In Experiment 2 participants received incidental-orthographic learning instructions. The results showed that the spacing effect was absent for both same-language repetitions and different-language repetitions. The results of Experiment 1A, Experiment 1B, and Experiment 2 combined suggest that successful study-phase retrieval occurs only if (a) repeated items share the semantic level of representation, and (b) semantic level of representation is activated at both occurrences of a repeated item.*

Memory for stimuli improves with repetition. However, the beneficial effect is larger for repetitions separated by interjected events (spaced repetitions) than for repetitions that occur in immediate succession (massed repetitions). This finding has been known as *the spacing effect* and it has been demonstrated in explicit-memory tasks such as free recall, recognition, cued-recall, and frequency estimation (e.g., Challis, 1993; Braun & Rubin, 1998; Greene, 1989, 1990; Hintzmann & Block, 1973; Hintzmann, Summers, & Block, 1975; Madigan, 1969; Mammarella, Russo, & Avons, 2002; Melton, 1967; Russo & Mammarella, 2002; Russo, Mammarella, & Avons, 2002; Russo, Parkin, Taylor, & Wilks, 1998). Although the spacing effect is a highly robust phenomenon it has defied a unitary explanation. Currently, different mechanisms have been put forward to account for the spacing effect in free recall on one hand, and for the spacing effect in cued-memory tasks on the other (for reviews on proposed theoretical mechanisms see: Crowder, 1976; Dempster, 1996; Hintzman, 1974, 1976, and Kintsch, 1970).

To date, a two-factor account (e.g., Raaijmakers, 2003; Verkoeijen, Rikers, & Schmidt, 2004) is proposed to explain the spacing effects in free recall tasks. In this view, contextual change that occurs between a repeated item's first presentation and its second presentation will be automatically encoded with the item. As contextual change becomes greater with time, the number of contextual elements incorporated in a repeated item's memory trace will increase as a function of the length of the inter-repetition interval. Consequently, the number of available retrieval routes, and therefore free recall, will also increase as a function of inter-repetition spacing. However, a crucial assumption in the two-factor account is that the spacing effect in free recalls task will only emerge in case of successful study-phase retrieval. Items that are not retrieved from long-term store at their repetition are not expected to reveal spacing effects.

The notion that study-phase retrieval is a necessary condition for the spacing effect to occur (e.g., Raaijmakers, 2003; Verkoeijen et al., 2004) has been empirically supported in a number of studies. For instance, in their second experiment, Johnston and Uhl (1976) presented participants with a word list containing once-presented words and words repeated in either a massed fashion or a spaced fashion. The participants were instructed to determine for each word whether it was old (i.e., a repetition) or new. After the continuous-recognition task, they had to write down as many words of the previously presented list as they could remember. The free recall data demonstrated a spacing effect only for words that were recognized as repetitions. Furthermore, in a study by Thios and D'Agostino (1976), participants had to study, for an unspecified memory test, a list of phrases that were repeated in a massed or a spaced fashion. In the retrieval condition, the first occurrence was a complete phrase, such as *the conductor boarded the express train*, and the second occurrence consisted of fragment of the previously shown phrase, for instance *express train*. Upon presentation of this fragment, participants had to retrieve the complete phrase, and they had to transform the phrase into a passive form (i.e., *the express train was boarded by the instructor*). In the no-retrieval condition, phrases were simply repeated. The results revealed a spacing effect in the retrieval condition, but they failed to shown a spacing effect in the no-retrieval condition. Recently, Toppino and Bloom (2002), and Toppino, Hara, and Hackman (2002) showed that spacing effects, obtained for words repeated at relatively short inter-repetition intervals, disappeared when words were repeated at relatively long inter-repetition intervals. The investigators argued that the spacing effects had been erased because the relatively long inter-repetition intervals had disrupted the study-phase retrieval of the majority of the spaced items.

Although the results of the aforementioned studies suggest that study-phase retrieval of repeated items is a necessary condition for the spacing effect in free recall, little research has been conducted aimed at the identification of the determining factors of the study-phase retrieval mechanism itself. Among the few exceptions are the studies of Toppino and Bloom (2002), and Toppino et al., (2002) which suggest that the length of the spacing interval can negatively influence study-phase retrieval. Further, failure to retrieve the study-phase of an item seems dependent on the amount of contextual change. In a study by Verkoeijen et al., (2004), participants studied massed and spaced repetitions presented twice either with the same background color (i.e., white - white, or olive-green - olive-green) or twice with different background colors. It was found that spaced repetitions presented in the same context to be recalled better than spaced repetitions presented in different contexts. Given that in the different-background condition, the meaning of the repeated word did not change, that is, the repeated word was still identical at a semantic level of representation, the results reported by Verkoeijen et al., (2004) suggest that the study-phase retrieval is sensitive to superficial modifications of repeated items.

However, this interpretation of the findings of Verkoeijen et al., (2004) is difficult to reconcile with the results obtained in other studies (e.g., Glanzer & Duarte, 1971; Paivio, Clark, & Lambert, 1988) in which the physical structure of to-be-remembered repeated target items (i.e., the orthography of a target item) was varied, and the meaning of the target items was held constant. For instance, in a study of Glanzer and Duarte (1971; for a replication see Paivio et al., 1988), English-Spanish bilingual participants learned, for an upcoming free recall test, a list of massed and spaced items that were repeated either in the same language (e.g., *house-house*) or in a different language (e.g., *house-casa*). The results demonstrated that massed items repeated in a different language were better recalled than massed items repeated in the same language; a finding that was attributed to a richer encoding of different-language repetitions relative to same-language repetitions. More important for the present paper, however, is that the language in which the second occurrence of a repeated item was presented did not influence free recall performance of spaced repetitions. That is, different-language repetitions were recalled equally well as same-language repetitions. Under the assumption that translation pairs, such as *house-casa*, have a shared representation at a semantic level of representation, and language-specific, unconnected representations at an orthographic level of representation (e.g., Chen & Leung, 1989; De Groot & Hoeks, 1995; Tzelgov, Henck, & Leiser, 1990; Zeelenberg & Pecher, 2003), the results in the spaced-repetition condition suggest, somewhat contrary to the findings reported by Verkoeijen et al., (2004), that superficial, orthographic dissimilarities between repeated items do not affect study-phase retrieval.

However, in the studies of Glanzer and Duarte (1971) and Paivio et al., (1988), learning of repeated target items occurred intentionally, that is, participants were informed about of the upcoming memory test on the studied target items. It has been argued (e.g., Greene, 1990) that under these intentional learning conditions, participants attempt to organize the to-be-remembered target items in order to aid their performance at test. If translation pairs, such as *house-casa,* are presented during study, then an effective organizational strategy is to integrate both words of the pair into a single, semantically based memory unit. Hence, if a translation pair is presented in a spaced manner, a participant might try to retrieve the first word (*house*) at the occurrence of the second word in order to encode both words into a single memory unit. Thus, in the studies of Glanzer and Duarte (1971) and of Paivio et al., (1988), study-phase retrieval might be considered as a by-product of the used intentional learning instructions. However, study-phase retrieval is thought to operate automatically, and, therefore, it should take place even in the absence of a deliberate retrieval attempt (e.g., Greene, 1989; Raaijmakers, 2003; Verkoeijen et al., 2004). As a consequence, the findings of Glanzer and Duarte (1971) and Paivio et al., (1988) provide little information about whether the study-phase retrieval mechanism per se is influenced by changing the orthography between repeated words. The present study was conducted to address this shortcoming.

As part of the present study, we conducted 3 experiments in which bilingual participants were shown massed and spaced items repeated either in the same language (i.e., Dutch-Dutch, or English-English) or in a different language (i.e., Dutch-English or English-Dutch), before being tested on the repeated items in a free recall memory task. In Experiment 1A, participants received intentional learning instructions. In this experiment, we expected to replicate the findings of Glanzer and Duarte (1971) and Paivio et al., (1988). Namely, for massed items, a relatively rich encoding should provide different-language repetitions with a free recall advantage over same-language repetitions. For spaced repetitions, free recall should not differ between different-language repetitions and same-language repetitions. By contrast, in Experiment 1B, participants received incidental-semantic learning instructions. Specifically, they had to give a pleasantness rating, and an animacy decision (i.e., does the word represent a living or a non-living object) for each repeated word. These learning instructions direct participants' processing efforts toward individual items, and, unlike the intentional learning instructions used in Experiment 1A, they avert participants from imposing an organizational structure on the target items. With respect to the free recall patterns in Experiment 1B, we formulated the following predictions. First, regarding massed items, we predicted the free recall of different-language repetitions to be superior to free recall of same-language repetitions. Second, with respect to spaced items, two alternative hypotheses were generated. If orthographic modifications of repeated items disrupt study-phase retrieval, then free recall of same-language repetitions should be better than free recall of different-language repetitions. Alternatively, if study-phase retrieval is insensitive to orthographic modifications of repeated items, i.e., if study-phase retrieval requires an overlap solely at the semantic level of representation, then free recall of spaced items should not differ between same-language repetitions and different-language repetitions.

## Experiment 1A

## Method

### Participants

Eighteen first-year psychology students from Erasmus University Rotterdam, the Netherlands, took part in the experiment in order to fulfill a course requirement. For all participants Dutch was their first and English their second language (for some students English was their third language). As of 1993, English is taught in elementary schools in the Netherlands in grade 7 (age of 10) and grade 8. Subsequently, students receive an additional 6 years of English training in secondary school. Therefore, at the start of their academic education students have already had 8 years of formal English training. At the university this training continues as most teaching materials, for example textbooks and scientific articles, are written in English. In a more informal setting Dutch students are regularly exposed to the English language because a substantial part of the movies and series on Dutch television is in English (subtitles are typically used instead of voice-overs). Furthermore, similar populations have been used in other research directed at bilingual memory representation and processing (e.g., Zeelenberg & Pecher, 2003).

### Materials

Experimental stimuli were 36 non-cognate, Dutch-English translation pairs, such as *frog-kikker*. These non-cognate translation equivalents are semantically identical but orthographically dissimilar. Half of the translation pairs represented something inanimate, whereas the other half represented something animate. The translation pairs were divided into 3 equally sized sets, (I, II, and III) consisting each of 6 inanimate and 6 animate translation pairs. Further, 8 once-presented English words (4 inanimate, and 4 animate), and 8 once-presented Dutch words (4 inanimate, and 4 animate) were selected to serve as primacy and recency buffers. In addition, 10 once-presented English words (5 inanimate, and 5 animate), and 10 once-presented Dutch words (5 inanimate, and 5 animate) were selected to serve in a practice trial. The study list consisted of 76 slots. The slots 1-8, and 69-76 were reserved for primacy and recency buffers respectively. The slots 9-68 were reserved for 12 once-presented words, 12 massed repetitions (lag 0), and 12 spaced repetitions, each with four intervening items (lag 4). With respect to once-presented words, half of the words served as once-presented experimental items, whereas the other half served as once-presented filler items. Furthermore, for both massed repetitions and spaced repetitions, half of the items were repeated in the same language and the other half of the items was repeated in a different language. To control for serial positions effects, it was made sure that the mean serial position of the repeated items' first presentation did not differ significantly ($\alpha = .05$) between lag-0 repetitions, lag-4 repetitions, and once-presented words ($M$ = 40.00). This applied to same-language repetitions ($M_{lag\ 0}$ = 36.83, $M_{lag\ 4}$ = 34.67) as well as to different-language repetitions ($M_{lag\ 0}$ = 39.17, $M_{lag\ 4}$ = 36.00). In addition, the mean serial position of the repeated items' second presentation did not differ significantly between lag-0 repetitions, lag-4 repetitions, and once-presented words for same language repetitions ($M_{lag\ 0}$ = 37.83, $M_{lag\ 4}$ = 39.67), and for different language repetitions ($M_{lag\ 0}$ = 40.17, $M_{lag\ 4}$ = 41.00). To create study list 1a, the translation pairs of set I were assigned to the slots of the once-presented words. However, only one component of the translation pair, i.e., either the Dutch or the English component, could be presented. Therefore, a random half of the available slots was filled with the Dutch components of the translations pairs, and the other half of the slots was filled with the English components of the remaining translations pairs. The translation pairs of set II were assigned to the slots of lag 0-words, and the translation pairs of set III were assigned to the slots of lag-4 words. Within each lag condition, same language repetitions were presented twice in Dutch, and different language repetitions were first presented in Dutch and repeated in English. Subsequently, mirroring study list 1a formed study list 1b. That is, once-presented words that had been presented in Dutch in study list 1a were presented in English in study list 1b, and vice versa. Same-language repetitions in study list 1b were repeated in English, and different-language repetitions were first presented in English and repeated in Dutch. In order to obtain the study lists 2a, 2b, 3a, and 3b, the sets of translations pairs were rotated through the once-presented condition, and the lag conditions. It should be noted that study list 2a, and 2b, as well as study lists 3a, and 3b, were constructed according to the same procedure that was used for the construction of study lists 1a, and 1b. Each of the study lists was administered to an equal number of participants.

## Procedure

Participants saw a list of 76 words. The words in the list were presented sequentially and each word appeared 3 seconds in the center of the computer screen. Each word was preceded by a fixation mark (****) that was shown for 500 ms. Learning took place intentionally. Participants were informed that some of the words in the list were repeated and that some words were repeated in a different language (i.e., different from Dutch). The experiment leader told the participants that they had to study the words in the list for an unspecified memory test. Following the presentation of the word list, participants were engaged in a distraction task for 2 minutes. Subsequently, they were asked to write down on a sheet as many words of the list as they could remember. As an additional instruction, the experiment leader reminded the participants that some of the repeated words had occurred once in English and once in Dutch. The experiment leader told the participants that, in case they remembered such a different-language repetition, they should write down both the English and the Dutch version of the repeated word. Participants were allowed a maximum of 10 minutes for the free recall task. All participants were tested individually.

## Results and discussion

In the present study, the mean percentage of accurately recalled words from the study list was the dependent variable. Because during the free recall task participants were not required to provide a frequency judgment for the same-language repetitions that occurred in the study list, a same-language repetition pair was scored as correct if it was mentioned once in free recall. In order to allow for a comparison between same-language repetitions and different-language repetitions, a different-language repetition pair was scored as correct if at least one of the items was mentioned in free recall. For instance, imagine that the different-language repetition pair *frog-kikker* was presented in the study list. In that case, the pair would be scored as correct if either *frog* or *kikker* was recalled or if both *frog,* and *kikker* were recalled. This scoring method is identical to the one used by Glanzer and Duarte (1971). Independent variables in the present study were spacing (two levels: lag 0 versus lag 4) and repetition language (two levels: same versus different), both factors being manipulated within-subjects. The list factor (A study lists vs. B study lists) was not incorporated as an independent variable in the statistical analyses of the present study. The rationale underlying the exclusion of the list factor was that preliminary analyses failed to demonstrate significant main effects, second-order interactions, and third-order interactions of the list factor on free recall performance. Therefore, the free recall data were examined by means of a 2 (spacing: lag 0 vs. lag 4) x 2 (repetition language: same language vs. different language) within-subjects ANOVA. Paired t-tests were used to specify simple main effects. The criterion for statistical significance was set at $p = 0.05$ for all tests. In addition to $p$-values, effects sizes were determined. For the ANOVA's, effect size ($\eta^2$) was expressed in terms of proportion of total variance accounted for by a single factor or by the interaction of two factors. The guidelines provided by Cohen (1988) were used to interpret the effect sizes. A small effect size corresponds with $0.01 \leq \eta^2 \leq 0.06$, a medium effect size with $0.06 < \eta^2 \leq 0.14$, and a large effect size with $\eta^2 > 0.14$. For the paired t-tests, $d$ (i.e., the mean difference divided by the standard deviation of the distribution of difference scores) was used as measure of effect size. In this case, a small effect size corresponds with $0.20 \leq d \leq 0.50$, a medium effect size with $0.50 < d \leq 0.80$, and a large effect size with $d > 0.80$ (Aron & Aron, 2003).

Table 1 depicts the mean percentage of accurate free recall as a function of condition (i.e., lag-0 repetitions, lag-4 repetitions, and once-presented words) and repetition language. Because frequency of occurrence and spacing are different constructs, separate analyses were conducted to compare free recall of once-presented words to that of repeated words. In each repetition language condition, the effect frequency (once-presented words vs. twice-presented words, collapsed across spacing conditions) was assessed by means of paired t-tests. Analyses demonstrated that free recall of repeated items was higher than free recall of once-presented words both in the same-language condition $t(17) = 3.69$, $p < .001$, $d = .87$, and in the different-language condition $t(17) = 4.70$ , $p < .001$, $d = 1.11$.
The 2 x 2 within-subject ANOVA on spacing effect data showed significant main effects of spacing $F(1, 17) = 14.27$, $MSE = 294.45$, $p < .01$, $\eta^2 = .46$, and repetition language $F(1, 17) = 5.47$, $MSE = 359.09$, $p < .05$, $\eta^2 = .24$. Respectively, these results indicate that free recall of lag-4 repetitions surpassed free recall of lag-0 repetitions, and that different-language repetitions were better recalled than same-language repetitions. Furthermore, there was a significant interaction between spacing and repetition language $F(1, 17) = 5.21$, $MSE = 126.59$, $p < .05$, $\eta^2 = .24$. Analyses of the simple main effects demonstrated a spacing effect for same-language repetitions $t(17) = 3.99$, $p < .001$, $d = .94$, and an attenuated spacing effect for different-language repetitions $t(17) = 2.16$, $p < .05$, $d = .51$. The attenuated spacing effect for different-language repetitions could be traced back to the fact that free recall of different-language repetitions surpassed free recall of same-language repetitions in the massed condition $t(17) = 3.69$, $p < .001$, $d = .87$. By contrast, in the spaced condition, free recall did not differ between different-language repetitions and same-language repetitions $t(17) = .75$, *ns*, $d = .18$.

**Table 1**

*Mean percentage of accurate free recall and standard errors in Experiment 1A (intentional learning instructions) as a function of condition and repetition language.*

| | Condition | | | | | |
|---|---|---|---|---|---|---|
| | Lag 0 | | Lag 4 | | Once | |
| Repetition language | *M* | *SE* | *M* | *SE* | *M* | *SE* |
| Same language | 21.44 | 4.42 | 42.78 | 5.43 | 20.39 | 3.18 |
| Different language | 37.94 | 6.28 | 47.17 | 5.61 | | |

The results of Experiment 1A replicate the results obtained by Glanzer and Duarte (1971) and Paivio et al., (1988). It was shown that relative to same-language repetitions, repeating items in different languages improved free recall only under the condition of massed presentation. Arguably, this finding reflects a richer encoding of different-language repetitions in comparison to same-language repetitions. By contrast, if presented in a spaced manner, free recall of different-language repetitions was comparable to free recall of same-language repetitions, suggesting that study-phase retrieval had been successful for both item categories. This finding can be interpreted in two different ways. First, it might indicate that study-phase retrieval operates on the semantic features of repeated items. Second, as already pointed out in the introduction, it might also be possible that participants, being aware of the upcoming memory test, deliberately tried to retrieve the first word of a spaced different-language pair at the presentation of the second word. Namely, actual study-phase retrieval of the second word would allow for the organization of both words into a single easy-to-recall memory unit. Thus, the results reported in the spaced condition of Experiment 1A might be considered as a byproduct of the intentional learning instructions. In that case, these results provide little information about whether study-phase retrieval requires repeated items to overlap solely at the semantic level of representation, or at the semantic and the orthographic level of representation. To determine which of the two above interpretations is correct, Experiment 1B was conducted.

## Experiment 1B

In Experiment 1B, participants performed two semantic orientating tasks on each repetition pair, and they were not informed about the free recall test that followed after the encoding phase. These incidental-semantic learning instructions were assumed to promote processing of individual items, and, predominantly for spaced items, to suppress inter-item processing. As study-phase retrieval is assumed to be an automatic process (e.g., Raaijmakers, 2003; Verkoeijen et al., 2004) it must take place under the incidental-semantic learning instructions. At the same time, the probability of spaced different-language pairs becoming organized into single memory units was reduced to a minimum. Given that the organization of different-language pairs was disrupted, the results for spaced different language pairs in Experiment 1B must be attributed exclusively to the study-phase retrieval mechanism. If now, study-phase retrieval requires repeated items to share only the semantic level of representation, then study-phase retrieval should be successful for same-language-repetitions and different-language repetitions. In that case, free recall of spaced items should not differ between same-language repetitions and spaced-language repetitions. Alternatively, if study-phase retrieval requires repeated items to share both the semantic and the orthographic level of representation, then study-phase retrieval should be successful for same-language repetitions, but not for different-language repetitions. In that case, free recall of spaced same-language pairs should be superior to free recall of spaced different-language pairs.

Finally, with respect to free recall of massed items, we expected to reproduce the findings obtained in Experiment 1A. If pairs are repeated in a massed fashion, the first word is still in the short-term buffer at the occurrence of the second word. Because in different-language pairs the second word is different from the first word, these pairs will be richer encoded than same-language pairs, in which the second word is merely a repetition of the first word. Hence, for massed items, free recall of different-language pairs was predicted to surpass free recall of same-language pairs.

## Method

### Participants

Thirty first-year psychology students from Erasmus University Rotterdam, the Netherlands, took part in the experiment in order to fulfil a course requirement. None of the participants in Experiment 1B had taken part in Experiment 1A.

### Materials and procedure

The materials and the procedure were identical to the materials and the procedure used in Experiment 1A, with the exception that learning occurred incidentally rather than intentionally. The experiment leader told the participants that the aim of the experiment was to obtain conceptual ratings of the words in the list. Participants were instructed to give an animacy rating (on a 2-point scale; either animate or inanimate) if the # sign was presented to the right of a word. If no sign was presented to the right of a word, participants had to give a pleasantness rating (on a 2-point scale; either pleasant or non-pleasant). This was done to ensure that the stimulus materials were processed semantically. The animacy and the pleasantness ratings were written down on an answer sheet. Participants were required to provide two different ratings of each word, instead of repeating the same rating, in order to prevent them from basing their responses to the second occurrence on their recollection of the first. By doing so we could rule out the possibility of finding an artificial spacing effect, which is suggested to occur in case of repeating the same rating (Greene, 1989). Given that participants had to perform two different orienting tasks for each word, the animacy rating was assigned as the first orienting task to a random half of the repetitions in each of the spacing (lag 0 versus lag 4) x repetition language (same versus different language) conditions. For the remaining half of the repetitions the pleasantness rating was the first orienting task. Following the study-phase, participants were given a free recall test on the incidentally encoded words.

## Results and discussion

Table 2 presents the mean percentage of accurate free recall as a function of condition (i.e., lag-0 repetitions, lag-4 repetitions, and once-presented words) and repetition language. In each repetition language condition, paired t-tests were used to assess the effect frequency (once-presented words vs. twice-presented words, collapsed across spacing conditions). Analyses demonstrated that free recall of repeated items surpassed free recall of once-presented words both in the same-language condition $t(29) = 5.27$, $p < .001$, $d = .96$, and in the different-language condition $t(29) = 6.63$, $p < .001$, $d = 1.21$.

The spacing effect data were examined by means of a 2 (spacing: lag 0 vs. lag 4) x 2 (repetition language: same language vs. different language) within-subjects ANOVA. Analysis revealed a marginally significant effect of spacing on free recall performance $F(1, 29) = 3.49$, $MSE = 168.62$, $p = .07$, $\eta^2 = .11$, suggesting that, collapsed across the repetition language levels, lag-4 repetitions were recalled better than lag-0 repetitions. Further, it was demonstrated that repetition language did not influence free recall performance $F(1, 29) = 1.72$, $MSE = 186.19$, *ns*, $\eta^2 = .06$. However, the spacing x repetition language interaction turned out to be significant $F(1, 29) = 5.33$, $MSE = 174.55$, $p < .05$, $\eta^2 = .16$. The specification of the spacing x repetition language interaction effect showed that there was a significant spacing effect for same-language repetitions $t(29) = 2.49$, $p < .01$, $d = .46$, but not for different-language repetitions $t(29) = .43$, *ns*, $d = .08$. The latter finding could be attributed to superior recall of massed different-language repetitions relative to massed same-language repetitions $t(29) = 2.29$, $p < .05$, $d = .42$. In the spaced condition, free recall performance did not differ between same-language repetitions and different-language repetitions $t(29) = .76$, *ns*, $d = .14$.

**Table 2**

*Mean percentage of accurate free recall and standard errors in Experiment 1B (incidental-semantic learning instructions) as a function of condition and repetition language.*

| | **Condition** | | | | | |
|---|---|---|---|---|---|---|
| | Lag 0 | | Lag 4 | | Once | |
| Repetition language | *M* | *SE* | *M* | *SE* | *M* | *SE* |
| Same language | 22.30 | 2.54 | 32.30 | 3.28 | 13.23 | 1.33 |
| Different language | 31.13 | 2.59 | 30.00 | 2.68 | | |

Given that successful retrieval of an item's first presentation at its second occurrence is assumed to be a necessary condition for the spacing effect to emerge (e.g., Raaijmakers, 2003; Verkoeijen et al., 2004), the results of Experiment 1B provide interesting information on the enabling conditions of study-phase retrieval. The finding that free recall of spaced items did not differ between same-language repetitions and different-language repetitions suggest that successful study-phase retrieval requires items to share the same semantic level of representation. However, it might be that sharing the same semantic level of representation is not sufficient to induce study-phase retrieval. It could be argued that study-phase retrieval will only take place if the semantic level of representation is *activated* at both occurrences of a repeated item. An implication of this hypothesis is that the study-phase retrieval will fail if participants activate merely the orthographic level of representation of repeated items. Under these conditions, the spacing effect in free recall that was revealed for same-language repetitions in Experiment 1A and Experiment 1B should disappear. Furthermore, the spacing effect should also be absent for different-language repetitions. To test these predictions we conducted another experiment.

# Experiment 2

## Method

### Participants

Thirty first-year psychology students from Erasmus University Rotterdam, the Netherlands, participated in the experiment to fulfill a course requirement. For all participants Dutch was their first and English their second language (for some students English was their third language). None of the participants in Experiment 2 had participated in the Experiment 1A or in Experiment 1B.

### Materials and procedure

The materials and the procedure were identical to the materials and the procedure used in Experiment 1B, with the exception that participants were given incidental orthographic, instead of incidental semantic learning instructions. Participants were told that if an item appeared with the # sign to the right of it they had to count the number of letters that extended above or below the main body of the word. Otherwise they had to count the number of letters that did not extend above or below the main body of the word. Responses were written down on a sheet provided by the experimenter.

## Results and discussion

Table 3 shows the mean percentage of accurate free recall as a function of condition (i.e., lag-0 repetitions, lag-4 repetitions, and once-presented words) and repetition language. The scoring procedure of the recall protocols was identical to the procedure used in Experiment 1A en Experiment 1B. Two paired t-tests demonstrated repeated items (collapsed across the repetition conditions) were better recalled than once-presented words in the same-language condition $t(29) = 2.74$, $p < .01$, $d = .49$, and in the different-language condition $t(29) = 4.01$, $p < .001$, $d = .75$. These findings are remarkable because they demonstrate a basic repetition effect for words processed under shallow, orthographic learning instructions.

The spacing effect data were analyzed by means of a 2 (spacing: lag 0 vs. lag 4) x 2 (repetition language: same language vs. different language) within-subjects ANOVA. Analysis revealed that neither repetition language $F(1, 29) = 1.73$, $MSE = 111.12$, *ns*, $\eta^2 = .06$ nor spacing $F < 1$, $\eta^2 = .03$ influenced free recall performance. In addition, the interaction effect between repetition language and spacing failed to reach significance $F < 1$, $\eta^2 < .01$. Consistent with our predictions, and contrary the findings in Experiment 1A and Experiment 1B, the results of Experiment 2 demonstrate that the spacing effect was absent for same-language repetitions and for different-language repetitions. These results suggest that the orthographic and the semantic level of representation should be activated in order to induce successful study-phase retrieval. If only the orthographic level of representation is activated, study-phase retrieval will generally not take place and as a consequence the spacing effect in free recall will not emerge.

**Table 3**

*Mean percentage of accurate free recall and standard errors in Experiment 2 (incidental orthographic learning instructions) as a function of condition and repetition language.*

| | **Condition** | | | | | |
|---|---|---|---|---|---|---|
| | Lag 0 | | Lag 4 | | Once | |
| Repetition language | *M* | *SE* | *M* | *SE* | *M* | *SE* |
| Same language | 8.43 | 2.64 | 10.63 | 2.46 | 4.96 | 1.37 |
| Different language | 11.20 | 2.16 | 12.93 | 2.22 | | |

## General discussion

Although sufficient empirical support has been provided to conclude that the spacing effect in free recall will only take place in case the first presentation of a repeated item is successfully retrieved at its second occurrence (e.g., Braun & Rubin, 1998; Johnston & Uhl, 1976; Thios & D'Agostino, 1976; Toppino & Bloom, 2002; Toppino et al., 2002; Verkoeijen et al., 2004), the determining factors of study-phase retrieval have been largely left uncovered. The aim of the present study was to investigate to what extent the degree of the overlap between linguistic representation levels of repeated items affects study-phase retrieval. Under learning instructions that promoted semantic processing of target items, i.e., the intentional learning instructions in Experiment 1A and the incidental-semantic learning instructions in Experiment 1B, free recall improved with inter-repetition spacing for same-language repetitions, but not, or only to a relatively limited extent (Experiment 1A), for different-language repetitions. This interaction between inter-repetition spacing and repetition language could be attributed to the fact that for massed items, different-language repetitions were better recalled than same-language repetitions, whereas for spaced items, free recall did not differ between both item categories. The latter finding indicates that study-phase retrieval requires repeated items to share the semantic level of representation. However, it could be argued that an overlap between repeated items at the semantic level of representation will only lead to study-phase retrieval if the semantic level of representation is activated at both occurrences of a repeated item. This line of reasoning implies that the spacing effect should disappear for same language repetitions under learning instructions that prevent participants from activating the semantic level of representation of a repeated item. This hypothesis was tested in Experiment 2 in which participants studied repeated target items under incidental-orthographic learning instructions. Consistent with our predictions, the results of Experiment 2 demonstrated that inter-repetition spacing had neither influenced free recall of same-language repetitions, nor free recall of different-language repetitions. In conclusion, the combined results of Experiment 1A, Experiment 1B, and Experiment 2 suggest that successful study-phase retrieval occurs under the condition that (a) repeated items share the semantic level of representation, and (b) that the semantic level of representation is activated at both occurrences of a repeated item.

Although the findings of the present study provide new information on the study-phase-retrieval mechanism, and hence on the spacing effect in free recall, there are two aspects of the present study that need some critical consideration. First, on the basis of the low mean percentage of accurate free recall in Experiment 2, it might be concluded that the observed free recall data in this experiment merely represent a floor effect. However, the finding that, collapsed across spacing conditions, same-language repetitions and different-language repetitions were recalled better than once-presented words, is at variance with this conclusion. Namely, in case of a floor effect, it would be unlikely to obtain the demonstrated beneficial effect of repetition on free recall relative to once-presented words.

Second, in the present study, information about the mechanism underlying study-phase retrieval was derived indirectly from free recall of different-language repetitions and same-language repetitions. However, to corroborate the conclusions presented in the present study, further research should be conducted, using experimental procedures that allow for a direct investigation of the study-phase retrieval mechanism. For instance, a repetition-priming paradigm might be used in which participants have to perform as fast and as accurately as possible a semantic orienting task on items that are repeated in the same language and items that are repeated in a different language. Subsequently, they receive a surprise free recall task on the studied items. If participants retrieve the first occurrence of a repeated item at its second presentation, then decision times on the semantic orienting task should be faster for second occurrences of different-language repetitions and same-language repetitions than for once-presented words. This facilitative effect of study-phase retrieval (i.e., priming) should decrease with increases of inter-repetition spacing. Furthermore, under the assumption that priming indicates study-phase retrieval, a spacing effect should only be observed for primed repetitions, but not for non-primed repetitions.

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# *Chapter 5*

# Recognition of semantically related pairs:

## *Evidence against the semantic priming account of the spacing effect in cued-memory tasks?*[1]

[1] *Verkoeijen, P. P. J. L. , Rikers, R. M. J. P., & Schmidt, H. G. Recognition of Semantically Related pairs: Evidence against the Semantic Priming Account of the Spacing Effect in Cued-Memory Tasks? Manuscript in preparation.*

*The spacing effect refers to the finding that memory of repeated items improves as a function of inter-repetition spacing. The spacing effect in semantic cued-memory tasks is generally explained in terms of a semantic priming account. According to this view, spacing effects must occur not only for repetitions but also for semantically related pairs. Contrary to this prediction, previous studies using as stimulus materials synonyms have demonstrated reversed spacing effects. In Experiment 1 of the present study, we sought to demonstrate the reversed spacing effect in yes/no recognition for semantically associated pairs. Participants studied a word list consisting of repetitions or of semantically related pairs under intentional learning instructions. Memory performance showed a spacing effect for repetitions, and a reversed spacing effect for semantically related pairs. However, the experimental procedure used in Experiment 1 made it difficult to draw a definite conclusion about the semantic priming account. Therefore, a second experiment was conducted, in which an experimental procedure was employed that allowed for the identification of semantic priming effects on memory performance. A spacing effect was obtained for repetitions, but the reversed spacing effect for semantically related pairs, demonstrated in Experiment 1, disappeared in Experiment 2. Furthermore, memory performance in the semantically related pairs condition showed that, for massed pairs, memory of second position words was worse than memory of first position words. In this respect no differences were found for spaced pairs. The results of Experiment 2 are not completely in line with the semantic priming account of spacing effects in cued-memory tasks.*

The *spacing effect* refers to the phenomenon that memory for repeated items improves as the interval between their first occurrences and their second occurrences increases. Thus, spaced repetitions separated by time or interspersed events are better remembered than massed items that are presented in immediate succession. The spacing effect is a remarkably robust phenomenon and has been demonstrated in a variety of memory tasks (e.g., Challis, 1993; Greene, 1989, 1990; Greene, & Stillwell, 1995; Hintzmann & Block, 1973; Mammarella, Avons, & Russo, 2004; Mammarella, Russo, & Avons, 2002; Russo & Mammarella, 2002; Russo, Mammarella, & Avons, 2002; Russo, Parkin, Taylor, & Wilks, 1998). However, notwithstanding its robustness, it has been difficult to find a unitary explanation for the spacing effect (for reviews on proposed theoretical mechanisms see: Crowder, 1976; Dempster, 1996; Hintzman, 1974, 1976; Kintsch, 1970). To date, different mechanisms account for the spacing effect in free recall, and cued-memory tasks, such as yes/no recognition, word-stem completion, cued recall and frequency judgments. Moreover, theorists have proposed different mechanisms to explain the spacing effect in cued-memory tasks for semantically processed stimulus materials on one hand, and for stimulus materials unlikely to be processed semantically, for instance non-words and unfamiliar faces, on the other hand (e.g., Mammarella et al., 2002; Russo & Mammarella, 2002; Russo et al., 2002). In this article, we will focus on the explanatory mechanism for semantically processed materials.

Challis (1993) conducted two experiments in which participants studied a word list containing both massed and spaced repetitions either under intentional learning instructions (which were assumed to involve semantic processing of the words), under incidental-semantic learning instructions, or under incidental non-semantic (graphemic) learning instructions. Subsequently, the three groups were compared with respect to their performance on a cued-memory task. The results demonstrated spacing effects in both the intentional and the incidental-semantic learning condition. In contrast, no spacing effect was obtained in the incidental non-semantic learning condition. Based on these findings, Challis (1993) concluded that the spacing effect in cued-memory tasks for semantically processed stimulus materials should be explained in terms of a *semantic priming theory.* According to this account, which has been tacitly accepted by other researchers in the field (e.g., Mammarella et al., 2002, 2004; Russo & Mammarella, 2002; Russo et al., 2002), the semantic representation of a repeated item is activated by its first occurrence, and it remains active for a short period (e.g., Kirsner, Smith, Lockhart, & King, 1984). Under massed repetition, but not under spaced repetition, the second occurrence of a repeated item will be presented while the semantic representation of the item's first occurrence is still elevated. Consequently, less semantic processing will be directed at the second occurrence of a massed repetition than at the second occurrence of a spaced repetition. Hence, the total semantic processing directed at repetitions will be less extensive for massed repetitions than for spaced repetitions, giving rise to the spacing effect in cued-memory tasks.

A main prediction of the semantic priming account is that spacing effects should emerge not only for repetitions but also for semantically related words. Imagine a situation in which participants are required to study a word list consisting of synonyms, such as *odd* and *unusual,* which are presented either in immediate succession (i.e., massed presentation) or with a lag between the first and the second synonym (i.e., spaced presentation). After the study phase, participants are tested in a cued-memory task. Because synonyms have largely overlapping semantic representations, the semantic priming theory (Challis, 1993) predicts that, for massed pairs, the activation of the semantic representation of the first word (*odd*) facilitates the semantic processing of the second word (*unusual*). However, for spaced pairs, this priming effect will be reduced or even absent. As a result, the semantic processing directed at the second word will be larger for spaced synonym pairs than for massed synonym pairs. Hence, if synonym pairs are presented in a massed fashion, memory performance for the second word is expected to be worse than memory performance for the first word. By contrast, for spaced synonym pairs, memory performance will not differ between the first and the second word. Combining the expected memory patterns for massed and spaced pairs leads to the prediction that the probability of remembering at least one of the words of a synonym pair is lower for massed than for spaced pairs.

However, the results of studies using as stimulus materials synonyms (e.g., Greene, 1989; Stern & Hintzman, 1979) are at variance with the afore prediction of the semantic priming account (Challis, 1993). For instance, Stern and Hintzman (1979) presented participants with a list of massed synonym pairs and spaced synonym pairs that were shown in identical sentence contexts (e.g., the hotel manager's manner was *courteous* vs. the hotel manager's manner was *polite*). Participants were either instructed to learn the sentences in the list for a following memory test (Experiment 1; intentional learning instruction), or to form an image of the scene or situation described in each of the sentences (Experiment 2; incidental learning instruction). In both Experiment 1 and Experiment 2, participants received a recognition memory test after they had studied the sentences in the list. Specifically, participants were given a sheet of paper containing all words from the synonym pairs that had previously been studied as well as distractor items. Participants had to decide for each word on the test sheet whether it had been presented in the study phase. The results demonstrated that recognition of massed synonym pairs was superior to recognition of spaced synonym pairs following both intentional learning and incidental learning. This reversed spacing effect was also shown in a study of Greene (1990), in which participants intentionally learned synonym pairs for a later free recall test. Thus, contrary to the prediction of the semantic priming theory, these studies show detrimental effects of spaced practice on memory (i.e., a reversed spacing effect).

The aim of the first experiment of the present study was to obtain further evidence against the semantic priming theory (Challis, 1993) by demonstrating a reversed spacing effect in recognition performance for semantically associated pairs, such as *nurse* and *doctor.* To our knowledge, there is only one earlier study (i.e., Hintzman, Summers, & Block, 1975) that examined the effect of massed versus spaced practice on the recognition of semantically associated pairs. The results of this study revealed that recognition performance for massed pairs surpassed recognition performance for spaced pairs. However, target items in the study list were organized in such a way that semantically associated pairs were associated in a backward direction. That is, the second presented word of a pair evoked the first word, but the first word did not evoke the second word. Given that semantic priming operates in a forward direction (i.e., from the first word to the second word), it is unclear to what extent the demonstrated reversed spacing effect can be interpreted as evidence against the semantic priming explanation. To address this methodological shortcoming, we made sure that the semantically associated pairs used in the present study were associated in a forward direction. In Experiment 1, participants studied for a yes/no recognition test either semantically associated pairs or repetitions under intentional learning instructions. Regarding recognition performance for repetitions, we expected to find a spacing effect. For semantically associated pairs a reversed spacing effect was predicted.

# Experiment 1

## Method

### Participants

Thirty-six undergraduate psychology students from the Erasmus University Rotterdam participated in the experiment in order to fulfill a course requirement. Participants were randomly assigned to the repetition condition or the related pairs condition.

### Materials

One list template comprising 120 serial positions was created. Slots 11-110 were reserved for 20 once-presented filler items and for 40 twice-presented targets representing both the lag conditions of the experiment. Twenty targets were presented at lag 0 (massed presentation) and 20 were presented at lag 6 (spaced presentation). Because the second presentations of repeated items, on average, tend to occur near the end of the study list as the inter-repetition interval increases, an observed spacing effect in free recall might in fact be the result of an extended recency effect (e.g., Underwood, 1969). To avoid confounding the spacing of stimuli with the length of the retention interval, the mean serial position of the first presentation of the repeated items was equated across the lag conditions, and this in turn was equated with the mean serial position of once-presented items. Similarly, the mean serial position of the second presentation of the repeated items did not differ between the lag conditions, and this was equated with the mean serial position of once-presented items. To control for further serial position effects, the list structure began and ended with slots for 10 primacy and 10 recency buffers, respectively.

In the repetition condition, stimuli consisted of 60 words that were three to ten letters in length and were high frequency words according to Dutch word frequency norms (Uit den Bogaart, 1975). No semantic relationship existed between the included words. The stimuli were divided into three equally sized sets (A, B, and C). Subsequently, three study lists were created from the list template. To create the first study list, the stimulus sets A, B and C were assigned to the slots reserved for the once-presented, the slots reserved for lag-0 repetitions and the slots reserved for lag-6 repetitions respectively. In order to generate the second and the third study list, the stimulus sets were rotated through the spacing conditions. Consequently, the stimulus sets corresponding to the once-presented items, lag-0 repetitions, and lag-6 repetitions were CAB in the second and BCA in the third study list. Thus, across lists, each experimental condition was represented equally often by the same items. The slots for the primacy and recency buffers were filled with 20 high frequency words. Finally, the test list comprised the 60 experimental words from the study list along with 60 distractor words. The distractor words were comparable to the experimental words in terms of word length and word frequency. All words in the test list were presented in random order.

In the related pairs condition, stimuli were 60 semantically associated word pairs, such as *clown-circus, egg-chicken,* and *spoon-fork*. These word pairs were created by coupling each of the 60 words used in the repetition condition to a semantically related counterpart. Pairs were used with a pre-existing unidirectional association from the first word (e.g., *clown*) to second word (e.g., *circus*). This implies that the first word evokes the second, but that the second word does not evoke the first. The median associative strength from the first word to second word was 32%, and this can be considered a high associative strength. By contrast, the median associative strength from the second word to first word was 5%, which can be considered a low associative strength. In addition, mean word frequency did not differ significantly between the first words and the seconds of the pairs. Modifying the three study lists used in the repetition condition created the study lists in the semantically related conditions. In each study list of the repetition condition, the primacy and recency buffers, the once-presented words, and the second occurrences of the lag 0 repetitions and the lag 6 repetitions remained unaltered. However, in each study list of the repetition condition, the semantically related counterparts of the second occurrences replaced the first occurrences of the lag-0 repetitions and the lag-6 repetitions. The test list consisted of the 120 experimental words in combination with 120 distractor words, which were comparable to the experimental words in terms of word length and word frequency. All words in the test list were presented in random order.

## Procedure

In both the repetition and the related pairs condition, participants were informed that they would be presented with a list of 120 words and that they had to try to remember as many words of the list as possible for a later unspecified memory task. Each word was presented for 3 seconds in the center of the computer screen with a 500ms inter-stimulus interval. During the inter-stimulus interval a row, consisting of four asterisks was displayed in the center of the screen. In order to familiarize the participants with the procedure a practice trial of 15 words was shown to them prior to the presentation of the experimental word list. After they had studied all words on the list, participants engaged in a distraction task for three minutes. Following the distraction task, participants were asked to perform a yes/no recognition task. The items of the test list, containing the studied experimental items plus non-studied distracter items were presented in random order on the computer screen. Participants pressed the *j* key, if they remembered having seen the item during the study phase, or the *n* key if they did not remember having seen the item during the study phase. The *j* and *n* key were used because they are the first letters of the Dutch words *ja* (yes) and *nee* (no). Participants were told that there was no time limit for making their decision. Each item remained on the computer screen until participants made their decision. Participants were tested individually or in groups. In case of the latter situation, participants were seated in separate cubicles. The experimental session took about 25 minutes.

## Results and discussion

Percentages of hits, false alarms, and *d'* scores were calculated. Because frequency of occurrence (i.e., once versus twice-presented items) and spacing (i.e., massed versus spaced items) are two conceptually distinct variables, separate analyses were conducted to determine their effects on recognition performance.

For each participant, the *d'* scores were collapsed across lag 0 and lag 6 items and a mean *d'* score was calculated. Two paired t-tests were conducted on these mean *d'* scores. The results demonstrated that, in the repetition condition, twice-presented items (mean $d' = 3.11$) were recognized better than once-presented items (mean $d' = 2.33$), $t(17) = 4.55$, $p < .001$. In the semantically related words condition, recognition of semantically related words (mean $d' = 2.11$) was superior to that of once-presented items (mean $d' = 1.95$), $t(17) = 1.90$, $p < .05$. This finding provides evidence for the associative connection between the words in the semantically related word pairs.

The mean *d'* scores obtained in the repetition condition are depicted as a function of lag in Table 1. A one-tail, paired sample t-test revealed a significant spacing effect. It turned out that words repeated at lag 6 were recognized better than words repeated at lag 0, $t(17) = 3.52$, $p < .01$.

The mean *d'* scores obtained in the related pairs condition are presented in Table 2 as a function of lag and the position of a word in a related pair. A 2 (lag: lag 0 vs. lag 6) x 2 (position: first position vs. second position) repeated measures analysis of variance revealed a significant effect of lag, $F(1, 17) = 7.11$, $MSE = .12$, $p < .05$, indicating that, on average, recognition performance was better for Lag 0 pairs than for Lag 6 pairs. Further, it was demonstrated that, overall, words presented at the first position were recognized better than words presented at the second position $F(1, 17) = 4.36$, $MSE = 0.07$, $p < .05$. The interaction effect between lag and position failed to reach significance $F < 1$.

**Table 1**

*Mean percentage of hits, false alarms (FA), mean d' score and standard errors (SE) in the repetition condition as a function of study condition.*

| | **Repetition** | |
|---|---|---|
| Study Condition | % | *SE* |
| Once | 77.50 | 2.98 |
| Lag 0 | 83.61 | 2.32 |
| Lag 6 | 91.39 | 2.28 |
| FA | 11.06 | 2.43 |
| | *d'* | *SE* |
| Once | 2,33 | .27 |
| Lag 0 | 2.56 | .24 |
| Lag 6 | 3.65 | .39 |

**Table 2**

*Mean percentage of hits, false alarms (FA), mean d' score and standard errors (SE) in the related pairs condition as a function of study condition and word position.*

| | | | | **Related pairs** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lag 0 | | | | Lag 6 | | | |
| Fa | | Once | | First | | Second | | First | | Second | |
| % | *SE* | % | *SE* | % | *SE* | % | *SE* | % | *SE* | % | *SE* |
| 11.39 | 1.91 | 70.83 | 2.92 | 80.83 | 2.43 | 76.11 | 3.20 | 74.17 | 2.87 | 71.67 | 3.28 |
| | | *d'* | *SE* | *d'* | *SE* | *d'* | *SE* | *d'* | *SE* | *d'* | *SE* |
| | | 1.95 | .12 | 2.27 | .13 | 2.11 | .11 | 2.03 | .13 | 1.93 | .14 |

Consistent with our predictions, recognition performance in the repetition condition demonstrated a spacing effect, whereas a reversed spacing effect was obtained in the related pairs condition. The latter finding is consistent with the results reported in studies using as stimulus materials synonym pairs (i.e., Greene, 1990; Stern & Hintzman, 1979). At first sight, the findings of Experiment 1 seem hard to accommodate by the semantic priming theory (Challis, 1993). However, it could be argued that neither Experiment 1, nor the studies of Greene (1990) and Stern and Hintzman (1979) were tailored to assess the predictions of the semantic priming theory regarding memory of semantically related pairs.

The semantic priming theory proposes a negative correlation between the degree of semantic priming received by a word and the probability of remembering that word at a memory test. Therefore, the identification of the proposed relationship between priming and memory requires an experimental design in which variation in memory performance can be attributed predominantly to priming effects occurring during the study of semantically related pairs. The experimental designs used in Experiment 1 of the present study and in the studies of Greene (1990), and Stern and Hintzman (1979) did not meet this requirement. In all of these studies, participants were given intentional learning instructions before studying a list containing massed and spaced semantically related pairs. Under these learning instructions, it is reasonable to assume that participants attempted to organize the to-be-remembered items into clusters to augment subsequent test performance. Furthermore, in Stern and Hintzman's (1979) second experiment, related pairs might also have become clustered, albeit not as a result of the used learning instructions. Participants in their experiment incidentally studied massed and spaced synonym pairs presented in identical context sentences. By embedding the pairs in identical context sentences, the presentation of the second sentence may have served as a strong retrieval cue for the first sentence. Moreover, successful retrieval of the first sentence at its second occurrence could have made participants aware of the semantic relationship between the words of a synonym pair. This, in turn, may have led to the organization of the words in a single unit. To summarize, either the learning instructions or the stimulus materials may have invoked to-be-studied items to become organized in memory. Given the vast amount of research demonstrating the profound effect of stimulus organization on memory performance (e.g., Puff, 1974; Greene, 1990), it might be conceivable that the results revealed in the described studies reflect the operation of organizational processes, rather than the operation of semantic priming mechanisms. Indeed, the observed reversed spacing effects can be explained in terms of the organizational structure imposed on the studied items. If semantically related words are presented in immediate succession, and if the experimental design directs participants' attention to the relationship between the words, then it is very likely that the related words will be stored in a single unit. However, if semantically related words are presented in a spaced manner, the relationship will be less obvious, reducing the chances that the words are clustered. At test, the probability of remembering related words is positively related to the degree of clustering. Hence, massed words will be remembered better than spaced words, giving rise to the reversed spacing effect.

## Experiment 2

The aim of the second experiment of the present study was to adequately test the predictions of the semantic priming theory regarding memory of semantically related pairs. To this aim, an experimental design was used that, in contrast to the designs used in the above-discussed studies (i.e., Experiment 1 of the present study; Greene, 1990; Stern Hintzman, 1979), directly allows for the identification of the influence of semantic priming on cued-memory performance. Specifically, participants in Experiment 2 received incidental learning instructions that required them to rate each target item on a pleasantness scale (i.e., pleasant vs. unpleasant) or on an animacy scale (i.e., alive vs. lifeless). An important implication of the used learning instructions was that repetitions' first occurrence and the second occurrences, as well as first words and second words of semantically associated pairs, were rated on different dimensions. As a consequence, participants were averted from the existing relationship between the semantically associated pairs, decreasing the probability that words in the pairs were organized into single units. However, because the learning instructions promoted the activation of the target items' semantic features, the semantic priming mechanism operating on the target items during study was not disrupted. Thus, an experimental setting was constructed in which memory performance of semantically related pairs was influenced by semantic priming mechanisms, and not, or only to a limited extent, by organizational processes.

If, as proposed by Challis (1993), semantic priming underlies spacing effects in cued-memory tasks, then the incidental learning instructions in Experiment 2 should produce an overall spacing effect in recognition memory for semantically related pairs. That is, the probability of remembering at least one word of a pairs must be lower for massed pairs than for spaced pairs. Furthermore, the semantic priming theory assumes that priming effects tap onto the second word of a pair, and that the magnitude of the priming effects decreases over time. Hence, a spacing effect must be obtained for the pairs' second words, but not for the pairs' first words. In addition, for massed pairs, first word recognition performance must surpass second word recognition performance, whereas for spaced pairs, no difference is expected. Finally, in the repetition condition, a spacing effect should be demonstrated. This prediction is based on the fact that spacing effect for repeated items were reported in other studies (e.g., Challis, 1993; Russo et al., 2002) using similar incidental-semantic learning instructions.

## Method

### Participants

Thirty-six undergraduate psychology students from the Erasmus University Rotterdam participated in the experiment in order to fulfill a course requirement. Participants were randomly assigned to the repetition condition or the related words condition. None of the participants in Experiment 2 had taken part in Experiment 1.

### Materials and procedure

The materials, and the yes/no recognition task used in Experiment 2 were the same as those in Experiment 1. The only difference between the experiments was the learning instruction given to the participants. In Experiment 2 participants were informed that they would be presented with a list of 120 words and that the aim of the experiment was to obtain ratings for these words. They were instructed to give an animacy rating (on a 2-point scale; either animate or inanimate) if the # sign was presented to the right of a word. If no sign was presented to the right of a word, participants had to give a pleasantness rating (on a 2-point scale; either pleasant or non-pleasant). The animacy and the pleasantness ratings were written down on a response sheet. Participants were required to provide two different ratings of each word (or of the words in a semantically related pair), instead of repeating the same rating, in order to prevent them from basing their response to the item's second occurrence on their recollection of the response to the first. By this means we could rule out the possibility of finding an artificial spacing effect, which is suggested to occur in case of repeating the same rating (Greene, 1989). The animacy rating was assigned as the first orienting task to a random half of the repetitions in each of the lag (lag 0 vs. lag 6) conditions. For the remaining half of the repetitions, the first orienting task was the pleasantness rating. Each word was presented automatically for 3 seconds in the center of the computer screen with a 500ms inter-stimulus interval. During the inter-stimulus interval a row, consisting of four asterisks, was displayed in the center of the screen. In order to familiarize the participants with the task a practice phase of 15 words was given to them prior to the presentation of the experimental word list.

## Results and discussion

Percentages of hits, false alarms, and *d'* scores were calculated. To determine the effect of frequency of occurrence (i.e., once versus twice-presented items) and spacing (i.e., massed versus spaced items) on recognition performance, for each participant, the *d'* scores were collapsed across lag-0 and lag-6 items and a mean *d'* score was calculated. Two paired t-tests were conducted on these mean *d'* scores. The results demonstrated that, in the repetition condition, twice-presented items (mean *d'* = 3.75) were recognized better than once-presented items (mean *d'* = 2.41), $t$ (17) = 5.24, $p < .001$. Furthermore, recognition of semantically related words (mean *d'* = 2.36) did not differ significantly from that of once-presented items (mean *d'* = 2.27), $t$ (17) = 1.17, *ns*.

Table 3 (on the next page) shows mean *d'* score in the repetition condition as a function of lag. A paired t-test demonstrated a spacing effect, indicating that word repeated at lag 6 were recognized better than words repeated at lag 0, $t$ (17) = 3.56, $p < .001$.

Table 4 (on the next page) depicts mean *d'* score in the related pairs condition as a function of lag and word position. A 2 (lag: lag 0 vs. lag 6) x 2 (position: first position vs. second position) repeated measures analysis of variance demonstrated that the main effects of lag and position were non-significant, *F's* < 1. This suggests that mean recognition performance did not differ between lag-0 pairs and lag-6 pairs. Moreover, mean recognition performance was similar for words presented at the first position and for words presented at the second position. However, the interaction effect between lag and position turned out to be significant $F$ (1, 17) = 5.57, *MSE* = .08, $p < .05$. This interaction effect could be attributed to the fact that recognition of first words surpassed recognition of second words for massed pairs, $t$ (17) = 2.15, $p < .05$, but not for spaced pairs, $t$ (17) = 1.00, *ns.* Furthermore, a marginally significant spacing effect was shown for the pairs' second words $t$ (17) = 1.59, $p = .06$, whereas a marginally significant reversed spacing effect was obtained for the pairs' first words $t$ (17) = 1.42, $p = .09$.

**Table 3**

*Mean percentage of hits, false alarms (FA), mean d' score and standard errors (SE) in the repetition condition as a function of study condition.*

| | Repetition | |
|---|---|---|
| Study Condition | *%* | *SE* |
| Once | 78.06 | 3.79 |
| Lag 0 | 85.83 | 3.64 |
| Lag 6 | 91.94 | 4.39 |
| FA | 9.38 | 3.38 |

| | *d'* | *SE* |
|---|---|---|
| Once | 2.41 | .23 |
| Lag 0 | 3.19 | .39 |
| Lag 6 | 4.30 | .46 |

**Table 4**

*Mean percentage of hits, false alarms (FA), mean d' score and standard errors (SE) in the related pairs condition as a function of study condition and word position.*

| Related pairs | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lag 0 | | | | Lag 6 | | | |
| Fa | | Once | | First | | Second | | First | | Second | |
| *%* | *SE* | *%* | *SE* | *%* | *SE* | *%* | *SE* | *%* | *SE* | *%* | *SE* |
| 5.61 | .78 | 71.39 | 3.23 | 76.94 | 2.53 | 70.28 | 3.27 | 72.22 | 2.86 | 75.83 | 2.50 |
| | | *d'* | *SE* | *d'* | *SE* | *d'* | *SE* | *d'* | *SE* | *d'* | *SE* |
| | | 2.27 | .08 | 2.46 | .10 | 2.24 | .11 | 2.32 | .13 | 2.41 | .13 |

The results of Experiment 2 are largely in line with our hypotheses. First, a spacing effect was obtained in the repetition condition. Second, consistent with the semantic priming account (Challis, 1993), it was shown for the related pairs that first word recognition performance was worse than second word recognition performance under the condition of massed presentation, but not under the condition of spaced presentation. In addition, a marginally significant spacing effect was observed for related pairs' second words. However, we failed to demonstrate an overall spacing effect for recognition of related pairs, a finding that is to hard to accommodate by the semantic priming account. This issue will be addressed in the General discussion.

## General discussion

The present series of experiments was motivated by Challis' (1993) semantic priming account of spacing effects in cued-memory tasks. This theory centers around two assumptions: 1) the first occurrence of a repeated item primes the second occurrence, reducing the semantic processing allocated to the second occurrence, and 2) the facilitative effect of priming decays rapidly as a function of time. As a result, the total semantic processing (i.e., semantic processing directed at both occurrences of a repeated item) is lower for massed than for spaced repetitions, leading to the spacing effect in cued-memory tasks.

A straightforward prediction that can be derived from the semantic priming account is that spacing effects should not only be demonstrated for repetitions but also for semantically related pairs. Contrary to this prediction, studies using as stimulus materials synonyms (e.g., Greene, 1990; Stern and Hinztman, 1979) typically demonstrate that memory for massed pairs was better than memory for spaced pairs (i.e., reversed spacing effects). Experiment 1 of the present study was conducted to garner further evidence against the semantic priming theory by showing a reversed spacing effect for semantically associated pairs, such as *nurse* and *doctor.* Participants in Experiment 1 intentionally studied either repetitions, or forwardly associated semantically related pairs, presented in a massed or a spaced mode. Subsequently they received a yes/no recognition test on the target items. The results revealed a spacing effect for repetition, whereas a reversed spacing effect was obtained for semantically associated pairs.

However, in the above studies (i.e., Experiment 1 of the present study; Greene, 1990; Stern & Hintzman, 1979), the learning instructions did not prevent participants from organizing the to-be-remembered target pairs. It could be argued that subsequent memory performance on the related pairs reflected the organizational processes taking place during study. If related pairs were presented in a massed fashion, participants were more likely to organize the words of a pair in a single unit than if pairs were presented in a spaced fashion. Hence, memory performance for massed pairs surpassed that of spaced pairs. However, the influence of organizational processes on memory performance may have been so strong that it completely masked the effects of semantic priming on memory. Therefore, it is difficult to discard semantic priming theory as an explanation of the spacing effect on the basis of the results obtained in the above studies. To overcome this problem, in Experiment 2 of the present study an experimental design was introduced in which memory performance on related pairs was determined by semantic priming mechanisms, and not by organizational processes. The use of such experimental design allowed for an adequate evaluation of the predictions of the semantic priming theory regarding memory for related pairs.

Experiment 2 was identical to Experiment 1 with the only exception that participants were given incidental semantic learning instructions. It was assumed that under the incidental learning instructions recognition performance for related pairs reflects semantic priming mechanisms taking place during study, instead of organizational processes. The results of Experiment 2 demonstrated that spaced practice had a beneficial effect on recognition of repetitions. By contrast, spaced practice did not influence recognition for related pairs. The finding that a reversed spacing effect was obtained for intentionally learned pairs (Experiment 1), but not for incidentally learned pairs (Experiment 2) provides evidence for the notion that reversed spacing effects for related pairs might be attributed to the organization imposed on these pairs.

Furthermore, the findings obtained in Experiment 2 yielded important conclusions regarding the relationship between recognition performance for related pairs and semantic priming mechanisms operating on the pairs during study. The semantic priming theory (Challis, 1993) states that a related pair's first word primes the second word, reducing the second word's semantic processing. In addition, the priming effect decreases as the spacing between the first word and the second word increases. Consequently, a spacing effect in recognition memory is predicted for related pairs' first words, but not for related pairs' second words. Also, in case of massed presentation, recognition performance for first words should be worse than memory for second words. Alternatively, in case of spaced presentation, recognition performance should be similar for first words and for second words. The recognition data in the related pairs condition of Experiment 2 largely supported these predictions. However, the depression of second word recognition performance did not produce an overall spacing effect. By contrast, a reliable spacing effect was observed in the repetition condition. This discrepancy is clearly at variance with the semantic priming theory that predicts spacing effect both for repetitions and related words. The absence of a spacing effect for related pairs can be interpreted in two ways.

First, it might be possible that the overlap at the semantic level of representation between the words in the related pairs was not sufficiently large to induce a level of semantic priming that is required to obtain a spacing effect. However, given the high associative strength from the first to the second word in the related pairs (i.e., a median associative strength of 32%), it is unlikely that the resultant priming level was too weak to generate a spacing effect.

Second, it could be argued that the semantic priming alone cannot offer a complete explanation of spacing effects in cued-memory tasks. Perhaps, a theoretical framework of spacing effects in cued-memory task should be multi factorial, including mechanisms that have been traditionally associated with theories on spacing effects in free recall tasks. For example, a number of studies suggest that study-phase retrieval is a determinant of spacing effects in free recall tasks (e.g., Braun & Rubin, 1998; Johnston & Uhl, 1976; Thois & D'Agostino, 1976; Toppino & Bloom, 2002; Toppino, Hara, & Hackman, 2002). These studies demonstrated that spacing effects in free recall are only obtained if a repeated item's first occurrence is retrieved from long-term memory at its second presentation. For repeated items that were not retrieved at their second occurrence the spacing effect was not revealed. In the present study, the association between the first word and the second word in the related pairs was unidirectional from the first word to the second. That is, the first word evoked the second, but the second word did not evoke the first. Due to this unidirectional association, study-phase retrieval of the first word at the presentation of the second word would have been problematic, particularly for spaced pairs. It might be possible that the spacing effect was not obtained for related pairs because study-phase retrieval was largely unsuccessful for spaced pairs.

A study of Verkoeijen, Schmidt, and Rikers (2004) provides an experimental design that might be appropriate to empirically test the outlined hypothesis that study-phase retrieval influences the spacing effect in cued-memory tasks. In this study participants learned a word list consisting of massed and spaced items, which were presented twice in the same context or in different contexts. From the literature on the encoding specificity of memory (e.g., Godden & Baddeley, 1975; Sahakyan & Kelley, 2002; Smith, Glenberg, & Bjork, 1978; Tulving, 1983; Tulving & Thomson, 1973), it can be derived that the probability of retrieving a particular memory trace is positively related to the degree of overlap between contextual cues at retrieval and the context information stored in the memory trace. Based on this encoding specificity principle, Verkoeijen et al., (2004) hypothesized that on average study-phase retrieval would be less successful for spaced repetitions presented in different contexts than for spaced repetitions presented in the same context. Therefore, spaced repetitions presented in the same context were expected to be recalled better than spaced repetitions presented in different contexts. The data in their study provided evidence for this prediction. Recently, it has been demonstrated that the encoding specificity principle operates not only in free recall memory, but also in recognition (e.g., Murnane, Phelps, & Malmberg, 1999; Smith & Vela, 2001). If now, a study-phase retrieval mechanism is involved in producing spacing effects in cued-memory tasks, then future studies, using the same methodology as Verkoeijen et al., (2004) should find that context variation impairs recognition performance of spaced repetitions.

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*Chapter 6*

# Summary and discussion

Memory for repeated items improves when the length of the inter-repetition interval increases. This phenomenon has been known as the spacing effect, and it has been demonstrated under a broad range of experimental conditions, and in a variety of memory tasks (e.g., Greene, 1989, 1990; Greene & Stillwell, 1995; Hintzman, Block, & Summers, 1973; Melton, 1967; Russo, Parkin, Taylor, & Wilks, 1998). To account for the spacing effect, different theoretical frameworks have been proposed in the course of years (for reviews see; Crowder, 1976; Dempster, 1996; Hintzman, 1974, 1976). To date, a distinction is made between a theoretical mechanism underlying the spacing effect in free recall tasks, and a theoretical mechanism for the spacing effect in explicit cued-memory tasks.

With respect to free recall tasks, a type of contextual-variability mechanism, dubbed the study-phase retrieval theory (Greene, 1989), is thought to give rise to the spacing effect. According to the study-phase retrieval theory, contextual change occurring during the interval between the first and the second occurrence of a repeated item is automatically encoded with the repeated item's memory trace. Because contextual change increases with the length of the inter-repetition interval, the number of encoded contextual elements also increases with the length of the inter-repetition interval. Given that free recall performance depends largely on the availability of contextual retrieval cues, it follows that the probability of remembering a repeated item is positively related to the length of the inter-repetition interval. However, an important assumption in the study-phase retrieval theory is that elements of contextual change will only be encoded if an item's first occurrence is retrieved from long-term store at its second presentation. Hence, spacing effects in free recall will only be observed for repeated items that have been identified as repetitions.

To explain the spacing effects in explicit cued-memory tasks, a transfer-appropriate processing approach (e.g., Morris, Bransford, & Franks, 1977) is proposed in conjunction with qualitatively different priming mechanisms. Specifically, under the condition that repeated items are semantically processed during study and test, a semantic priming mechanism (e.g., Challis, 1993) is assumed to cause the spacing effect in cued-memory tasks. The first occurrence of a repeated item activates the corresponding semantic representation in memory. If now, the second occurrence of a repeated item is presented immediately following the first (i.e., massed presentation), the semantic representation of the first occurrence will still be elevated. As a result, the semantic processing of the second occurrence will be facilitated. However, the facilitative effect of semantic priming effect decays rapidly over time. Therefore, the total amount of semantic processing directed at both occurrences of a repeated item increases as a function of the inter-repetition interval, resulting in the spacing effect in cued-memory tasks. Alternatively, if, for some reason, semantic analysis of repeated items is made impossible during study and test, a structural-perceptual priming mechanism (e.g., Mammarella, Avons, & Russo, 2004; Mammarella, Russo, & Avons, 2002; Russo et al., 1998; Russo &

Mammarella, 2002; Russo, Mammarella, & Avons, 2002) is assumed to underlie the spacing effect in cued-memory tasks. The structural priming explanation of spacing effects is conceptually analogous to the semantic priming mechanism, with the exception that the structural-perceptual mechanism operates at a repetition's orthographic level of representation rather than at its semantic level of representation.

This thesis investigated different aspects of the above-described two-process account of spacing effects. The study presented in Chapter 2 was conducted to test the hypothesis that a comprehensive explanation of the spacing effect in free recall tasks requires a theoretical framework that combines the contextual-variability mechanism (e.g., Glenberg, 1979; Madigan, 1969; Melton, 1970) and the study-phase retrieval mechanism (e.g., Greene, 1989). The study in Chapter 3 was performed to examine whether the relationship between inter-repetition spacing and free recall of repeated items follows an inverted u-shaped function. The study in Chapter 4 investigated to what extent the orthographic dissimilarity between (semantically identical) repetitions and the nature of the learning instructions interacted to influence the spacing effect in free recall. In contrast to the studies presented in Chapters 2 through 4, which focussed on the spacing effect in free recall tasks, the study in Chapter 5 was directed at the spacing effect in cued-memory tasks. Specifically, in this study, semantically associated pairs, such as *nurse* and *doctor*, were used to assess the semantic priming account of spacing effects in cued-memory tasks (e.g., Challis, 1993). In the remainder of this chapter, the main results of the conducted studies will be summarized, and the implications of these results for theories on the spacing effect will be discussed.

## Summary of the main results

In the study presented in **Chapter 2**, two experiments were conducted in which participants received a free recall test on intentionally learned massed and spaced repetitions that were presented either on the same background or on different backgrounds. The difference between the two experiments was the form of the background manipulation. In Experiment 1, the color of the presentation background was varied between a repeated item's first occurrence and its second occurrence. By contrast, in Experiment 2, a repeated item was presented once on the background of a forest landscape, and once on the background of a city landscape. The results in both experiments revealed that background variation improved free recall performance for massed repetitions, whereas it depressed free recall performance for spaced repetitions. Moreover, the spacing effect was revealed for words repeated on the same background, but it was not demonstrated for words repeated on different backgrounds. Interestingly, none of the existing theories on the spacing effect in free recall tasks alone could provide a complete account of these findings.

According to the study-phase retrieval theory (e.g., Greene, 1989) elements of contextual change are automatically encoded with a repeated item's memory trace. However, encoding of contextual elements will only take place if a repeated item's first occurrence is retrieved from long-term store at its second presentation (i.e., study-phase retrieval). The spacing effect emerges because the number of encoded elements, and therefore the number of available retrieval cues, increases with the length of the inter-repetition interval. Based on the principle of encoding specificity (Smith & Vela, 2001; Tulving, 1983; Tulving & Thomson, 1973), it can be assumed that, in comparison to repeated items presented on the same background, the probability of study-phase retrieval will be lower for items repeated on a different background. As a result, the encoding of contextual elements will fail for a larger proportion of spaced different-background repetitions than of spaced same-background repetitions, and therefore free recall will be worse for spaced different-background repetitions than for spaced same-background repetitions. The predicted free recall pattern for spaced repetitions was indeed confirmed in the two experiments presented in Chapter 2. However, in case of massed repetition, the first presentation can be expected to be still in the short-term buffer at its second occurrence, and consequently it will not be retrieved from long-term store. This in turn will prevent the encoding of the experimentally induced contextual change (i.e., the change in presentation background). Hence, free recall will be similar for massed same-background repetitions and massed different-background repetitions. Contrary to this prediction, the experiments of Chapter 2 consistently showed that free recall of massed repetitions improved as a result of the background variation. To explain the beneficial effect of background variation on the free recall of massed repetitions, a contextual-variability mechanism is required.

Similar to the study-phase retrieval theory (e.g., Greene, 1989), the contextual-variability theory (e.g., Glenberg, 1979; Madigan, 1969; Melton, 1970) proposes that elements of contextual change are automatically encoded with a repeated items memory trace. However, the contextual-variability theory does not make the auxiliary assumption that the encoding of contextual elements is conditional upon study-phase retrieval. In this view, variation of presentation background exerts a greater influence on free recall performance of massed repetitions than on free recall performance of spaced repetitions. Namely, if items are repeated on different backgrounds, the increase of encoded contextual elements, relative to the situation in which items are repeated on the same background, will be larger for massed than for spaced repetitions. Therefore, background variation is expected to improve free recall of massed repetitions, but not (or only to a limited extent) free recall of spaced repetitions. Thus, a contextual-variability mechanism can explain the free recall pattern for massed repetitions that was demonstrated in the experiments of Chapter 2. Taken together, the findings of the experiments in Chapter 2 suggest that the spacing effect in free recall can be best explained in terms of a theoretical framework that combines the study-phase retrieval mechanism, and the contextual-variability mechanism. Recently, Raaijmakers (2003) introduced a formalized version of such a two-factor model in applying the search of associative memory (SAM) model (Raaijmakers & Shiffrin, 1980, 1981) to the spacing effect in free recall.

The study reported in **Chapter 3** tested a straightforward prediction of the two-factor model (e.g., Raaijmakers 2003) of the spacing effect in free recall tasks that was outlined in Chapter 2. In this model, two opposing processes govern free recall of repetitions as the length of the inter-repetition interval increases: (1) due to the operation of the contextual-variability mechanism, the number of contextual elements that can be potentially encoded with a repeated item's memory trace increases, (2) the probability of successful study-phase retrieval decreases. Initially, study-phase retrieval will be successful for the majority of the repeated items, and the first process dominates. As a result, free recall rises with the length of the inter-repetition interval. However, at a certain inter-repetition interval, the second process starts to overrule the first. From this inter-repetition interval onwards, free recall declines with the length of the inter-repetition interval. Thus, the combined model of spacing effects in free recall predicts that free recall performance is expressed as an inverted u-shaped function of inter-repetition spacing. The empirical evidence for this predicted inverted u-shaped function is scarce and indirect (i.e., Toppino & Bloom, 2002; for similar results with a-typical stimulus materials see also Toppino, Hara, & Hackman, 2002). The goal of the study presented in Chapter 3, therefore, was to directly demonstrate an inverted u-shaped relationship between free recall performance and the length of the inter-repetition interval.

In the first experiment, participants studied, under intentional learning instructions or under incidental learning instructions, a list containing items that were repeated either in immediate succession (i.e., massed repetition), with two intervening items (i.e., lag 2), or with eight intervening items (i.e., lag 8). Subsequently, a free recall test was administered on the studied items. It was hypothesized that the incidental learning instructions (i.e., finding a rule that determined the order in which the words in the list were presented) promoted a shallower level of item processing than the intentional learning instructions. Consequently, under incidental learning instructions, the probability of successful study-phase retrieval was assumed to start to decrease at a shorter inter-repetition interval than under intentional learning instructions. With respect to free recall performance, this assumption led to the prediction that the maximum performance in the inverted u-shaped function must be located at a shorter inter-repetition interval following incidental learning than following intentional learning. Specifically, in

Experiment 1, maximum free recall performance in the intentional learning condition was expected to occur beyond the longest lag (i.e., lag 8), whereas the maximum free recall performance in the incidental learning condition was expected to be located at an inter-repetition interval of two items (i.e., lag 2). The results of Experiment 1 partially confirmed these predictions. It was demonstrated that the relationship between inter-repetition spacing and free recall was different for the two learning conditions. In the intentional learning condition, it was shown that free recall of lag-8 repetitions surpassed free recall of massed repetitions and of lag-2 repetitions. However, in the incidental learning condition, the predicted inverted u-shaped relationship between spacing and free recall was not obtained. Instead, free recall performance improved as the length of the inter-repetition interval increased from zero (i.e., massed repetition) to two intervening items. Moving from an interval of two intervening items to an interval of eight intervening items, free recall performance remained constant. The failure to reveal the inverted u-shaped function could be taken as evidence against a model that combines mechanisms of contextual-variability and study-phase retrieval to explain the spacing effects in free recall. However, it could also be argued that the number of spacing levels used in Experiment 1 was simply not sufficient to unearth the inverted u-shaped function between spacing and free recall. To remedy this problem, a second experiment was performed.

Experiment 2 was identical to Experiment 1 with the only exception that the study list comprised, besides massed repetitions, repetitions at five spacing levels (i.e., lag 2, lag 5, lag 8, lag 14, and lag 20), as opposed to repetitions at only two spacing levels (i.e., lag 2, and lag 8) in Experiment 1. The results demonstrated an inverted u-shaped function between inter-repetition spacing and free recall for incidentally learned repetitions and for intentionally learned repetitions. Furthermore, the maximum free recall performance was located at a shorter inter-repetition interval for incidentally learned repetitions (i.e., lag 8) than for intentionally learned repetitions (i.e., lag 14). These findings are consistent with the above two-factor model of the spacing effect in free recall tasks.

The experiments described in Chapter 2 demonstrated that changing the presentation background between a repeated item's first occurrence and its second occurrence depresses the free recall performance on that repeated item relative to a situation in which the representation background remains constant. This finding was interpreted in terms of a lower probability of study-phase retrieval for items repeated on a different background in comparison to items repeated on the same background, thereby suggesting that dissimilarities between repeated items at a non-semantic level of representation can disrupt study-phase retrieval. In the study presented in **Chapter 4** we sought to investigate whether a non-semantic dissimilarity between repeated items, other than a difference in presentation background, also exerts a negative influence on study-phase retrieval, and hence on the free recall of repeated items. More specifically, we examined whether a difference between repeated items at the orthographic level of representation affects study-phase retrieval. Theories of language processing make a distinction between an orthographic and a semantic level of representation (e.g., Gollan & Kroll, 2001; Potter, So, Von Eckhart, & Feldman, 1984). The orthographic level represents the physical appearance of a word whereas the semantic level represents the meaning of a word. It could be argued that overlap at the semantic level of representation is sufficient to ensure successful study-phase retrieval. On the other hand, it might be possible that study-phase retrieval will only occur for repetitions that overlap at the semantic and the orthographic level of representation. To investigate which of these alternatives is correct, three experiments were conducted. Bilingual participants studied massed and spaced items repeated either in the same language (i.e., Dutch-Dutch, or English-English) or in a different language (i.e., Dutch-English or English-Dutch), before being tested on the repeated items in a free recall task. In Experiment 1A, participants received intentional learning instructions, whereas in Experiment 1B they received incidental-semantic learning instructions. Both experiments showed that free recall was governed by an interaction between inter-repetition spacing and repetition-language. For massed items, different-language repetitions were better recalled than same-language repetitions, a finding that might be attributed to a richer encoding of different-language repetitions. By contrast, for spaced items free recall did not differ between different-language repetitions and same-language repetitions. This suggests that the study-phase retrieval mechanism is dependent on the semantic, and not on the orthographic overlap between repeated items. However, it could be argued that sharing the same semantic level of representation alone is not sufficient to ensure study-phase retrieval. Instead, it is reasonable to assert that the shared level of semantic representation should be accessed in memory on both occurrences of a repeated item to induce study-phase retrieval. To test this hypothesis, a third experiment was performed.

The third experiment (Experiment 2) was identical to Experiment 1B with the exception that the learning instructions directed participants towards processing of the orthographic features rather than the semantic features of repeated items. If study-phase retrieval requires accessing the semantic level of representation on both occurrences of a repeated item, then the spacing effect in free recall should be absent for different-language repetitions, and for same-language repetitions under orthographic learning instructions. Consistent with this prediction, the spacing effect in free recall performance was neither observed for same-language repetitions, nor for different-language repetitions.

The studies described in Chapters 2 through 4 were directed at the theoretical mechanism underlying the spacing effect in free recall tasks. However, the study presented in **Chapter 5** focused on the theoretical mechanism underlying the spacing effect in cued-memory tasks. Specifically, the study in Chapter 5 investigated the semantic priming explanation of the spacing effect in cued-memory tasks (e.g., Challis, 1993). In this view, the semantic analysis of a repeated item's first occurrences facilitates semantic processing of its second occurrence. The spacing effect in memory is thought to arise because semantic priming of a repeated word's second occurrence is larger for massed items than for spaced items. According to the semantic priming account, the spacing effect should not only be demonstrated for repeated words but also for semantically related pairs, such as *doctor* and *nurse*. Namely, given that related pairs share some semantic features in memory, the presentation of the first word (*doctor*) enhances the subsequent processing of the second word (*nurse*). Analogous to the mechanism for repetitions, the magnitude of priming is expected to be smaller for massed related pairs than for spaced related pairs, and this should produce a spacing effect for related pairs. Contrary to this prediction, studies typically demonstrate that memory for related pairs displays a reversed spacing effect, implying that massed pairs are better remembered than spaced pairs (e.g., Greene, 1989; Hintzman, Summers, & Block, 1975; Stern & Hintzman, 1979). However, in these studies participants were given learning instructions that promoted the organization of the to-be-studied items. It might be possible that the demonstrated reversed spacing effects reflect the organizational structure participants imposed on the items. That is, the probability of becoming encoded into a single memory unit is higher for massed pairs than for spaced pairs, and this could have provided the massed pairs with a memory advantage above spaced pairs. Moreover, the strong influence of organizational processes on memory performance might have masked to influence of semantic priming on memory performance. Thus, the learning instructions used in the aforementioned studies might not be apt to test the semantic priming account. To address this shortcoming, the study presented in Chapter 5 was conducted.

In Experiment 1, participants intentionally learned a word list containing repetitions and related pairs presented either in a massed or a spaced fashion. Subsequently, they received a yes/no recognition test on the words in the list. Experiment 2 was identical to Experiment 1 with the only exception that participants received incidental learning instructions. These incidental learning instructions directed participants towards the processing of the individual items, and averted them from using organizational processes during study. In both experiments, recognition of repetitions demonstrated a spacing effect. More interesting, however, were the findings on the recognition of related pairs. Under intentional learning instructions (Experiment 1), a reversed spacing effect was shown, thereby replicating the findings of earlier studies (e.g., Greene, 1989; Hintzman et al., 1975; Stern & Hintzman, 1979). Conversely, under incidental learning instructions (Experiment 2), massed pairs were remembered as well as spaced pairs. Although this result is at variance with the spacing effect predicted by the semantic priming account (e.g., Challis, 1993), more fine grained analyses yielded some results that could be taken as an evidence in favour of the semantic priming account. As already mentioned, the semantic priming account states that the deficient processing mechanism (i.e., priming) operates at the second occurrence of a repeated or related item, and that the priming effect is larger for massed items than for spaced items. Hence, memory of massed related pairs' second presentations should be worse than memory of massed related pairs' first presentations. With this respect, no memory differences are expected for spaced related pairs. These predictions were met by the results obtained in Experiment 2. Furthermore, the semantic priming account predicts a spacing effect for the related pairs' second presentations, but not for the related pairs' first presentations. In line with this prediction, it was shown that recognition of second presentations revealed a marginally significant spacing effect.

## Discussion

In the previous section, a summary of the main findings of this thesis has been offered. In the next section, some of these findings will be submitted to a closer examination.

First, the results in Chapter 2 and in Chapter 3 were interpreted in terms of a two-factor model that combines a contextual-variability mechanism with a study-phase retrieval mechanism (e.g., Raaijmakers, 2003, Verkoeijen, Rikers & Schmidt, 2003; hereafter referred to as the CVSR-model). However, an alternative account might be provided in the form of a two-factor model that incorporates a deficient processing mechanism, and a study-phase retrieval mechanism (hereafter referred to as a DPSR-model). A DPSR-model proposes that the processing effort allocated to a repeated item's *second occurrence* is an inverse function of the accessibility of its *first occurrence* in memory (e.g., Cuddy & Jacoby, 1983; Jacoby, 1978). As the inter-repetition interval becomes longer, the accessibility of the first occurrence decreases, and the processing effort directed at a repeated item's second occurrence increases. Consequently, memory performance for a repetition rises with the length of the inter-repetition interval. However, a DPSR-model makes the additional assumption that the spacing effect will only be revealed for repetitions, of which the first occurrence is retrieved from memory at its second occurrence (i.e., for repetitions that have undergone study-phase retrieval).

A DPSR-model can readily explain the findings presented in Chapter 2 of this thesis. If a repeated item's second occurrence is offered immediately after an identical first occurrence (i.e., massed presentation), a participant can bypass much of the processing that would otherwise required to encode the second occurrence, because a copy (i.e., the first occurrence) is available in short-term store. In contrast, if a repeated item's second occurrence contains features that were present in the first occurrence, such as a novel presentation background, a participant can no longer rely on the previously stored first occurrence to encode the second occurrence. Instead, an effort should be made to process the new features in the second occurrence. Hence, with respect to massed items, the deficient processing component of a DPSR-model predicts that free recall of items repeated on a different background surpasses free recall of items repeated on the same background. The free recall patterns for massed items obtained in the experiments reported in Chapter 2 are consistent with this prediction. Regarding spaced items, the encoding specificity principle (e.g., Tulving, 1983; Tulving & Thomson, 1973) states that the probability of retrieving a repeated item's first occurrence at its second occurrence is lower for different-background repetitions than for same-background repetitions. Therefore, the study-phase retrieval component of a DPSR-model dictates, in line with the free recall patterns for spaced items revealed in the experiments presented in Chapter 2, that free recall is worse for spaced items repeated on a different background than for spaced items repeated on the same background.

In a similar vein, a DPSR-model can account for the inverted u-shaped functions between inter-repetition spacing and free recall revealed in Experiment 2 in Chapter 3. Specifically, as the inter-repetition interval increases, the probability of study-phase retrieval gradually decreases. At the same time, the deficient processing component of a DPSR-model proposes that retrieved repeated items receive an increasing amount of processing effort. Initially, the second process dominates, thereby producing a spacing effect in free recall of repeated items. However, from a certain inter-repetition interval onwards, the first process starts to outweigh the second process, resulting in a decline of free recall performance with further inter-repetition spacing. Thus, like the CVSR-model (e.g., Raaijmakers, 2003; Verkoeijen et al., 2004), a DPSR-model assumes that free recall of repetitions can be expressed as an inverted u-shaped function of inter-repetition spacing. Furthermore, a DPSR-model proposes that the point of maximum performance in the inverted u-shaped function is dependent on depth of item processing. If the learning instructions induce a relatively shallow level of item processing (i.e., the incidental learning instructions in Experiment 2), the onset of the negative consequences of study-phase retrieval failure on free recall performance will begin at a shorter inter-repetition interval than if the learning instructions promote a relatively deep level of processing (i.e., the intentional learning instructions in Experiment 2). Consequently, the point of maximum performance will be situated at a shorter inter-repetition interval for relatively shallowly processed repetitions than for relatively deeply processed items. The results of Experiment 2 in Chapter 3 confirmed this prediction, as the maximum point of performance was located at a shorter inter-repetition interval for incidentally learned repetitions than for intentionally learned repetitions.

To summarize, the findings presented in Chapter 2 and Chapter 3 of this thesis can not only be accommodated by the CVSR-model (e.g., Raaijmakers, 2003;

Verkoeijen et al., 2004) but also by the above-outlined DPSR-model. The obvious next question is: which of these models is correct? To answer this question, further research is needed employing an experimental manipulation that competitively compares the deficient-processing (DP) mechanism with the contextual-variability (CV) mechanism. However, given the broad definition of the concept of contextual-variability it is extremely difficult to come up with a manipulation that taps on one mechanism, and leaves the other unaffected. For example, changing the surface form of a repeated sentence (e.g., Krug, Davis, & Glover, 1990; Delarosa & Bourne, 1983) might, one hand, be considered as a experimental manipulation that increases the number of to-be-encoded contextual elements relative to a condition in which the same sentence is shown twice. On the other hand, it could be argued that the second occurrence of a repeated sentence receives more processing when presented in a different surface form than when presented in the same surface form. Thus, a challenge of upcoming research at the spacing effect is to find an experimental manipulation that can disentangle the deficient-processing mechanism and the contextual-variability mechanism.

A second issue that deserves discussion is the discrepancy between free recall of spaced items demonstrated in the experiments reported in Chapter 2, and the free recall of spaced items in the first two experiments of Chapter 4. Both experiments in Chapter 2 showed that the variation in presentation background between the first occurrence and the second occurrence of a repeated item had a detrimental effect on the free recall of that item. Namely, the probability of recalling spaced items was lower for items repeated on a different background than for items repeated on the same background. Briefly put, the observed free recall pattern was explained by proposing that (1) inter-repetition spacing will only exert a positive influence on memory of a repeated item if study-phase retrieval takes place for this item, and (2) the encoding specificity principle (e.g., Tulving, 1983; Tulving & Thomson, 1973) caused study-phase retrieval to fail for a larger proportion of spaced different-background repetitions than of spaced same-background repetitions. If this explanation holds true then it seems reasonable to conclude that non-semantic dissimilarities between the two occurrences of a repeated item disrupt study-phase retrieval. However, the results obtained in Experiment 1A and Experiment 1B in Chapter 4 suggest that such a conclusion is not entirely correct. Using learning instructions that induced a semantic mode of item processing, these experiments demonstrated that spaced items repeated in a different language were recalled as well as spaced items repeated in the same language. This suggests that changing the orthography of a repeated item, a manipulation that taps onto the non-semantic level of representation of a stimulus (similar to the context manipulation employed in the experiments in Chapter 2) does not obstruct study-phase retrieval. Thus, taken together, the findings obtained in Chapter 2 and Chapter 4 seem to indicate that the study-phase retrieval mechanism operates on a repeated item's semantic features and on the context in which the item is presented, and it is not dependent on a repeated item's orthographic features.

A third point of discussion is the recognition pattern obtained in Experiment 2 of Chapter 5. In this experiment participants learned, under incidental-semantic instructions, either repetitions or semantically related pairs (e.g., doctor-nurse). After the study-phase, they were tested on the target items in a recognition tasks. According to the semantic priming theory of spacing effect in cued-memory tasks (e.g., Challis, 1993), the first occurrence of a repetition or a semantically related pair primes its second presentation. Furthermore, the magnitude of the priming effect decreases as the inter-repetition interval becomes longer, leading to the spacing effect in memory performance. Therefore, in Experiment 2, a spacing effect in recognition was predicted for both repetitions and semantically related pairs. Moreover, because priming taps onto a related pairs' second occurrence, a spacing effect was predicted for the related pairs' second occurrences but not for their first occurrences.

The recognition data obtained in Experiment 2 presented in Chapter 5 were not entirely consistent with these predictions. For repetitions, recognition data were straightforward, displaying a standard spacing effect. However, for semantically related pairs, spacing failed to influence overall recognition performance (i.e., recognition for the first and the second occurrence), a finding that argues against the semantic priming theory. At the same time, and in line with the semantic priming theory, the recognition of second occurrences showed a marginally significant spacing effect, whereas the spacing effect was absent in the recognition of first occurrences. But what can be inferred from these somewhat ambivalent recognition data about the proposed relationship between semantic priming and the spacing effect in cued-memory tasks? Reasoning in favour of the semantic priming theory, it might be possible that the spacing effect for the recognition of related pairs' second occurrences was caused by larger priming effect for massed items in comparison to spaced items. In addition, the absence of a spacing effect for related pairs' overall recognition performance might be explained by suggesting that priming was not sufficiently large to induce the spacing effect. However, the outlined account of the data is merely speculative because in the present experiment there was no direct way to determine the relationship between priming and recognition. To resolve this issue, further research should be conducted in which both semantic priming of related pairs' second occurrences and recognition performance is assessed. If the semantic priming theory provides a valid explanation of the spacing effect in cued-memory tasks, a negative correlation between priming and memory performance should be revealed.

## Conclusion

On the basis of the findings reported in the present thesis it could be concluded that a two-factor model, incorporating a study-phase retrieval mechanism and a contextual-variability mechanism, is needed to provide a complete account of the spacing effect in free recall tasks. This conclusion is interesting because it runs counter to the generally accepted notion that the spacing effect in free recall can be accounted for by a single-factor model (e.g., Greene, 1989, 1990; Russo et al, 1998, 2002). Furthermore, the study-phase retrieval mechanism in the two-factor model is found to operate on a repeated item's semantic representation and on its presentation context. That is, study-phase retrieval occurs under the condition that the two occurrences of a repeated item overlap in terms of activated semantic features and in presentation context.

Regarding the semantic priming theory on spacing effects in cued-memory tasks (e.g., Challis, 1993), the present thesis can only provide a preliminary conclusion. Compatible with the semantic priming theory, the second experiment presented in Chapter 5 showed a marginally significant spacing effect for related pairs' second occurrences. This finding might reflect the negative influence of semantic priming on recognition performance. However, such interpretation should be regarded with extreme caution given that (1) the overall recognition data for related pairs were inconsistent with the semantic priming theory (i.e., the predicted spacing effect was not obtained), and (2) the proposed relationship between priming and recognition could not be verified.

## Suggestions for further research

The results reported in the present thesis provided new insights into the mechanisms underlying the spacing effect in free recall tasks and in cued-memory tasks. Having said that, there are still many important issues related to the spacing effect that have not been investigated in this thesis, but that need to be addressed in future studies.

First, an effort should be made to further examine the merits of the semantic priming account of the spacing effect in cued-memory tasks (e.g., Challis, 1993). According to this account, the spacing effect can be attributed to the fact that the priming of a repeated item's second occurrence is larger for massed repetitions than for spaced repetitions. Reasoning from the semantic priming theory, it follows, amongst other things, that an experimentally induced elimination of priming should increase the memory performance of massed repetitions to the level of spaced repetitions, causing the spacing effect to disappear. However, direct empirical evidence in favour of this prediction is non-existent, and upcoming research should be conducted to fill the caveat. An experimental procedure that may be used to manipulate the priming effect is the one used in a study by Vriezen, Moscovitch, and Bellos (1995). In this study, participants performed either the same semantic decision task on the occurrences of a repeated item (i.e., a man-made decision or a size decision), or they performed two different semantic tasks on the occurrences of a repeated item. The results demonstrated a priming effect in the condition that required participants to repeat their decision. In contrast, no priming effect was revealed in the condition that required participants to make two different decisions. However, the study of Vriezen et al., (1995) concerned long-term repetition priming, whereas a typical spacing-effect study involves short-term repetition priming. Hence, before the procedure put forward by Vriezen et al., (1995) can be incorporated in a spacing-effect study, it should be made sure that it is also effective in the manipulation of short-term priming.

The second suggestion for further research relates to the practical application of the spacing effect. The studies in the present thesis used a standard spacing paradigm (e.g., Melton, 1967) in which the presentation time of repeated items as well as the inter-repetition interval was experimentally controlled. Despite the fact that the results obtained in this paradigm yield important information about the spacing effect in memory, it is hard to generalize them to real-life learning situations. That is, in real-life learning situations, people themselves determine the amount of processing time that they wish to invest in to-be-studied materials. Moreover, if they decide on using a rehearsal strategy to acquire mastery of certain to-be-studied materials, then they control the length of the inter-repetition interval. The latter notion was the starting point of an experiment by Son (2004).

In this experiment, participants were required to learn word-synonym pairs, each pair being shown for 1s. After the pairs' presentation, participants had to indicate the probability that they would be able to recall the synonym when shown the corresponding word at a later memory test, that is, they had to give a judgment of learning (JOL) for each pair. Subsequently, they were presented with three options: "study now", "study later", or "done". If "study now" was chosen, the word-synonym pair was repeated immediately (i.e., massed presentation). If "study later" was chosen, the pair was repeated at the end of the list (i.e., spaced presentation), and if "done" was chosen, the pair was not shown again. Remarkably, the results demonstrated that spacing strategy interacted with the judged difficulty (JOL) of a word-synonym pair. More specifically, it was revealed that participants predominantly used massed strategies when pairs were relatively difficult, whereas they used spaced strategies when pairs where relatively easy. These findings were interpreted in terms of the *metacognitive hypothesis* (cf. Metcalfe, 2003), which suggests that learners control repetition strategies on the basis of metacognitive knowledge about to-be-studied materials. If an item is well learned (i.e., high in metacognitive knowledge, and high JOL), then it will not be necessary to study the same item again. Under that condition, waiting a while before the same item is shown again might be an obvious strategy. Alternatively, if an item is not yet learned (i.e., low in metacognitive knowledge, and low JOL), then continuing to study might be beneficial.

Although the above findings are in support of the metacognitive hypothesis, there are numerous predictions of this hypothesis that yet remain untested. For instance, according to the metacognitive hypothesis, factor such as the learner's level of expertise, and the amount of study time available at the first presentation of an item should influence the selection of repetition strategies. These, and other predictions of the metacognitive hypothesis may be submitted to the scrutiny of further research. Furthermore, it may be interesting to investigate whether learners can employ their metacognitive knowledge to select repetition strategies that improve their learning.

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# Samenvatting en conclusies

Stelt u zich de volgende situatie eens voor: u neemt deel aan een psychologisch experiment en u dient een lijst met woorden te bestuderen waarbij ieder woord automatisch en gedurende een van te voren vastgestelde tijd op een computerscherm wordt getoond. Sommige woorden in de lijst komen slechts éénmaal voor terwijl andere woorden herhaald worden. Tevens varieert de afstand tussen de eerste en de tweede aanbieding van woorden. Soms volgt de herhaling onmiddellijk, zoals in ***vis-vis****-zoon-straat-straat-bakker;* soms pas na een paar andere woorden: ***vis****-zoon-straat-straat-bakker-****vis***. Nadat alle woorden in de lijst bestudeerd zijn, wordt het geheugen voor de bestudeerde woorden getest. Dergelijke experimenten laten meestal de volgende resultaten zien: allereerst worden woorden die tweemaal gepresenteerd zijn beter onthouden dan woorden die éénmaal gepresenteerd zijn. Daarnaast worden herhaalde woorden beter onthouden naarmate de afstand tussen de eerste en de tweede aanbieding van een woord groter wordt. Dit laatste fenomeen staat bekend als *het spreidingseffect (in het Engels: spacing effect)* en het is aangetoond onder een groot aantal experimentele omstandigheden en bij uiteenlopende geheugentests. Het lijkt erop dat de oorzaak van een spreidingseffect dat bij free recall tests optreedt, een andere is dan die bij cued-recall tests. Daarom wordt tegenwoordig een onderscheid gemaakt tussen een theoretische verklaring voor het spreidingseffect in free recall geheugentests en een theoretische verklaring voor het spreidingseffect in expliciete, cued-memory tests.

Het spreidingseffect in free recall geheugentests wordt verklaard aan de hand van de *studiefaseherinneringstheorie (in het Engels: study-phase retrieval theory)*. In die benadering speelt de context waarin de woorden geleerd worden een centrale rol. Met context wordt niet alleen bedoeld de kleur van het papier waarop de woorden gedrukt staan maar ook kenmerken van de directe omgeving: de inrichting van het laboratorium etc. (Aangetoond is dat die contextinformatie tegelijk met de woorden wordt opgeslagen). Volgens de *studiefaseherinneringstheorie* worden aspecten van de context die veranderen gedurende het interval tussen de eerste en de tweede aanbieding van een woord automatisch opgeslagen in het langetermijngeheugen samen met het geheugenspoor van het herhaalde woord. In een free recall geheugentest worden de opgeslagen contextuele elementen gebruikt om het bewuste woord terug te halen uit het langetermijngeheugen. Hoe meer contextuele elementen beschikbaar zijn, hoe groter de kans dat een woord op een free recall test gereproduceerd zal worden. Aangezien de contextuele verandering toeneemt naarmate het herhalingsinterval langer wordt, stijgt het aantal opgeslagen contextuele elementen als een functie van de lengte van het herhalingsinterval. Hieruit volgt dat de kans om een bepaald woord te reproduceren op een free recall test eveneens stijgt als een functie van de lengte van het herhalingsinterval. Echter, een belangrijke veronderstelling van de studiefaseherinneringstheorie is dat de encodering van contextuele elementen alleen zal plaatsvinden als het geheugenspoor behorende bij de eerste aanbieding van een woord teruggehaald wordt uit het langetermijngeheugen op het moment dat het woord voor de tweede keer wordt aangeboden (studiefaseherinnering). Dientengevolge voorspelt de studiefaseherinneringstheorie dat het spreidingseffect alleen zal plaatsvinden voor herhaalde woorden die geïdentificeerd zijn als herhalingen.

Om het spreidingseffect in expliciete, cued-memory tests te verklaren wordt een *transfer-appropriate processing* benadering gecombineerd met twee kwalitatief verschillende preactivatiemechanismen (*in het Engels: priming mechanisms)*. Indien herhaalde woorden zowel tijdens de bestudering als tijdens de geheugentest betekenisvol (semantisch) verwerkt worden dan wordt het spreidingseffect verklaard aan de hand van een semantisch preactivatie mechanisme. Volgens dit mechanisme activeert de eerste aanbieding van een woord de semantische representatie van het woord in het langetermijngeheugen. Wanneer nu de tweede aanbieding van het woord direct volgt op de eerste aanbieding dan is de semantische representatie van de eerste aanbieding nog steeds geactiveerd. Het gevolg is dat de semantische verwerking van de tweede aanbieding vergemakkelijkt zal worden door de eerste aanbieding. Echter, dit faciliterende effect neemt zeer snel af met de lengte van het herhalingsinterval. De totale hoeveelheid semantische verwerking die een woord ontvangt, zal dus toenemen als een functie van de lengte van het herhalingsinterval en hierdoor ontstaat het spreidingseffect in cued-memory tests. Indien echter, om welke reden dan ook, de semantische verwerking van herhaalde woorden niet mogelijk is tijdens de bestudering en tijdens de test dan wordt verondersteld dat het spreidingseffect in cued-memory tests veroorzaakt wordt door een structureel-perceptueel preactivatie mechanisme. Het structureel-perceptuele preactivatie mechanisme is conceptueel analoog aan het semantische preactivatie mechanisme met als enige uitzondering dat het plaatsvindt op het orthografische niveau van woordrepresentatie en niet op het semantische niveau van woordrepresentatie.

De in dit proefschrift beschreven studies zijn gericht op verschillende aspecten van de voornoemde theoretische verklaringen van het spreidingseffect. De studies in de hoofdstukken 2 t/m 4 hebben betrekking op het spreidingseffect in free recall geheugentests. De studie in hoofdstuk 5 daarentegen is uitgevoerd om het spreidingseffect in cued-memory tests nader te onderzoeken.

## Overzicht van de empirische bevindingen

De studie in **Hoofdstuk 2** omvatte twee experimenten waarin deelnemers intentioneel een lijst dienden te bestuderen bestaande uit woorden die eenmaal gepresenteerd werden, woorden die direct achter elkaar herhaald werden (gegroepeerde herhalingen) en woorden die na een interval van zes tussenliggende woorden herhaald werden (gespreide herhalingen). Daarnaast werd de helft van de herhaalde woorden tweemaal gepresenteerd tegen dezelfde achtergrond, terwijl de andere helft gepresenteerd werd tegen verschillende achtergronden. De achtergrond werd in de twee experimenten op verschillende manieren gemanipuleerd. In Experiment 1 werd de achtergrondkleur gevarieerd tussen de eerste en de tweede aanbieding van een woord. In Experiment 2, daarentegen, werd één van de twee aanbiedingen van een woord gepresenteerd tegen de achtergrond van een boslandschap, terwijl de andere aanbieding gepresenteerd werd tegen de achtergrond van een stadslandschap. Na afloop van zowel Experiment 1 als Experiment 2 werd deelnemers gevraagd om zoveel mogelijk woorden uit de bestudeerde lijst op te schrijven als zij zich nog konden herinneren (een free recall test). In beide experimenten werd aangetoond dat, ten opzichte van de conditie waarin de achtergrond tussen de eerste en de tweede aanbieding van een woord constant bleef, de achtergrondvariatie de free recall van gegroepeerde herhalingen verhoogde, maar dat zij de free recall van gespreide herhalingen verlaagde. Tevens werd in beide experimenten een spreidingseffect gevonden voor woorden die herhaald werden tegen dezelfde achtergrond. Voor herhalingen gepresenteerd tegen verschillende achtergronden werd echter geen spreidingseffect aangetoond. Deze bevindingen zijn interessant omdat geen van de bestaande theorieën over het spreidingseffect in free recall geheugentests in staat is de bevindingen volledig te verklaren.

De studiefaseherinneringstheorie gaat er, zoals reeds vermeld, vanuit dat contextuele elementen automatisch opgeslagen worden in het langetermijngeheugen met het spoor van het herhaalde woord. Het spreidingseffect ontstaat omdat het aantal opgeslagen contextuele elementen, en daarmee de toegankelijkheid van een bepaald woord tijdens de free recall geheugentest, toeneemt wanneer het herhalingsinterval langer wordt. Echter, de encodering van contextuele elementen zal alleen plaatsvinden als studiefaseherinnering heeft plaatsgevonden. Op basis van eerder onderzoek kan worden afgeleid dat de kans op studiefaseherinnering lager is voor woorden die herhaald worden tegen een verschillende achtergrond dan voor woorden die herhaald worden tegen dezelfde achtergrond. Dit impliceert dat de encodering van contextuele elementen proportioneel vaker zal falen voor gespreide woorden die herhaald worden tegen een verschillende achtergrond dan voor gespreide woorden die herhaald worden tegen dezelfde achtergrond. Vanuit de studiefaseherinneringstheorie leidt dit gegeven tot de voorspelling dat gespreide woorden minder goed onthouden worden wanneer ze herhaald zijn tegen een verschillende achtergrond dan wanneer ze herhaald zijn tegen dezelfde achtergrond. Deze voorspelling werd ondersteund door de resultaten van de experimenten beschreven in hoofdstuk 2. De studiefaseherinneringstheorie heeft echter problemen met het verklaren van de resultaten die gevonden werden voor gegroepeerde woorden. In het geval van gegroepeerde woorden is de eerste aanbieding namelijk nog in het kortetermijngeheugen op het moment dat de tweede aanbieding gepresenteerd wordt. Volgens de studiefaseherinneringstheorie heeft dit tot gevolg dat contextuele elementen, zoals achtergrondveranderingen, niet opgeslagen worden met het herhaalde woord. Met betrekking tot free recall van gegroepeerde woorden voorspelt de studiefaseherinneringstheorie daarom ook geen verschillen tussen woorden die herhaald zijn tegen een verschillende achtergrond en woorden die herhaald zijn tegen dezelfde achtergrond. Deze voorspelling werd tegengesproken door de resultaten van de experimenten in hoofdstuk 2 die lieten zien dat achtergrondvariatie een positieve invloed heeft op de free recall van gegroepeerde woorden. Om dit positieve effect te verklaren dient een tweede mechanisme gepostuleerd te worden.

Vergelijkbaar met de studiefaseherinneringstheorie gaat de contextuele-variatie benadering ervan uit dat contextuele elementen automatisch opgeslagen worden met het spoor van het herhaalde woord. Echter, in tegenstelling tot de studiefaseherinneringstheorie doet de contextuele-variatie benadering niet de additionele aanname dat studiefaseherinnering vereist is voor de encodering van contextuele elementen. Indien herhaalde woorden gepresenteerd worden tegen verschillende achtergronden dan voorspelt de contextuele-variatie benadering dat de relatieve stijging van het aantal opgeslagen contextuele elementen, ten opzichte van de situatie waarin herhaalde woorden gepresenteerd worden tegen dezelfde achtergrond, groter zal zijn voor gegroepeerde woorden dan voor gespreide woorden. Dientengevolge voorspelt de contextuele-variatie benadering dat achtergrondvariatie de free recall van gegroepeerde woorden meer zal verbeteren dan de free recall van gespreide woorden. Het eerste gedeelte van de voorspelling werd bevestigd door de resultaten van de experimenten in hoofdstuk 2, maar het tweede gedeelte van de voorspelling werd tegengesproken door de resultaten. Wanneer we de resultaten van de experimenten in hoofdstuk 2 in beschouwing nemen dan zou er geconcludeerd worden dat zowel een studiefaseherinnering mechanisme als een contextuele-variatie mechanisme vereist zijn om een volledige verklaring te bieden voor het spreidingseffect in free recall tests.

De studie die beschreven is in **Hoofdstuk 3** werd uitgevoerd om een voorspelling te toetsen die volgt uit het twee-factoren model van het spreidingseffect in free recall tests dat gepostuleerd werd op basis van de resultaten van de studie in hoofdstuk 2. Volgens het twee-factoren model wordt het effect van de lengte van het herhalingsinterval op de free recall van woorden bepaald door twee processen. Enerzijds zorgt de werking van het contextuele-variatie mechanisme ervoor dat het aantal opgeslagen contextuele elementen toeneemt, maar anderzijds neemt de kans op studiefaseherinnering af. Aanvankelijk zal, met de toename van de lengte van het herhalingsinterval, studiefaseherinnering optreden voor de overgrote meerderheid van de woorden. Gegeven dat de contextuele variatie toeneemt naarmate het herhalingsinterval langer wordt, zal free recall aanvankelijk stijgen als een functie van de lengte van het herhalingsinterval. Echter, vanaf een bepaald herhalingsinterval zal het percentage woorden waarvoor studiefaseherinnering optreedt zodanig klein zijn dat de negatieve invloed van studiefaseherinnering op de geheugenprestatie de positieve invloed van contextuele variatie overschaduwt.

Het gevolg hiervan is dat free recall vanaf dit bewuste herhalingsinterval zal dalen als een functie van de lengte van het herhalingsinterval. Samenvattend kan dus gesteld worden dat het in hoofdstuk 2 beschreven twee-factoren model een soort bergparabolische relatie voorspelt tussen free recall van woorden en de lengte van het herhalingsinterval. Het doel van de studie in hoofdstuk 3 was om empirische ondersteuning te vinden voor deze voorspelde bergbarabolische relatie.

In Experiment 1 bestudeerden deelnemers een lijst met woorden nadat zij ofwel een incidentele leerinstructie ("probeer een regel te vinden die de aanbiedingsvolgorde van de woorden bepaalt") ofwel een intentionele leerinstructie ("probeer zoveel mogelijk woorden te onthouden voor een latere geheugentaak") hadden ontvangen. De lijst bestond uit woorden die eenmaal gepresenteerd werden, woorden die direct na elkaar herhaald werden, woorden die na twee tussenliggende woorden herhaald werden (lag-2 woorden) en woorden die na acht tussenliggende woorden herhaald werden (lag-8 woorden). Alle woorden werden één voor één automatisch getoond in het midden van een computerscherm en ieder woord was 10 seconden in beeld. Nadat alle woorden bestudeerd waren, ontvingen de deelnemers een free recall test over de bestudeerde woorden.

Op basis van de resultaten die in eerdere onderzoeken gerapporteerd werden, gingen wij ervan uit dat de semantische verwerking oppervlakkiger zou zijn voor incidenteel bestudeerde woorden dan voor intentioneel bestudeerde woorden. In vergelijking met de situatie waarin de eerste aanbieding van een woord relatief diep verwerkt is, zal de kans op studiefaseherinnering van de eerste aanbieding van een relatief oppervlakkig verwerkt woord reeds bij een korter herhalingsinterval beginnen te dalen. Met betrekking tot de relatie tussen free recall van woorden en de lengte van het herhalingsinterval impliceert dit dat de top van de veronderstelde bergparabolische functie voor incidenteel bestudeerde woorden samen zal vallen met een korter herhalingsinterval dan voor intentioneel bestudeerde woorden. De resultaten van Experiment 1 lieten echter geen bergparabolische functie zien. In de intentionele conditie was het geheugen voor lag-8 herhalingen beter dan het geheugen voor zowel gegroepeerde herhalingen als voor lag-2 herhalingen. In de incidentele conditie daarentegen was het geheugen voor lag-2 herhalingen beter dan voor gegroepeerde herhalingen, maar werd er geen verschil gevonden tussen lag-2 herhalingen en lag-8 herhalingen. Het feit dat de voorspelde bergparabolische functie niet aangetoond werd in Experiment 1 zou op twee manieren geïnterpreteerd kunnen worden. Ten eerste zou het opgevat kunnen worden als een empirisch bewijs tegen het twee-factoren model van het spreidingseffect in free recall tests. Daarnaast zou het mogelijk kunnen zijn dat de bergparabolische fucntie niet werd aangetoond omdat er slechts een beperkt aantal herhalingsintervallen gebruikt werd. Om de laatste interpretatie te toetsen werd een tweede experiment uitgevoerd.

Experiment 2 was identiek aan het eerste experiment met als enige uitzondering dat er in plaats van drie herhalingsintervallen (gegroepeerde herhaling, lag-2 herhaling en lag-8 herhaling) er nu zes herhalingsintervallen (gegroepeerde herhaling, lag-2 herhaling, lag-5 herhaling, lag-8 herhaling, lag-14 herhaling en lag-20 herhaling) gebruikt werden. De resultaten lieten in zowel de intentionele conditie als in de incidentele conditie een bergparabolische relatie tussen de free recall van woorden en de lengte van het herhalingsinterval zien. Bovendien bleek de top van de bergparabolische functie in de intentionele conditie samen te vallen met een langere herhalingsafstand dan in de incidentele conditie. Deze resultaten zijn volledig in overeenstemming met de voorspelling van het twee-factoren model.

In hoofdstuk 2 werd aangetoond dat gespreide herhalingen beter onthouden werden wanneer ze tweemaal gepresenteerd werden tegen dezelfde achtergrond dan wanneer ze tweemaal gepresenteerd werden tegen verschillende achtergronden. Deze bevinding werd geïnterpreteerd in termen van een studiefaseherinneringsmechanisme. De kans op studiefaseherinnering zou lager zijn voor woorden die herhaald werden tegen een verschillende achtergrond dan voor woorden die herhaald werden tegen dezelfde achtergrond met als gevolg een betere free recall prestatie voor de laatstgenoemde categorie van woorden. Een dergelijke interpretatie veronderstelt dat het studiefaseherinneringsmechanisme gevoelig is voor non-semantische verschillen tussen de eerste en tweede aanbieding van een woord, zoals verschillen in de achtergrond waartegen beide aanbiedingen gepresenteerd worden. De studie beschreven in **Hoofdstuk 4** werd uitgevoerd om te bepalen of, naast achtergrondverschillen, andere non-semantische verschillen tussen de beide aanbiedingen van een woord het studiefaseherinneringsmechanisme kunnen beïnvloeden. Meer specifiek gesteld, werd er bekeken of studiefaseherinnering, en daarmee free recall, beïnvloed zou worden door orthografische verschillen tussen de twee aanbiedingen van een woord. Hiertoe werden Engels-Nederlandse herhaalparen gebruikt zoals *shark-haai*, die in het geheugen dezelfde semantische representatie hebben maar die op orthografisch niveau afzonderlijk gerepresenteerd zijn. In de controle conditie werden woorden gebruikt die tweemaal gepresenteerd werden in het Engels of tweemaal in het Nederlands. Als studiefaseherinnering bemoeilijkt zou worden door het ontbreken van orthografische gelijkenis tussen de twee aanbiedingen van een woord dan zou free recall van gespreide herhalingen slechter moeten zijn voor woorden die gepresenteerd worden in verschillende talen dan voor woorden die gepresenteerd worden in dezelfde taal. Indien echter studiefaseherinnering niet beïnvloed zou worden door orthografische verschillen tussen de twee aanbiedingen van een woord dan zou free recall van gespreide woorden gepresenteerd in verschillende talen niet moeten afwijken van free recall van woorden gepresenteerd in dezelfde taal. Om te bepalen welke van de twee hypopthesen juist is, werden twee experimenten (Experiment 1A en Experiment 1B) uitgevoerd. In beide experimenten leerden tweetalige deelnemers herhaalde woorden die gepresenteerd werden in verschillende talen en herhaalde woorden die gepresenteerd werden in dezelfde taal. Sommige woorden werden direct na elkaar herhaald en andere woorden werden na een interval van zes tussenliggende woorden herhaald. Alle woorden werden drie seconden in het midden van een computerscherm getoond. Het onderscheid tussen de beide experimenten werd gevormd door de leerinstructie: in Experiment 1A ontvingen de deelnemers een intentionele leerinstructie, terwijl de deelnemers in Experiment 1B een incidenteel-semantische instructie ontvingen. Zowel in Experiment 1A als in Experiment 1B werd aangetoond dat free recall voor gegroepeerde herhalingen beter was indien woorden gepresenteerd werden in verschillende talen dan indien woorden gepresenteerd werden in dezelfde taal. Free recall van gespreide woorden was echter hetzelfde in beide condities. De laatste bevinding ondersteunt de hypothese dat orthografische verschillen tussen de eerste en de tweede aanbieding van een woord geen effect hebben op het studiefaseherinneringsmechanisme. Tevens suggereert zij dat studiefaseherinnering in dit geval plaatsvindt als woorden dezelfde semantische representatie delen in het langetermijngeheugen. Echter, het is aannemelijk dat het delen van een semantische representatie niet voldoende is om studiefaseherinnering te waarborgen. Zo zou er bijvoorbeeld verondersteld kunnen worden dat studiefaseherinnering alleen dan plaatsvindt als de gedeelde semantische representatie tijdens de eerste en tijdens de tweede aanbieding van een woord geactiveerd wordt. Om deze veronderstelling te toetsen werd nog een experiment uitgevoerd.

Experiment 2 was identiek aan Experiment 1B met als enige uitzondering dat deelnemers geen incidenteel-semantische instructie maar een incidenteel-orthografische leerinstructie ontvingen. Als studiefaseherinnering zich alleen voordoet op het moment dat het semantische representatieniveau geactiveerd wordt tijdens beide aanbiedingen van een woord dan zou het spreidingseffect afwezig moeten zijn voor herhalingen in verschillende talen én voor herhalingen in dezelfde taal in het geval dat de leerinstructie de deelnemers dwingt om zich te richten op de orthografische kenmerken van herhaalde woorden. De resultaten van Experiment 2 ondersteunden deze voorspelling

De studies beschreven in de hoofdstukken 2 tot en met 4 waren gericht op het mechanisme dat ten grondslag ligt aan het spreidingseffect in free recall geheugentests. De studie in **Hoofdstuk 5** daarentegen werd uitgevoerd om het mechanisme nader te onderzoeken dat ten grondslag zou liggen aan het spreidingseffect in cued-memory tests. De gangbare verklaring voor het spreidingseffect in dergelijke tests wordt gegeven in de vorm van de semantische preactivatie theorie. Volgens deze theorie faciliteert de semantische verwerking van de eerste aanbieding van een woord de verwerking van de tweede aanbieding. Daar het faciliterende effect afneemt naarmate de lengte van het herhalingsinterval toeneemt, neemt de totale hoeveelheid semantische verwerking die een woord ontvangt toe met de lengte van het herhalingsinterval. Dit resulteert vervolgens in het spreidingseffect op een cued-memory test. Volgens de semantische preactivatie theorie zouden spreidingseffecten echter niet alleen gevonden moeten worden bij identieke herhalingen maar ook bij semantisch gerelateerde woordparen zoals *vader* en *moeder*. Semantisch gerelateerde woorden delen namelijk bepaalde representatiekenmerken in het langetermijngeheugen en daardoor zal de aanbieding van het eerste woord (*vader*) de verwerking van het tweede woord (*moeder*) vergemakkelijken. Analoog aan de situatie die zich voordoet bij herhalingen, neemt het faciliterende effect af met de lengte van het herhalingsinterval. Dientengevolge zou er voor gerelateerde woordparen eveneens een spreidingseffect op moeten treden. Deze voorspelling wordt echter tegengesproken door studies die laten zien dat er een negatief spreidingseffect bestaat voor gerelateerde paren; gerelateerde woorden die direct na elkaar gepresenteerd worden, worden beter onthouden dan gespreide gerelateerde woorden. Echter, in deze studies werden leerinstructies gebruikt die de deelnemers aanzetten tot de clustering van de bestudeerde woorden. Het zou mogelijk kunnen zijn dat de gevonden negatieve spreidingseffecten een reflectie vormen van de clusterstructuur die de deelnemers aanbrachten in de bestudeerde woorden. Immers, de kans dat twee gerelateerde worden in hetzelfde geheugencluster worden ondergebracht, is groter wanneer de twee gerelateerde worden direct na elkaar gepresententeerd worden (gegroepeerde presentatie) dan wanneer de woorden gescheiden worden door tussenliggende woorden. Aangezien geclusterde woorden beter onthouden worden dan niet-geclusterde woorden zal het geheugen voor gegroepeerde gerelateerde woorden beter zijn dan voor gespreide gerelateerde woorden met als resultaat een negatief spreidingseffect. Echter, doordat de groepering van bestudeerde woorden zo'n sterke invloed heeft op het geheugen voor deze woorden, is het vrijwel onmogelijk om het effect van andere mechanismen, zoals semantische preactivatie, te bepalen. Om de invloed van semantische preactivatie op het geheugen te testen zou het dus raadzaam zijn om leerinstructies te gebruiken die verhinderen dat deelnemers de te bestuderen woorden gaan clusteren. Naar aanleiding van deze constatering werd de studie beschreven in hoofdstuk 5 uitgevoerd.

In Experiment 1 kregen de deelnemers intentionele leerinstructies voordat zij een lijst bestaande uit herhaalde woorden en uit gerelateerde woordparen dienden te bestuderen. De herhaalde woorden en de gerelateerde woorden werden ofwel direct na elkaar gepresenteerd ofwel na een interval van zes tussenliggende woorden. Nadat de woorden bestudeerd waren, ontvingen de deelnemers een herkenningstaak. Experiment 2 was identiek aan Experiment 1 met als enige verschil dat de deelnemers een incidenteel-semantische leerinstructie in plaats van een intentionele leerinstructie kregen. Deze incidentele leerinstructie was erop gericht om deelnemers aan te zetten tot de semantische verwerking van individuele woorden en om de groepering van woorden zoveel mogelijk te beperken. De resultaten in Experiment 1 en Experiment 2 lieten een spreidingseffect zien in de herkenning van herhaalde woorden. In dit geval waren we echter meer geïnteresseerd in de resultaten die betrekking hadden op de herkenning van gerelateerde woorden. Voor intentioneel bestudeerde woorden gold dat gerelateerde woordparen beter onthouden werden wanneer de woorden direct na elkaar gepresenteerd werden dan wanneer ze gespreid gepresenteerd werden. Het gevonden negatieve spreidingseffect zou toegeschreven kunnen worden aan de gebruikte leerinstructie die de groepering van de te bestuderen woorden bevorderde. Voor incidenteel bestudeerde woorden daarentegen werd aangetoond dat gegroepeerde gerelateerde woorden net zo goed onthouden werden als gespreide gerelateerde woorden. Dit laatste resultaat is niet in overeenstemming met de semantische preactivatie theorie die een spreidingseffect voor gerelateerde woordparen voorspelt. De bevindingen van meer specifieke analyses suggereerden echter dat de semantische preactivatie benadering niet direct verworpen kan worden als een verklaring voor het spreidingseffect in cued-memory geheugentests. Volgens de semantische preactivatie theorie grijpt de facilitatie aan op het tweede woord (*moeder*) in gerelateerde woordparen (*vader-moeder*). Dientengevolge zou het spreidingseffect dus alleen geobserveerd moeten worden voor tweede woorden maar niet voor eerste woorden. Deze voorspelling werd deels bevestigd in Experiment 2: voor de eerste woorden werd geen spreidingseffect gevonden, terwijl voor de tweede woorden een klein spreidingseffect werd aangetoond.

## Conclusies

Op basis van de bevindingen in dit proefschrift kunnen twee belangrijke conclusies getrokken worden. Ten eerste kan er geconcludeerd worden dat het spreidingseffect in free recall geheugentests verklaard dient te worden in termen van een model dat een context-variatie mechanisme combineert met een studiefase-herinneringsmechanisme. Deze conclusie gaat in tegen de tot nu toe in de literatuur gehanteerde hypothese dat het spreidingseffect in free recall tests bepaald wordt door één enkel mechanisme. Ten tweede bieden de resultaten van de studie in hoofdstuk 5 enige ondersteuning voor de semantische preactivatie verklaring van het spreidingseffect in cued-memory tests. In overeenstemming met de voorspelling op basis van de semantische preactivatie benadering werd er een klein spreidingseffect gevonden voor tweede woorden van gerelateerde woordparen. Deze bevinding zou geïnterpreteerd kunnen worden als een indicatie van de negatieve invloed van preactivatie op het geheugen. Echter, in het geval we een dergelijke interpretatie van de resultaten willen aanhangen, is voorzichtigheid geboden. Wanneer de herkenning van de eerste en tweede woorden in gerelateerde paren gecombineerd werd dan was er, in tegenstelling tot wat de semantische preactivatie theorie zou voorspellen, geen sprake van een spreidingseffect. Daarnaast werd preactivatie niet gemeten in deze studie, waardoor het niet mogelijk was om expliciet de relatie tussen preactivatie en het geheugen voor gerelateerde woordparen te bepalen.

# Curriculum vitae

Peter Verkoeijen was born in Willich (Federal Republic Germany) on December 20, 1977. Upon completion of gymnasium ß at the Raayland College in Venray, he studied psychology at Maastricht University from 1996 until 2000. His graduation research was a study on mechanisms underlying the change in knowledge structures during the development of medical expertise. On the basis of this study he received a master's degree in cognitive psychology. Shortly after graduation, he started working as a Ph.D. student at the Department of Methodology and Statistics, Maastricht University, on a research project concerned with the improvement of statistics education. In February 2001, he was offered a position of assistant professor at the Department of Psychology, Erasmus University Rotterdam, where he became involved in the development of a new academic psychology curriculum. As a consequence, he was engaged in a broad range of educational activities, such as developing and conducting statistics courses, fulfilling the role of chair of the examination board, and tutoring in a variety of first-year, second-year, and third-year courses. These educational activities were combined with Ph.D. research on the spacing effect in memory.

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