Episodic Retrieval Processes in Auditory Negative Priming: Evidence from Event-Related Brain Potentials and Multinomial Modeling

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Table of Contents

Abstract

This thesis focuses on the phenomenon of auditory negative priming and its underlying mechanisms. The negative priming effect is characterized by slowed-down or more error-prone reactions to a previously ignored stimulus (ignored repetition condition) compared to a new stimulus (control condition). In a series of four experiments, event-related brain potentials (ERPs) and multinomial modeling of response category data were used to investigate the phenomenon. Experiment 1 revealed an ERP correlate of auditory negative priming in the form of a parietally located negativity. This correlate probably reflects a retrieval process rather than an inhibitory component, and, hence, is more consistent with a memory retrieval mechanism than with a distractor inhibition model of negative priming. The original episodic retrieval model assumes that retrieval of inappropriate response information associated with the previous distractor slows down responding when that stimulus becomes the target. Experiment 2 tested a new variant of the model according to which the retrieval of the prime response interferes with responding. Consistent with this new model variant, participants erroneously responded with the prime response more frequently in the ignored repetition condition than in the control condition. Experiment 3 replicated this finding in the visual modality. Experiment 4 validated the new variant of the episodic retrieval model and provided clarification as to its relevance for reaction time as well as error negative priming effects. The reported experiments provide evidence for an episodic retrieval mechanism one component of which is the retrieval of inappropriate prime responses. The mechanism works in the auditory as well as the visual modality and seems to be primarily responsible for error effects of negative priming.

1 The Phenomenon of Negative Priming

The phenomenon of negative priming has been discovered by accident. When investigating the phenomenon of the Stroop color-word test, Dalrymple-Alford and Budayr (1966) observed that the slowing in ink-naming was increased when the color to be named in trial *n* was congruent to the task-irrelevant color word in trial *n*-1. Neill (1977) replicated this finding. It took until 1985 that the phenomenon of slowed-down responding to an previously ignored object relative to a new object was called the *negative priming* effect (Tipper, 1985)[1]. In his Experiment 1, two superimposed objects were briefly presented. Participants had to identify, though not to name, the red object while ignoring the green one. After a second, again, two superimposed objects were presented of which the red one had to be identified and named. When the to-be-named object was identical to the ignored object of the previous display, participants responded about 50 ms slower than when the objects were unrelated. The notion of *negative priming* was chosen for this effect in contrast to the positive priming effect, the phenomenon of facilitated responding to an object that had been previously attended (see Neumann & DeSchepper, 1991).

Until today the phenomenon of negative priming has provoked abundant research endeavors (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995; Tipper, 2001). The great interest in this phenomenon can be explained by the significance which has been attributed to it as a tool to understand human selective attention. Selective attention denotes the hypothetical mental process that enables humans to restrict thought and action to the goal-relevant objects in the environment while ignoring the vast amount of irrelevant information (Neill & Valdes, 1996). For a long time, models of attention assumed that selective attention is accomplished by selectively enhancing the representations of goal-relevant information whereas irrelevant information was assumed to be

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[1] Strictly speaking, Marcel (1980) already used the term "negative priming" and employed it as a synonym to "inhibition". In the reported experiment, the speed-up in lexical decision time for words whose meaning had been primed was interpreted in terms of automatic spreading activation. In contrast, in another experimental condition response slowing was found. Marcel assumed that the meaning of the words in this condition had been inhibited. Since his understanding of "negative priming" did not contain core aspects of the phenomenon as defined by Tipper (1985) and other researchers (such as the crucial role of the probe target as a prime distractor), Marcel is not considered as the originator of naming the phenomenon.

processed to some—highly controversial—level without attention, but thereafter it was assumed not to be processed any further (e.g. Broadbent, 1958; for a review see Pashler, 1998a, 1998b). In contrast, more recent developments assume a two-process model of selective attention in which an excitatory mechanism enhances goal-relevant representations and an inhibitory mechanism suppresses activated but non-relevant representations. The idea that inhibition of distracting information is important in the process of attention is not at all new but dates back to Wundt (1904; zit. n. Houghton & Tipper, 1994). However, direct empirical evidence of inhibitory mechanisms in attention had not been provided until the work of Moran and Desimone (1985) who demonstrated suppressed cell activation in the prestriate area V4 and the inferior temporal cortex of rhesus monkeys to an otherwise effective stimulus when attention was drawn away from this stimulus to another location within the receptive field of the cell.

At first sight, a dual mechanism approach seems to be less parsimonious than necessary because selection can, in principal, be achieved by only one single mechanism (either excitatory or inhibitory). Nevertheless, the dual mechanism approach to selective attention is advantageous for two reasons (Houghton & Tipper, 1994). First, the degree to which one signal can be boosted relative to another signal is biologically limited. With two mechanisms simultaneously acting the net "difference" between signal and noise can be doubled. Second, a system with two opposing mechanisms can work effectively independent of the base level. Highly activated stimuli can barely be further excited, and rather weak stimuli cannot be further inhibited. Effective signal differentiation in the former situation can only be accomplished by inhibiting the distractor among the highly activated stimuli, whereas in the latter situation only excitation of the target among the group of weak distractors is an efficient strategy.

The negative priming phenomenon has been supposed to be a cognitive index for this inhibitory component of selective attention (Houghton & Tipper, 1994; Tipper, 1985). It was assumed that a distractor representation would be suppressed to support selection of the goal-relevant target stimulus, and that this inhibition would persist for some time. When, in the subsequent display, the former distractor would become the relevant target, responding would be hampered because of the persistence of inhibition imposed on it.

A typical negative priming task features a prime display in which participants select and respond to the identity of a target stimulus—defined, for instance, by color, location, or identity—in the presence of one or more irrelevant distractor stimuli. The critical manipulation is in the relation between the prime and the subsequent probe display. In the so-called *ignored repetition* trial participants have to respond to a probe target that had been ignored in the previous prime display. The only difference in a parallel *control* trial is that the prime distractor is replaced by a neutral fourth stimulus. The probe stimuli and the prime target are identical to the ignored repetition trial (see Figure 1-1 for an example). Usually, probe reactions in ignored repetition trials are slower and often also more error-prone than probe reactions in control trials.

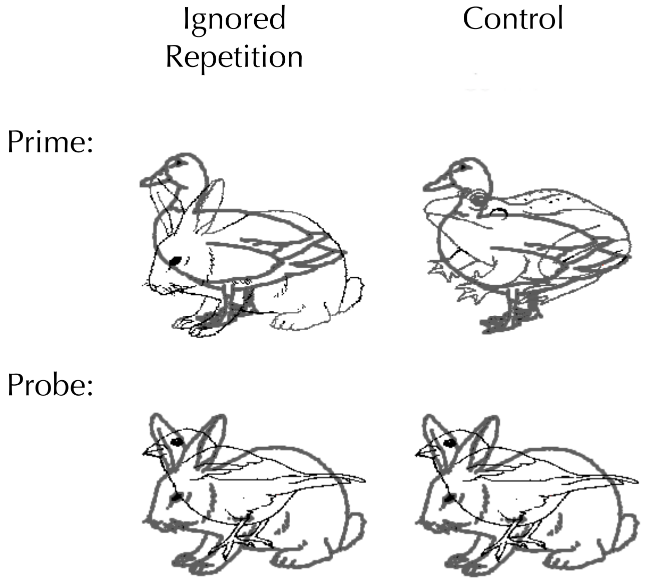


Figure 1-1: Example of a prime and probe display for an ignored repetition (left) and a parallel control trial (right). The task is to name the animal printed in grey bold face.

By far the largest number of empirical investigations of the negative priming phenomenon has been undertaken in the visual domain (for reviews, see Fox, 1995; May et al., 1995; Tipper, 2001). The phenomenon has been demonstrated with a wide range of stimulus materials (such as pictures, line drawings, words, letters, and Stroop color words) and task requirements (such as naming, identification, categorization, same-different judgements, temporal order judgements, etc.), strengthening the assumption that the phenomenon reflects a rather universal mechanism in human selective information processing. Initial evidence of auditory negative priming has been presented by Banks, Roberts, and Ciranni (1995) who demonstrated slowed-down shadowing of words that had been previously presented to the ignored ear. More recently, the effect has been repeatedly demonstrated in the auditory modality (Buchner & Mayr, 2004, 2005; Buchner & Steffens, 2001; Mayr, Niedeggen, Buchner, & Orgs, 2004; Mayr, Niedeggen, Buchner, & Pietrowsky, 2003; Mondor, Leboe, & Leboe, in press) and across modalities (Buchner, Zabal, & Mayr, 2003).

This work will primarily focus on the phenomenon of auditory negative priming, and on the mechanisms involved in creating it. Before the auditory negative priming phenomenon is addressed in detail (Chapter 3), the main theoretical accounts will be outlined of how the effect can be explained (Chapter 2). It turns out that two of the theories considered—distractor inhibition (Houghton & Tipper, 1994; Tipper, 1985; Tipper & Cranston, 1985) and episodic retrieval (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992)—are by far the most established models, both for the visual as well as the auditory domain.

In the empirical part of this work, the phenomenon of auditory negative priming is investigated using two new methodological approaches, that is, event-related brain potentials and multinomial modeling of accuracy/error data. Event-related potentials (ERP) may reveal a neurophysiological correlate of the phenomenon. They may help in theory differentiation (Chapter 4). Experiment 1 measures neurophysiological correlates of auditory negative priming (Chapter 5). To anticipate, such a correlate can indeed be identified. What is more, it seems to reflect a retrieval process rather than an inhibitory component which favors—together with recent behavioral evidence (Buchner & Mayr, 2005)—the episodic retrieval model of negative priming. In the subsequent chapters, a modified variant of the episodic retrieval model is proposed (Chapter 6) that stresses the retrieval of the prime response instead of non-response information associated with the prime distractor as a major cause of negative priming. This model variant is tested in two experiments using a multinomial modeling approach. Evidence favoring this new model variant is found for both the auditory (Experiment 2, Chapter 7) as well as the visual domain (Experiment 3, Chapter 8). Finally, a procedure to validate the new model variant is proposed (Chapter 9) and applied in Experiment 4 (Chapter 10). The results of Experiment 4 successfully validate the new variant of the episodic retrieval model and provide clarification as to its relevance for reaction time as well as error negative priming effects.

2 Theories of Negative Priming

Whereas the rising interest in the negative priming phenomenon within the 1980s was immanently associated with its interpretation as an index for inhibition of distractor stimuli, several other theories of the emergence of negative priming have been proposed that either challenge the distractor inhibition model in general or question its exclusive responsibility for causing negative priming effects. In the following paragraphs, the most established accounts that have been considered as causal explanations will be presented, contrasted, and discussed in the light of empirical findings. First, the distractor inhibition model and its further developments will be described (Chapter 2.1), then the episodic retrieval model will be depicted (Chapter 2.2). Subsequently, temporal discrimination and feature mismatch will be presented (Chapter 2.3 and 2.4). Finally, the explanatory power of the different approaches will be compared and proposals to reconcile the accounts will be discussed (Chapter 2.5).

2.1 Distractor Inhibition Model

In the following, the formation and development of a distractor inhibition models is outlined chronologically. In the beginnings negative priming was seen as a mandatory aftereffect of a selection process in the prime episode (Chapter 2.1.1). Later on, it was conceptualized as a response block dependent on participant's strategies (Chapter 2.1.2). A connectionist model of selective attention including inhibitory processes is depicted as the latest theoretical development (Chapter 2.1.3).

2.1.1 Negative Priming as an Aftereffect of Distractor Inhibition

The response slowing in ignored repetition relative to control trials in Tipper's (1985) experiments (see Chapter 1) was interpreted as reflecting inhibitory processes. The author assumed that within the initial parallel analysis of a scene, and independent of attention, meaningful and well-learned objects are categorically represented. Subsequently, in order to focus to the task-relevant objects, a mechanism of selective attention was supposed to inhibit the internal representations of to-be-ignored objects. Tipper (1985) investigated the question to what level of representation distractor stimuli were processed and/or at what level of representation inhibitory mechanisms took place. In his Experiment 3, a semantic negative priming effect was demonstrated: Responses to a probe target semantically related to the prime distractor (such as dog to cat) were slowed down compared to responses to an unrelated object (such as dog to table). The author assumed that the internal semantic representation of an ignored object is accessed and that inhibition can take place beyond the feature level at the abstract level of categorical representations. The results suggest that inhibition to a representation spreads to semantically related representations, analogously to the spreading of activation which is assumed to underlie semantic positive priming effects (Neumann & DeSchepper, 1991). Unfortunately, the interpretation of this result is ambiguous because semantically related objects such as dog and cat also share physical features. Tipper and Driver (1988) demonstrated negative priming across symbolic domains—that is, between pictures and words—which unambiguously favors that inhibition takes place at an abstract, categorical level and thereby rules out inhibition at the feature level. Note however, that an interpretation of inhibition at the categorical level for this experiment does not exclude the possibility of an (additional) inhibitory component at a physical feature level for other experimental situations, particularly because the negative priming effects in Tipper's Experiment 3 (1985) were somewhat smaller—though not significantly so—between semantically related objects than between identical objects.

2.1.2 Inhibition as a Response Block

Lowe (1979) observed that the negative priming effect with Stroop stimuli depends on the nature of the probe display. A negative priming effect was found when the probe consisted of a Stroop color word but a facilitatory effect was found for probes that did not require a selection between target and distractor information, such as when naming the color of a color patch or of a colored random-letter string. This finding has been confirmed with other tasks (Moore, 1994; Tipper & Cranston, 1985). For instance, Tipper and Cranston (Experiment 3, 1985) found negative priming in a letter identification task, but only when both the prime and the probe consisted of a to-be-attended red uppercase letter and a to-be-ignored green uppercase letter. When there was only one single, lowercase (black) probe letter to be named, the slowing effect switched to facilitation.

The finding of facilitated responding in situations such as those described above is incompatible with a simple distractor inhibition model. If negative priming effects are the consequence of a prime distractor suppression alone, the nature of the probe display should not have any effect. To account for this finding within the scope of an inhibition approach it was assumed that both excitatory and inhibitory components are involved in the processing of objects (see Tipper & Cranston, 1985). Whereas the representations of both the attended and the ignored objects remain activated subsequent to processing, only the internal representation of the selected object is translated into a response code. This translation process from perception to action is inhibited for the prime distractor. Consequently, the internal representation of the prime distractor remains activated, but the response translation is inhibited in order to prevent erroneous responding. Whether a response slowing or speed-up results when the prime distractor becomes the probe target depends on the net effect of excitatory and inhibitory components. When the inhibitory effect exceeds the excitatory effect, response slowing will be found and vice versa. When both effects are equal in size, no priming effect will result. Excitation was supposed to be a slowly and passively decaying process, whereas inhibition was assumed to be a more labile and strategic component influenced by task demands. Tipper and Cranston (1985) assumed that participants are able to deliberately maintain a selection state when response selection is difficult (such as when the probe display requires selecting between two objects). Inhibition would stay active and prevent fast responding to the suppressed object. On the other hand, when the probe target is easy to select or does not require a selection at all, the selection state is abandoned, and inhibition vanishes quickly. Consequently, only the excitatory component remains and is revealed by facilitated responding as was found in probes without selection requirement.

Moore (1994) narrowed down what makes probe processing easy or difficult. Similar to the studies above, she employed conflict and non-conflict probe displays. The former included distractors associated to an incorrect response, the latter could contain distractors, but these were not associated with a conflicting response. Two factors that were supposed to influence the ease of identifying a non-conflict display were manipulated, that is, the predictability of a non-conflict display and the similarity of conflict and non-conflict displays. Moore presented trials with conflict and non-conflict probe displays that were either randomly presented or blocked. In addition, the obviousness of non-conflict displays was varied. For instance, they could have lacked a distractor completely (Experiment 1) or they could have included a distractor which was not associated to a specific response (Experiment 2). Negative priming was eliminated when the context predicted the appearance of a non-conflict display (as in pure blocks). When the context was unpredictable, as in mixed blocks, the negative priming effect was only eliminated when conflict and non-conflict displays could be easily discriminated from each other (such as in Experiment 1, but not in Experiment 2). An interpretation in terms of the response blocking account (Tipper & Cranston, 1985) assumes that the quick identification of a non-conflict display implies that there is no information potentially conflicting with the correct response. Therefore the inhibition of response translation can be abandoned. Note, however, that in none of the experiments reported by Moore (1994) facilitatory effects were found for predictable or easy-discriminable non-conflict displays. This is actually unexpected from a response block model as one would expect facilitated responding for experimental contexts where the inhibition of response translation is supposed to be abandoned and then to vanish quickly.

2.1.3 An Active Inhibitory Mechanism within a Neural Network Model

Houghton and Tipper (1994; Houghton & Tipper, 1998; Houghton, Tipper, Weaver, & Shore, 1996) have proposed a model of the dynamics of selective attention that incorporates active inhibition of distracting information as a central mechanism in the selection process. The model has been implemented as a mathematically specified neural network model. The basic premise is that attention coordinates the interaction between largely parallel perceptual processes and goal-directed serial behavior. Based on empirical evidence of semantic negative priming as illustrated above (see Chapter 2.1.1, pp. 11) the authors assume that selection can take place after perceptual grouping at the level of object-based representations.

According to the model, selective attention is organized via several functionally separate systems (so-called *fields*). So-called *property units* representing preattentively activated features of objects (i.e. perceptual and semantic properties) are bound together forming unified representations that are represented in the *object field*. Object information is fed forward to response systems where the parameters of activated action schema have to be bound with the action-relevant object information. For instance, for a grasping scheme the location and shape information of the object to grasp has to be specified. A *target field* represents the momentary internal template, a specification of the target stimulus features. To guarantee goal-directed behavior, the externally activated object representations fitting the target specification have to be selected. This is obtained via a matching process between the (internally driven) target and the (externally driven) perceptual object representations in the so-called *match-mismatch field*. This matching process yields signals feeding back into the object field leading to a foregrounding/activation of object representations containing features that match the target description and to a suppression of object representations with mismatching features. By help of the emerging activation difference between target and distractor representations, the binding of the target object's parameters into the current action scheme is facilitated.

Implementation of the differential activation of target and distractor objects is achieved to some extend by suppression of the distractor representation, conceived in the following way: Each property unit of an object in the object field is linked to a self-excitatory and a self-inhibitory feedback loop (i.e. an *on-cell* and an *off-cell*). By default, self-excitation and self-inhibition are weighted similarly so that the bottom-up excitation of a property unit due to constant perceptual input is not modified by the self-regulatory feedback system. Selective attention comes into play by intervening into this feedback system. Given a match between an external object property and an internal target property, the respective property unit is activated via excitation of its on-cell. In contrast, all mismatching property units receive activation of their off-cells. The object-based character of selection can be understood by the fact that the property units of one object assembly/representation are linked: Excitatory feedback loops are linked excitatorily. Inhibitory feedback loops are linked excitatorily, too. On-cells and off-cells of opposing character are linked inhibitorily within one object assembly. Consequently, the excitation of one property of an object representation leads to the excitation of the whole representation, neural activity of this object representation increases. In contrast, inhibition of one property unit is aggravated in that the neural activity to the whole object representation is suppressed.

A consequence of the depicted implementation is the fact that the activation of ignored (distractor) stimuli is reduced relative to an attended (target) stimulus due to the counteracting inhibitory feedback loops. But the activation of distractor objects does no fall below resting level because of the bottom-up excitation during the permanent external input. However, when the distractor is physically offset and external activation does no longer take place, the internally generated inhibitory effects due to target mismatch remain and lead to an inhibitory rebound below resting level representing suppressed responsiveness. This post-offset inhibitory rebound is supposed to be the cause of the negative priming effect. If the distractor is again presented as a target during the time when the internal representation is still suppressed, re-establishment of the target representation is impaired and takes more time to take dominance relative to a new probe distractor representation that has an initial activation advantage. Probably, there is a certain degree of activatory dominance of one object representation relative to another necessary in order to bind the response parameters of the current action scheme. Consequently, reaction time should be slowed-down and greater interference effects from the co-present probe distractor should take place in an ignored repetition trial.

The described model has been validated by simulations for a range of data (Houghton & Tipper, 1994). For example the model predicts the elimination of a negative priming effect for probe displays without distractor (Lowe, 1979; Moore, 1994; Tipper & Cranston, 1985). A suppression aftereffect does not prevent that the representation of the probe target when undisturbed by distractors rapidly reaches a significant activation level which is necessary for response selection. However, the model cannot account for a facilitatory effect of ignored repetition trials without probe distractor which has occasionally been found (Lowe, 1979; Tipper & Cranston, 1985).

2.2 Episodic Retrieval Model

The episodic retrieval model has been proposed by Neill and colleagues (Neill & Valdes, 1992; Neill et al., 1992). In the following, the model will be illustrated (Chapter 2.2.1), then, the strongest empirical evidence for episodic retrieval will be depicted. This evidence is based on the finding that the persistence of the negative priming effect depends on the experimental design (Chapter 2.2.2). Finally, further empirical evidence in favor of the model will be discussed (Chapter 2.2.3).

2.2.1 The Episodic Retrieval Model

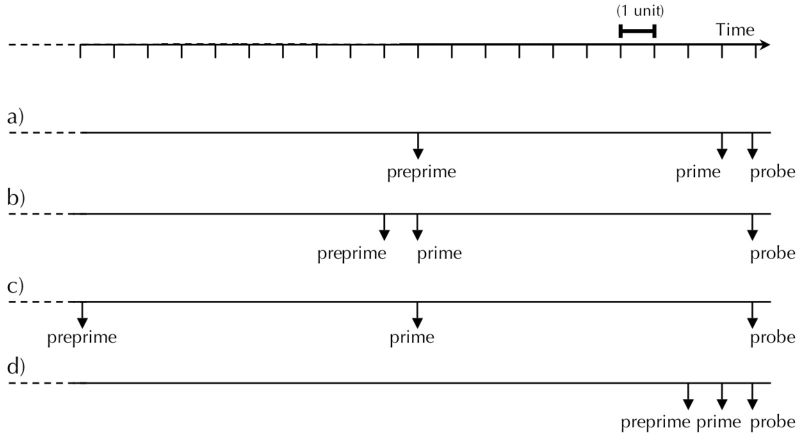
Logan's instance theory of automatization (1988) can be seen as the precursor of the episodic retrieval model of negative priming. Logan's theory assumes that, as a consequence of attention, every encounter with a stimulus (i.e. an episode or instance) is obligatorily encoded and separately stored in memory. The stored episode contains information about the stimulus as well as the given response. Performance in a task can be accomplished in one of two ways, either by analytically computing a response or by directly retrieving previous encounters with the same stimulus from memory. Whether responding is based on the algorithm or the retrieved episode depends on which of the two is faster. Logan's instance theory of automatization (1988) conceives of automaticity as a memory retrieval phenomenon. Automatization of a task is gained by the accumulation of separate episodes throughout time. The more episodes of a stimulus exist, the more likely a relevant episode will be retrieved before the algorithm has come to a result. Consequently, automatization is the transition from algorithm-based performance to memory-based performance.

Similarly, Neill and Valdes (1992) argued that negative priming is the result of retrieving the prime episode when exposed to the probe stimulus. The probe target causes retrieval of the prime episode due to repetition of the prime distractor. However, part of the retrieved episode is a form of non-response information tied to the prime distractor. This response information conflicts with the need to respond to this stimulus in the probe episode. Resolving this conflict is time-consuming. As Logan (1988) infers from the conceptualization of automatization as a memory retrieval phenomenon governed by the principles of memory, negative priming should also depend on factors influencing the probability of successful episodic retrieval, such as recency, temporal discriminability, and contextual similarity (Neill & Valdes, 1992).

2.2.2 Experimental Design Influences the Persistence of the Negative Priming Effect

The strongest empirical arguments favoring episodic retrieval come from studies that manipulated the interval between participants' response and the presentation of the next stimulus, that is the response-to-stimulus interval (RSI; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Neill & Valdes, 1992; Neill & Westberry, 1987; RSI; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991). These studies were originally intended to determine how long the negative priming effect persists over time, implying investigation of the question when inhibition starts to decay and at what rate the decay will occur. However, experimental results were very heterogeneous. Neill and Westberry (1987) and Neill and Valdes (1992) found decreases of negative priming with increasing prime-probe RSI. In contrast to this, Tipper et al.'s (1991) and Hasher et al.'s (1991) studies revealed no influence of the prime-probe RSI on the size of the negative priming effect. These empirical inconsistencies could not simply be resolved by the differences in implemented RSI. Whereas Neill and Westberry (1987) found a complete loss of negative priming with an RSI of 2020 ms, Tipper et al. (1991) did not find any reduction up to an RSI of 6600 ms. However, a difference between the former and the latter two studies was the experimental design. When negative priming decreased over time, prime-probe RSI was manipulated as a randomized, within-subject variable, whereas the studies without negative priming decreases over time were either based on a between-subjects design (Tipper et al., 1991) or on the comparison of two experiments (Hasher et al., 1991).

Neill and Valdes (1992) argued that the retrieval probability of the recent episode depends not directly on the prime-probe RSI but on the ratio of this interval to the preceding RSI (preprime-prime RSI). All of the experiments mentioned in the previous paragraph were continuous priming tasks without breaks between probe reactions and subsequent prime displays. For these types of tasks a randomized-trials design implicates that a short prime-probe RSI is sometimes preceded by a long preprime-prime RSI and vice versa. If the prime-probe RSI between probe display *n* and prime display *n* – 1 is short, but the preprime-prime RSI between prime display *n* – 1 and the preceding display *n* – 2 is long, the retrieval probability of display *n* – 1 should be large because the prime episode *n* – 1 is easily discriminable in time from the preceding episode (for a demonstration, see case (a) in Figure 2-1). However, if the prime-probe RSI between probe display *n* and prime display *n* – 1 is long, but the preprime-prime RSI between prime display *n* – 1 and the preceding display *n* – 2 short, the prime display *n* – 1 should be poorly discriminable from the episode before (see case (b) in Figure 2-1). Retrieval probability would, in turn, be reduced. Following the episodic retrieval model, negative priming increases with the probability of retrieving the prime episode because only in the case of successful retrieval, the prime distractor with its associated non-response information can interfere with probe task responding. Consequently, the crucial factor for the size of the negative priming effect should be the temporal discriminability of the prime episode at the time of the probe presentation which is equivalent to the ratio of [(preprime-prime RSI + prime-probe RSI)/prime-probe RSI]. If the ratio is large (for the situation of a long preprime-prime RSI and a short prime-probe RSI), a large negative priming effect is predicted. If the ratio is small (for the situation of short preprime-prime RSI and long prime-probe RSI), negative priming should be reduced. The prime-probe RSI in a between-subjects design (and also in a blocked within-subject design) is always confounded with the preprime-prime RSI. For these designs, at the time of the probe, the discrimination of one display relative to the preceding display is always the same (long preprime-prime RSI/long prime-probe RSI or short preprime-prime RSI/ short prime-probe RSI, see cases (c) and (d) in Figure 2-1, respectively) regardless of what size the absolute prime-probe RSI is. Consequently, the negative priming effect should be independent of prime-probe RSI which is what was found (Hasher et al., 1991; Tipper et al., 1991). A distractor inhibition model cannot account for this pattern of results. Negative priming should depend only on the RSI between prime and probe. A reduction of negative priming with increasing prime-probe RSI would be interpreted as the decrease of inhibition over time. However, the influence of the relation between the prime-probe RSI and the preprime-prime RSI should not be of any importance for the strength of prime distractor inhibition.



	Delay at probe		Temporal discriminability
	preprime	*prime*	
a)	10	1	10
b)	11	10	1.1
c)	20	10	2
d)	2	1	2

Figure 2-1: Depicted are the preprime-prime and prime-probe RSIs on a time bar. Cases a) to d) demonstrate all four possible combinations of long and short intervals. To make the idea of temporal discriminability clear, RSI is varied as either a 1-time-unit interval or a 10-time-unit interval. The temporal discriminability value (at probe) is the ratio of [(preprime-prime RSI + prime-probe RSI)/prime-probe RSI]. The larger this value, the better is the temporal discriminability of the prime episode at the time of the probe presentation.

Neill et al. (1992) tested their predictions of the influence of temporal discriminability for the size of the negative priming effect by varying the prime-probe RSI (500 ms, 4000 ms) either in a randomized design (Experiment 1) or in a blocked within-subject design (Experiment 2). As predicted, negative priming in Experiment 1 was largest when the ratio of preprime-prime RSI/prime-probe RSI was of size (4000/500 ms), and smallest for the case of (500/4000 ms). When preprime-prime RSI and prime-probe RSI were of the same size (500/500 ms or 4000/4000 ms) the negative priming effect was similar and of intermediate size relative to the former two conditions. In the case of the blocked design (Experiment 2) no significant "decay" of negative priming was obtained with longer delays.

2.2.3 Further Empirical Evidence for the Episodic Retrieval Model

Further evidence in support of the episodic retrieval model comes from studies demonstrating that the size of the negative priming effect is governed by the same factors that influence the probability of successful memory retrieval in general. The size of the negative priming effect should be monotonically related to the probability of successful retrieval of prime-associated non-response information. It is generally accepted that one of the main parameters of successful retrieval is the similarity between the context during encoding and retrieval (Tulving, 1983). Consequently, contextual similarity between prime (encoding) and probe (retrieval) should determine the size of the negative priming effect.

Neill (1997), Fox and de Fockert (1998) as well as Stolz and Neely (2001) all varied the contextual similarity between the prime and probe displays. In Neill's study, participants had to identify the central letter of a three-letter string. In ignored repetition trials the distracting outer letters from the prime display were repeated as the central target letter in the probe display. In addition, the onset of the distractor letters was varied. Their onset was either simultaneous or 400 ms after the target letter onset. Onset timing was either the same for prime and probe (simultaneous-simultaneous or delayed-delayed) or not (simultaneous-delayed, or vice versa). Negative priming was most robust when the distractor onsets matched in the prime and probe displays. This is easily explicable by more likely successful retrieval induced by contextual similarity. It is difficult to accommodate by a forward operating inhibition model. Inhibitory aftereffects should be primarily determined by features of the prime situation, whereas the importance of the interaction of features of the prime and probe episode is not immanent to the inhibition model.

Fox and de Fockert (1998) manipulated contextual similarity in a similar letter-identification task by varying the stimulus intensities of adjacent displays. Intensities could be either bright or dim, equivalent for prime and probe (bright-bright or dim-dim) or changing between them (bright-dim or dim-bright). Negative priming was larger when intensities matched between prime and probe, regardless of whether they were bright or dim. Similar results have been found by Stolz and Neely (2001) in a same-different letter-matching task.

2.3 Temporal Discrimination Model

The distractor inhibition model and the episodic retrieval model explain the emergence of negative priming in terms of the consequence of selecting against the prime distractor. This selection is accomplished via a suppressed distractor representation (or a block of the translation between the representation and a response code) (Houghton & Tipper, 1994, 1998; Houghton et al., 1996; Tipper, 1985; Tipper & Cranston, 1985) or via non-response information attached to the retrieved prime distractor (Neill, 1997; Neill & Valdes, 1992; Neill et al., 1992). In contrast, the temporal discrimination model proposed by Milliken, Joordens, Merikle, and Seiffert (1998) does not assume selection processes during the prime task as the basis of negative priming. Instead, it is assumed that negative priming is caused at the moment of response formation during the probe. Following Logan's (1988) instance theory of automatization, responses can either be analytically computed or—if the same task situation has already been encountered—directly retrieved from memory. The former mode of responding corresponds to new learning applied when new or unexpected stimuli have to be reacted to, the latter to reinstating learned behavior. Following Milliken et al. (1998) the decision which of the two response modes guides behavior in the probe task is based on a categorization of the probe target as either old or new. If the probe target is categorized as new, a response is generated on the basis of perceptual analysis. This is the case for control trials with probe targets unrelated to any prime stimuli. In the case of attended repetition trials the repetition of the prime target as the probe target results in a categorization as old, leading to a retrieval of the appropriate response from memory. The slower reaction times in control trials relative to attended repetition trials can be explained by the fact that response formation by perceptual analysis takes longer than response formation by automatic retrieval. However, for a probe target in an ignored repetition trial, Milliken et al. (1998) assume an ambiguity in the categorization process. Its familiarity due to its appearance in the prime prevents a quick categorization as new, but is insufficient for a categorization as old. Metaphorically speaking, the decision process gets stuck which is the reason for slowed down reaction times.

The authors provide empirical support for the model by their Experiment 2 (Milliken et al., 1998) in which brief single masked prime words were presented, followed by two interleaved probe words, one of which had to be named. Participants were not informed about the presence of the primes and did not have to respond to them. They were typically not aware of them either. Trials were either unrepeated (prime and probes were different) or repeated (the prime was repeated as the probe target). Significant negative priming was found, that is, a slow-down for the repeated compared to the unrepeated condition. Following the authors' reasoning, selection against a distractor did not take place in the prime displays of their experiment because no prime target had to be selected and responded to. They further argued that neither the inhibition model nor the episodic retrieval model predict a negative priming effect for this situation because both of them postulate a selection against a prime distractor. Instead, the authors supposed that the prime stimulus had not been attentionally processed and that this was the reason why negative priming accrued. Along their line of argumentation, a briefly presented irrelevant prime stimulus is only marginally processed. Therefore, the categorization of this stimulus when repeated as the probe target, is ambiguous. Its faint familiarity prevents a categorization as new but is not enough to lead to an old response. Consequently, prime items presented for brief durations (as in Experiment 2) are functionally similar to prime items presented for longer durations that are not attended to (as a classical prime distractor). The authors tried to show in their Experiment 4 that instead of a brief prime duration instructions can limit attentive processing of a prime and thereby induce negative priming. Participants were instructed to read silently (i.e. attend) or to ignore a single prime (200 ms, rather than 33 ms in Experiment 2). Negative priming was predicted for the ignore group, whereas positive priming was expected for the group which attended the prime. The hypotheses were confirmed. Whereas attending the prime helps to quickly categorize its repetition as old in the probe, ignoring the stimulus in the prime leads to an ambiguity in deciding whether the stimulus was old or new when it reappears again.

Milliken et al's (1998) main argument why the negative priming effects in their experiments cannot be caused by conventional selective attention accounts is the fact that participants in their experiments are not instructed to select against a distractor in the prime display. They argue that even when this typical selective attention situation is not given, a negative priming effect can be evoked. However, it is questionable whether people really do not select against a distractor in a situation like a single prime presentation. Possibly, a selection against the single prime stimulus or the display as a whole is made. In terms of selective inhibition this would mean that the representation of the single prime would be suppressed. In terms of episodic retrieval this would mean that a non-response information would be attached to the single prime. Consequently, an inhibition or episodic retrieval model cannot be excluded for any of the findings reported in Milliken et al's (1998) seminal paper.

Healy and Burt (2003) pitted the temporal discrimination model against the episodic retrieval model. In their Experiments 3 and 4, participants saw two prime words, one of grey and one of white color, for 900 ms and 1200 ms, respectively, but no response was required. In the following probe display, a red word had to be named while ignoring a green word. In half of the primes one of the words was replaced by a consonant string (Experiment 3) or a pronounceable non-word (Experiment 4). In these cases, a response had to be given to the prime. These trials requiring a prime response were included to ensure that participants processed the prime stimuli with attention. However, only trials without a prime response allowed to derive predictions that can differentiate between the models. Following the temporal discrimination model, the attentionally processed prime stimuli, when repeated in the probe, should be quickly categorized as old. Consequently, a response should be easily retrieved from memory. Therefore, a temporal discrimination model predicts no negative priming effect. From the point of view of episodic retrieval, the prime stimuli of trials without a prime response should have been associated with a non-response information. This non-response information should have been retrieved when the stimulus was repeated as the probe target. Interference of this information with the required naming response would be the consequence. Therefore, the episodic retrieval model predicts a negative priming effect. The results were in line with the episodic retrieval model in that for both experiments a significant negative priming effect. Responding in trials in which one of the prime words was repeated as the to-be-attended probe word was slower compared to trials without a repetition. As the authors note, the results are also compatible with an inhibition model assuming that withholding a prime response functions analogously to selecting against a distractor in producing inhibition.

Further evidence against the temporal discrimination model has recently been provided by Frings (2005). According to Frings, for an experimental condition in which the distractor stimulus is the same in prime and probe, the temporal discrimination model cannot predict a reaction time speed-up. Due to its appearance in the prime, the probe distractor has gained some degree of familiarity, but since it has not been processed attentionally in the prime, this familiarity should be insufficient for a quick categorization as old. The temporal discrimination model predicts either a slow-down in responding for a distractor-to-distractor trial or no effect at all. Following the author, whether the former or the latter outcome is predicted, depends on the degree to which an old-new categorization to distractor stimuli is obligatory or can be skipped[2]. If distractor stimuli were not categorized as either old or new, repetition of distractor stimuli should be of no importance. A null effect would be predicted. In contrast, if distractor stimuli were categorized as being old or new, a repeated distractor would lead to an ambiguity in deciding. This should lead to a slow-down in responding to the probe target.

However, in two experiments, Frings (2005) demonstrated a speed-up in responding for the distractor-to-distractor condition, which has repeatedly been demonstrated by others (Experiment 1, Lowe, 1979; Experiment 3, Neumann & DeSchepper, 1991; Experiment 1, Tipper & Cranston, 1985). Both, inhibition as well as episodic retrieval models can explain this reaction time decrease. In terms of an inhibition model, it is plausible that an inhibited representation of a distractor interferes less. Probe target processing is therefore facilitated. Following an episodic retrieval model, the repetition of a stimulus increases the contextual similarity between prime and probe which makes retrieval of the prime episode with its associated non-response information more probable.

In sum, the temporal discrimination model is not convincing at all. It is based on evidence entirely explicable by either of the two well-established models (inhibition or episodic retrieval). In addition, first empirical evidence against the model has been demonstrated.

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[2] The temporal discrimination model assumes that target stimuli are categorized as old or new in order to decide whether an old response is retrieved from memory or a new response has to be generated. Whether the same categorization process takes place for distractor stimuli is not specified by the model. Because distractor stimuli do not require a response (or rather, always require a non-response, irrespective of being old or new stimuli), an old-new categorization seems to be dispensable.

2.4 Feature Mismatch Model

Park and Kanwisher (1994) proposed that the negative priming effect was the result of interference due to a feature mismatch between the prime and probe display. Empirical evidence for this assumption comes from their Experiment 4 in which they investigated negative priming in a target localization task. In a typical target localization task (see e.g. Tipper, Brehaut, & Driver, 1990), participants are presented with displays containing four position markers with a target symbol (e.g. O) over one position marker and a distractor symbol (e.g. +) over another (see Figure 2-2 for an illustration). In the localization negative priming paradigm, a response to the location of the target stimulus has to be carried out, instead of a reaction to the target identity. In this paradigm, ignored repetition trials are trials in which the probe target appears at the same location as the prime distractor. Tipper et al. (1990) demonstrated negative priming effects for the localization task in that response times were slower for ignored repetition trials than for control trials in which the probe target appeared in a previously unoccupied location. They interpreted the effect as the result of an inhibition in the selection and execution of response to the prime target's spatial location.

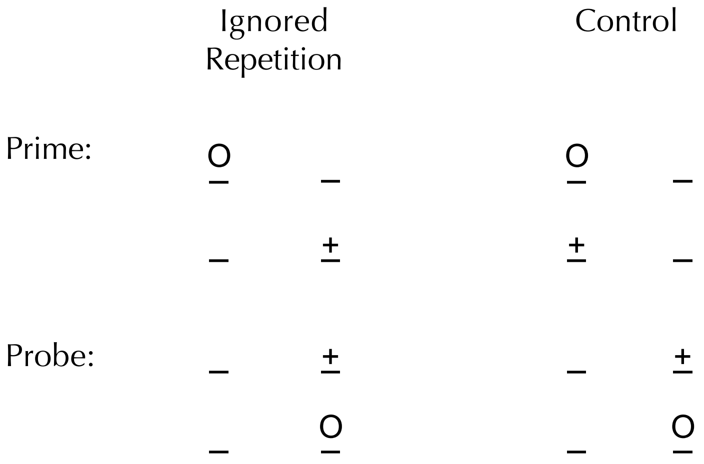

Figure 2-2: Example of a prime and probe display for an ignored repetition (left) and a parallel control trial (right) in a localization task. The task is to respond to the location of the symbol "O".

Park and Kanwisher (1994) opposed this distractor inhibition explanation by their feature mismatch model. They suggested that responses in ignored repetition trials were slowed when the probe target (O) differed from the item that occupied the same position in the prime display (+). Critical for the emergence of negative priming following the feature mismatch model is a prime-to-probe change in the binding of the symbol identity to the location. In their Experiment 4, the authors pitted the feature mismatch model and the distractor inhibition model against each other by exchanging the target identities between the prime (+) and the probe (O). In the so-called "symbol-mismatch" condition, the probe target (O) appeared in the prime target (+) position. For this scenario the inhibition model does not predict negative priming since the probe target location had also been attended in the prime. In contrast, the feature mismatch model predicts a slow-down because the symbol at the probe target location changes between prime and probe. In the so-called "symbol-match" condition, the probe target (O) appears in the same location as the prime distractor (O) which should result in slowed responding following the inhibition model. The feature mismatch model predicts no response-slowing for this situation since there is no prime to probe symbol change at the probe target location. Whereas negative priming was found for the so-called "symbol-mismatch" condition, faster responding was measured in the "symbol-match" condition which fitted the predictions of the feature mismatch model and conflicts to an distractor inhibition model.

The feature mismatch model—which has also been called code coordination hypothesis by others (see Neill & Valdes, 1996; Tipper & Cranston, 1985) —may provide a viable explanation of the emergence of location negative priming, but it cannot explain identity negative priming effects (Fox, 1995). A feature mismatch explanation of identity negative priming has been excluded by Tipper and Cranston (1985, Experiment 4) in a letter-naming task. By changing the target selection criterion between prime and probe (naming the red letter in the prime, naming the green letter in the probe), they avoided a color-to-identity mismatch (as the analogue to an identity-to-location mismatch in a spatial localization task) between prime and probe. Nevertheless, negative priming was found which is consistent with the inhibition model but not with the feature mismatch model. Fox (1995) concluded that the distractor inhibition model and the episodic retrieval model are better explanations for negative priming when the selection is based on identity. In addition, it is usually easy to take provisions in the experimental setup that allow to exclude feature mismatch as a valid explanation for the potential negative priming effect. For instance, varying the selection criterion between prime and probe (as did Tipper & Cranston, 1985, Experiment 4) guarantees a feature match between the prime distractor and the probe target. When negative priming is nevertheless revealed, other mechanisms than feature mismatch have to be responsible.

2.5 Reconciliation of Accounts

Four accounts to explain the negative priming phenomenon have been described and the essential empirical evidence has been reviewed briefly. Considering empirical evidence, the feature mismatch model (Park & Kanwisher, 1994) cannot be considered an adequate account for identity negative priming, at least not for the visual modality in which all of the relevant experiments have been undertaken. To anticipate, the same will be true for the auditory modality, as will be addressed in the next section of this paper (see Chapter 3).

Milliken et al's (1998) temporal discrimination model as the most recently proposed account lacks strong empirical support. The inhibition model and the episodic retrieval model cannot be refuted by any of the experiments stated in their seminal paper. In addition, some evidence exist that contradicts the temporal discrimination model, at least at its current level of specification (Frings, 2005; Healy & Burt, 2003). It seems to be rather the task for the proponents of the model to provide unambiguous evidence in favor of the account against the two well-established theories—that is, the inhibition (Houghton & Tipper, 1994; Tipper, 1985; Tipper & Cranston, 1985) and the episodic retrieval model (Neill & Valdes, 1992; Neill et al., 1992)—than to call the latter two into question.

The inhibition model as well as the episodic retrieval model have triggered a vast amount of research trying to differentiate between them (for detailed reviews, see Fox, 1995; May et al., 1995; Tipper, 2001). There are properties and dependencies of the negative priming phenomenon that favor one over the other model. For example, the influence of temporal discriminability of the prime episode relative to the preceeding episodes is more easily accommodated by episodic retrieval (Neill et al., 1992) than by inhibition. The same is true for evidence that shows that the effect increases when the contextual similarity between prime and probe is increased (Fox & de Fockert, 1998; Neill, 1997; Stolz & Neely, 2001). However, the existence of semantic negative priming effects (Tipper, 1985) is more easily accounted for by an inhibition model. An inhibition model is based on the assumption of an underlying semantic network within which—analogously to spreading activation—spreading inhibition is assumed to operate (Neumann & DeSchepper, 1991). In contrast, the episodic retrieval model is based on the memory concept of specific instances (episodes) which is not directly associated to the idea of semantic network activation.

Paying tribute to the fact that the available empirical evidence does not clearly favor one model over the other, some authors have tried to reconciliate the models (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; May et al., 1995; Tipper, 2001). In their dual-mechanism account of negative priming, May et al. (1995) and Kane et al. (1997) propose that inhibition as well as memory retrieval can be the source of negative priming, but that the experimental context specifies which of the two mechanisms is expected to operate. By default, inhibition is supposed to produce negative priming except for those situations in which episodic retrieval is induced by the experimental context. When elicited, episodic retrieval works automatically and without attention. A situational condition that triggers the retrieval of the previous episode is the presentation of the probe stimuli under difficult perceptual conditions (such as degradation or limited exposure time). When stimulus perception is difficult, participants are thought to retrieve the prime episode to aid the current probe target identification. Negative priming in this situation will then be caused by retrieving the task-inappropriate non-response information attached to the prime distractor. In contrast, when identification is easy as with undegraded stimuli or stimuli that were presented sufficiently long, no retrieval of prior episodes is induced and the negative priming effect will be caused by inhibition. Another experimental situation eliciting episodic retrieval are contexts including a significant proportion of repeated target trials (attended repetition). With repeated target trials a retrieval of the prime is useful since retrieving the previous response requirement is task-appropriate for the current probe response and therefore facilitates performance. Kane et al. (1997) try to provide evidence that negative priming is produced by episodic retrieval in the specified contexts but otherwise generated by inhibition. However, and without going into detail, their reasoning is based on the highly controversial assumption that the elderly suffer from diminished inhibitory mechanisms whereas their retrieval mechanisms are uncompromised (see Buchner & Mayr, 2004; Gamboz, Russo, & Fox, 2002). Taking this problem into account, the dual-mechanism account lacks empirical support.

Whereas the dual-mechanism account assumes mutual exclusiveness of processes—the negative priming effect is either produced by inhibition or by episodic retrieval—Tipper (2001) proposed an integrated model. He assumes that a complete explanation of the phenomenon must include forward-acting (encoding) and backward-acting (retrieval) processes at the same time but that so far each of the two models has emphasized only one of these aspects. Following Tipper, a comprehensive theory of negative priming embraces distractor inhibition mechanisms during encoding in the prime display as well as retrieval mechanisms to retrieve prior episodes during the probe display. Consequently, there is no necessary conflict between the two approaches and "the difference between the two is analogous to the differences between approaches to memory that emphasize encoding versus retrieval" (Tipper, 2001, p. 329).

However, the knowledge that both aspects take part in the manifestation of the negative priming effect does not make all empirical investigations regarding the causal factors irrelevant. Depending on experimental context and circumstances—for instance, task, stimulus material, participant population—the contribution of inhibitory and retrieval processes might be very different. Also, theory formation has been undertaken on the basis of empirical evidences in the visual domain. The mechanism(s) underlying the effect may be entirely different in another modality such as the auditory modality which will be the focus of interest in the following chapter.

3 Investigating the Mechanisms of Auditory Negative Priming

In comparison to the vast amount of studies investigating the visual negative priming effect and its mechanism(s), there exist only a few studies that examined auditory negative priming (Banks et al., 1995; Buchner & Mayr, 2004, 2005; Buchner & Steffens, 2001; Buchner et al., 2003; Mondor et al., in press). Whereas Banks et al. (1995) found a negative priming effect in a shadowing task when participants had to repeat the words spoken in a female voice while ignoring simultaneously played words spoken in a male voice, the studies of Buchner and Steffens (2001; see also Buchner & Mayr, 2004, 2005; Buchner et al., 2003) measured slowed-down responding in a tone categorization task for sounds that had to be ignored in the previous display. Animal voices and/or musical instruments were used as tones. Mondor et al. (in press) revealed negative priming in a four-tone identification task for artificially generated sounds.

It is far from trivial that negative priming has also been found in the auditory modality given the intrinsic differences in the organization of visual and auditory perception and the way selective attention operates in the two modalities. In the visual domain, attentional focusing is most of the time—but not always, given the phenomenon of covert visual attention (Posner, 1980)—achieved by foveating the object of interest. As a consequence, interference by the irrelevant information is reduced as it is represented in areas of lower acuity. Foveating can be obtained by peripheral mechanisms such as eye movements, accommodation, and head movements. In contrast, attentional selection in audition spares peripheral mechanisms almost completely. Attention in this domain is mostly independent of the position of head and ears, although limited increase in loudness and in signal-to-noise ratio can be gained by turning the head (Scharf, 1998). But apart from this, focusing auditory attention has to be achieved by central mechanisms. Consequently, it is conceivable that central selective attention mechanisms in audition are differentially organized and also more pronounced than in vision. This might also be true for the negative priming phenomenon as it reflects a mechanism of attentional selection.

In principal, all models of negative priming presented in the previous chapter can also be applied to explain auditory negative priming. Therefore, in the remaining part of the present chapter, the limited behavioral evidence that has been reported of auditory negative priming is analyzed with regard to whether the findings are similar to what was found in the visual domain. To anticipate, the few auditory studies mostly replicated findings made in the visual modality.

In Experiment 1 of Buchner and Steffens (2001) participants had to categorize one of a pair of dichotically presented tones as a wind or a string instrument by a manual keypress. In Experiment 2, the manual response to the probe (but not to the prime) was replaced by a temporal order judgment. Participants were simply to judge which of the two probe tones had occurred earlier. Two tones were in fact asynchronous only during the training phase, but were presented simultaneously during the experiment proper. It turned out that the act of ignoring a tone on a prime presentation resulted in a reduced probability of accepting that tone as antecedent on the subsequent probe presentation relative to the control condition in which the same tone had not occurred on the prime presentation.

This finding is consistent with the prediction of the distractor inhibition model according to which inhibitory processes suppress the competing distractor inputs which, in turn, leads to less efficient signal processing when a previously ignored stimulus is presented again (Houghton & Tipper, 1994; Tipper, 1985). Therefore, a tendency to perceive an ignored event as occurring later is to be expected. In contrast, such a result is not predicted by episodic retrieval, which is a response-based mechanism: The retrieval of the non-response information encoded with the ignored prime conflicts with the requirement to respond when the same stimulus is subsequently presented as the attended probe. It therefore cannot affect perceptual judgments such as those of the temporal order of auditory signals. Note that these findings do not exclude the retrieval of inappropriate response information from prior processing episodes (Neill & Valdes, 1992; Neill, Valdes, & Terry, 1995; Neill et al., 1992) as a factor for the classical, response-time variety of the negative priming phenomenon.

Banks et al. (1995) varied in their Experiment 2 the lag between the prime pair of words and the probe pair of words. There was either no intervening pair (probe at lag 1), a set of two intervening pairs (probe at lag 3), or a set of four intervening pairs (probe at lag 5). Following an inhibition model, the authors reasoned that negative priming as an aftereffect of facilitating prime selection should diminish. Therefore, a reduction in negative priming was predicted for lag 3 and lag 5. However, this prediction is not specific to an inhibition model, since successful episodic retrieval should also decrease with an increasing interval between prime and probe, thereby reducing the negative priming effect for longer lags. The result of this experiment was unexpected in that a negative priming effect was found for lag 1, but positive priming effects were found for lag 3 and lag 5. This is consistent with an inhibitory response block account as formulated by Tipper and Cranston (1985) or the approach by Houghton and Tipper (1994), both of which assume an excitatory and inhibitory component of different persistence, but episodic retrieval cannot accommodate these results.

However, there is also direct evidence in favor of an episodic retrieval mechanism of auditory negative priming. Buchner and Mayr (2005) transferred the experimental logic of Neill et al. (1992) into the auditory domain by demonstrating temporal discriminability effects for tones. In their Experiment 1, prime-probe RSIs were manipulated in the task developed by Buchner and Steffens (2001). Participants received prime-probe-pairs of auditory stimuli. They classified the prime and probe targets as either wind or string instruments. Prime-probe RSI was manipulated in three steps (250 ms, 500 ms, 5000 ms). The size of the negative priming effect stayed constant across the three prime-probe intervals as both, an inhibition model as well as an episodic retrieval model, would predict. The inhibition model would imply that inhibition evolves within 250 ms and persists at least 5000 ms. The episodic retrieval model would posit that prime retrieval probability is constant within this interval. Crucially, in Experiments 2a and 2b, the duration of an additional preprime-prime interval relative to the prime-probe interval was manipulated. In Experiment 2a, when preprime-prime and prime-probe intervals differed in duration—either 500 ms and 5000 ms or 5000 ms and 500 ms—the negative priming effect was larger when the prime-probe interval was short and the preprime-prime interval long. In contrast, in Experiment 2b, when both intervals had the same duration, no matter how long they lasted —either 500 ms or 5000 ms—no difference in the size of the negative priming effect was found. The results of Experiment 1, 2a, and 2b together replicate those found in the visual modality (Neill et al., 1992) in that the *absolute* duration of the prime-probe interval is irrelevant for the size of the negative priming effect whereas the *relative* size of this interval in comparison to the preprime-prime interval is crucial. The study impressively demonstrates that a factor (such as temporal discriminability) which influences retrieval probability determines the size of the auditory negative priming effect. Consequently, a mnemonic base of auditory negative priming can be inferred.

Regarding the alternative feature mismatch model the empirical situation is clear-cut insofar as feature mismatch is out of question to explain auditory negative priming effects. Some experiments manipulated the location-(sound) identity match, in that in half of the trials the ignored prime was presented on the same ear as the attended probe (match) and in half of the trials it switched to the other ear (mismatch; Experiment 1, Buchner & Mayr, 2004; Experiment 2, Buchner & Steffens, 2001; Mondor et al., in press). Location-identity match did not modulate the negative priming effect in any of these experiments. Another line of studies avoided location-identity mismatches completely in order to eliminate an explanation in terms of feature mismatch (Experiment 2, Buchner & Mayr, 2004; Buchner & Mayr, 2005; Buchner et al., 2003). Nonetheless, these experiments revealed robust negative priming effects.

Buchner et al. (2003) provided empirical evidence that is hardly reconcilable with the temporal discrimination model. In their experiment negative priming was only observed after conflict prime displays, that is, prime displays in which the target and the distractor were associated to different response categories. The authors explain this either by an inhibition mechanism and the assumption that non-conflict prime distractors do not interfere with the prime reaction and, therefore, do not have to be inhibited, or by an episodic retrieval mechanism assuming that non-conflict prime distractors do not receive a non-response tag. As is, the temporal discrimination model cannot explain this finding. The model would have to be extended by the assumption that non-conflict displays are processed more superficially than conflict displays in order to accommodate this finding. In addition, Mondor et al. (Experiment 1, in press) found decreased response times in a distractor-to-distractor repetition condition, a finding similarly to the visual domain, that has been claimed as inconsistent to a temporal discrimination model (Frings, 2005).

As far as valid conclusions can be drawn from the limited amount of empirical evidence at the current state of affairs, the studies of the negative priming effect in the auditory domain essentially replicate the findings from the visual domain. The available empirical evidence supports inhibitory as well as episodic retrieval explanations of the phenomenon. Parallel to identity negative priming in the visual domain, feature mismatch does not seem to be a valid explanation for auditory negative priming. As for temporal discrimination, evidence in the auditory domain is rather scarce, but so far does not support the model. So far, the mechanisms of visual and auditory negative priming seem to work similarly.

There is one exception to this rule. Mondor et al. (Experiment 3, in press) found an auditory negative priming effect in a single probe condition. In the visual domain, in contrast, positive priming or null effects were found for single-probe situations (see Chapter 2.1.2, pp. 12). Mondor et al. (in press) do not provide an explanation for this intriguing modality difference in negative priming.

Thus, while there are major parallels between vision and audition as far as negative priming is concerned, there are also differences, the significance of which cannot be judged at the moment because too little evidence is available. Therefore, it would be highly desirable to find a new methodological access for exploring the phenomenon of auditory negative priming. In the subsequent chapter event-related brain potentials are introduced for investigating the phenomenon and—possibly—for differentiating between models.

4 Measuring Event-Related Potentials to Investigate Auditory Negative Priming

To date, studies of negative priming have almost exclusively been using reaction times and error rates as dependent variables. This is astonishing because interindividual differences in the negative priming effect have been repeatedly related to changes in neurophysiological functioning (e.g. Metzler & Parkin, 2000; Stuss et al., 1999). Metzler and Parkin (2000) provide evidence that a majority of patients with frontal lesions shows no negative but positive priming in a visual identity negative priming task (letter naming). They interpret their findings in terms of a frontal (dis)inhibition hypothesis which implies that the frontal lobe plays a crucial role in filtering and suppressing irrelevant information. As a consequence of frontal lobe damage, inhibitory control should be impaired. Evidence in favor of this hypothesis has been provided by a variety of neuropsychological studies that reported impaired functioning of patients with damaged frontal lobes in experimental tasks which probably include inhibitory components such as the Stroop task (e.g. Perret, 1974), the Go/No-Go task (e.g. Leimkuhler & Mesulam, 1985), and the Wisconsin Card Sorting test (e.g. Nelson, 1976). Similarly, frontal lobe impairments have also been discussed as reasons for findings of reduced negative priming in the elderly or in schizophrenic patients, even though the current evidence for reduced negative priming in these groups is highly controversial (see Buchner & Mayr, 2004; Gamboz et al., 2002; Zabal & Buchner, in press).

Neurophysiology has already made its way into theories of negative priming as Houghton et al. (Houghton & Tipper, 1994, 1998) speculate about the anatomical and neuropsychological correlates of their neural network model. The authors assume that attention involves the interaction of many anatomically as well as functionally separate systems, and they propose that inhibitory processes are not supplied by a single "central inhibitor" (Houghton & Tipper, 1998, p. 65). Instead, inhibition is assumed to be accomplished via distributed networks. The authors stress the particular importance of the prefrontal cortex in the activation and maintenance of internal descriptions of the to-be-selected target features. In terms of the model, the prefrontal cortex is supposed to represent the target field upon which excitatory and inhibitory selective modulation of perceptual information can be implemented. Following Metzler and Parkin (2000), impaired inhibitory control due to a lesioned prefrontal cortex could be explained within the model by the inability of generating selection criteria (target descriptions) with the consequence that the system does not know which object to select and therefore cannot activate local inhibitory processes.

However, so far, there is only one functional magnetic resonance imaging (fMRI) study reported by Steel et al. (2001) that tried to find neurophysiological correlates of the negative priming effect. In this study, brain activation was measured while participants had to execute a Stroop interference task in which the hue of an incongruent color word had to be named. Stroop trials of the ignored repetition type were implemented by repeating the color word of display *n* as the color hue in display *n* + 1. Brain activity specific to the negative priming component of the Stroop task was measured by comparing cortical activity within the ignored repetition condition to cortical activity in the standard Stroop interference trials. Steel et al. reported activation in a widespread cortical network involving left temporal, inferior parietal as well as frontal areas that was specific to the ignored repetition condition.

Unfortunately, certain aspects of the experimental design of the study constrain the interpretation of the results as correlates of a negative priming mechanism. Typical to fMRI studies, a blocked presentation mode was chosen, that is. ignored repetition trials were presented in row. If a color word always becomes the target color hue in the next display, it seems likely that participants will learn and take advantage of this fact, so that responses in the ignored repetition condition may represent processes that are totally different from those of typical ignored repetition trials[3]. Since no reaction times were measured during fMRI data acquisition, there is no way of validating that negative priming occurred at all. Therefore, it is not clear whether the found correlates of the ignored repetition trial activation do indeed reflect a process relevant to the negative priming phenomenon.

An alternative to the functional imaging approach is presented in this chapter. Event-related potentials (ERPs) are introduced as a methodological approach to investigate neurophysiological correlates of the negative priming phenomenon and—possibly—to

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[3] Hasher et al. (1991) report results from a subgroup of participants in their Experiment 2 that were aware of the sequential contiguity of ignored repetition trials. These participants produced facilitatory responding in ignored repetition trials compared to control trials.

differentiate among theoretical accounts of the phenomenon. ERPs were chosen as the method of choice since they permit the measurement of neural activity changes to the scale of milliseconds which allows for an accurate temporal tracking of the involved cognitive processes. In contrast, functional neuroimaging techniques such as fMRI or positron emission tomography (PET)—that measure the blood oxygenation level and the regional cerebral blood flow, respectively—use far more inertial indicators of neural activity and, additionally, allow for a far less temporal resolution (Haxby, Courtney, & Clark, 1998). The problem of inertia usually enforces blocked experimental designs which implicate strategic components that change the nature of the task (see the above discussion of Steel et al., 2001; for reviews, see Coles, Smid, Scheffers, & Otten, 1995; Rugg, 1995, respectively). Therefore, these imaging techniques appeared to be inadequate for investigating negative priming tasks.

In a first section, the basics of ERP measurement, methodology, and inference drawing will be outlined (Chapter 4.1) to the degree to which this is necessary knowledge for the purpose of the upcoming Experiment 1. A vast amount of ERP evidence exists that is supposed to reflect inhibitory as well as memory retrieval processes (for reviews, see Coles & Rugg, 1995; Münte, Urbach, Duüzel, & Kutas, 2000). On the basis of this empirical evidence hypotheses are developed as to the temporal and spatial ERP correlates of the negative priming effect. To anticipate, this will be essential in directing the interpretation of ERP data in Experiment 1. Therefore, evidence of ERP correlates of inhibitory and memory retrieval processes will be recapitulated in the following two sections (Chapter 4.2 and Chapter 4.3).

4.1 ERP Methodology and Inferences

The electroencephalogram (EEG) is a voltage variation measured at the scalp over time. It reflects electrical neuronal activity—dendritic rather than axonal—in the central nervous system, largely in the neocortex. The so-called event-related potential (ERP) is EEG variation that is measured time-locked to some definable event (e.g. the onset or offset of a stimulus). It is assumed that these time-locked voltage changes are systematically related to the occurrence of the stimulus and the brain's response to it (Coles & Rugg, 1995). Since the stimulus-related systematic response is in the order of microvolts, it is obscured in the spontaneous EEG waveform which is in the order of tens of microvolts. Under the assumption that ERP activity systematically varies time-locked to stimulus onset whereas spontaneous EEG is unsystematic in relation to stimulation, the ERP "signal" is usually extracted from the spontaneous "noise" activity by help of time-locked averaging over multiple stimulus presentations (typically, 20 -50; Rugg & Allan, 2000) belonging to the same experimental condition (for an illustration, see Figure 4-1). Since unsystematic activity levels out in the process of averaging, the residual waveform should mainly reflect activity temporally related to the event of stimulation.

The average waveform consists of a number of positive and negative peaks over time, each of which can be described by its polarity, latency, distribution across the scalp as well as its sensitivity to experimental manipulation. The deflections are set in relation to anatomical generators within the brain—the so-called "physiological" approach to component definition following Coles and Rugg (1995)[4]—or in relation to information processing operations such as sensory, central, and motor processes—the so-called "functional" approach to component definition (Coles & Rugg, 1995). Usually both approaches are combined, in that physiological aspects such as polarity and distribution across the scalp as well as the psychological aspects such as latency and sensitivity to experimental manipulation are used as defining characteristics of a component. For example, a very characteristic deflection after auditory stimulation is a negative peak at about 100 ms after stimulus onset, of maximal amplitude in the vertex region (see Figure 4-1), which is influenced by physical and temporal aspects as well as the general state of the subject. This so-called "N1" has been interpreted as an auditory sensory component (at least partly) generated in primary auditory cortex, reflecting detector activity (Näätänen & Picton, 1987; Näätänen, Sams, Alho, & Paavilainen, 1988).

The functional interpretation of ERP data is limited in several respects (Rugg & Coles, 1995b). Most importantly, neural activity that produces electrical fields which can be measured at the scalp must stem from sizable populations of synchronously active neurons which have to be arranged in a certain geometric configuration that summate to dipolar fields. Ideally, neurons would be aligned in a parallel orientation and perpendicular to the cortical surface. In addition, electrical activity must be of adequate ampli-

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[4] Anatomical sources can be inferred by mathematical source localization procedures that suffer from the problem that there is no unique solution in inferring from a two-dimensional activation pattern to a three-dimensional activation pattern of an unknown number of dipoles. Since this approach has not been pursued in the current study, its details will not be described here (for details, see Coles & Rugg, 1995).

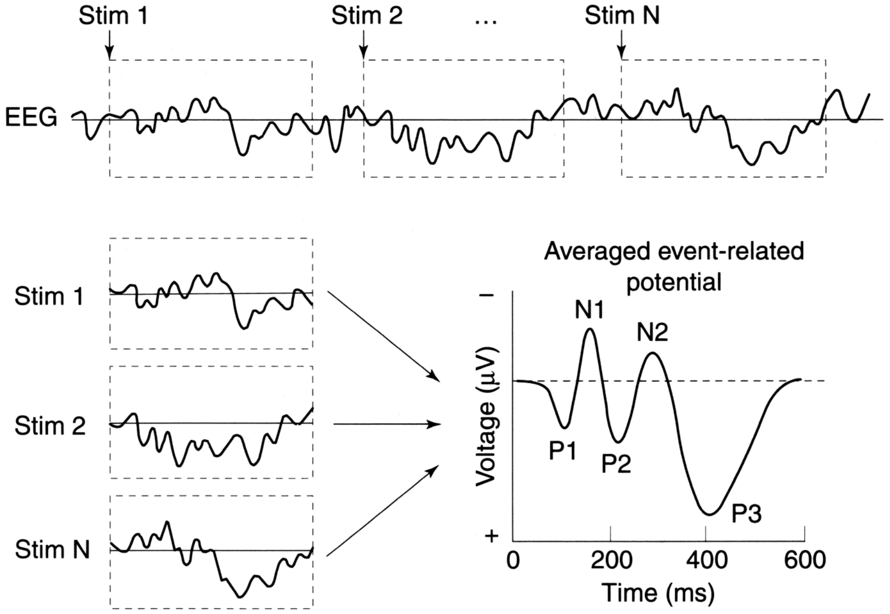

Figure 4-1: Depicted is the principle of signal-averaging of ERP data. EEG fluctuation is recorded in temporal relation to repeated (auditory) stimulation (Stim 1, 2, N; above). Individual EEG segments are extracted from the EEG data stream with respect to stimulus onset (left below). Individual segments are then averaged (right below). The resulting average waveform consists of a set of positive and negative peaks in temporal relation to the onset of the stimulus (here at time zero). The diagrammed idealized average waveform comprises typical components related to auditory stimulation (e.g. N1). By convention, negative is plotted upward (taken from Luck, 1998, Figure 7.2 (b), p. 262).

tude to be detectable at the scalp. Consequently, much neural activity will not be measurable at the scalp. Therefore, functionally important processes might be never detectable via ERPs. Any failure to find ERP differences between experimental conditions will therefore be ambiguous. It could either reflect functional similarity of the processes involved or it could be the consequence of differential activity that is not detectable at the scalp.

4.2 ERP Correlates of Inhibitory Processes

The Go/NoGo task, the Eriksen flanker task, as well as the Stroop task are three paradigms that are thought to reflect inhibitory processes. For all of them, multiple studies have been reported that investigated the electrophysiological correlates of task performance.

In the Go/NoGo task participants have to respond to one class of stimuli but to refrain from responding to another class of stimuli. These stimuli are called "Go" and "NoGo" stimuli, respectively. Several ERP studies have found a frontally located negative shift with a maximum at Fz in the NoGo condition at a latency of about 150-400 ms (e.g. Eimer, 1993; e.g. Falkenstein, Hoormann, & Hohnsbein, 1999). This so-called "NoGo-N2" (see Figure 4-2 for an example) has been interpreted as the correlate of a frontal inhibition mechanism which is activated in NoGo trials to prevent responding (cf. Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Kopp, Rist, & Mattler, 1996). It has already been suggested as a validation tool for tasks in which inhibitory activity has been assumed but not yet demonstrated. The "NoGo-N2" itself has been validated as a measure of inhibition in a recent study (Falkenstein et al., 1999) in which participants with high and low false alarm rates were compared. Assuming that high rates of reactions (i.e. false alarms) in NoGo trials indicate less efficient inhibition, it was expected that participants committing many false alarms would reveal a smaller and a later NoGo-N2 than participants with low false alarm rates. This hypothesis was confirmed. Additional evidence for an inhibitory interpretation of the "NoGo-N2" has been reported by Jodo and Kayama (1992). They showed that the "NoGo -N2" becomes larger when time pressure is enhanced.

The NoGo-N2 is usually found with visual stimuli, but it is very small (or even absent) with auditory stimulus presentation (Falkenstein et al., 1999; Falkenstein, Hoormann, & Hohnsbein, 2002). Therefore, it is interpreted as a modality-specific inhibition process which is further evidence that this component acts at an earlier than the (modality unspecific) motor level (Heil et al., 2000; Kopp, Mattler, Goertz, & Rist, 1996; Kopp, Rist et al., 1996)[5].

Given the task requirements in a Go/NoGo task, the inhibitory processes active in the NoGo condition might be confined to the very late level of overt motor response inhibition. Timing and topology of the associated NoGo-N2 indicate that this is not likely. In addition, Pfefferbaum, Ford, Weller, and Kopell (1985) demonstrated that similar NoGo

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[5] The less consistently found so-called "NoGo-P3", a positive shift with a maximum at Fz and Cz at a latency of 300-500 ms, has also been discussed as an inhibition correlate (for an example, see Eimer, 1993). Theoretical arguments but also empirical evidence contradicts this interpretation. First, assuming a roughly equivalent timing of processing in Go and NoGo trials, a NoGo component that peaks at or even after the response time in a Go trial can hardly represent an (effective) inhibitory mechanism. Second, Falkenstein et al. (1999) empirically showed that this component does not depend on the performance level (false alarms rates) but this is a critical property of the NoGo-N2.

ERP components were obtained regardless of whether the participants had to press a button on Go trials (and to withhold the button press in NoGo trials) or to count Go stimuli (and not to count NoGo stimuli). Different from an overt response inhibition process, the NoGo components seem to reflect inhibitory executive control functions.

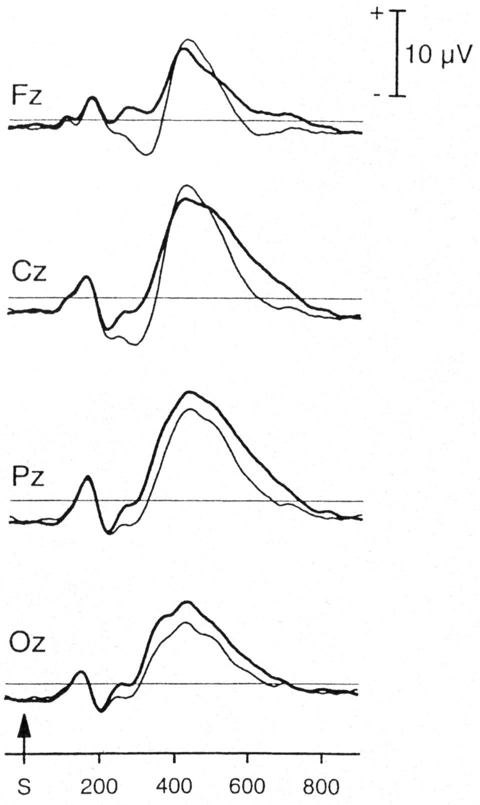

Figure 4-2: A typical example of a "NoGo-N2". Depicted are the grand average ERPs of correct Go (bold line) and NoGo (thin line) trials after visual stimulation (S = stimulus onset) in the experiment of Falkenstein et al. (1999, see their Figure 1, p. 276). The "NoGo-N2" is seen as a negative deflection with frontal maximum (at Fz) between about 200 and 400 ms. Note that positive is plotted upward.

Another well-established paradigm to investigate executive inhibitory processes is the Eriksen flanker task. In a typical Eriksen flanker task, participants have to respond to the middle letter (target) of a row of letters while ignoring the surrounding letters (flankers). The target letter is assigned to one of two response keys. Flankers can either be assigned to the same response key (compatible), the alternate response key (incompatible) or no response key (neutral). Response times are fastest for compatible flankers, slowest for incompatible flankers and intermediate for neutral flankers. Supposedly, an incompatible flanker pre-activates its associated response which is inappropriate for the current trial and has to be inhibited. ERP studies of the Eriksen flanker task (Kopp, Rist et al.,

1996) and of studies combining Eriksen flanker and Go/NoGo tasks (Heil et al., 2000; Kopp, Mattler et al., 1996) revealed a fronto-central negativity similar to the NoGo-N2 in incompatible flanker trials when participants had to change from an inappropriately pre-activated response to the response that was required by the actual target. Whether this negativity reflects the same process as the NoGo-N2 is still unclear. However, this negativity seems to be the correlate of an inhibitory executive control process—that is, of inhibiting an automatically primed but irrelevant response—and not the inhibition of a motor response per se.

A further task that is thought to require inhibitory executive control is the Stroop task (Stroop, 1935). Participants have to name the ink colors of written words. Naming times (measured by voice onset) are influenced by the congruence between the ink color of the word and the meaning of the word. The typical Stroop effect is measured as a slow-down in naming when the meaning of the word is incompatible to the color name compared to a condition in which the meaning and the ink color are compatible or non-conflicting. The Stroop effect has been explained as the result of the faster analysis of the irrelevant stimulus attribute (i.e. word meaning) compared to the time taken to analyze the relevant stimulus attribute (i.e. color). It is assumed that the inappropriate response to the irrelevant attribute is available first, and therefore has to be inhibited (Liotti, Woldorff, Perez, & Mayberg, 2000).

Repeatedly, ERP correlates of the Stroop effect have been found at (left) frontocentral electrodes. In an interval between either 350-450 ms (Markela-Lerenc et al., 2004) or 350-500 ms (Liotti et al., 2000; see also West & Alain, 1999), incompatible trials revealed a more negative deflection than compatible or neutral trials. The degree of spatial restriction of this effect depends on response modality (Liotti et al., 2000). This frontal negativity presumably relates to the suppression or the overriding of processing the incongruent and task-irrelevant word meaning. Some studies have found an immediately following second effect over midline frontocentral regions, but different polarities of this effect have been reported. Incompatible trials were more positive in Markela-Lerenc et al. (2004), but more negative in West and Alain (1999). These two frontal components have been associated to neural generators in lateral prefrontal cortex and anterior cingulate cortex, respectively. Markela-Lerenc et al. (2004) assume that the prefrontal cortex signals to the anterior cingulate cortex when executive control is necessary, and they assume that the anterior cingulate implements this control. West and Alain (1999) assume that conflict detection is achieved by the lateral prefrontal cortex, whereas conflict resolution is achieved by the anterior cingulate. Findings in neuroimaging studies of the anterior cingulate cortex have been interpreted similarly (for a review, cf. Bush, Luu, & Posner, 2000).

In sum, ERP research of the most-prominent behavioral paradigms that are supposed to measure inhibitory components converges on finding frontally and fronto-centrally located effects in a temporal range of 150-500 ms post-onset.

4.3 ERP Correlates of Mnemonic Processes

A rather uniform finding in ERP memory research is the modulation of ERP morphology between an item's first and second presentation. Typically, this ERP effect is expressed as a more positive-going deflection to the repeated presentation (reviewed by Rugg & Coles, 1995a; Rugg & Doyle, 1994). Even though temporal and spatial characteristics depend to some extend on the experimental task and the type of stimulus material, the repetition-dependent modulation starts at about 300 ms after stimulus onset and persists several hundred milliseconds. It tends to be maximally expressed over central and parietal sites (Rugg & Coles, 1995a).

ERP correlates of this kind have been measured in the absence of overt behavioural responding. Occasional target stimuli (e.g. non-words) are presented in a stream of non-target stimuli (e.g. words). Participants have to respond to the targets, but the potentials associated to the onset of non-target stimuli are of central interest. The number and time interval of repetitions of the non-target words are usually manipulated. The ERP effect due to stimulus repetition in this indirect test of memory—in which there is no reference made to the repetition of the stimulus—has been named the "ERP repetition effect" (Rugg & Coles, 1995a, see Figure 4.3 for an example). A similar effect has also been found in direct tests of memory in which explicit reference to a previous learning episode is made, such as in word recognition tests. The general finding here is the more positive-going ERP deflection for correctly classified old items relative to new ones. This is conventionally called the "ERP old/new effect" (e.g. Rugg & Doyle, 1992).

ERP effects due to stimulus repetition have been found with diverse stimulus materials such as words (e.g. Rugg, 1987), pronounceable nonwords (e.g. Curran & Cleary, 2003), meaningful pictures (e.g. Curran & Dien, 2003; Rugg, Doyle, & Melan, 1993), and across modalities (Rugg & Coles, 1995a; Rugg & Doyle, 1994).

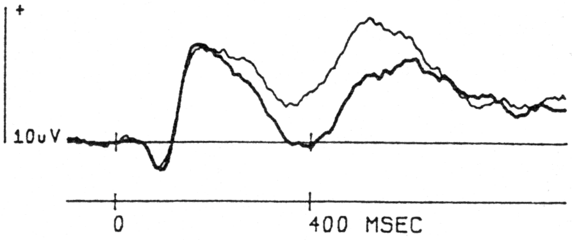

Figure 4-3: A typical example of an "ERP repetition effect". Depicted are the grand average ERPs for first (bold line) and second presentation (thin line) of repeated words. Participants task was to respond to occasionally interspersed nonwords but to withhold responses to words a proportion of which were repetitions of previously presented items. The "ERP repetition effect" is seen as a positive deflection with onset at around 250 ms post stimulus (depicted at Cz, example taken from Rugg and Doyle, 1994, see their Figure 1, p. 125). Note that positive is plotted upward.

There are different interpretations of the functional significance of the effect. It has been assumed that at least two underlying components contribute to its emergence (Rugg & Doyle, 1994). One candidate component of the ERP repetition and presumably also the ERP old/new effect has been a reduction in N400 due to repetition. The ease of integrating an item into the presentation context is expressed in the size of the negative-going N400 which peaks around 400 ms post-stimulus. The easier the integration is, the smaller is the N400 component (Rugg, 1995). This interpretation has been exclusively derived from studies of meaningful verbal or pictorial stimulus material. Classically, the N400 is modulated in contextual priming paradigms in which ERPs to unpredictable semantically incongruent terminating words of sentences are compared to predictable, semantically congruent terminations. The larger N400 for unpredictable words is supposed to reflect the increased difficulty of integrating this word into the context created by the preceding words. Rugg and Doyle (1994) suggested that contextual integration is facilitated by repeated exposure. A smaller N400 due to repetition would therefore reduce the negativity of the overall deflection to a repeated item and turn it into a more positive deflection.

In addition to this early component, a later repetition-based increase of the P3 (or P300, late-positive component) for repeated items has also been interpreted as contributing to the ERP effect due to repetition (Rugg, 1995). This component has been discussed as reflecting recognition processes, although the question has not been answered whether it reflects recollection-based or familiarity-based components of recognition. However, this distinction presupposes that a dual-process conception of recognition memory is appropriate which is arguable (for an alternative single process model account see Hintzman, 1988). Rugg (1995) suggests that the recollective component including retrieval of contextual information about the study episode is probably reflected in ERP old/new effects. This assumption is primarily based on a study by Wilding, Doyle, and Rugg (1995; see also Wilding, 2000) who varied the presentation mode of words in the study phase (visual vs. auditory). In the recognition test which was either visual (Experiment 1) or auditory (Experiment 2) participants had to judge whether words were old or new, and whether old items had been presented visually or auditorily. An ERP repetition effect was only found for old items assigned to the correct study modality. Thus the retrieval of the context information was related to the P3. Others have interpreted this effect as the correlate of relative familiarity (Rugg, 1990; Rugg & Doyle, 1994). Rugg (1990) found a repetition effect only for low-frequency words but not for high-frequency words which he attributed to the fact that words of low-frequency have a low degree of extra-experimental familiarity that is boosted by intra-experimental repetition to a larger degree than the already high level of extra-experimental familiarity inherent to high-frequency words[6].

In sum, ERP memory research typically reveals more-positive going deflections to repeated/old items in comparison to unrepeated/new items that start at about 300 ms, persist over several hundred milliseconds and are maximally expressed over central and parietal sites.

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[6] This explanation for an ERP correlate of repetition is based on the explanation of the word-frequency effect which commonly describes the finding that low-frequency words are better recognized than high-frequency words, even though the opposite is true for recall performance (Mandler, 1980).

5 Experiment 1[7]

An auditory negative priming experiment will be reported for which electrophysiological data were recorded in addition to reaction times and error rates. Regarding the electrophysiological measurement approach, the first objective was to investigate whether the negative priming effect is reflected in any measurable electrophysiological correlate. To this point, there have not been any reports of ERP correlates of auditory negative priming. Consequently, the electrophysiological approach necessarily was somewhat exploratory. If a unique ERP correlate of auditory negative priming was found, the second objective would be to use ERP data in an attempt to test the adequacy of negative priming theories. The ERP results will be compared to well-established components found in other paradigms thought to imply similar cognitive processes.

As has been shown in the previous chapter, inhibitory processes involved in Go/NoGo, Eriksen flanker, and Stroop tasks are reflected in frontally (or fronto-centrally) located effects of negative polarity at a temporal range of 150–500 ms post stimulus (see Chapter 4.2, pp. 39). The frontal (dis)inhibition hypothesis based on neuropsychological evidence supports the assumption that the (pre)frontal cortex is crucial for inhibitory processes (see Chapter 4, p. 35). Thus, if the negative priming effect in this experiment reflects a similar form of inhibition, a frontally located effect of negative polarity within a similar temporal range would be expected.

In contrast, typical ERP correlates of memory retrieval are effects with a central-parietal topography starting at about 300 ms and lasting for several hundred milliseconds (see Chapter 4.3, pp. 43). If the negative priming phenomenon reflects a memory mechanism retrieving the prime episode, its ERP correlate would be expected to exhibit these characteristics, too. These expectations were used to guide the data analysis in Experiment 1.

The experimental negative priming task used in Experiment 1 was the same task that had been used in the study of Buchner and Steffens (Experiment 1, 2001) for which auditory negative priming has been successfully demonstrated. Participants had to cate-

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[7] Experiment 1 has already been reported (cf. Mayr, S., Niedeggen, M., Buchner, A., & Pietrowsky, R. (2003). ERP correlates of auditory negative priming. *Cognition, 90*, 11-21).

gorize one of two dichotically presented tones as either an animal or musical instrument tone. In ignored repetition trials the ignored prime tone was repeated as the to-be-attended probe tone for which slowed-down and/or more error-prone responses relative to the control conditions (see Chapter 5.1.2 for details) were expected.

5.1 Method

5.1.1 Participants

Participants were 15 adults (mostly students), 8 of whom were female. They ranged in age from 19 to 35 years (*M* = 25.71, *SD* = 4.65). Participants had no history of neurological disorders or hearing disabilities. The data of one further participant who had to abort the experimental session due to eye and hearing problems had to be discarded. Participants were tested individually. They were paid € 15.00 for their participation.

5.1.2 Materials

The stimuli were three digitized musical instrument (piano, guitar, and cornet) and three digitized animal tones (frog, bird, and hen). Each tone was 300 ms long, complete with attack and decay. The participants heard the tones over headphones that were connected via loudspeakers to a personal computer. Tones were played at about 70 dB(A) but participants were allowed to adjust loudness.

A 20 ms metronome click indicated the ear (left or right) at which the to-be-attended tone would be presented. After the cue a pair of sounds was presented dichotically, the target tone to the cued ear, the distractor tone to the opposite ear. Participants reacted to the tone by pressing the “instrument” (upper button) or “animal” (lower button) key on a response box with their index fingers. The response box was directly plugged into the personal computer. The response hand (left vs. right) was interindividually assigned in alternating order to the response keys (“instrument” vs. “animal”). The keys were aligned sagittally to prevent spatial compatibility effects between the target’s location and the required response (cf. Buchner & Steffens, 2001).

Each experimental trial consisted of a prime and a probe display. Each display consisted of a target and a simultaneously presented distractor. Ignored repetition and control trials were constructed to be parallel, as is illustrated in Table 5-1. First, control trials were generated by randomly combining four of the six different tones as prime and probe targets and distractors with the restriction that the attended and ignored primes had to be from different response categories (upper middle column of Table 5-1), because earlier experiments with a similar paradigm had shown negative priming only for this target-distractor configuration (Buchner et al., 2003). In the same way, attended and ignored probes had to belong to different categories. Next, a corresponding ignored repetition trial was constructed by replacing the ignored prime of the control trial by the attended probe (upper left column of Table 5-1). This implies that the response category of the ignored prime was always the same for an ignored repetition and its corresponding control trial. As a consequence, any performance differences between control and ignored repetition trials must be due to the stimulus identity of the prime distractor and cannot be due to the response category associated to it. Furthermore, the probe stimulus pair was identical for an ignored repetition and its matching control trial, thus enabling an unequivocal comparison of the probe reactions.

Table 5-1

Examples of the stimulus configuration for the different trial types (Experiment 1).

	Ignored Repetition		Control		Reversed Repetition Control	
	Attended Ear	Ignored Ear	Attended Ear	Ignored Ear	Attended Ear	Ignored Ear
Prime	Piano	Frog	Piano	Bird	Guitar	Bird
Probe	Frog	Guitar	Frog	Guitar	Frog	Guitar

	Filler Type I		Filler Type II	
	Attended Ear	Ignored Ear	Attended Ear	Ignored Ear
Prime	Bird	Piano	Bird	Guitar
Probe	Frog	Guitar	Frog	Guitar

In order to control for ERP effects evoked by stimulus repetition independent of attentional allocation (Rugg & Doyle, 1994), additional reversed repetition control trials were constructed out of the control trials by replacing the attended prime tone with the ignored probe tone in each control trial (upper right column of Table 5-1). As the ignored repetition trials, the reversed repetition control trials included a stimulus repetition from prime to probe, even though this repetition was from prime target to probe distractor.

The ignored repetition, control, and reversed repetition control trials were parallel in that the response categories of prime target and prime distractor were different as well as those of prime target and probe target. Given only these three trial types, the required probe response would have been perfectly predictable from the prime display. To control for response bias, filler trials were added in which the prime and probe target categories and as a consequence the required prime and probe responses were the same. Filler type I trials were created by exchanging the prime target and prime distractor of the control trials (lower left column of Table 5-1). Filler type II trials were created by exchanging the prime target and prime distractor of the reversed repetition control trials (lower right column of Table 5-1). As a consequence, filler type II trials included a repetition of the prime distractor as the probe distractor. Filler type I trials were duplicated.

Overall, there were 72 ignored repetition trials, 72 control trials, 72 reversed repetition control trials, 144 filler type I trials, and 72 filler type II trials. In half of all trials there was a repetition of tones between prime and probe (ignored prime as attended probe in ignored repetition trials, attended prime as ignored probe in reversed repetition control trials, and ignored prime as ignored probe in filler type II trials), and in half of the trials there was no repetition. In half of the trials there was a response category change from prime target to probe target, in half of the trials there was no change. The 432 trials were brought into a random sequence. This sequence was presented to all participants.

5.1.3 Procedure

After the electrodes had been affixed, participants were given oral instructions upon the experimental task. In order to familiarize participants with the tone stimuli and their task, participants responded to 48 prime-probe training trials that were identical to the later experimental trials (see below) but comprised only a subset of these. A run of another 48 training trials was given provided participants had committed too many errors in the first run, they had frequently responded too slow, or they reported subjective uncertainty with the task.

Each of the 432 experimental trials began with the metronome click, followed by a 750 ms cue-target interval and the prime display of tones. After the prime response, a response to stimulus interval of 1800 ms preceded the click that cued the to-be-attended probe side. The probe click was presented to the opposite side as the prime cue and it was followed by a 750 ms cue-target interval, after which the probe display was presented. Prime or probe reactions faster than 100 ms and slower than 1500 ms were counted as invalid. Participants received no trial feedback. However, if they committed multiple errors or timeouts or if they made eyeblinks or eye movements during the trial, the experimenter called their attention to these problems. After the participant's response the word "TASTE" ("key") appeared in the center of the screen indicating that the next trial could be started by an arbitrary press of one of the two response keys. After 2000 ms the next prime cue started.

To avoid eye movements which provoke electrophysiological measurement artifacts overlapping the brain activity of interest, a fixation cross was presented in the middle of the screen. Participants were told to fixate the cross throughout each trial. The cross was shown 1300 ms before the prime cue started and stayed on the screen until 200 ms after the prime response. After a short 300 ms interval and 1300 ms before the probe cue the cross was presented again and stayed there until the probe response had been executed. Participants were to avoid eyeblinks during the trials. Eye blinks were explicitly allowed between trials.

In the middle of the experimental session a break of about 10 minutes was made. After the final trial, all participants were informed about the purpose of the experiment. The experiment took about 80 minutes.

5.1.4 EEG Recording and Data Analysis

An elastic cap with predefined electrode positions (Falk-Minow-Services, Munich) was mounted on the participant's head. The recorded electrode positions are shown in Figure 5-1. The 30 active silver-silver chloride electrodes were referenced to linked mastoids, with impedance kept below 5 kOhm. Vertical and horizontal EOGs were recorded to control for ocular artefacts. Biosignals were recorded continuously (EEG-8 amplifiers, Contact Precision Instruments, London), sampled at 250 Hz, and online band pass-filtered (0.03 to 200 Hz). Offline, EEG data were segmented according to the sound onset in each display (-100 to 1000 ms epoch length), filtered (0.5 – 40 Hz, -48 dB cut-offs), and baseline corrected (-100 to 0 ms). Single EEG sweeps containing muscular or ocular (vEOG, hEOG) artefacts were excluded from the analysis. The remaining sweeps were averaged according to trial type (ignored repetition, control, reversed repetition control, filler type I, and filler type II) and electrode position, separately for prime and probe displays. ERP responses evoked in filler trials, as well as ERPs evoked in prime displays will not be discussed in detail, but note that prime ERPs did not differ between the different trial type conditions.

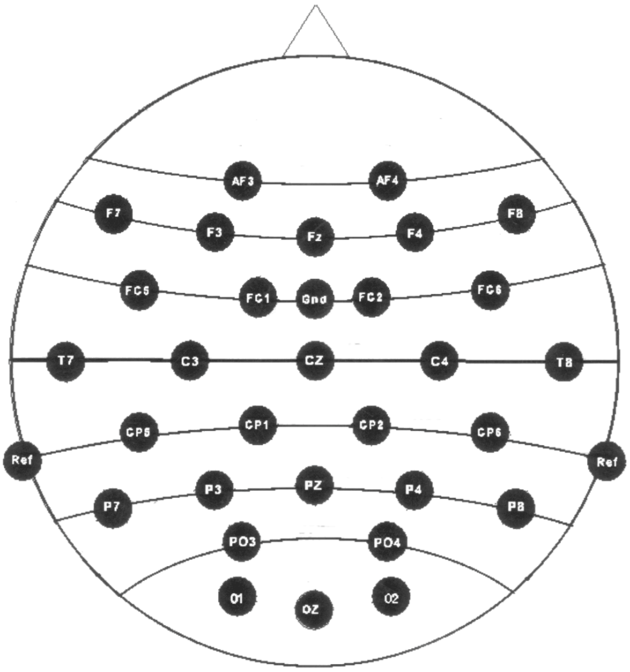

Figure 5-1: Recorded electrode positions (Experiment 1). The reference electrodes at the mastoids are indicated by "Ref". "Gnd" indicates the ground electrode. The following clusters were formed: left anterior (AF3, F3, F7), middle anterior (Fz, FC1, FC2), right anterior (AF4, F4, F8), left central (FC5, C3, T7, CP5), middle central (Cz, CP1, CP2), right central (FC6, C4, T8, CP6), left posterior (P3, P7, O1), middle posterior (Pz, PO3, PO4, Oz), and right posterior (P4, P8, O2).

Based on the grand-averaged ERPs, four time windows were determined (80-130 ms, 250-300 ms, 300-450 ms, and 450-600 ms) which represented distinct transient components and the time course of a sustained ERP effect (N1 complex, frontal negativity [FN], and late positive complex early [$\text{LPC}_{\text{early}}$] and late [$\text{LPC}_{\text{late}}$]). Mean reference-to-baseline amplitudes within these windows were computed for each participant, trial type, and electrode. Topographical effects were considered by splitting the electrodes according to the spatial factors of caudality (anterior vs. central vs. posterior) and laterality (left vs. middle vs. right) (see Figure 5-1 for details of clustering).

5.1.5 Design

With respect to the reaction time data, the experiment comprised a one-factorial design with trial type (ignored repetition vs. control vs. reversed repetition control) as within-subject variable. The primary dependent variables were participants' probe reaction times and probe error rates.

Buchner and Steffens (2001) found a negative priming effect of size $\eta^2 = .30$, (equivalent to $d_z = 0.66$, which is between "medium" and "large" effects as defined by Cohen, 1988) in their Experiment 1 with a comparable categorization task. A compromise power analysis (Erdfelder, Faul, & Buchner, 1996) showed that given the sample size of $N = 15$, a negative priming effect of size $\eta^2 = .30$ could be detected with $\alpha = \beta = 0.107$. In order to give type I and type II errors equal importance in statistical reasoning, all statistical analyses were based on an error probability level of $\alpha = .10$.

With respect to the electrophysiological data, the experimental design was extended to a three-factorial design with trial type (ignored repetition vs. control vs. reversed repetition control), caudality (anterior vs. central vs. posterior), and laterality (left vs. middle vs. right) as within-subject variables. The analyses were separately performed for the four different time windows of interest. In keeping consistence to the behavioral analyses, the level of alpha was maintained at .10. For all statistical tests, individual—and in the case of *t*-tests two-tailed—*p* values are reported as well as partial η^2 as an effect size measure.

5.2 Results

For both the behavioral as well as the electrophysiological analyses, there was no hypothesis including all three levels of the trial type variable. Rather, the tests of interest were the direct comparisons between the ignored repetition condition and each of the two control conditions (control and reversed repetition control). For simplicity of presentation, the focus will be on each of the three direct comparisons between two of the three levels of the trial type variable. For the same reason, for the ERP data, significant interactions of trial type and electrode position (caudality and/or laterality) are reported only if the effect was confirmed at an electrode cluster by post-hoc comparisons.

5.2.1 Reaction Time and Overall Error Analysis

Probe reaction times were evaluated only for trials in which both the prime and the probe reactions were correct. Probe errors were evaluated only if they followed a correct prime response. The means of participants' mean reaction times and the error rates are presented in the left and right panels of Figure 5-2, respectively.

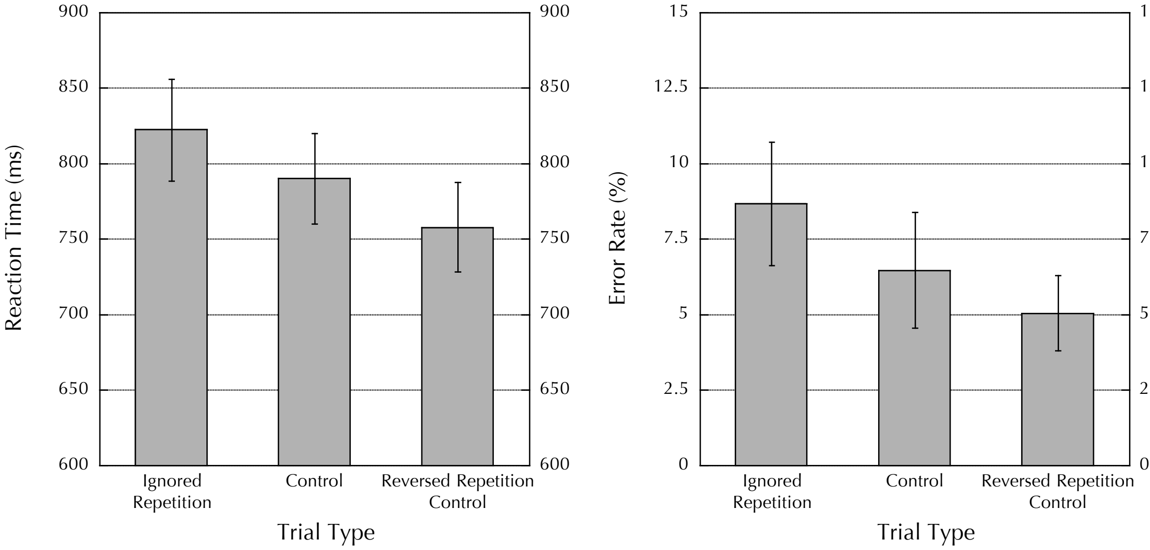

Figure 5-2: Reaction times (left panel) and error rates (right panel) as a function of trial type (Experiment 1). The error bars depict the standard errors of the means.

Reaction times were longest in the ignored repetition and shortest in the reversed repetition control condition. The ignored repetition and control condition differed significantly, $t(14) = 3.20$, $p = .006$, $\eta^2 = .41$, as did the control condition and the reversed repetition control, $t(14) = 4.63$, $p < .001$, $\eta^2 = .59$. At a descriptive level, the pattern was similar for the mean error rates that were largest in the ignored repetition condition, intermediate in the control condition, and lowest in the reversed repetition control condition. Differences were not significant between the ignored repetition and the control condition, $t(14) = 1.24$, $p = .237$, $\eta^2 = .09$, but between the ignored repetition and the reversed repetition control condition, $t(14) = 2.37$, $p = .033$, $\eta^2 = .27$. The two control conditions did not differ significantly, $t(14) = 1.00$, $p = .334$, $\eta^2 = .06$. Consequently, there is a clear negative priming effect in the reaction times which is not compromised by a speed-accuracy trade-off.

For control purposes, prime reaction times and prime error rates were also analyzed. At the time of the prime presentation no systematic differences between conditions should exist. Participants' mean prime reaction times should therefore be equal between conditions. Indeed, the mean prime reaction times and prime error rates did not differ significantly between trial types, $F(2,13) = 1.41$, $p = .280$, $\eta^2 = .18$, and $F(2,13) = 0.76$, $p = .486$, $\eta^2 = .11$, respectively.

5.2.2 ERP Data

Grand-averaged ERPs evoked by the probe sounds are depicted in Figure 5-3. In line with previous ERP findings (Näätänen et al., 1988), auditory stimulation evoked a transient negative peak at 100 ms (N1), followed by a positivity peaking at about 180 ms (P2). At fronto-central leads, the transient components were followed by a slow negative wave extending from 200 to 800 ms post stimulus onset, including a local negative maximum between 250 and 300 ms (frontal negativity, labeled as FN). At centro-parietal leads, the negative wave returned to baseline at about 450 ms, and was then released by a late positive component (LPC) extending up to 900 ms.

As mentioned above, the statistical analysis comprised the three pairwise comparisons of the three trial type conditions, separately for the four temporal ERP epochs (N1, FN, $\text{LPC}_{\text{early}}$, and LPC_{late}). For the ease of description, only significant tests are reported.

5.2.2.1 Analysis of the N1 Epoch

For the N1 component, comparing the ignored repetition and the control condition revealed an interaction between trial type and electrode caudality, $F(2,13) = 3.68$, $p = .054$, $\eta^2 = .36$. Post-hoc tests revealed a significant amplitude reduction in the ignored repetition condition at frontal leads, $t(14) = 2.31$, $p = .037$, $\eta^2 = .26$ (all ERP mean amplitude effects as a function of time window, trial type, and electrode caudality are depicted in Figure 5-4). No interaction effects with electrode position were found when the ignored repetition condition was compared to the reversed repetition control condition. Differences between the two control conditions also depended on electrode caudality, $F(2,13) = 3.02$, $p = .084$, $\eta^2 =.32$, primarily reflecting a significant anterior reduction for the reversed repetition control, $t(14) = 2.36$, $p = .033$, $\eta^2 = .27$, that extended to central electrodes, $t(14) = 1.99$, $p = .067$, $\eta^2 = .21$. The spatial distribution of the N1 (as well as the other components) is illustrated in the average-referenced topographical maps reflecting the difference waves (ignored repetition vs. control, and ignored repetition vs. reversed repetition control; see Figure 5-3, below).

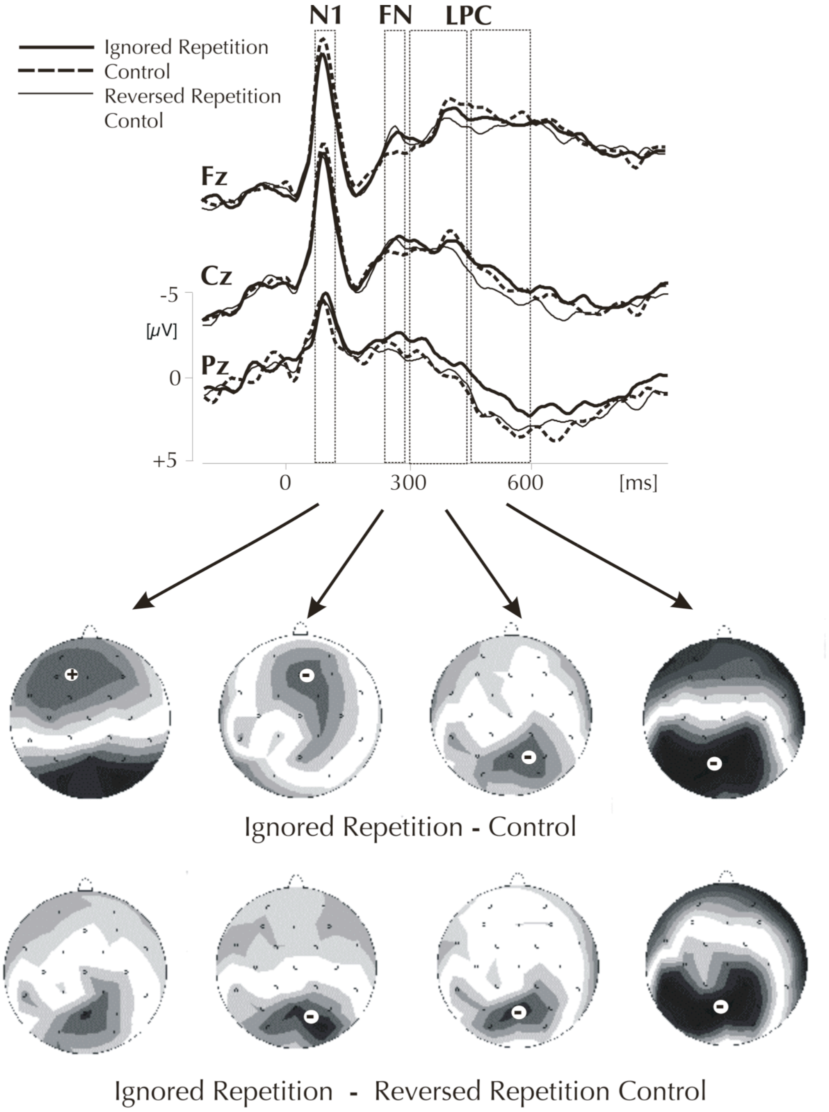

Figure 5-3: Grand average ERPs evoked in the three trial type conditions of interest (upper panel), and the average-referenced topographic maps referring to selected time windows (lower panel). The ERP traces recorded at frontal (Fz), central (Cz), and parietal (Pz) sites are superimposed for ignored repetition condition (bold), the control condition (dashed), and the reversed repetition control condition (thin). Analysis focuses on the N1 component (80-130 ms), a transient frontal negativity (FN: 250-300 ms), and the early and late part of a late positive complex (LPC: early 300-450 ms; late 450-600 ms). The maps illustrate the topographical distribution of ERP effects between conditions within the aforementioned time windows. The top row refers to the spatial distribution of the difference waves between the ignored repetition condition and the control condition, and the bottom row to the corresponding difference between the ignored repetition condition and the reversed repetition control condition.

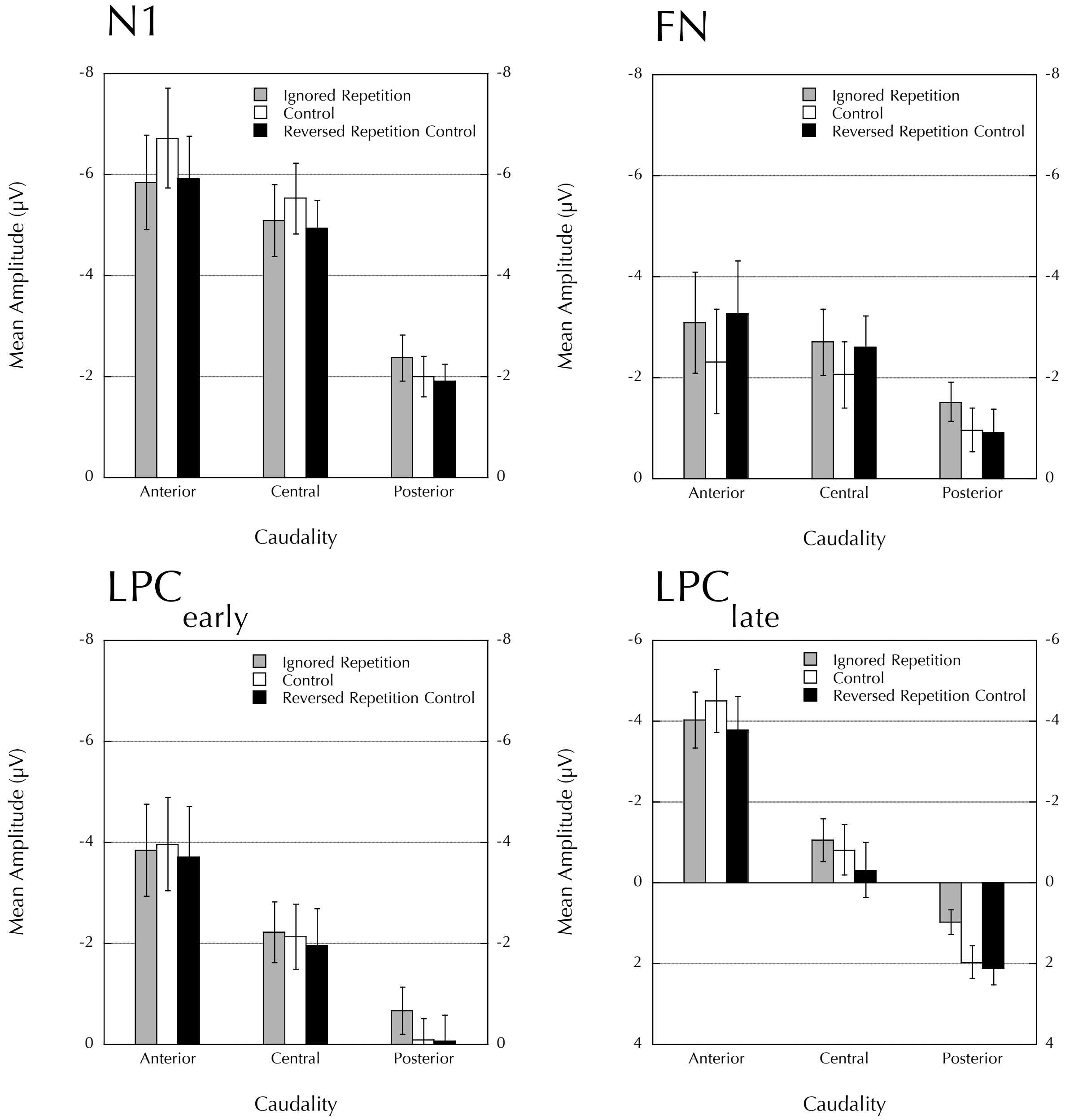

Figure 5-4: ERP mean amplitude effects as a function of time window (upper panel: N1 [left], FN [right]; lower panel: $\mathrm{LPC}_{\mathrm{early}}$ [left], $\mathrm{LPC}_{\mathrm{late}}$ [right]) and electrode caudality (Experiment 1). The error bars depict the standard errors of the means.

5.2.2.2 *Analysis of the FN Epoch*

Within the 250 to 300 ms time window, the ERPs of the ignored repetition condition were slightly enhanced but did not differ significantly from the control condition. There was also no differential activation pattern for the ignored repetition and the reversed repetition control condition. The difference between the reversed repetition control and the control condition depended on electrode caudality, $F(2,13) = 5.85$, $p = .015$, $\eta^2 = .47$, and was primarily due to an enhanced frontal negativity in the reversed repetition control, $t(14) = -3.34$, $p = .005$, $\eta^2 = .43$, that extended to central leads, $t(14) = -2.26$, $p = .041$, $\eta^2 = .25$.

5.2.2.3 Analysis of the LPC_e Epoch

The LPC_e (300 - 450 ms) differentiated between the ignored repetition and the two control conditions: The difference between the ignored repetition condition and the control condition depended on electrode caudality, $F(2,13) = 5.39$, $p = .020$, $\eta^2 = .45$, indicating that the mean amplitude was more negative in the ignored repetition condition at posterior sites, $t(14) = -3.22$, $p = .006$, $\eta^2 = .41$. Similarly, the difference between the ignored repetition and the reversed repetition control conditions depended on electrode caudality, $F(2,13) = 4.05$, $p = .043$, $\eta^2 = .38$, and was due to a greater negativity in the ignored repetition condition at posterior leads, $t(14) = -3.35$, $p = .005$, $\eta^2 = .43$. ERPs did not differ between the two control conditions.

5.2.2.4 Analysis of the LPC_l Epoch

The ERP effect that characterized the ignored repetition condition in the LPC_e was also observed in the LPC_l (450 - 600 ms). The difference between the ignored repetition and the control condition as well as between the ignored repetition and the reversed repetition control condition depended on electrode caudality, $F(2,13) = 7.26$, $p = .008$, $\eta^2 = .53$, and $F(2,13) = 7.80$, $p = .006$, $\eta^2 = .55$, respectively. For both comparisons, the ignored repetition condition was associated with a less positive wave at posterior leads, $t(14) = -3.32$, $p = .005$, $\eta^2 = .43$, and $t(14) = -4.35$, $p = .001$, $\eta^2 = .56$, respectively. The difference between the ignored repetition and the reversed repetition control condition was also significant at central positions, $t(14) = -2.52$, $p = .024$, $\eta^2 = .30$. In addition to an interaction with caudality, the ERP differences between the ignored repetition and the reversed repetition control condition also depended on laterality, $F(2,13) = 9.11$, $p = .003$, $\eta^2 = .58$. Even though ignored repetition was less positive than reversed repetition control at all three lateralities (left, middle, right), this difference was strongest at middle electrodes, $t(14) = -3.14$, $p = .007$, $\eta^2 = .40$, compared to left and right electrodes, $t(14) = -2.39$, $p = .032$, $\eta^2 = .28$, and $t(14) = -1.88$, $p = .081$, $\eta^2 = .19$, respectively. There were no ERP interactions of trial type and electrode position between the two control conditions.

5.3 Discussion

The present experiment revealed a typical negative priming effect in both the reaction times and the error rates. Probe responses to sounds that had previously been ignored were slowed down relative to responses to new sounds. This negative priming effect was paralleled by increased probe error rates to previously ignored sounds, but these differences were not statistically significant. Importantly, the slow-down in reaction time was not compromised by a speed-accuracy trade-off. On the contrary, responses to target sounds were faster and descriptively less error-prone when the simultaneously presented distractor was a previously attended sound.

Irrespective of the behavioural effects, stimulus repetition of any form (first ignored and then attended as in the ignored repetition condition or first attended and then ignored as in the reversed repetition control condition) significantly attenuated the auditory N1 component, and slightly increased a frontal negativity. Electrophysiological correlates that were unique to the ignored repetition condition were confined to posterior electrodes, and were reflected in a diminished late positive complex starting about 300 ms and extending up to 600 ms.

Auditory negative priming as reflected in an increased reaction time for previously ignored sounds confirms previous findings using a similar experimental paradigm (Buchner & Steffens, 2001). The decreased reaction times in the reversed repetition control condition also have been observed in similar negative priming studies (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; Lowe, 1979; Neill, 1978). A plausible explanation for this effect has been given by Kane et al. (1994) who suggested that in experimental designs lacking attended repetition trials (the prime target is repeated as the probe target) participants learn across the experiment that a prime target never repeats as the to-be-attended probe. Consequently, when a prime target is repeated, it has to be the irrelevant probe distractor. The authors assume that this knowledge facilitates probe selection in that the repeated item is easily rejected as a candidate for response. As a consequence of facilitated selection, response time decreases. The authors back up this explanation by pointing to the fact that studies including attended repetition trials failed to demonstrate a target-to-distractor facilitation. Since there were no attended repetition trials in the design of Experiment 1, the account given by Kane et al. (1994) seems to be adequate to explain the speed-up in the reversed repetition control condition.

Turning to the ERP findings of this experiment, the first significant ERP effect revealed in the ignored repetition condition was a reduced N1 amplitude. However, the N1 attenuation cannot reflect an (early sensory) inhibitory component since it was also recorded in the reversed repetition control condition that resulted in a response time speed-up (and not in a slow-down as the ignored repetition condition did). In fact, this result is in line with the N1 interpretation by Näätänen and Picton (1987). In their review, they report that the N1 wave[8] is attenuated with stimulus repetition and—more generally speaking—with the degree of similarity between consecutive auditory stimuli. It has been assumed that the N1 reflects activation of feature detectors that show refractory effects with stimulus repetition rather than habituation. The repetition of a stimulus independent of the attentional allocation to it—either ignore-to-attend as in the ignored repetition condition or attend-to-ignore as in the reversed repetition control condition—seems to cause this effect.

Topography and latency of the frontal negativity (FN) were similar to those of anterior ERPs observed in other paradigms in which these ERP components were thought to be related to central inhibitory processes (see Chapter 4.2, pp. 39). However, in Experiment 1 the transient segment of the frontal wave between 250-300 ms was not uniquely related to the ignored repetition condition. The ignored repetition condition shared the frontal activation pattern with the reversed repetition control condition in which the negativity was even more prominent. There was also no frontally located later effect of the ignored repetition condition. Obviously, the negative priming effect is not reflected in an ERP component similar to those found in NoGo, Eriksen flanker, and Stroop tasks (Eimer, 1993; Falkenstein et al., 1999; Falkenstein et al., 2002; Heil et al., 2000; Kopp, Rist et al., 1996; Liotti et al., 2000; Markela-Lerenc et al., 2004; West & Alain, 1999, 2000) that are usually interpreted as reflecting inhibitory executive control functions. Bearing in mind that inferences upon the absence of effects can only be drawn with the sensitivity allowed by the measurement device, these data are incompatible with the assumption that negative priming is sufficiently explained in terms of a central inhibition mechanism located in the prefrontal cortex (Fuster, 1997). Note, that

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[8] The authors use the term "N1 wave" and not "N1 component" for the deflection measurable at the scalp which is supposed to consist of several components. Each component is generated by a specific neurophysiological source (Näätänen & Picton, 1987). For the current purposes, only determinants of the measureable N1 wave are of interest.

the data do not disprove a distractor inhibition model *in general* as inhibition may also be implemented without frontal involvement. However, the crucial point is that negative priming does not reflect any of those ERP effects which have been validated as correlates of inhibitory executive control (see Chapter 4.2, pp. 39).

The only ERP effect that was uniquely related to the ignored repetition condition was a late posterior complex which shares polarity, time course, and topography of old/new (or repetition) ERP effects usually obtained in studies on recognition memory and repetition (see Chapter 4.3, pp. 43). Amongst others, this effect has been interpreted as the correlate of a gain in familiarity due to intra-experimental repetition (Rugg, 1990; Rugg & Doyle, 1994). The increase in an event's relative familiarity, in turn, has been associated with more fluent processing of an event (Johnston, Dark, & Jacoby, 1985).

In the current experiment, stimulus familiarity was generally high because only six different auditory stimuli were presented repeatedly throughout. Therefore, partial stimulus repetition from prime to probe—as in the ignored repetition or the reversed repetition control condition—was *per se* not expected to be sufficient to increase the baseline familiarity of the stimuli, and to induce an old/new ERP effect. This expectation was confirmed for the reversed repetition control condition which did not differ from the control condition with respect to the LPC. In contrast, the repetition of a previously ignored stimulus in the ignored repetition condition evoked a less positive-going complex. This suggests that the processing of a previously ignored stimulus is functionally equivalent to the less fluent processing of a novel stimulus. The topographic distribution and the sustained temporal characteristics of the negative priming LPC effect might be interpreted to support a memory-based account.

Recapitulating the new insights gained from Experiment 1, the first objective of this experiment was successful in that for the first time an ERP correlate of auditory negative priming was found. The auditory negative priming effect in reaction time was accompanied by a parietally located negative ERP deflection in the time range between 300 and 600 ms post-stimulus (LPC_e and LPC_l). The second objective of this study was to gain information about the underlying mechanism of negative priming. Due to its resemblance to ERP correlates of recognition memory (old/new ERP effect and ERP repetition effect), the effect found is consistent with a memory retrieval mechanism of negative priming and not with a frontal inhibition mechanism

6 Episodic Retrieval of Prime Responses

Experiment 1 provided additional evidence consistent with a memory retrieval mechanism, substantiating the episodic retrieval evidence in reaction time data reported elsewhere (Buchner & Mayr, 2005). The next logical step concerns the question of exactly what the "inappropriate" information is that is remembered and that interferes with responding to the probe. The original episodic retrieval model (Neill & Valdes, 1992) assumes that the retrieved prime distractor is associated with "some form of nonresponse" (p. 574) information. When retrieved, this non-response information may conflict with the requirement to respond to the same stimulus when it appears as the probe target. The conflict takes time to resolve.

Although this is a reasonable explanation of the negative priming phenomenon, it is not the only one that is possible within the episodic retrieval model. Alternatively, the response associated with the prime target could be a significant aspect of the prime episode. When retrieved in ignored repetition trials, this response would be inappropriate and lead to a conflict when responding to the probe target. For instance, in Experiment 1, the correct prime and probe responses always differed in category (or else negative priming cannot be observed, cf. Buchner et al., 2003). Similarly, in standard negative priming tasks in which participants need to name or otherwise identity (features of) the targets, the probe response is different from the prime response (cf. Fox, 1995; May et al., 1995; Neill et al., 1995; cf. Tipper, 2001). If, on ignored repetition trials, the probe target cued the prime response together with the prime episode, then this response would conflict with the probe response. Negative priming should result. Experiments 2 and 3 were designed to test this new variant of the episodic retrieval model.

This modified variant of the episodic retrieval model, henceforth named "prime-response retrieval variant" in contrast to the "non-response retrieval variant" as originally proposed by Neill et al. (1992), has a certain degree of a priori plausibility. Since one focuses on the target stimulus and on the task of responding to it when following instructions in a typical selective attention task, the prime response should be a prominent aspect of the retrieved prime episode. It is conceivable that the physically performed prime response is a far more prominent detail of the prime episode than a non-response information hypothetically associated to the prime distractor.

Obviously, both the original non-response and the prime-response retrieval variant of the episodic retrieval model can explain the reaction time pattern for ignored repetition as opposed to control trials of the present Experiment 1 as well as of other studies reporting auditory negative priming (Banks et al., 1995; Buchner & Mayr, 2004, 2005; Buchner & Steffens, 2001; Buchner et al., 2003; Mondor et al., in press, but see their Experiment 2 for an exception). However, the prime-response retrieval variant allows deriving a unique prediction about the relative frequencies of the different probe error types: If the prime-response retrieval variant has any validity, then incorrect repetitions of the prime response as a reaction to the probe target should be over-represented in the error rates of ignored repetition trials. In order to test this prediction the two-alternative categorization task developed by Buchner and Steffens (2001, Experiment 1) and used in Experiment 1 was transformed into a four-alternative identification task in which every stimulus required a unique response.

Table 6-1 depicts an example of an ignored repetition and a corresponding control trial configuration and their required responses as they were employed in the upcoming Experiment 2. The probe display is identical for both trial types, as is the required probe response (“*piano*”) and the preceding prime response (“*frog*”). The only difference is that the prime distractor is the *piano* in the ignored repetition condition and the *bell* in the control condition. The prime-response retrieval variant of the episodic retrieval model predicts that the repetition of *piano* in the ignored repetition condition triggers the retrieval of the prime display and the prime response (“*frog*”), which conflicts with the correct probe response (“*piano*”). Nothing is repeated in the relevant control condition, hence there is nothing to cue the retrieval of the prime response. If these assumptions were appropriate, erroneous probe reactions with the prime response should occur more often among the errors in the ignored repetition than the control condition. In contrast, the non-response retrieval variant of the episodic retrieval model predicts that the probe target cues the retrieval of a non-response information or—more metaphorically speaking—a “do-not-respond” tag associated with the previous distractor in ignored repetition trials. The resolution of the conflict of non-response information with the requirement to respond to the probe target should slow down responding and perhaps increase the overall error rate, but there is no reason as to why one should expect an increase specifically in the probability of erroneous prime target responses in the probe. An inhibition model cannot explain an increase in prime response errors either.

Within this model, inhibition of the prime distractor and/or the response to it persists over time and hampers a responding to this stimulus when it becomes the probe target. The former prime target response is of no importance for this mechanism. Therefore no increase in prime response errors should be expected[9].

Table 6-1

Examples of stimulus configurations and required responses (in quotes) used in Experiment 2.

	Ignored Repetition		Control	
	Attended Ear	Ignored Ear	Attended Ear	Ignored Ear
Prime	Frog *"frog"*	Piano	Frog *"frog"*	Bell
Probe	Piano *"piano"*	Drum	Piano *"piano"*	Drum

Figure 6-1 depicts a multinomial processing tree model (e.g. Erdfelder, 2000; Hu & Batchelder, 1994; Riefer & Batchelder, 1988) that was used to evaluate the prime response retrieval variant against the non-response retrieval variant of the episodic retrieval model. Since this model will be of central importance for hypotheses formation and testing in the following experiments, multinomial modeling will first be illustrated, using this model as an example (Chapter 6.1). Then, the relevant statistical methodology to test hypotheses within this modeling approach will be outlined (Chapter 6.2). Finally, reasons for favoring this methodological approach over conventional parametric or nonparametric statistical methods are given (Chapter 6.3).

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[9] If anything, the distractor inhibition account predicts an increased probability of responding with the probe distractor stimulus. This idea will be elaborated and discussed later on, in the General Discussion (see Chapter 11, pp. 110).

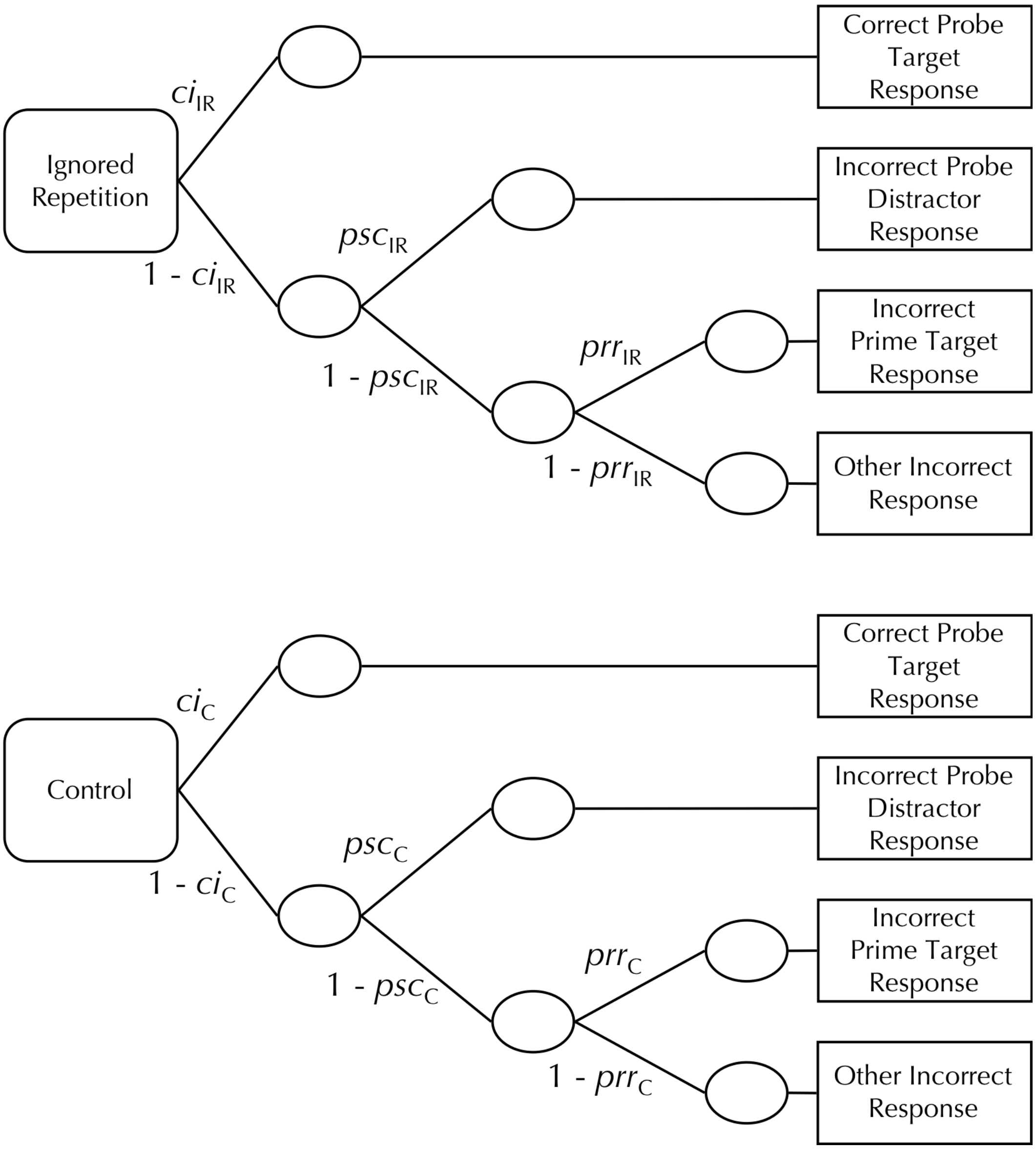

Figure 6-1: Multinomial processing tree model ("prime-response retrieval variant") for analyzing the probe reactions in the trial type condition "Ignored Repetition" (above) and "Control" (below). For details see text.

6.1 Formulating the Probe Response Situation as a Multinomial Processing Tree Model

Multinomial models are stochastic models that are aimed at estimating the probabilities of latent (unobservable) processes on the basis of observed categorical (i.e. nomial) behavior (cf. Erdfelder, 2000; Hu & Batchelder, 1994; Riefer & Batchelder, 1988). Multinomial models were extensively applied in scientific fields outside psychology, for example, in statistical genetics, but they have gained popularity in modeling cognitive processes, particularly in the field of memory functioning (e.g. for source monitoring, see Batchelder & Riefer, 1990; for the measurement of conscious and unconsious memory processes, see Buchner, Erdfelder, & Vaterrodt-Plünnecke, 1995; for separating recollection and reconstruction in hindsight, see Erdfelder & Buchner, 1998). The explanation for this popularity presumably lies in the fact that multinomial models are based on one of the core assumptions implied by many cognitive theories: Information processing can be conceived of as involving a finite set of discrete processing stages (Riefer & Batchelder, 1988). Accordingly, within the framework of multinomial modeling, it is assumed that observed behavior is the result of one or more levels of cognitive processing. Different from standard statistical approaches such as the general linear model analysis of variance (ANOVA), multinomial models measure and test directly at the level of the cognitive processes assumed to underlie observed behavior or—as stated by Riefer and Batchelder (1988, p. 319)— "Multinomial modeling is one simple way theoretical ideas can be represented in data analysis".

Multinomial models can be formally characterized as follows: Within an experimental paradigm, C_j , $j = 1,\ldots, J$, mutually exclusive behavioral categories can be observed. For the modeled probe response situation of the negative priming task displayed in Figure 6-1 these are the correct probe target responses, the incorrect probe distractor responses, the incorrect prime target responses, and the other incorrect responses in the ignored repetition condition and the control condition (i.e. $J = 8$). The observed frequencies of the behavior categories C_j are denoted by Y_j. Together, the behavior categories have to be exhaustive in that any event can be assigned to one of the j categories, $N = \Sigma_{j=1}^{J} Y_j$. Let p_j be the probability that an observation falls into C_j, with $\Sigma_{j=1}^{J} p_j = 1$. If the observations are mutually independent, the joint multinomial distribution of observed data is given by

$$P(Y_1,\ldots,Y_J;p_1,\ldots,p_J) = N!\prod_{j=1}^{J}\frac{p_j^{Y_j}}{Y_j!}. \tag{1}$$

The parameter space of the general model comprises all possible probability combinations of p_j

$$\Gamma = \left\{(p_1,\ldots,p_J)\middle| 0 \le p_j \le 1, \sum_{j=1}^{J} p_j = 1\right\}. \tag{2}$$

A substantive multinomial model representing a cognitive theory is a restriction of the general model. To each cognitive process that is postulated by the model a parameter value θ is assigned. It represents the probability with which this process occurs. Each of the functionally independent parameters $\theta_1, \ldots, \theta_s$, $1 \leq S < J$, lies within an interval of real numbers I_s, such as [0,1]. The parameter space of the substantive multinomial model is given by

$$\Omega = \left\{ \theta = \left(\theta_1, \ldots, \theta_s, \ldots, \theta_S \right) \middle| \theta_s \in I_s, s = 1, \ldots, S \right\}. \tag{3}$$

The categorical probabilities p_j (see Equation 2) can be expressed as functions of the latent parameters representing the postulated cognitive processes. A function f: $\Omega \rightarrow \Gamma$ has to be specified that maps the parameter values of the latent processes onto the probabilities of observable events. A substantive model is globally identifiable if the function f is a one-to-one mapping which means that a different set of model parameters always leads to different category probabilities (i.e. if $\theta \neq \theta'$, then $f(\theta) \neq f(\theta')$). This property implies that the inversion from a set of category probabilities to the underlying parameters is unambiguous (i.e. the inverse function f' leads to unique values of θ).

A plain description of the parameter space of the substantive model and of the model equations defined by f: $\Omega \rightarrow \Gamma$ can be displayed as a processing tree model, as is done for the prime-response retrieval variant of the episodic retrieval model in Figure 6-1. Processing tree models depict the parameters representing the latent cognitive processes and all theoretically relevant sequences of processes that are supposed to result in the behavioral categories C_j. The processing tree model in Figure 6-1 represents the cognitive processes that were assumed to be involved in generating a probe response for both the ignored repetition (upper part) and the control condition (lower part). Processing tree models such as the one depicted that include more than one processing tree are called joint multinomial models.

With parameter probability *ci* participants correctly identify the probe target and respond to it without making an error. Selecting the probe target against the probe distractor is difficult. It was therefore assumed that if an error occurs (with probability 1 – *ci*), it will predominantly be the confusion of the probe target with the probe distractor. Probe stimulus confusion occurs with the conditional probability *psc* and leads to incorrect probe distractor responses. If probe stimulus confusion does not dominate responding (with probability 1 – *psc*), then, with the conditional probability *prr*, prime response retrieval may occur and lead to incorrect prime target responses. For completeness, if none of the processes mentioned so far dominates responding, the person inevitably reacts (with probability 1 – *prr*) with the only remaining incorrect response. In sum, the mental processes that are assumed to mediate observable behavior are depicted by the parameters θ_s (with $S = 6$, here: ci_{IR}, psc_{IR}, prr_{IR}, and ci_C, psc_C, prr_C) that represent the conditional probabilities with which the respective processes take place. For each processing tree the number of *independent* response categories is one less than the number of all possible behavior categories of this tree. The reason for this is that the number of observations in one category is completely determined by the observed frequencies of all other categories and the total number of observations in this tree. For the model in Figure 6-1 there are three independent response categories for each of the two model trees.

The system of equations for the probe response situation depicted in Figure 6-1 can be explicitly stated as follows

$$p_{IR}(\text{correct probe target response}) = ci_{IR} \tag{4}$$

$$p_{IR}(\text{incorrect probe distractor response}) = \left(1 - ci_{IR}\right) \cdot psc_{IR} \tag{5}$$

$$p_{IR}(\text{incorrect prime target response}) = \left(1 - ci_{IR}\right) \cdot \left(1 - psc_{IR}\right) \cdot prr_{IR} \tag{6}$$

$$p_{C}(\text{correct probe target response}) = ci_{C} \tag{7}$$

$$p_{C}(\text{incorrect probe distractor response}) = \left(1 - ci_{C}\right) \cdot psc_{C} \tag{8}$$

$$p_{C}(\text{incorrect prime target response}) = \left(1 - ci_{C}\right) \cdot \left(1 - psc_{C}\right) \cdot prr_{C}. \tag{9}$$

The parameter values θ_s can be determined from the categorical probabilities p_j which can be estimated from the observed categorical frequencies Y_j. Riefer and Batchelder (1988) illustrate how *maximum likelihood estimates* (MLE) for the process parameters θ_s can be derived. Basically, a likelihood function of the model is generated that expresses the probability of the data as a function of the parameter values. MLEs of θ_s are the values that maximize the likelihood function. This means that they maximize the correspondence between empirically found category frequencies and the expected frequencies, where the expected frequencies are a function of the estimated parameter values. This estimation process corresponds to minimizing a power divergence statistic PD_λ. For $\lambda = 0$, PD_λ is equal to the log-likelihood ratio statistic G^2 (Erdfelder, 2000). G^2 is a commonly used minimum power-divergence estimate in multinomial modeling. MLEs have desirable asymptotic properties. They are asymptotically unbiased and asymptotically normally distributed. They are efficient in that their variance in not larger than that of any other asymptotically unbiased estimator. It is possible to compute confidence intervals for the parameters θ_s. MLEs of θ_s are usually determined iteratively by help of computer programs (such as AppleTree for binary processing tree models, see Rothkegel, 1999). However, sometimes model equations can be solved analytically. For these cases, determining the inverse function f' that maps Γ on Ω amounts to a proof of global identifiability of the model[10]. This is the case for the current model. In Equation 10 and Equation 11 the algebraic terms of prr_{IR} and prr_{c} are displayed that express the parameters as a function of the probabilities of the categorical events[11].

Equation (10):

$$prr_{\mathrm{IR}} = \frac{p_{\mathrm{IR}}(\text{incorrect prime target response})}{\left[1 - p_{\mathrm{IR}}(\text{correct probe target response})\right] \cdot \left[1 - \frac{p_{\mathrm{IR}}(\text{incorrect probe distractor response})}{(1 - p_{\mathrm{IR}}(\text{correct probe target response}))}\right]}$$

Equation (11):

$$prr_{\mathrm{C}} = \frac{p_{\mathrm{C}}(\text{incorrect prime target response})}{\left[1 - p_{\mathrm{C}}(\text{correct probe target response})\right] \cdot \left[1 - \frac{p_{\mathrm{C}}(\text{incorrect probe distractor response})}{(1 - p_{\mathrm{C}}(\text{correct probe target response}))}\right]}$$

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[10] But see Riefer and Batchelder (1988) for details as regards forms of identifiability.

[11] The model of interest is a multinomial model for which every branch leads to a unique category. For models of this type, inverse functions exist as long as all category probabilities are positive (Erdfelder, 2000). Equations 10 and 11 show that the model is identifiable given the probabilities of correct probe target responses are smaller than one. (A probability of one for correct probe target responses would imply that no errors were made, that is, probabilities of all error categories would be zero.) In general, the interval margins of zero and one are excluded in order to guarantee identifiability of parameter estimates. For the current model, this restriction does not seem to be of any relevance: Perfect, error-free probe responding is never given, at least not at a group level.

Multinomial models are based on two assumptions (Erdfelder, 2000). For any multinomial model the observations have to be independently and identically distributed over the behavioral categories. These sampling assumptions are often violated. Data are usually aggregated over participants/items and several observations are obtained from each participant. This common practice ignores the problem of interindividual differences and within-subject changes over time. As a consequence, category probabilities may not be constants and observations may be correlated. However, many models are fairly robust against a certain degree of violation of the sampling assumptions (Riefer & Batchelder, 1988) which means that parameter estimation and confidence intervals stay valid in spite of these violations. A pragmatic procedure to test the robustness of a model are Monte Carlo studies into which violations of the model assumptions are introduced (Riefer & Batchelder, 1988). If the results are uninfluenced by theses violations, the model is said to be robust.

6.2 Hypothesis Testing within the Multinomial Modeling Approach

The framework of multinomial modeling allows to perform statistical hypothesis tests directly at the level of the assumed processes rather than indirectly at the level of raw performance scores. Basically, any hypothesis within the framework of multinomial modeling constitutes restrictions of the dimensionality of the parameter space Ω. Restrictions can be that certain parameters are constrained to each other or that a certain parameter is set equal to a specific value.

For instance, in the present case the critical model process for which the prime-response retrieval and the non-response retrieval variants of the episodic retrieval model make different predictions is the process of prime response retrieval (*prr*). The probability of retrieving a prime response in the ignored repetition condition, prr_{IR}, is expected to be larger than prr_C, the probability of retrieving a prime response in the control condition if the prime-response retrieval variant, but not if only the non-response retrieval variant of the episodic retrieval model is correct. This hypothesis can be tested by implementing the restriction that $prr_{IR} = prr_C$.

Hypothesis testing is accomplished via the parameter estimation procedure (as described in Chapter 6.1) under model restrictions that implement the hypothesis that is to be tested. The deviation of the expected category frequencies (which result from the

MLEs) from the empirical category frequencies can be assessed statistically. The log-likelihood ratio statistic G^2 is asymptotically (i.e. for $N \rightarrow \infty$) χ^2-distributed with df = (number of independent categories – number of independent parameters) when the restricted model is true. This means that given a sufficiently large sample size, comparing the empirically obtained G^2 statistic to the critical value of the $\chi^2_{(df)}$-distribution is an approximate goodness-of-fit test of the model. A restriction that leads to a G^2 exceeding the a priori fixed α error level of the relevant $\chi^2_{(df)}$-distribution implies a model that does not fit the data and hence will be dismissed. For the current situation, this would equal the rejecting of the null hypothesis that the probability of prime response retrieval is of same size for the ignored repetition and the control condition, that is $prr_{IR} = prr_C$. Rejecting the null hypothesis and given $prr_{IR} > prr_C$ would be evidence for the prime-response retrieval variant of the episodic retrieval model. In contrast, when the parameters estimated under the restriction $prr_{IR} = prr_C$ would not lead to a significant missfit, the restriction—that is, the null hypothesis—could not be abandoned. This would be counted as evidence in favor of the non-response retrieval variant of the episodic retrieval model.

6.3 Reasons for Favoring a Multinomial Modeling Approach

The multinomial modeling approach was preferred over a conventional parametric *t*-test approach (using the relative frequency of prime response type errors in the ignored repetition and the control condition as the dependent variable) or a Wilcoxon signed rank test (based on the signed ranks of the relative frequency of prime response type errors in the ignored repetition and the control condition). Statistical reasons argue against the use of these two alternatives. The expected serious violation of the normality assumption in the error data in form of an extremely skewed distribution of the prime response type error scores was seen to be problematic for a parametric *t*-test approach because of potentially distorted Type I error rates (Myers & Well, 1995). The problem of potential violation of the normal distribution assumption is, of course, a general problem that also applies to the overall error rates. Nonetheless, overall error rates were analyzed with a conventional parametric approach (*t*-test or analysis of variance). This differential handling of overall and specific prime response type errors seemed justified as the potential problem applies much more seriously to the specific response type errors as a very rare sub-category of the overall errors than to the overall errors themselves. This can be exemplified by looking at the data: The crucial type of prime response errors occurred extremely rarely. In fact, 68 of the 74 participants in the upcoming Experiment 2 committed no prime-response type error in the control condition. A problem of the Wilcoxon signed rank test is the loss of power due to tied ranks which were very frequent in the present case. For instance, for 27 of the 74 participants in Experiment 2, the ratio of prime-response type errors was the same for the ignored repetition and the control condition.

The multinomial modeling approach is based on categorical data and does not require any such distributional assumptions. Instead it requires the sampling assumptions of equality in process probabilities for participants and/or items over which data are aggregated (see Chapter 6.1)—an assumption which is tacitly made for parametric tests, too—and stochastic independence of observations. Fortunately, many multinomial models are fairly robust to a certain degree of violation in the sampling assumptions (Riefer & Batchelder, 1988), so that this problem does not appears to be serious. The multinomial modeling approach is also appealing because it allows to perform statistical tests of the hypotheses directly at the level of the assumed processes rather than indirectly at the level of some performance scores.

7 Experiment 2

This experiment was designed as a test of the prime-response retrieval variant of the episodic retrieval model which assumes that part of the conflict producing prime episode retrieval is the retrieval of the prime response. Participants took part in a new four-choice identification task of tones that were dichotically presented as prime and probe pairs. In ignored repetition trials the prime distractor tone was repeated as the probe target tone. In control trials four different tones were presented in the prime and probe. Probe reaction times and error rates were measured. In order to validate that the new four-choice task can be considered a typical negative priming eliciting task, longer response times as well as larger overall error rates were expected in the ignored repetition condition than in the control condition. For the central hypothesis, the frequencies of the specific probe errors were analyzed using the multinomial model introduced in Chapter 6. It was expected that parameter *prr* differed between the ignored repetition and the control condition.

7.1 Method

7.1.1 Participants

Participants were 74 adults (mostly students), 57 of whom were female. They ranged in age from 20 to 43 years (*M* = 25.87, *SD* = 5.27). Four additional participants did not reach the learning criterion of 60% correct reactions in the training phase. The data of one further participant who showed excessive error rates (≥ 50% in the primes) were also discarded. Test sessions were run with one to four persons in parallel. Participants were paid € 5.00 for their participation.

7.1.2 Materials

The stimuli were four digitized tones (frog, piano, drum, and bell). Each tone was 300 ms long, complete with attack and decay. Participants heard the tones over earphones that were fitted with noise-insulation covers and plugged directly into an Apple iMac computer. Tones were played at about 70 dB(A) but participants were allowed to adjust loudness.

A 20 ms metronome click indicated the ear (left or right) at which the to-be-attended tone would be presented. After the cue a pair of tones was presented dichotically, the target tone to the cued ear and the distractor tone to the opposite ear. Participants reacted to the attended tone by pressing the response key assigned to the tone. Response keys were the four sagitally aligned keys "9" (frog), "6" (piano), "3" (drum), and "." (bell) on the numeric keypad of the computer keyboard. A sagittal response key arrangement prevented spatial compatibility effects between the target's location and the required response (see e.g. Buchner & Steffens, 2001). Participants were instructed to press the two upper keys ("9" and "6") with middle and index finger of the right hand and the two lower keys with middle and index finger of the left hand. Keys were labeled with the color of the drawing associated to the respective tone (green for frog, white for piano, blue for drum, and red for bell) in order to facilitate initial learning of the sound-key association.

Each experimental trial consisted of a prime and a probe display. Each display consisted of a target and a simultaneously presented distractor. Ignored repetition trials were constructed by randomly selecting three of the four different stimuli as prime and probe targets and distractors with the restriction that the ignored prime had to be identical to the attended probe (upper left quadrant of Table 7-1). Next, parallel control trials were constructed by replacing the ignored prime with the remaining stimulus (upper right quadrant of Table 7-1 where *piano* has been replaced by *bell*). Within these two types of trials the ignored prime would have been the correct probe response on 50% of the trials, and the prime response would never have been equal to the probe response. To avoid that participants would learn these contingencies and would develop response bias, filler trials were included. Filler trials were constructed by randomly selecting three of the four different types of stimuli as prime and probe targets and distractors with the restriction that the attended prime had to be identical to the attended probe (named attended repetition filler trials in the lower left quadrant of Table 7-1). Additional filler trials (named control filler trials in the lower right quadrant of Table 7-1) were constructed by replacing, in the attended repetition filler trials, the attended prime with the remaining stimulus. For the entire set of stimuli, the correct probe reaction could not be inferred from the prime response, that is each of the four tones had a probe target probability of 25% given any prime response.

Table 7-1

Examples of the stimulus configuration for the different trial types (Experiment 2).

	Ignored Repetition		Control	
	Attended Ear	Ignored Ear	Attended Ear	Ignored Ear
Prime	frog	piano	frog	bell
Probe	piano	drum	piano	drum

	Attended Repetition Filler		Control Filler	
	Attended Ear	Ignored Ear	Attended Ear	Ignored Ear
Prime	piano	bell	frog	bell
Probe	piano	drum	piano	drum

Note that an ignored repetition trial always shared its control trial with an attended repetition filler trial (see Table 7-1 for an example). In using the entire set of trials that can be generated by the algorithm just described, every control trial would have occurred twice. This was unacceptable because an expected reaction time increase in the ignored repetition trials relative to the control trials would have been ambiguous, either being interpreted as the consequence of the negative priming mechanism or the result of learning due to trial repetition of the control trials. In order to avoid this confound for control trials, ignored repetition and attended repetition filler trials together with their corresponding control trials were systematically assigned to Set 1 or Set 2 with three restrictions: First, identical control trials had to belong to different sets. Second, within each trial type, the frequencies of the different tones had to be identical. Third, the frequencies of the combinations of attended and ignored tones, both within the prime and within the probe pairs, had to be equal for the different trial types. Sets 1 and Set 2 were completely parallel with respect to the second and the third restriction. For each set, the required prime response did not predict the required probe response. Participants were randomly assigned to Set 1 or Set 2. 37 participants were tested with Set 1 or Set 2, respectively.

Each set included 12 different trials of each of the four trials types (ignored repetition, control, attended repetition filler, and control filler). Each of the trials was once implemented with the attended prime on the left and the attended probe on the right side, and once with the opposite arrangement. Consequently, each set comprised 96 unique trials. Attentional switching between prime and probe (from left to right ear or from right to left ear) implicated that the ignored primes and the attended probes were always presented to the same location. A set was presented four times, resulting in 384 experimental trials which were presented in a different random sequence for each participant.

7.1.3 Procedure

In order to familiarize participants with the tone stimuli, drawings of a frog, a piano, a drum, and a bell were shown in the initial instructions, and participants could hear the corresponding sound when clicking on the drawing with the computer mouse. Next, participants heard and reacted to pairs of tones. Preceding the sound pair, the metronome click indicated the randomly selected ear at which the to-be-attended tone would be presented. Following a 500 ms click-target interval, a randomly selected target tone was presented at that ear and another to-be-ignored distractor was presented simultaneously to the other ear. Participants reacted to the target tone by quickly pressing the corresponding key. They were given feedback about the correctness of each reaction after which they initiated the next trial. The tone-response association (i.e. the key alignment) was shown in the upper left corner of the display during the first 25 training trials. Participants entered the experiment proper when 60% of the preceding 50 responses had been correct. Participants who did not reach this criterion within 150 trials were given a choice to quit the experiment or to start again with the training.

Each of the 384 experimental trials began with the metronome click, followed by a 500 ms cue-target interval and the prime pair of tones. After the prime reaction, a RSI of 500 ms preceded the click that cued the to-be-attended probe. The probe click (presented to the opposite of the prime target presentation side) was followed by a 500 ms cue-target interval, after which the probe pair of tones was presented. After each prime-probe pair participants were given feedback about the correctness of their prime and probe reactions for 1100 ms, followed by a 1800 ms inter-trial interval. Prime or probe reactions faster than 100 ms and slower than 3000 ms were counted as invalid and the entire trial was repeated after the last experimental trial. (Repeated trials were included in the analysis. They were very rare events [rates less than .01 on average]). After every tenth trial, participants received a summary feedback about both their average reaction time and their error percentage. After the final trial, all participants were informed about the purpose of the experiment. The experiment took about 60 minutes.

7.1.4 Design

The experiment comprised a one-factorial design with trial type (ignored repetition vs. control) as the independent within-subject variable[12]. The dependent variable of greatest interest was the frequency of probe responses with the prime target, accumulated across participants, but participants' mean probe reaction times and overall probe error rates were also analyzed in order to validate that the task used here generated a typical negative priming effect.

When sounds have to be categorized, auditory negative priming effects are typically quite large, with effect sizes of $\eta^2 = .41$ (which corresponds to $f = 0.325$ given a population correlation of $\rho = .7$ between the ignored repetition and the control reaction times) in Experiment 1 and of $\eta^2 = .30$ (which corresponds to $f = 0.255$ given $\rho = .7$ between the ignored repetition and the control reaction times) in the study of Buchner and Steffens (2001). For the current a priori power analysis, a more conservative approach seemed reasonable. More precisely, an effect of size $f = 0.175$ (i.e. between "small" and "medium" effects defined by Cohen, 1988) was expected to allow for finding a possibly smaller effect in this new four-choice identification task. Given $f = 0.175$ and a population correlation of $\rho = .7$ between the ignored repetition and control reaction time variables (which corresponds to $\eta^2 = .17$) and desired levels of $\alpha = \beta = .05$, the a priori power analysis resulted in a necessary sample size of $N = 66$. Data from $N = 74$ participants could be collected, so that the actual power was $1 - \beta = .97$. The level of alpha was maintained at .05. Individual p values are reported as well as partial η^2 as an effect size measure. This applies to all experiments reported in this and the subsequent chapters.

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[12] Attended repetition filler and control filler trials were irrelevant to the substantive hypotheses tested in Experiment 2. For completeness, however, note that responses were significantly faster on attended repetition filler than on control filler trials. The same is true for Experiment 3.

Sample size considerations with respect to the multinomial modeling analysis of the specific probe error frequencies do not only depend on total sample size (i.e. number of all valid probe reactions summed over all participants) but also on how these observations are distributed in the multinomial model tree structure (Erdfelder, 2000). Since this distribution of errors depends on the unknown amount and types of errors actually committed, sample size considerations for the model-based analysis were set aside.

7.2 Results

Reaction times and overall error rates are first reported in order to evaluate whether the experimental task gave rise to a negative priming effect (Chapter 7.2.1). Next, the specific probe error frequencies are analyzed to test the central hypothesis whether more prime response errors are committed in ignored repetition trials than in control trials (Chapter 7.2.2).

7.2.1 Reaction Time and Overall Error Analysis

Probe reaction times were evaluated only for trials in which both the probe and the prime reactions were correct. Probe errors were evaluated only if they followed a correct prime response. The means of participants' mean reaction times and the overall error rates are presented in the left and right panels of Figure 7-1, respectively.

Reactions were significantly slower in ignored repetition trials than in control trials, $t(73) = 6.37$, $p < .001$, $\eta^2 = .36$, and participants made more errors in the ignored repetition condition than in the control condition, $t(73) = 6.38$, $p < .001$, $\eta^2 = .36$. Consequently, there is a clear negative priming effect in the reaction times which is not compromised by a speed-accuracy trade-off.

For control purposes, prime reaction times and overall prime error rates were analyzed. On average, participants reacted after 915.60 ms ($SE = 15.28$ ms) in ignored repetition trials and after 902.55 ms ($SE = 13.89$ ms) in control trials. Unexpectedly, the mean averages differed significantly, $t(73) = 2.65$, $p = .010$, $\eta^2 = .09$. The prime errors rates of 5.77% were exactly the same for ignored repetition and control trials ($SE = 0.61\%$ and $SE = 0.65\%$ for ignored repetition and control trials, respectively).

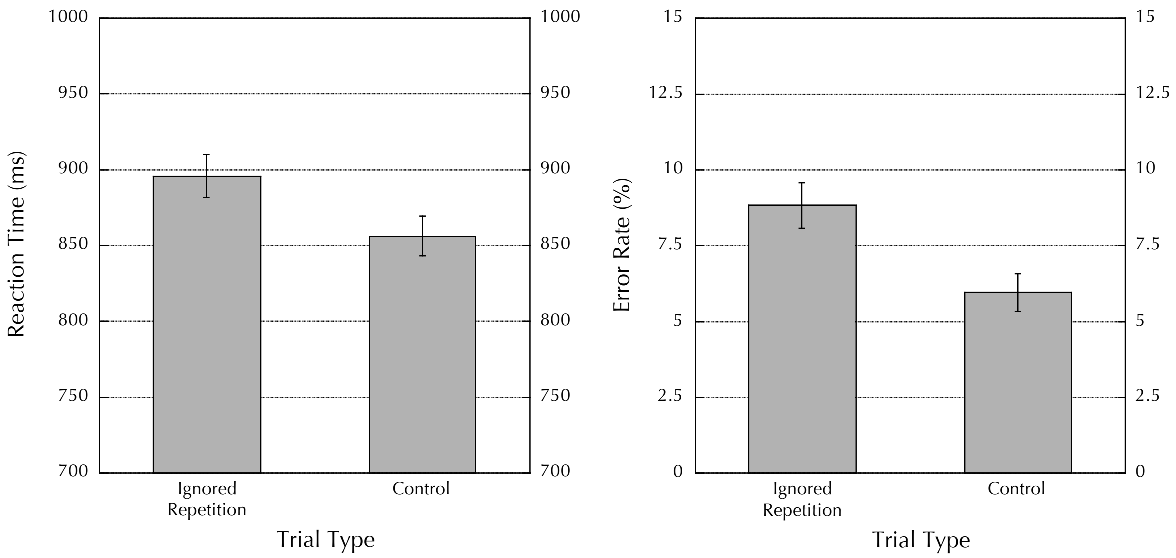

Figure 7-1: Probe reaction times (left panel) and probe error rates (right panel) as a function of trial type (Experiment 2). The error bars depict the standard errors of the means.

7.2.2 Specific Probe Error Analysis

In the ignored repetition condition, 19.69% (*SE* = 2.49%) of all probe errors were incorrect prime target responses whereas only 1.3% (*SE* = 0.57%) of all probe errors in the control condition were of this type. The absolute frequencies of the correct probe responses and of the different probe error types are displayed in Table 7-2.

Table 7-2

Accumulated absolute frequencies of the correct probe responses and of the different types of probe errors for the ignored repetition condition and the control condition (Experiment 2).

	Ignored Repetition	Control
Correct probe target responses	*6119*	*6311*
Incorrect probe distractor responses	*412*	*326*
Incorrect prime target responses	*111*	*7*
Other incorrect responses*	*52*	*50*

* *Ignored repetition trials:* Incorrect responses using the key that was assigned to the non-presented stimulus.
Control trials: Incorrect prime distractor responses.

The multinomial model displayed in Figure 6-1 (see p. 64) has as many identifiable parameters as there are independent category probabilities to fit (i.e. 6). Thus, the goodness-of-fit test of this model has zero degrees of freedom, and it fitted the frequency data of Experiment 2 perfectly. The parameter estimates of the critical retrieval process (prr_{IR} and prr_{C}) are illustrated in Figure 7-2. In order to test the prime-response retrieval variant of the episodic retrieval model against the non-response retrieval variant, the goodness-of-fit of the model with the restriction that $prr_{IR} = prr_{C}$, which is implied by the non-response retrieval variant, was tested. The restricted model did not fit the data, $G^2(1) = 57.24$, $p < .001$, and had to be rejected.

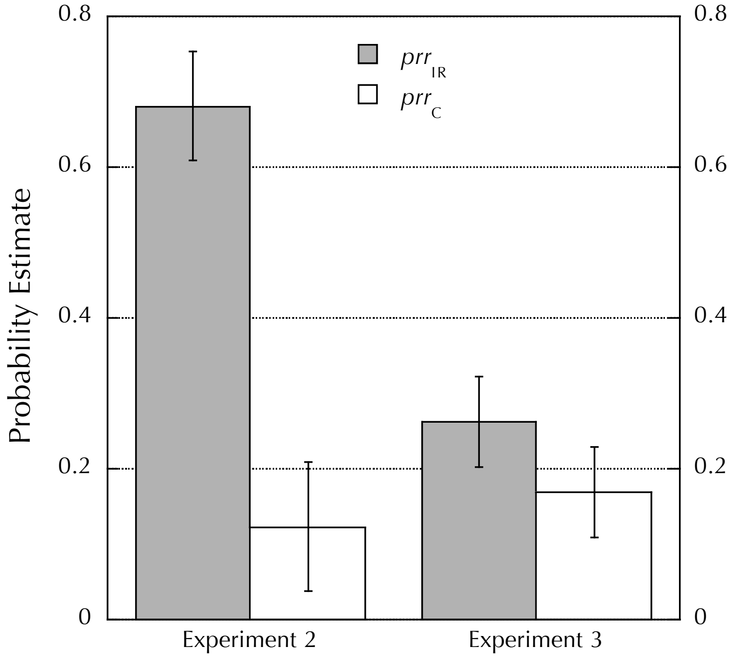

Figure 7-2: Probability estimates for the model parameters representing the probability of prime-response retrieval as a function of material (auditory in Experiment 2 and visual in Experiment 3) and trial type. The error bars depict the .95 confidence intervals.

7.3 Discussion

Experiment 2 demonstrated a standard negative priming effect in both the reaction times and the overall probe errors. A detailed analysis of the probe errors using a multinomial modeling approach showed that the probability of prime response retrieval given that neither a probe target identification nor a simple probe stimulus confusion had occurred was significantly larger in the ignored repetition than in the control condition. This data pattern is unexpected given the non-response retrieval variant of the episodic retrieval model, but it is compatible with the prime-response retrieval variant.

Somewhat surprisingly, a small but significant reaction time effect was found in the prime data. Participants responded slightly faster in the control condition than in the ignored repetition condition. There is no obvious reason for this. Nevertheless, the data show that this prime effect cannot be the sole explanation for the negative priming effect found: The effect size in probe reaction times was much larger (η^2 = .36) than the effect size in prime reactions (η^2 = .09). There was also no effect in the overall prime errors but a significant effect in the overall probe errors (η^2 = .36). The prime effect in reaction times therefore seems to be due to a Type I error. To anticipate, this explanation will be substantiated because this data pattern did not replicate in any of the following experiments which used the same experimental task and stimuli.

To this end, it was demonstrated that prime-response retrieval is a viable explanation of auditory negative priming. In a next step it was tested whether such a mechanism could also be assumed for the visual modality. It is unclear whether the underlying mechanisms are the same in the visual and the auditory domain when taking into consideration that both senses are organized differently at a neurophysiological level and function in very different ways (see Chapter 3, pp. 30). Particularly, central selective attention mechanisms might be different for both senses given that diverse peripheral mechanisms—such as head movements, eye movements, and accommodation—in the visual domain help to focus attention but far less efficient peripheral means of excluding unattended auditory material exist. The differences between the two senses make modality specific investigations of the underlying mechanisms necessary as has been pointed out before. Therefore, Experiment 3 was designed to extend and replicate the results of Experiment 2 using visual stimuli.

8 Experiment 3

8.1 Method

8.1.1 Participants

Participants were 77 adults (mostly students), 50 of whom were female. They ranged in age from 19 to 44 years (*M* = 25.81, *SD* = 5.81). Test sessions were run with one to four persons in parallel. Participants either volunteered for their fellow students in a cognitive psychology class running this experiment or they were paid € 5.00 for their participation.

8.1.2 Materials

The stimuli were four line drawings (pentacle, crescent, heart, and arrow), each of which existed both as a blue outline and as a red outline before a white background. Drawings varied in size between 52 - 57 mm width and 51 - 55 mm height (viewing angles of 4.3° - 4.7° horizontally and 4.2° - 4.5° vertically). Participants heard auditory feedback over earphones that were fitted with noise-insulation covers and plugged directly into an Apple iMac computer with a 15″ color display and a screen resolution of 800×600 pixel.

A centrally located blue or red square (side length 17 mm or 1.4°) indicated the color in which the to-be-attended object would be presented. After the cue had disappeared two centrally aligned overlapping line drawings, one in red and one in blue, were presented simultaneously. Participants reacted to the attended drawing by pressing the response key assigned to the drawing. Response keys were the four sagittally aligned keys “9” (pentacle), “6” (crescent), “3” (heart), and “.” (arrow) on the numeric keypad of the computer keyboard. The key-to-finger assignment was identical to that of Experiment 2. Keys were labeled with the outline of the associated object in a neutral black color in order to facilitate initial learning of the drawing-key association.

Each experimental trial consisted of a prime and a probe display. Each display consisted of a target presented in one color and a simultaneously presented distractor drawing in the other color. The two line drawings were centrally aligned and overlapped each other. Stimulus Set 1 and Set 2 were created as in Experiment 3. Participants were randomly assigned to Set 1 or Set 2. 38 participants were tested with Set 1 and 39 with

Set 2. Each set included 12 different trials of each of the four trials types (ignored repetition, control, attended repetition filler, and control filler trials). Each of the trials was once implemented with the attended prime in blue and the attended probe in red, and once with the opposite arrangement. Consequently, each set comprised 96 unique trials. Attentional switching between prime and probe (from blue to red or from red to blue) implicated that the color of the ignored prime was always identical to the color of the attended probe. A set was presented four times, resulting in 384 experimental trials which were presented in an individually random sequence.

8.1.3 Procedure

The procedure was parallel to Experiment 2 with the following exceptions. A red or blue square cued the color of the target. The cue was presented for 150 ms. After an interval of 300 ms, a pair of line drawings was presented for 200 ms, after which 2000 ms were allowed for the probe response. Probe presentation started 400 ms after the prime response. The timeout for the probe response was 1300 ms. Tighter timing was used in an attempt to increase error rates which had been too low in pilot studies (see Experiment 1 of Buchner & Mayr, 2005, where a manipulation of the prime-probe RSI had that effect). Speed emphasis in the instructions served the same purpose.

Prime and probe responses faster than 200 ms, prime responses slower than 2000 ms, and probe responses slower than 1300 ms were counted as invalid and the entire trial was repeated after the last experimental trial. (As in Experiment 2, repeated trials were included in the analysis. Given the tighter timeout criterion in the probe, they were more frequent events than in Experiment 2 but still rather rare [rates less than .05 on average]). After each trial, participants received feedback about the correctness of their prime and probe reactions for 1100 ms. After an interval of 2200 ms the prime cue of the next trial was presented.

After every tenth trial, participants received a summary feedback about both their average reaction time and their error percentage. After the final trial, all participants were informed about the purpose of the experiment. The experiment took about 60 minutes.

8.1.4 Design

The design was identical to that of Experiment 3. The same was true for the a priori power considerations. Data from $N = 77$ participants could be collected, so that the actual power was $1 - \beta = .97$.

8.2 Results

Reaction times and overall error rates are first reported in order to evaluate whether the experimental task gave rise to a negative priming effect (Chapter 8.2.1). Then, the specific probe error frequencies are analyzed to test the central hypothesis whether more prime response errors are committed in ignored repetition trials than in control trials (Chapter 8.2.2).

8.2.1 Reaction Time and Overall Error Analysis

Probe reaction times were evaluated only for trials in which both the probe and the prime reactions were correct. Probe errors were evaluated only if they followed a correct prime response. The means of participants' mean reaction times and the overall error rates are presented in the left and right panels of Figure 8-1, respectively.

Reactions were significantly slower in ignored repetition trials than in control trials, $t(76) = 8.84$, $p < .001$, $\eta^2 = .50$, and participants made more errors in the ignored repetition condition than in the control condition, $t(76) = 2.71$, $p = .008$, $\eta^2 = .09$. Consequently, there is a clear negative priming effect in the reaction times which is not compromised by a speed-accuracy trade-off.

For control reasons, prime reaction times and overall prime error rates were analyzed. On average, participants reacted similarly fast after ignored repetition trials (746.51 ms, $SE = 11.93$ ms) as after control trials (747.11 ms, $SE = 11.55$ ms), $t(76) = 0.35$, $p = .728$, $\eta^2 < .01$. Prime errors were made in 5.10% ($SE = 0.53\%$) of the ignored repetition trials and in 5.00% ($SE = 0.53\%$) of the control trials. The prime error rates did not differ significantly between trial types, $t(76) = 0.35$, $p = .728$, $\eta^2 < .01$.

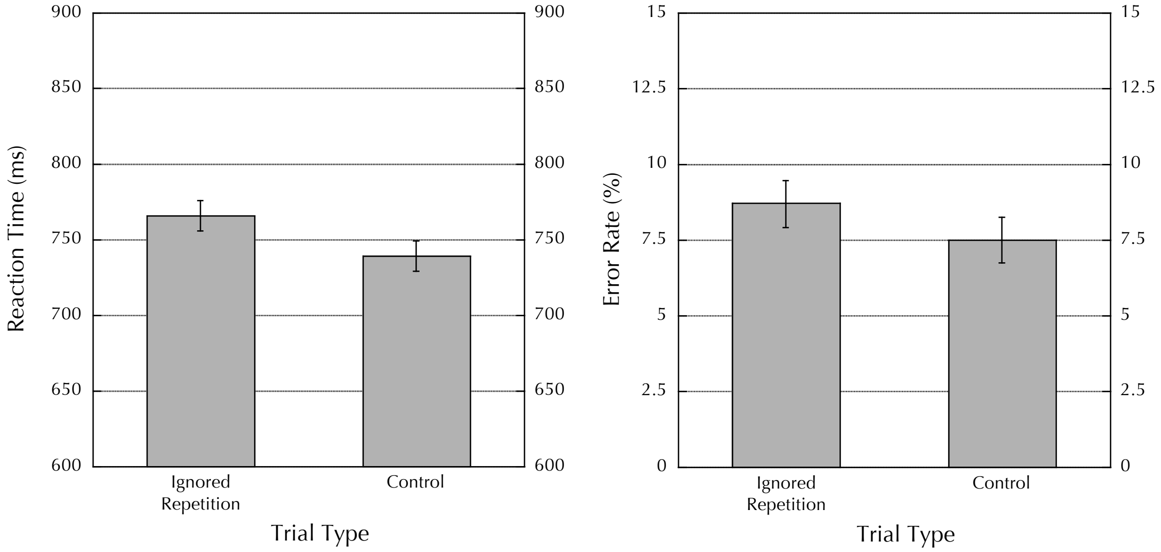

Figure 8-2: Probe reaction times (left panel) and probe error rates (right panel) as a function of trial type (Experiment 2). The error bars depict the standard errors of the means.

8.2.2 Specific Probe Error Analysis

In the ignored repetition condition 9.02% (*SE* = 1.68%) of all probe errors were incorrect prime target responses whereas only 6.56% (*SE* = 2.05%) of all probe errors in the control condition were of this type. The absolute frequencies of the correct probe responses and of the different probe error types are displayed in Table 8-1.

Table 8-1

Accumulated absolute frequencies of the correct probe responses and of the different types of probe errors for the ignored repetition condition and the control condition (Experiment 3).

	Ignored Repetition	Control
Correct probe target responses	*6425*	*6514*
Incorrect probe distractor responses	*389*	*357*
Incorrect prime target responses	*53*	*26*
Other incorrect responses*	*149*	*127*

* *Ignored repetition trials:* Incorrect responses using the key that was assigned to the non-presented stimulus.
Control trials: Incorrect prime distractor responses.

The goodness-of-fit test of the unrestricted multinomial model (see Figure 6-1, p. 64) has zero degrees of freedom, and it fitted the frequency data of Experiment 2 perfectly.

The parameter estimates of the critical retrieval process (prr_{IR} and prr_C) are illustrated in Figure 7-2 (see p. 79). In order to test the prime-response retrieval variant of the episodic retrieval model against the non-response retrieval variant, the goodness-of-fit of the model with the restriction that $prr_{IR} = prr_C$, which is implied by the non-response retrieval variant, was tested. The restricted model did not fit the data, $G^2(1) = 4.39$, $p = .036$, and had to be rejected.

8.3 Discussion

Experiment 3 replicated, for the visual domain, the results obtained with auditory stimuli in Experiment 2. Again, the probability of retrieving the prime response given that neither a correct identification of the probe nor a simple probe stimulus confusion had occurred was larger in the ignored repetition condition than in the control condition. Taken together with the findings from Experiment 2, this result supports the prime-response retrieval variant of the episodic retrieval model and is not expected given the non-response retrieval variant.

Based on the results of Experiment 1 as well as those of Buchner and Mayr (2005) there is evidence for an episodic retrieval mechanism in the auditory domain. This close parallel between the auditory and the visual domain is not trivial given that the two senses are organized and function differentially as has been outlined in Chapter 3 (pp. 30). What is more, the parallelism between the attentional mechanisms is even more specific: For both senses, at least one component of the episodic retrieval mechanism is the retrieval of prime-responses. However, the mechanism was stronger in the auditory than in the visual domain. This becomes apparent when looking at the error frequencies of Experiment 2 (Table 7-2, p. 78) and Experiment 3 (Table 8-1, p. 84). For both modalities, prime target responses heavily increased when comparing the control to the ignored repetition condition relative to the overall error increase. But this increase was far more pronounced in the auditory experiment (sixteen fold) than in the visual experiment (two fold). Whether this was due to differences in experimental variables (such as task difficulty) between Experiment 2 and 3 or whether the prime-response retrieval mechanism is generally stronger in the auditory domain cannot be judged from the restricted amount of evidence at the current state.

Different from Experiment 2, there was no prime reaction time effect in Experiment 3. Given that the stimulus configuration was identical to Experiment 2, this supports the assumption that the prime effect in Experiment 2 was due to a Type I error.

9 Validity and Relevance of the "Prime-Response Retrieval Model"

The relative increase of prime response errors in Experiments 2 and 3 was interpreted as evidence for a probe-cued retrieval of the prime response underlying the negative priming phenomenon. An additional validation that prime-response retrieval is causing the increase of prime-response errors—and not some other unknown confounded factor—would be desirable. Experiment 4 was planned as a validation of this new variant of the episodic retrieval model. The following validation strategy was pursued. If a relative increase of prime response errors in the probe is indeed evidence for probe-triggered prime response retrieval, then this relative increase should be eliminated in a situation where no prime response had been selected and carried out so that no prime response information could have been generated and attached to the prime episode.

Imagine an identification task identical to that of Experiments 2 and 3, but without a response requirement in the prime. Consequently, no response information can be created and attached to the prime episode. In ignored repetition trials the probe target could cue the retrieval of the prime episode, but there would not exist any prime response information in the retrieved prime episode. Therefore, no prime response could be remembered and bias the probe response. Consequently, no increase of prime response errors should be observed for the ignored repetition relative to the control condition.

In order to test this prediction, Experiment 4 was planned as a replication of Experiment 2 but with the additional manipulation that a prime response was required on some trials but not on others. Experiment 4 would return evidence for the prime-response retrieval variant of the episodic retrieval model if a relative increase of prime response errors would be found for ignored repetition trials *with* a prime response requirement (identical to the situation in Experiment 2) but not for ignored repetition trials *without* a prime response requirement.

The new manipulation of the prime response requirement in Experiment 4 was implemented by a visual cue presented shortly before the auditory prime cue. This visual cue indicated whether a prime response had to be executed (so-called "Go" trials) or withheld (so-called "NoGo" trials). The prime display itself was identical for "Go" and

"NoGo" trials, that is, participants heard a click on one ear and were supposed to identify the tone that followed on the cued ear while ignoring the irrelevant distractor presented to the other ear. The only difference between trials with and without response requirements was whether the response key assigned to the attended tone had to be pressed or not.

The comparability between trials with and without response requirement deserves closer attention. Critically, one could argue that a trial for which a participant knows in advance that no response is required will be processed differently relative to a trial for which a response has to be made. In the worst case, participants might withdraw their attention completely from the prime episode after the appearance of a "NoGo" signal. In this case, the finding of no specific prime-response error effect between ignored repetition and control trials without response requirement would not be theoretically informative but trivial. In order to control whether these measures were effective, it was analyzed whether negative priming effects would occur under both "Go" and "NoGo" conditions. An analysis of the prime-response errors will be useful only if a typical negative priming effect is found in both conditions.

Several measures were taken to guarantee equivalent attentional allocation in trials with and without response requirement. First, a peripheral auditory cue was used (a "click" as in Experiment 2) which is known to draw auditory covert attention to the cued ear (Mondor, Breau, & Milliken, 1998; Spence & Driver, 1994, 1997). Second, the cue-target interval was decreased to support the involuntary effects of auditory covert attention (Mondor et al., 1998). Third, a control task was included that was supposed to enhance prime target processing.

The same multinomial model that had been used for Experiments 2 and 3 (see Figure 6-1, p. 64) was applied. More precisely, there were two pairs of model trees, one for the "Go" condition and one for the "NoGo" condition. In order to test whether the prime-response retrieval variant of the episodic retrieval model was an effective mechanism for the negative priming effect in the "Go" condition but not for the negative priming effect in the "NoGo" condition, the goodness-of-fit of this joint multinomial model was tested once with the restriction of $prr_{\text{NoGo-IR}} = prr_{\text{NoGo-C}}$ and once with the additional restriction of $prr_{\text{Go-IR}} = prr_{\text{Go-C}}$. Whereas the former restriction implies that prime-response retrieval is of no significance for the "NoGo" condition, the latter restriction implies that prime-response retrieval is not a relevant mechanism for the "Go" condition. Consequently, if the above hypothesis were true, the data of Experiment 4 should fit the model with the first restriction $prr_{\text{NoGo-IR}} = prr_{\text{NoGo-C}}$, but they should not fit the model with the second restriction.

However, Experiment 4 was designed to reveal even more about the relevance of prime-response retrieval as a mechanism contributing to the negative priming phenomenon. If a negative priming effect is observed, then it can be inferred that one or more negative priming mechanism(s) had been operating. From an elimination of the specific prime-response error effect in the "NoGo" condition it could be concluded that the prime-response retrieval mechanism is operating in the "Go" but not in the "NoGo" condition. If the effect was produced by multiple mechanisms (e.g. prime-response retrieval, non-response retrieval, inhibition) in one condition (i.e. the "Go" condition) but by fewer mechanisms in another condition (i.e. the "NoGo" condition), one would expect a smaller overall effect for the latter condition. Whether this reasoning applies to the reaction time effect or the overall error effect or both is unclear, because it is not known whether all mechanisms have effects on both variables. However, it seems to be more plausible that the prime-response retrieval mechanism influences the overall error effect.

10 Experiment 4

Experiment 4 served two goals. First, it was designed to validate the prime-response retrieval variant of the episodic retrieval model. Second, it should allow to investigate the relevance of prime-response retrieval in inducing reaction time and overall error negative priming effects. Participants took part in the same auditory four-choice identification task as in Experiment 2. Different from Experiment 2, trials could be either "NoGo" trials on which a signal indicated that no prime response was allowed, or "Go" trials on which a signal indicated that a prime response had to be made. Probe displays always required a response.

An additional manipulation concerned the instructions. One group of participants was instructed to respond error-free at the expense of speed. A second group was instructed to respond fast, accuracy was of subordinate importance. Instructions in a third group stressed speed as well but to a minor extend than in the second group. This was done out of an uncertainty about the degree of difficulty of the task. Whether probe responding in the new "NoGo" task would be easier or equally difficult as in the "Go" task was unclear. On the one side, if probe responding in a "NoGo" task was easier than in a "Go" task, instructions stressing accuracy of responding as in Experiment 2 could yield an error level too small to analyze specific response errors. On the other side, stressing speed to induce more errors is associated with the risk of reducing or even eliminating the negative priming effect as has been shown by Neill and Westberry (1987, Experiment 1). A manipulation of the speed versus accuracy emphasis was implemented to control for both risks. To anticipate, the group manipulation did neither interact with the trial type nor the prime response manipulation as regards the reaction times and overall error rates.

10.1 Method

10.1.1 Participants

Participants were 90 adults (mostly students), 60 of whom were female. They ranged in age from 17 to 43 years (*M* = 24.40, *SD* = 5.46). 24 additional participants did not reach one of the two learning criterions of 75% correct reactions in the first training phase or of 60% correct reactions in the second training phase. For five further participants there was at least one condition with less than 10 valid probe reactions which was defined as the minimum for calculating reliable averages. The data of these participants were also discarded[13]. Participants were randomly assigned to one of the three speed-accuracy trade-off groups (accuracy emphasis, mild speed emphasis, strong speed emphasis) with the restriction that, at the end of the experiment, an equal number of participants had to be in each of these three groups. In each group 30 participants were tested. The groups did not differ in terms of age. Test sessions were run with one to five persons in parallel. Participants were paid € 8.00 for their participation.

10.1.2 Materials

Stimulus materials and task were the same as in Experiment 2 with the following exceptions. Participants used a response box for reacting, which was directly plugged into the computer. The four tones were assigned to four sagitally aligned buttons of the response box. Participants were instructed to press the two upper buttons with the middle and index fingers of the right hand and the two lower buttons with the middle and index fingers of the left hand. The buttons were labeled with the color of the drawing associated to the respective tone as in Experiment 2.

Visual cues were presented before the auditory prime and probe cues. They indicated whether participants had to react or to withhold a response to the next display. A black circle with a green walking man inside—similar to the “Walk” sign of a pedestrian traffic light—was the cue that prompted a reaction to the following auditory presentation. Analogously, a black circle with a red standing man inside—similar to the “Stop” sign of a pedestrian traffic light—indicated that a response should be withheld to the upcoming display. The visual cues were presented in the center of the screen. Their diameter was about 90 mm (viewing angle of 7.3°).

The stimulus configuration was similar to that of Experiment 2 in that the same sets of stimuli were presented. 45 participants were tested with Set 1 and Set 2, respectively. Each set of 48 unique trials (12 of each of the four trial types, i.e. ignored repetition, control, attended repetition filler, and control filler) was once implemented in the “Go” condition (with response requirement in the prime) and once implemented in the

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[13] In comparison to Experiment 2, there was a high rate of drop-outs. This was due to the additional task of switching between the “Go” and “NoGo” requirement that increased overall difficulty and the fact that participants had to pass two criteria instead of one.

"NoGo" condition (without response requirement in the prime). Throughout the entire experiment, the trials were presented four times, resulting in 384 experimental trials which were presented in an individually random sequence. For each trial, the attentional allocation (left in prime and right in probe versus right in prime and left in probe) was randomly assigned.

10.1.3 Procedure

The procedure was parallel to Experiment 2 with the following exceptions. After familiarization with the tones, participants received the same training as in Experiment 2, but the criterion to pass to the next experimental phase was more restrictive: Participants had to react correctly in more than 75% of the preceding 30 responses. Again, participants who did not reach this criterion within 150 trials were given a choice to quit the experiment or to start again with the training.

The tone identification task was extended relative to Experiment 2. Participants were introduced to the visual cues before the actual trials. They were told that before auditory stimulus presentation, either a green traffic light or a red traffic light sign could signal that a response had to be given or to be withheld, respectively. In the next training phase, prime and probe pairs were presented. The prime pair could either be preceded by a green or a red traffic light. The probe pair was always preceded by a green traffic light. After each prime-probe pair presentation, participants received feedback about the correctness of their responses. The next training trial started automatically. Participants entered the experiment proper when they had responded correctly in more than 60% of the preceding 45 training responses. For participants who did not reach this criterion within 150 trials, the experiment was aborted at that stage.

Instructions to the experiment proper introduced an additional task. Participants were informed, that sometimes a single additional tone was played after the probe response. Participants had to judge whether this tone had been the prime target of the current trial. This control question was supposed to increase attention to the prime tones, even when no response had to be carried out. The presented tone was always played on the attended prime side. If the tone was identical to the prime target tone, participants had to press a button left below the regular response buttons, if the tone was different from the prime target tone, they had to press a button right below the regular response buttons. To facilitate the task, the spatial arrangement of the two buttons ("Yes", i.e. identical, on the left; "No", i.e. different, on the right) was presented on the screen until the participant had responded. To familiarize participants with this task, they were exposed to five trials with the additional control question. In the experiment proper 25% randomly assigned trials were followed by this question. The question could follow prime-probe pairs of "Go" as well as of "NoGo" trials. In approximately 25% of these trials the correct answer was "Yes" (identical), in about 75% it was "No" (different).

Before the experiment proper started, participants were introduced to the scoring rules for the experiment. These rules were different for the three speed-accuracy trade-off groups. In the "accuracy emphasis" group, participants were instructed to respond as accurately as possible, but also to react quickly. For each correct response they gained ten points, for each incorrect response they lost ten points. No points could be gained or lost as a result of response speed. For the "mild speed emphasis" group and the "strong speed emphasis" group, instructions stressed speed first, then accuracy. For both groups, only five points could be gained or lost for correct or incorrect responding. In contrast, ten points were gained for fast probe responses and lost for slow probe responses[14]. The criterion of what was defined as "fast" and "slow" responding was not made explicit. In fact, throughout the experiment an adaptive criterion was calculated in the following way: For the "strong speed emphasis" group the current probe response was "fast" if it was below the median probe response time of the last 15 trials, and "slow" if it was above this median. For the first 15 trials a response criterion of 1200 ms was applied. Whenever probe reactions were slower than 1200 ms, they were replaced by 1200 ms for calculating the criterion. Calculations for the "mild speed emphasis" group were equivalent but the criterion was not the median but the 75th percentile of the last 15 probe response times.

Furthermore, all groups were informed that correct and incorrect responses to the control question would lead to a gain and loss of five points, respectively, that responding to displays with a red traffic light and not responding to displays with a green traffic light would lead to a loss of 50 points, and that too many errors in a block would lead to a loss of 50 points as well. The error criterion was set to 40% incorrect responses in a

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[14] Prime response speed was not reinforced because trials with incorrect prime responses cannot be used to calculate probe response time averages or probe error rates.

block. Before the first trial of the experiment proper started participants were shown their initial points (i.e. 1000).

Each of the 384 experimental trials began with the presentation of the visual cue, 150 ms after which the metronome click was played. Followed by a 400 ms cue-target interval, the prime pair of tones was presented. 2000 ms after the prime tone onset, the visual cue for the prime was replaced by the visual probe cue. A constant prime-probe interval was preferred to a constant response-to-stimulus interval (as implemented in Experiment 2) to prevent any experimental confounds in timing. In both the "NoGo" and the "Go" trials the entire timeout interval had to pass in order to avoid systematically longer prime-probe intervals for "NoGo" trials which would have resulted if only the duration of the response-to-stimulus interval had been controlled. Another 150 ms after the visual probe cue, the click that cued the to-be-attended probe was presented. The probe click (presented to the opposite of the prime target presentation side) was followed by a 400 ms cue-target interval, after which the probe pair of tones was presented. Within 1800 ms after onset of the prime stimuli and for 3000 ms after onset of the probe stimuli participants had to respond given it was a display to which responding was allowed. After each prime-probe pair participants were given auditory and visual feedback about their performance. In the "accuracy emphasis" group feedback depended exclusively on the correctness of their reactions. In the two other groups it depended on a combination of correctness and speed. Participants also saw how many points they had lost and/or gained in the current trial. Prime responses in "NoGo" trials, prime responses in "Go" trials slower than 1800 ms, and probe responses slower than 3000 ms were counted as invalid. Invalid responses were not repeated. After trial feedback, a 2200 ms inter-trial interval followed before the visual cue of the next trial was presented. After every twentieth trial, participants received a summary feedback in terms of the sum of points they had gained by this time. After the final trial, all participants were informed about the purpose of the experiment. The experiment took about 90 minutes.

10.1.4 Design

The experiment comprised a three-factorial design with speed-accuracy trade-off (accuracy emphasis vs. mild speed emphasis vs. strong speed emphasis) as between-subjects variable, and trial type (ignored repetition vs. control) as well as prime response ("Go" vs. "NoGo") as within-subject variables. The dependent variables were the frequency of probe responses with the prime target, accumulated across participants, participants' average reaction times and overall probe error rates.

For the a priori power analysis the interaction between the two within-subject variables trial type and prime response was relevant. In order to detect effects of size $f = 0.150$ (between "small" and "medium" effects as defined by Cohen, 1988) given a population correlation of $\rho = .7$ between the difference variables of reaction times (ignored repetition versus control) in the two levels of the prime response variable (or vice versa; this corresponds to assuming $\eta^2 = .13$ as the population effect size) and desired levels of $\alpha = \beta = .05$, data had to be collected from a sample of at least $N = 89$ participants. Data from $N = 90$ participants could be collected which did not change the actual power level substantially.

10.2 Results

Reaction times and overall error rates will be reported first (Chapter 10.2.1). Next, the specific probe error frequencies will be analyzed (Chapter 10.2.2). Subsequently, performance in the control task will be analyzed (Chapter 10.2.3), and finally the priming effects for attended repetition filler trials will be examined (Chapter 10.2.4).

10.2.1 Reaction time and overall error analysis

Probe reaction times were evaluated only for trials in which both the probe and the prime reactions were correct and not faster than 100 ms. Probe errors were evaluated only if they followed a correct prime response. Different from the preceding experiments, the following reaction time analyses are based on median reaction times. In this experiment the same total number of trials was presented as in Experiments 2 and 3 (i.e. 384). The inclusion of the additional within-subject variable prime response (Go, NoGo) cut the number of available reactions per condition in half. In addition, the speed emphasis for the "mild speed emphasis" and the "strong speed emphasis" groups further reduced the number of available error-free trials for some participants considerably. In some cases, less than 15 reaction times entered the calculation of individual conditional averages. The median was preferred as the average of choice since this sample statistic is less affected by extreme scores (Myers & Well, 1995) which carry more weight the smaller the sample of observations is. The means of participants' median reaction times and the overall error rates are presented in the upper and lower panels of Figure 10-1, respectively.

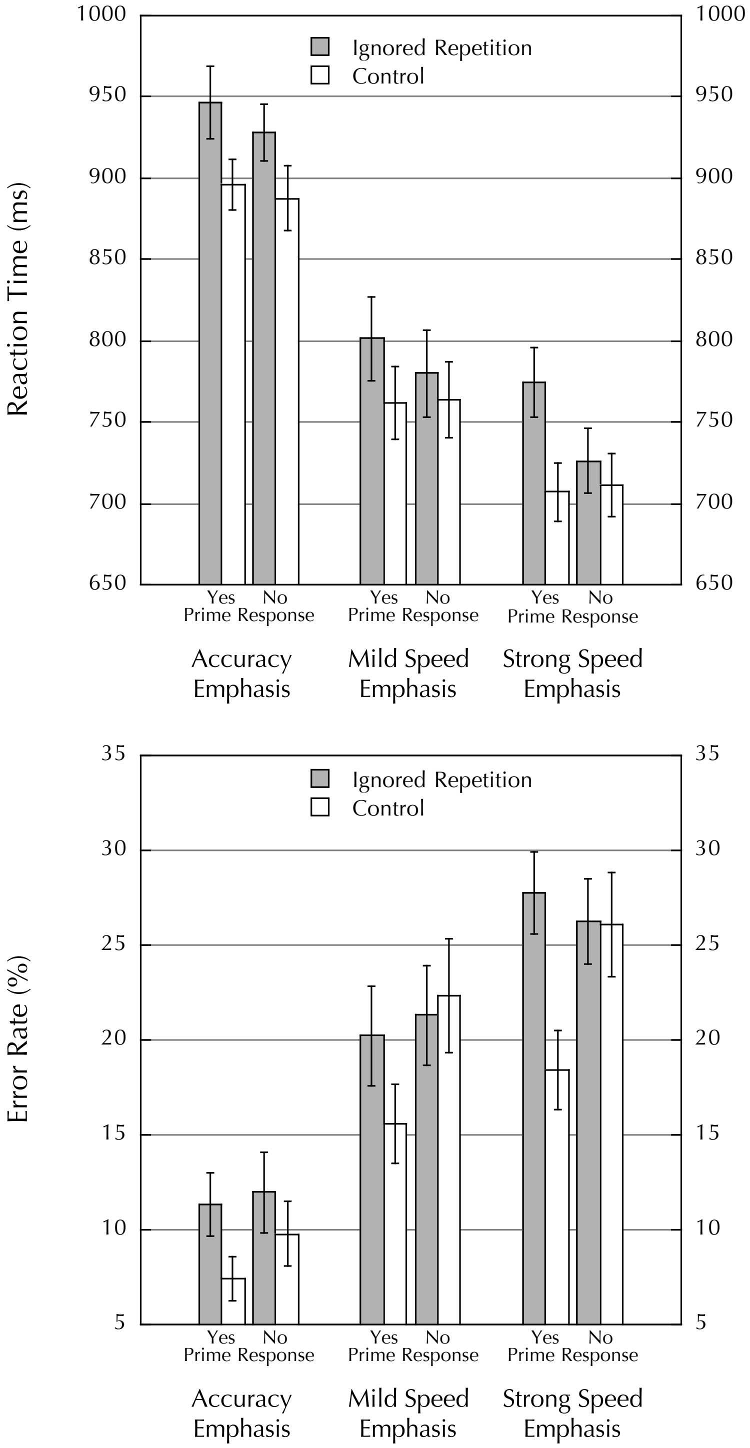

Figure 10-1: Probe reaction times (upper panel) and probe error rates (lower panel) as a function of speed-accuracy trade-off, prime response, and trial type (Experiment 4). The error bars depict the standard errors of the means.

The descriptive data clearly show that the speed-accuracy manipulation was successful in that the stronger the emphasis had been on speeded responding the faster participants responded but they did so at the expense of committing more errors. Overall, reaction times in the "Go" condition were somewhat slower but also less error-prone than in the "NoGo" condition. For response times, there is a negative priming effect visible for all groups and for both "Go" as well as "NoGo" conditions in that reactions were slower for ignored repetition than for control trials. However, the effect seems to be somewhat larger in the "Go" condition. Similarly, the negative priming effect in the error data is clearly expressed in the "Go" condition, whereas it is reduced or even eliminated in the "NoGo" condition.

A 3×2×2 multivariate analysis of variance (MANOVA) with speed-accuracy trade-off (accuracy emphasis vs. mild speed emphasis vs. strong speed emphasis) as between-subjects variable, and trial type (ignored repetition vs. control) as well as prime response (Go vs. NoGo) as within-subject variables showed significant main effects of speed-accuracy trade-off, $F(2, 87) = 24.79$, $p < .001$, $\eta^2 = .36$, of trial type, $F(1, 87) = 44.16$, $p < .001$, $\eta^2 = .34$, and of prime response, $F(1, 87) = 5.52$, $p = .021$, $\eta^2 = .06$. The only significant interaction was found between the two within-subject variables trial type and prime response, $F(1, 87) = 6.54$, $p = .012$, $\eta^2 = .07$. This implies that the size of the negative priming effect was modulated by the prime response requirement. Negative priming was larger in "Go" trials than in "NoGo" trials. None of the interactions of the between-subjects variable and any of the two within-subject variables was significant, $F(2, 87) = 0.84$, $p = .435$, $\eta^2 = .02$ for the interaction between speed-accuracy trade-off and trial type, $F(2, 87) = 0.30$, $p = .742$, $\eta^2 = .01$ for the interaction between speed-accuracy trade-off and prime response, and $F(2, 87) = 1.30$, $p = .277$, $\eta^2 = .03$ for the triple interaction between speed-accuracy trade-off, trial type, and prime response.

Negative priming was significant at both levels of the prime response variable, as is shown by follow-up tests using the Bonferroni-Holm method (Holm, 1979) of protecting against α-error accumulation, $t(89) = 6.31$, $p < .001$, $\eta^2 = .31$, for the "Go" condition and $t(89) = 3.16$, $p = .002$, $\eta^2 = .10$ for the "NoGo" condition.

The parallel analysis for the error data showed the same pattern of results in that there were significant main effects of speed-accuracy trade-off, $F(2, 87) = 14.66$, $p < .001$,

η^2 = .25, of trial type, *F*(1, 87) = 23.56, *p* < .001, η^2 = .21, and of prime response, *F*(1, 87) = 11.21, *p* = .001, η^2 = .11. Again, the only significant interaction was found between trial type and prime response, *F*(1, 87) = 13.41, *p* < .001, η^2 = .13, whereas none of the other interactions was significant, *F*(2, 87) = 1.64, *p* = .20, η^2 = .04 for the interaction between speed-accuracy trade-off and trial type, *F*(2, 87) = 0.71, *p* = .496, η^2 = .02 for the interaction between speed-accuracy trade-off and prime response, and *F*(2, 87) = 2.05, *p* = .135, η^2 = .05 for the triple interaction between speed-accuracy trade-off, trial type, and prime response.

Follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation showed that the negative priming effect in the error data was only significant for the "Go" condition of the prime response variable, *t*(89) = 5.78, *p* < .001, η^2 = .27, whereas for the "NoGo" condition probe errors did not differ between ignored repetition and control trials, *t*(89) = 0.45, *p* = .652, η^2 < .01.

For control purposes, prime reaction times and overall prime error rates were analyzed, ignoring the speed-accuracy trade-off between-subjects factor. It was tested separately for the "Go" and "NoGo" condition whether prime error rates and—for the "Go" condition only—whether median prime reaction times were similar for ignored repetition and control trials. On average, participants reacted as fast after ignored repetition trials (*M* = 826.67 ms, *SE* = 13.10 ms) as after control trials (*M* = 826.88 ms, *SE* = 14.13 ms) in the "Go" condition, *t*(89) = 0.41, *p* = .967, η^2 < .01. In the "Go" condition, prime errors were made in 17.50% (*SE* = 1.47%) in the ignored repetition condition and in 17.94% (*SE* = 1.62%) in the control condition, respectively. In the "NoGo" condition, prime errors were made in 1.44% (*SE* = 0.26%) in the ignored repetition condition and in 1.71% (*SE* = 0.25%) in the control condition, respectively. The prime error rates neither differed significantly between trial types in the "Go" condition, *t*(89) = 0.59, *p* = .559, η^2 < .01, nor in the "NoGo" condition, *t*(89) = 1.10, *p* = .276, η^2 = .01.

10.2.2 Specific Probe Error Analysis

The frequency of erroneous probe reactions with the prime target response was clearly influenced by the prime response manipulation. In the "Go" condition, participants committed clearly more prime target response errors in the ignored repetition condition (*M* = 26.32%, *SE* = 2.28%) than in the control condition (*M* = 7.62%, *SE* = 1.90%), whereas in the "NoGo" condition, the relative frequency of prime target responses was approximately the same for the ignored repetition and the control condition (M = 16.37%, SE = 1.70%, and M = 15.32%, SE = 1.58%, respectively). The absolute frequencies of the correct probe responses and of the different probe error types are displayed in Table 10-1.

Table 10-1

Accumulated absolute frequencies of correct probe responses and of the different types of probe errors for the "Go" and "NoGo" condition, separated for the ignored repetition condition and the control condition (Experiment 4).

	Go		NoGo	
	Ignored Repetition	Control	Ignored Repetition	Control
Correct probe target responses	*2904*	*3088*	*3378*	*3395*
Incorrect probe distractor responses	*368*	*315*	*483*	*488*
Incorrect prime target responses	*171*	*36*	*155*	*148*
Other incorrect responses*	*108*	*92*	*186*	*164*

* *Ignored repetition trials:* Incorrect responses using the key that was assigned to the non-presented stimulus.
Control trials: Incorrect prime distractor responses.

For the multinomial modeling analysis the underlying model comprised two pairs of the model trees illustrated in Figure 6-1 (p. 64), one for the "Go" condition and one for the "NoGo" condition. This joint model has as many identifiable parameters as there are independent category probabilities to fit (i.e. 12). Thus, the goodness-of-fit test of this model has zero degrees of freedom, and it fitted the frequency data of Experiment 4 perfectly. The parameter estimates of the critical retrieval process ($prr_{\text{Go-IR}}$ and $prr_{\text{Go-C}}$, $prr_{\text{NoGo-IR}}$ and $prr_{\text{NoGo-C}}$, for the "Go" and "NoGo" condition, respectively) are illustrated in Figure 10-2. In order to test whether the prime-response retrieval variant of the episodic retrieval model was an effective mechanism for the negative priming effect in the "Go" condition but not for the negative priming effect in the "NoGo" condition, the following sequence of goodness-of-fit tests was performed. First, the goodness-of-fit of the model with the restriction that $prr_{\text{NoGo-IR}} = prr_{\text{NoGo-C}}$, which is implied by the assumption that prime-response retrieval is of no significance for the "NoGo" condition, was tested. The restricted model fitted the data very well, $G^2(1) = 0.26$, $p = .612$. Second, the restriction that $prr_{\text{Go-IR}} = prr_{\text{Go-C}}$ which implies that prime-response retrieval is of no relevance for the "Go" condition, was tested. This restricted model did not fit the data, $G^2(1) = 39.58$, $p < .001$, and had to be rejected. A specific analysis of the probe error types for each of the three "speed-accuracy trade-off" groups was not performed because there were no a priori hypotheses whether and, if so, how much the speed-accuracy emphasis should modulate the prime target error probability.

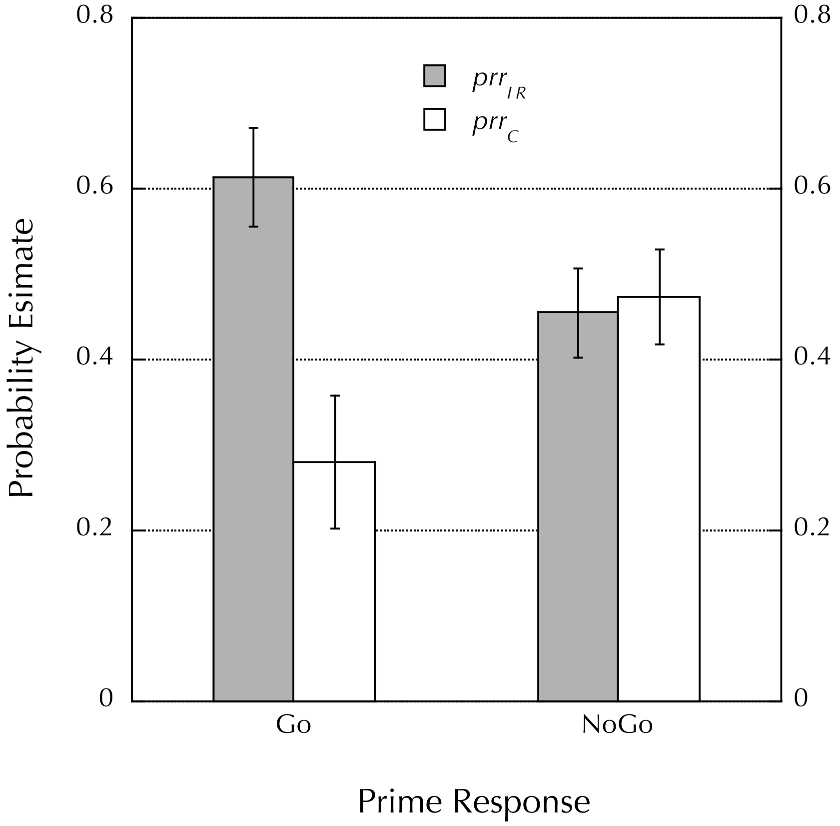

Figure 10-2: Probability estimates for the model parameters representing the probability of prime-response retrieval as a function of prime response and trial type (Experiment 4). The error bars depict the .95 confidence intervals.

10.2.3 Control Question Analysis

Performance in the control question was analyzed regardless of the speed-accuracy trade-off between-subjects factor. Figure 10-3 represents the mean estimates of P_r and B_r which reflect participants' discrimination performance and response bias, respectively, according to the two-high-threshold model (cf. Snodgrass & Corwin, 1988, Equations 7 and 8). Before computing the indices of sensitivity and bias, hit and false alarm rates were adjusted as suggested by Snodgrass and Corwin (1988). In the experiment, 25% of the trials were randomly selected and followed by a test tone. Also randomly selected, in approximately 25% of these trials, the test tone was identical to the prime target tone and the correct answer was "Yes". In about 75% of the trials a different test tone was presented with the correct answer being "No". As a consequence, not every participant necessarily was exposed to the control question in each of the eight possible categories [2("Go" vs. "NoGo")x2(ignored repetition vs. control)x2(identical tone vs. different tone)]. The following analyses were performed only for participants who provided responses in each of these eight categories (*N* = 68).

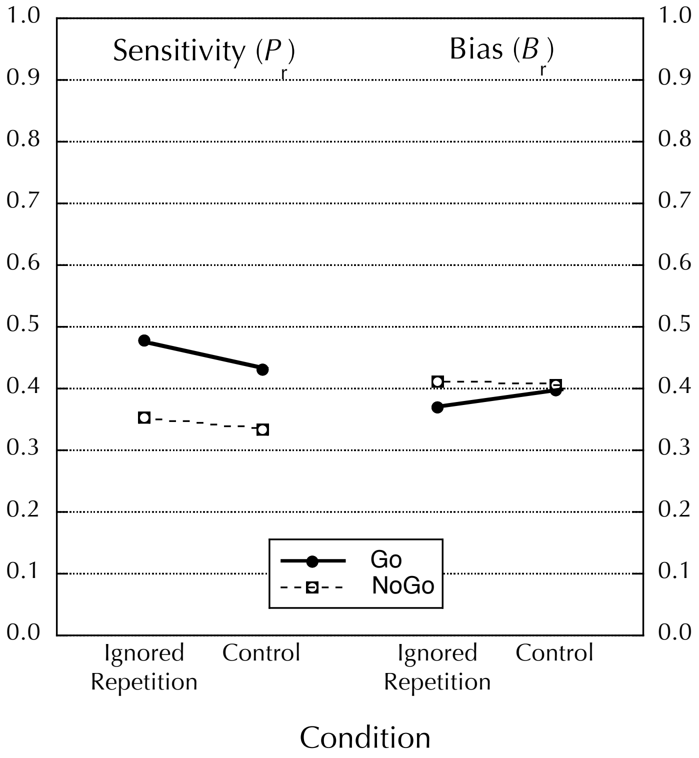

Figure 10-3: Sensitivity and response bias indices as a function of prime response and trial type (Experiment 4). For "Go" trials, hit and false alarm rate estimates were, respectively, .67 and .19 in the ignored repetition condition and .66 and .23 in the control condition. For "NoGo" trials, hit and false alarm rates were, respectively, .61 and .26 in the ignored repetition condition and .60 and .26 in the control condition.

Descriptively, participants demonstrated increased discrimination performance in "Go" trials compared to "NoGo" trials. The trial type manipulation did not seem to be of importance for discrimination performance. With respect to response bias, participants had a tendency of answering with "No" in all conditions which is in accordance with the base rate of .75 for trials with different test tones.

The statistical analysis confirmed the first impression. For the sensitivity index, there was a significant main effect of prime response, $F(1, 67) = 14.99$, $p < .001$, $\eta^2 = .18$, but neither a main effect of trial type, $F(1, 67) = 1.38$, $p = .244$, $\eta^2 = .02$, nor of the interaction between the two variables, $F(1, 67) = 0.32$, $p = .575$, $\eta^2 < .01$.

Follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation showed that the two trial type conditions differed neither in the "Go" condition, $t(67) = 1.28$, $p = .206$, $\eta^2 = .02$, nor in the "NoGo" condition, $t(67) = 0.47$, $p = .642$, $\eta^2 < .01$. In addition, discrimination performance was significantly better than zero for both trial types in the "Go" condition, $t(67) = 13.74$, $p < .001$, $\eta^2 = .74$, and $t(67) = 11.86$, $p < .001$, $\eta^2 = .67$, for ignored repetition and control trials, respectively. The same was true for the "NoGo" condition, $t(67) = 8.78$, $p < .001$, $\eta^2 = .53$, and $t(67) = 8.84$, $p < .001$, $\eta^2 = .53$, respectively.

The statistical analysis of response bias revealed neither a main effect of prime response, $F(1, 67) = 1.42$, $p = .237$, $\eta^2 = .02$, nor a main effect of trial type, $F(1, 67) = 0.20$, $p = .657$, $\eta^2 < .01$, nor a significant interaction between the two variables, $F(1, 67) = 0.69$, $p = .411$, $\eta^2 = .01$.

Follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation showed that the two trial type conditions did not differ from each other in the "Go" condition, $t(67) = -0.92$, $p = .360$, $\eta^2 = .01$, and in the "NoGo" condition, $t(67) = 0.22$, $p = .828$, $\eta^2 < .01$. Response bias was conservative for all conditions in that it was significantly smaller than .5 which marks the neutral value for B_r, $t(67) = -5.68$, $p < .001$, $\eta^2 = .32$, and $t(67) = -3.80$, $p < .001$, $\eta^2 = .18$, for ignored repetition and control trials in the "Go" condition, and $t(67) = -3.70$, $p < .001$, $\eta^2 = .17$, and $t(67) = -3.49$, $p = .001$, $\eta^2 = .15$, for ignored repetition and control trials in the "NoGo" condition.

10.2.4 Analysis of the Attended Repetition Filler Trials and Control Filler Trials

Probe reaction times for attended repetition filler trials and control filler trials were evaluated only for trials in which both the probe and the prime reactions were correct and not faster than 100 ms. Probe errors were evaluated only if they followed a correct prime response. To keep results concise, data were averaged over the speed accuracy trade-of between-subjects variable. The means of participants' median reaction times and the overall error rates are presented in the left and right panels of Figure 10-4, respectively.

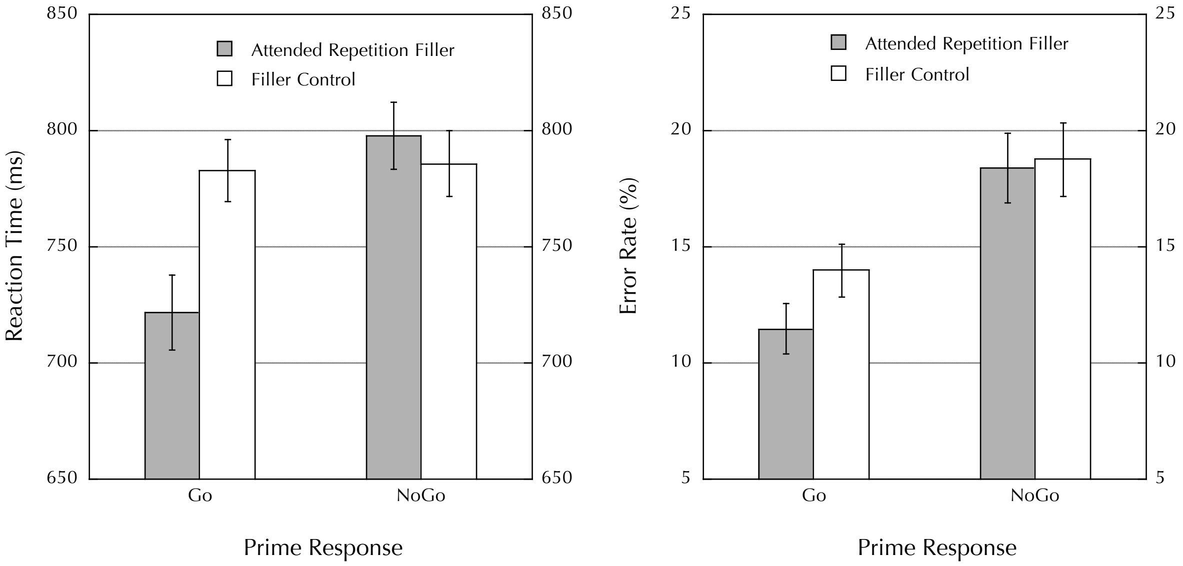

Figure 10-4: Probe reaction times (left panel) and probe error rates (right panel) as a function of prime response and trial type (Experiment 4). The error bars depict the standard errors of the means.

The descriptive data show a positive priming effect for the attended repetition filler trials in the "Go" condition whereas repetition of an attended stimulus leads to a negative priming effect in the "NoGo" condition. A 2×2 MANOVA with trial type (attended repetition filler vs. control filler) as well as prime response (Go vs. NoGo) as within-subject variables showed significant main effects of trial type, $F(1, 89) = 14.07$, $p < .001$, $\eta^2 = .14$, and of prime response, $F(1, 89) = 46.96$, $p < .001$, $\eta^2 = .35$. The interaction between trial type and prime response was also significant, $F(1, 89) = 42.72$, $p < .001$, $\eta^2 = .32$.

By follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation, it was found that for the "Go" condition, positive priming was significant, $t(89) = 6.14$, $p < .001$, $\eta^2 = .30$. For the "NoGo" condition, the negative priming effect was not significant, $t(89) = 1.76$, $p = .082$, $\eta^2 = .03$.

For the parallel analysis of the error rates, the descriptive data in Figure 10-4 show a positive priming effect in the "Go" condition in that there were fewer errors in the attended repetition filler condition than in the control filler condition whereas repetition of an attended stimulus did not seem to have any effect in the "NoGo" condition. A MANOVA revealed a significant main effect of trial type, $F(1, 89) = 4.65$, $p = .034$, $\eta^2 = .05$, and of prime response, $F(1, 89) = 42.06$, $p < .001$, $\eta^2 = .32$, but no significant interaction, $F(1, 89) = 2.25$, $p = .140$, $\eta^2 = .03$.

Follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation were used although the interaction between trial type and prime response did not reach significance. This was done to test whether the very small error decrease for attended repetition filler trials was significant for the "NoGo" condition. As expected for the "Go" condition, a significant reduction in error rates was measured for the attended repetition filler condition, $t(89) = 2.39$, $p = .019$, $\eta^2 = .06$. For the "NoGo" condition, there was no significant difference, $t(89) = 0.45$, $p = .657$, $\eta^2 < .01$.

For control reasons, prime reaction times and overall prime error rates were also analyzed for attended repetition filler and control filler trials. It was tested separately for the "Go" and "NoGo" condition whether prime error rates and—for the "Go" condition only—whether median prime reaction times were similar for attended repetition filler and control filler trials. On average, participants reacted as fast in attended repetition filler trials ($M = 820.24$ ms, $SE = 14.37$ ms) as in control filler trials ($M = 817.57$ ms, $SE = 12.72$ ms) in the "Go" condition, $t(89) = 0.42$, $p = .678$, $\eta^2 < .01$. In the "Go" condition, prime errors were made in 17.38% ($SE = 1.55\%$) of the attended repetition filler condition and in 19.00% ($SE = 1.54\%$) of the control filler condition, respectively. In the "NoGo" condition, prime errors were made in 1.69% ($SE = 0.23\%$) in the attended repetition filler condition and in 1.62% ($SE = 0.24\%$) in the control filler condition, respectively. The prime error rates were significantly smaller in the attended repetition filler condition than in the control filler condition for the "Go" condition, $t(89) = 2.39$, $p = .019$, $\eta^2 = .06$, but there was no prime error effect in the "NoGo" condition, $t(89) = 0.22$, $p = .823$, $\eta^2 < .01$.

10.3 Discussion

Experiment 4 was planned as a replication of Experiment 2, but with the additional manipulation of the prime response requirement. As in Experiments 2 and 3 a negative priming effect was found for the "Go" condition, both in reaction times as well as in overall error rates. In contrast, for the "NoGo" condition negative priming was demonstrated for the reaction time measure but not for the probe error rates. Nevertheless, for both conditions evidence for an effective negative priming mechanism was found which was a precondition for the central aim of this experiment, the validation of the prime-response retrieval variant of the episodic retrieval model.

A relative increase in prime response errors for ignored repetition trials with a prime response requirement combined with no increase of this error type for ignored repetition trials without a prime response requirement would be seen as evidence in favor of a prime-response retrieval mechanism. The same multinomial model that was used for Experiments 2 and 3 (see Figure 6-1, p. 64) was applied, but in an extended version with separate trees for the "Go" and the "NoGo" conditions. The model with the restriction that $prr_{\text{NoGo-IR}} = prr_{\text{NoGo-C}}$ fitted the data almost perfectly which implies that prime-response retrieval is of no significance for the "NoGo" trials. The restriction that $prr_{\text{Go-IR}} = prr_{\text{Go-C}}$ lead to a significant misfit of the model which implies that prime-response retrieval is a relevant mechanism for the "Go" condition. This pattern of results supports the assumption that a prime-response retrieval mechanism is active in the "Go" but not in the "NoGo" condition. Apparently, the prime response is an important aspect of the retrieved prime episode.

In sum, then, there are two central pieces of evidence in Experiment 4. First, negative priming was found in both the "Go" and the "NoGo" condition and prime-response retrieval is active in the "Go" but not in the "NoGo" condition. Further analyses of the reaction time and error data were performed. It was expected that a smaller negative priming effect should be found in the "NoGo" than in the "Go" condition because one negative priming inducing mechanism, that is, prime-response retrieval, was eliminated in the "NoGo" but not in the "Go" condition. Indeed, an interaction between the trial type and prime response variables was found in reaction times as well as in error rates and was also visible in effect size measures.

With respect to the reaction time effect, an interaction between the trial type and prime response variable was found in that the negative priming effect was larger in the "Go" (52.20 ms) than in the "NoGo" (24.07 ms) condition. Nevertheless, the effect was significant even in the "NoGo" condition.

There is one potential problem in interpreting the differences between the negative priming effects: Responses in "Go" trials were slightly slower than in "NoGo" trials (814.63 ms vs. 799.48 ms). Reaction time differences between conditions are more difficult to compare when there are also differences in the absolute reaction time level. There are two ways to solve this problem. One can either compare proportional effects or one can use standardized effect size measures that are independent of absolute reaction time level. With respect to proportional effects, there was a slow-down in ignored repetition relative to control trials of 6.62% in the "Go" condition but of only 3.06% in the "NoGo" condition. The standardized effect size measure of explained variance also shows that the effect was much larger for the "Go" than for the "NoGo" condition (η^2 = .30 vs. η^2 = .13). Obviously, a substantial reduction in negative priming was obtained in the "NoGo" condition relative to the "Go" condition, and this reduction was consistently observed at the level of raw reaction time differences, proportional reaction time reductions, and standardized effect sizes. The most obvious explanation is that the lack of prime-response retrieval in the "NoGo" condition was responsible for this reduction. According to this explanation, prime-response retrieval is not only a mechanism that induces a specific bias to react with the prime response but also slows down responding. Possibly, this is mediated by a confusion between the required probe response and the retrieved prime response. Resolving this confusion takes time.

Turning to the overall error effect, negative priming was found in the "Go" condition, but did not exist in the "NoGo" condition. Note that this cannot be interpreted in terms of a floor effect, since the absolute overall probe error level was actually larger in the "NoGo" condition. Therefore, an interpretation in terms of negative priming mechanisms seems necessary. Obviously, error effects of negative priming are exclusively induced by the prime-response retrieval mechanism which biases a reaction with the preceding prime response. If prime-response retrieval cannot take effect as in "NoGo" trials, there cannot be an increase in errors in the ignored repetition relative to the control condition. The influence of the prime-response retrieval mechanism on the overall error effect was not completely unexpected given that an effect of this mechanism on a specific error effect had already been demonstrated. What is surprising, however, is the importance of this mechanism. It seems to be the *only* cause of an overall error effect.

However, a critical consideration of the above interpretation is necessary. So far, the reductions of the negative priming effects in reaction times and error rates in the "NoGo" condition have been interpreted in terms of a lacking prime-response retrieval mechanism as the sole cause. This is based on the assumption that all other mechanisms remain constant between "Go" and "NoGo" trials, both qualitatively and quantitatively. Conceivably, other negative priming mechanisms involved in a "NoGo" trial work differently than in a "Go" trial. For example, whereas in the prime display of a "Go" condition an inhibitory component might suppress the representation of a distractor stimulus, an inhibitory process in the "NoGo" condition might suppress the whole episode. Correspondingly, in "NoGo" trials a non-response retrieval mechanism might attach a non-response information to the whole prime episode. It is difficult to estimate whether and how this might bear on the size of the negative priming effect for "NoGo" trials. Mondor et al. (in press) reported a *larger* negative priming effect for a situation with a single prime that did not require a response. Different to Experiment 4, the researchers did not manipulate the prime response requirement within one experiment but compared their Experiments 1 (with prime response) and 2 (without prime response) post-hoc, with the problem of further confounding factors. One of these was the presence of attended repetition trials in their Experiment 1 but not in their Experiment 2. Attended repetition trials usually induce a decrease in overall reaction time level[15]. This was also true for Mondor et al's (in press) Experiment 1 relative to their Experiment 2. Consequently, a larger absolute reaction time difference effect as was found in their Experiment 2 compared to their Experiment 1, might have been of same size when compared in proportional effect sizes or standardized effect sizes.

The additional control task might help to shed light on the differences in processing between "Go" and "NoGo" trials and their interpretation. This task had been implemented to prevent withdrawal from the prime display and thus to guarantee the same

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[15] The accelerating effect can be demonstrated by comparing Experiment 1 (with attended repetition trials) and 2 (without attended repetition trials) of Buchner & Mayr (2004). Note, however, that there were also some differences in timing parameters between the two experiments.

extent of attentional allocation in trials with and without response requirement. Discrimination performance for this task was analyzed to test whether this goal was achieved. For both prime response conditions the sensitivity index P_r did not differ between ignored repetition and ignored repetition control trials which means that the observed negative priming effects are not compromised by differential attentional processing in the critical conditions. However, there was a difference in sensitivity between "Go" and "NoGo" trials. Participants' discrimination performance was significantly better in "Go" trials than in "NoGo" trials. However, discrimination performance in "NoGo" trials was still significantly above chance which documents (together with the observed negative priming effect in reaction times) that participants processed the prime targets. But apparently, the degree of prime processing, encoding, or remembering was less pronounced for the "NoGo" than for the "Go" condition. Correspondingly, the attentional or mnemonic processes relevant for a negative priming effect might have been less pronounced, too, in the "NoGo" than in the "Go" condition. This would conform to the consideration explicated above that "Go" and "NoGo" trials differ in the quantity (and maybe additionally the quality) of the involved negative priming mechanisms.

Do these considerations make the results ambiguous and non-interpretable? With respect to the reaction time effect, there is indeed no unambiguous evidence that the reduction in negative priming in the "NoGo" condition was entirely due to the absence of the prime-response retrieval mechanism. The situation is different for the overall errors. The complete loss of the overall error effect can be unambiguously attributed to the absence of the prime-response retrieval mechanism in "NoGo" trials. The reaction time negative priming effect for "NoGo" trials showed that negative priming inducing mechanisms *were* active in this condition. But obviously, they were of no relevance in producing increased levels of wrong responses in the ignored repetition condition. Consequently, errors must have been produced by the prime-response retrieval mechanism exclusively.

Experiment 4 sheds light on the existence and relevance of the prime-response retrieval mechanism, but it also reveals evidence for the existence for another negative priming mechanism—be it an inhibitory or non-response retrieval mechanism. Almost trivial, the fact that a reaction time negative priming effect was found in the "NoGo" condition can only be explained by help of another negative priming component other than prime-response retrieval. Possibly, in a “NoGo” prime the whole display was inhibited or a non-response information was attached to both stimuli or the episode as a whole. An indication for inhibition of the whole prime episode or for a non-response tag attached to the whole episode can be seen in the attended repetition trials that were included in the experiment. As expected, a positive priming effect was found for the “Go” condition. For the “NoGo” condition this effect could not be expected because repetition effects are known to be primarily generated by directly linking a fairly early stimulus representation with a fairly specific response thereby shortcutting the response selection stage, but not by faster perceptual processing (Bertelson, 1965; Pashler & Baylis, 1991). Because there is no repetition of responses in a “NoGo” trial, there cannot be a benefit due to a repeated stimulus-response translation. However, attended repetition trials in the “NoGo” condition were answered more slowly than their control trials, although this effect just failed to reach statistical significance. Possibly, the prime target had been inhibited or provided with a non-response information which hampered responding when it was repeated as the probe target.

11 General Discussion

The general discussion starts with a résumé of this work (Chapter 11.1). In the following, the ERP approach to negative priming research, the reported findings and their implications will be discussed (Chapter 11.2). Then, the advancement in theory formation—that is, the development of the prime-response retrieval variant of the episodic retrieval model—will be evaluated (Chapter 11.3). Finally, future perspectives in (auditory) negative priming research emanating from this work will be elaborated (Chapter 11.4).

11.1 Résumé

This paper focused on the mechanisms underlying the negative priming effect, and more specifically, the negative priming effect in the auditory domain. Four models explaining the effect were presented, two of them—the feature mismatch model (Park & Kanwisher, 1994) and the temporal discrimination model (Milliken et al., 1998)—were discarded and shown to be inadequate explanations for identity negative priming. With respect to the two models with clear empirical support—the distractor inhibition model (Houghton & Tipper, 1994; Tipper, 1985) and the episodic retrieval model (Neill & Valdes, 1992; Neill et al., 1992)—available evidence does not clearly favor one model over the other. This has evoked the formation of some reconciliatory accounts incorporating both mechanisms (Kane et al., 1997; May et al., 1995; Tipper, 2001).

Negative priming in the auditory modality has been repeatedly demonstrated (Banks et al., 1995; Buchner & Mayr, 2004, 2005; Buchner & Steffens, 2001; Buchner et al., 2003; Mondor et al., in press; Zabal & Buchner, in press). Given the differenences in the neural organization of vision and audition, differences in the determinants and mechanisms of negative priming between the senses are conceivable. Most of the empirical evidence in the auditory domain was summarized as being parallel to the phenomenon's characteristics in the visual modality. However, the empirical basis is insufficient, so that further investigations are indispensable. Clarification of the underlying mechanism(s) of the auditory negative priming effect was the central concern of the empirical part of this work.

ERPs were introduced as a new methodological approach to investigate the phenomenon of auditory negative priming, particularly because of their favorable temporal resolution characteristics and the vast amount of empirical ERP data in related experimental paradigms. Although this first application of ERPs in auditory negative priming research was of primarily exploratory nature, expectations could be derived from ERP findings about the to-be-expected activation patterns given the phenomenon was of inhibitory or mnemonic nature.

Experiment 1 found, for the first time, an ERP correlate of auditory negative priming. This ERP correlate was characterized by a parietally located negative deflection in the time range between 300 and 600 ms post-stimulus (LPC_e and LPC_l). Topography and time course of the effect resembled correlates of recognition memory (old/new ERP effect and ERP repetition effect, Rugg, 1995), and were in contrast to the frontally located correlates found in experimental tasks that are closely related to inhibitory processes (such as Eimer, 1993; Kopp, Rist et al., 1996; Liotti et al., 2000). In none of the time intervals an ERP component was found that was located frontally and exclusive to the ignored repetition condition. Consequently, the results of this experiment are more consistent with a memory retrieval mechanism of negative priming than with a *frontal* inhibition mechanism.

The subsequent chapters addressed the episodic retrieval mechanism. The original variant of the episodic retrieval model postulates that, during prime processing, the prime distractor becomes associated with the information that it must not be responded to. It was supposed that, on ignored repetition trials, the probe target may cue the retrieval of the prime episode, in which case this non-response information may interfere with the required target response. This original variant was called the non-response retrieval variant of the episodic retrieval model. An alternative possibility was developed and referred to as the prime-response retrieval variant of the episodic retrieval model. This variant assumes that the prime response is retrieved as part of the prime episode in ignored repetition trials. The retrieved prime response is supposed to conflict with the required probe response. A multinomial model was developed that reflected the probe response situation and was suitable to test predictions of the prime-response retrieval variant of the episodic retrieval model.

Experiments 2 and 3 were designed to test a unique prediction of the prime-response retrieval variant. If the prime-response retrieval variant is valid, the probability of erroneous responding with the prime response in the probe task should be larger for ignored repetition than for control trials. This is exactly what was found. This pattern of results was unexpected from the perspective of both the original non-response retrieval variant of the episodic retrieval model and the distractor inhibition account. The fact that evidence of prime-response retrieval was found for the auditory (Experiment 2) as well as the visual modality (Experiment 3) substantiates the similarity of the negative priming mechanisms in both modalities.

Experiment 4 was designed to validate the prime-response retrieval variant of the episodic retrieval model and to assess the importance of this mechanism for the size of the negative priming effect. This experiment was similar to Experiment 2, but additionally manipulated whether prime responding was required or prohibited. It was successfully demonstrated that an increased probability of prime response errors was only observed in ignored repetition trials that included a prime response requirement. In contrast, for trials without a prime response requirement no prime response could be retrieved because no response had been performed in the prime. Therefore, no increase in prime response errors should be expected for ignored repetition trials of this type relative to the control trials. This hypothesis was confirmed by the data. Negative priming effects were smaller when no prime response had been given. Unfortunately, with respect to the reaction time effects, it could not unambiguously be inferred that the reduction in negative priming effects was only due to the lack of the prime-response retrieval mechanism. Confounded factors, such as the reduced extent of encoding the prime could have been responsible for this effect size reduction. However, the negative priming effect was completely abolished for the error data when no prime response had been given. The only plausible explanation for this is that prime-response retrieval is the only mechanism that causes increased errors in ignored repetition trials.

Overall, evidence for an episodic retrieval mechanism has been accrued in the present series of experiments. One component of the mechanism is a prime-response retrieval mechanism. Prime-response retrieval operates in the auditory as well as the visual modality. This mechanism seems to be responsible for negative priming error effects, and—possibly—also influences the size of the reaction time negative priming effect.

11.2 ERP Correlates of Auditory Negative Priming as a New Approach

This study reported, for the first time, an ERP correlate of the auditory negative priming effect in that the ignored repetition condition showed a relatively more negative deflection at parietal sites. The reliability of these ERP findings has been strengthened by a successful replication of Experiment 1 with the same stimulus material and design but with a sample size of $N = 30$ (Mayr et al., 2004). Again, no frontal effects were found, and the LPC component was the only ERP correlate of negative priming. However, the new finding was that reaction time level modulated the negative priming effect: The slower the overall reaction time, the larger the negative priming effect both in terms of reaction times and ERPs (see Figure 11-1).

The absence of a frontal negative priming correlate in the replication study despite increased statistical power[16] strengthens the conclusion that there are no frontal effects due to negative priming, at least none that are detectable via ERPs. The idea that negative priming is associated with an ERP effect similar to those found in tasks with inhibitory components—such as Go/NoGo tasks (e.g. Eimer, 1993; e.g. Falkenstein et al., 1999), Eriksen flanker tasks (e.g. Heil et al., 2000; Kopp, Mattler et al., 1996; Kopp, Rist et al., 1996), and Stroop tasks (e.g. Liotti et al., 2000; Markela-Lerenc et al., 2004; West & Alain, 1999)—is not sustainable.

Given the inconsistency with to an inhibitory account, the finding of a parietally located relative increase in negativity in the ignored repetition condition in Experiment 1 has been interpreted within a memory-based account. One possible interpretation was offered in that the familiarity level of an ignored prime stimulus was reduced. Reduced familiarity, in turn, could entail less fluent processing when the stimulus is repeated (as the probe target). This means that the processing of a previously ignored stimulus would be functionally equivalent to the less fluent processing of a novel stimulus. However, the concept of lower-than-baseline familiarity in the ignored repetition condition is not entirely different from Tipper's (2001) idea expressed in his reconciliatory

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[16] Given $N = 30$, a population correlation of $\rho = .7$ between the individual levels of the trial type variable (ignored repetition, control, and reversed repetition control), and $\alpha = \beta = .10$ (as in Experiment 1), a post-hoc power analysis resulted in a detectable effect size of about $f = 0.195$. This is somewhat smaller than a "medium" effect of $f = 0.25$ following the effect size conventions of Cohen (1988).

account of negative priming, in that he assumes that episodic retrieval can access tags but also inhibitory states. Possibly, the retrieval of an inhibited representation *is* synonymous with one of relative reduction in familiarity.

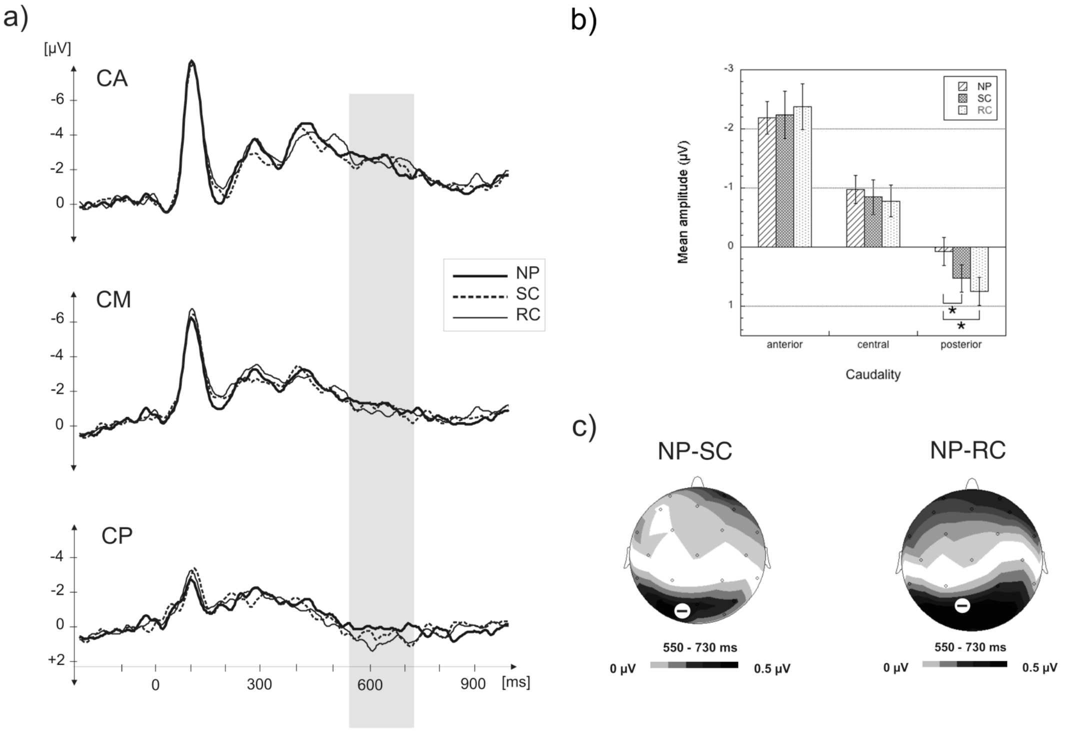

Figure 11-1: ERPs of the slow response (above median) data of the replication study (*N* = 30) (Mayr et al., 2004). a) Grand average ERPs b) mean ERP amplitudes, and c) average-referenced topographic maps. a) The ERP grand averages are separated according to caudality for central anterior (CA), central medial (CM), and central posterior (CP) sites. Condition averages are superimposed for ignored repetition (NP, thick line), control (SC, dashed line), and reversed repetition control (RC, thin line). The grey bars indicate the time window of most interest (550–730 ms post-stimulus). b) Mean ERP amplitudes are separated according to the caudality of the electrode location. Significant amplitude differences between conditions in the aforementioned time window are indexed by asterisks (*$p \leq .05$) for all cases in which the superordinate ANOVA was statistically significant. Error bars depict the standard errors of the means. c) The map illustrates the topographical distribution of the ERP effect associated with negative priming in the aforementioned time window. The left map refers to the spatial distribution of the difference waves between ignored repetition and control, the right map refers to the spatial distribution of the difference waves between ignored repetition and reversed repetition control.

11.3 Prime-Response Retrieval as an Advancement in Theory Formation

The prime-response retrieval variant of the episodic retrieval model was introduced, formulated as a multinomial processing tree model, and tested. This new model variant assumes that the prime response as part of the prime episode is retrieved during probe processing of ignored repetition trials. The retrieved prime response conflicts with the required probe response which is supposed to impede responding. An increased probability of prime-response errors in ignored repetition compared to control trials is uniquely predicted by the prime-response retrieval variant of the episodic retrieval model. This prediction was confirmed in three experiments (Experiments 2, 3, and 4).

However, empirical validation of the prime-response retrieval variant does *not* implicate falsification of the original variant of the episodic retrieval model, the non-response retrieval variant (Neill & Valdes, 1992; Neill et al., 1992). Both variants of the episodic retrieval model are not mutually exclusive. It may well be that prime-response information *and* non-response information are retrieved when the probe target serves as a cue to the prime episode. For instance, it could be argued that the conflict induced by prime-response retrieval shows up primarily in the error rates whereas conflicts due to non-response retrieval may be reflected in the slowing of responding in ignored repetition as opposed to control trials. This interpretation is consistent with the results of Experiment 4 in which the negative priming effect in the error rates vanished completely when the prime-response retrieval mechanism was eliminated (for trials without a prime response). It is currently unclear whether prime-response retrieval and non-response retrieval contribute jointly to the slowed-down and more error-prone responding on ignored repetition trials, or whether prime-response retrieval should be considered the sole memory-based mechanism behind this phenomenon.

The same argument as for the non-response retrieval mechanism of course holds for an inhibitory attentional mechanism: The validity of the prime-response retrieval mechanism does not call into question the additional influence of an inhibitory mechanism, for the operation of which some direct evidence exists (Buchner & Steffens, 2001). The fact that a negative priming effect was existent in trials without a prime-response requirement in Experiment 4 shows that mechanisms other than prime-response retrieval have been at work.

It was inferred from Experiment 4 that prime-response retrieval is the sole mechanism of inducing error effects of negative priming because the effect in error rates completely vanished when the prime-response retrieval mechanism was eliminated (for trials without a prime response). When looking at the error frequencies of Experiment 2 (Table 7-2, p. 78), Experiment 3 (Table 8-1, p. 84), and Experiment 4 ("Go" condition, Table 10-1, p. 99) it is obvious that prime target responses heavily increase when comparing the control to the ignored repetition condition (sixteen fold, two fold, and almost five fold in Experiment 2, 3, and 4, respectively). But the critical observer might object that the frequencies of the other error categories increase as well, albeit on a much smaller scale. Most plausible, the overall increase in errors reflects a spill-over of the general uncertainty about the correct response created by the conflict between the retrieved prime response and the response determined appropriate on the basis of the probe target analysis. Thus, the prime-response retrieval mechanism would also be responsible for the increase of all types of errors in the ignored repetition condition which fits well to the results of Experiment 4.

Interestingly, Rothermund, Wentura, and De Houwer (in press) have recently presented independent evidence of what they refer to as a "stimulus-response retrieval account" of negative priming, which is very similar to the prime-response retrieval variant of the episodic retrieval account discussed here. They report a series of experiments that make use of a task switch paradigm to get around the problem that in standard negative priming tasks, the response must necessarily change between prime and probe. For instance, in their Experiment 1 the color of a word had to be categorized (yellow vs. green) in the prime but the word's grammatical category (adjective vs. noun) had to be categorized in the probe. Response repetition could occur when the correct color response (a left or right key press) was the same as the correct grammatical-category response (also a left or right key press). A response switch could occur when the correct response keys differed between prime and probe. An ignored repetition trial was given when the prime word was repeated as the probe word, whereas prime and probe words differed on control trials. Negative priming was observed in the response-switch condition in which the retrieved prime response would interfere with the required probe response. In contrast, positive priming was observed in the response-repetition condition in which the retrieved prime response would be identical to the required probe response.

The data reported by Rothermund et al. (in press) and those reported here nicely complement each other in showing that probe-cued retrieval of prime responses is indeed a mechanism underlying the negative priming phenomenon. Rothermund et al. (in press) come to the same conclusion as the one made here in that prime-response retrieval is only one mechanism among others that produces negative priming[17]. However, by focusing on the concept of responses, the phenomenon of negative priming gains similarity with its classical counterpart of repetition priming. The similarity in underlying mechanisms of repetition priming and negative priming had already been emphasized by Neill (1997). For repetition priming trials in which reaction times to repeated stimuli are usually reduced, Neill presumed the episodic retrieval of the prime response. In contrast, for ignored repetition trials he assumed the episodic retrieval of the *non*-response information from the prime—in line with his original non-response retrieval variant of the episodic retrieval model. With the new prime-response retrieval variant of the episodic retrieval model, the similarity in underlying mechanisms becomes even more evident. In both situations the probe cues the retrieval of the prime response. The difference between the two situations is, however, that in the repetition priming situation, the retrieved prime response is task-appropriate and therefore facilitates probe responding, whereas in the negative priming situation, the retrieved prime response is task-inappropriate and therefore aggravates probe responding.

Albeit the validity of the prime-response mechanism has been demonstrated using the multinomial model developed for the present experiments, this model can also be used to test a prediction which can be derived from the distractor inhibition account formulated by Houghton and Tipper (1994). Within the framework of their neural network account, Houghton and Tipper (1994) assume that, in ignored repetition probe trials, the suppressed activation of the former prime distractor suffers greater interference from copresent probe distractor objects than the activation of a non-suppressed target on control probe trials. This increased interference from distractors is thought to result in the negative priming effect because the selection of the previously suppressed prime distractor as the new probe target necessitates greater suppression of the new probe distractor which has an initial activation advantage over a previously suppressed stimulus. Probe distractor suppression is more difficult in ignored repetition than in control

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[17] In their General Discussion, Rothermund et al. (in press) mention that negative priming effects found for experimental situations where no prime response was required are among the most critical results for their "stimulus-response retrieval account". Note, that this exactly hits the rationale of Experiment 4 in the present series of Experiments. For "Go" trials with a prime response, prime-response retrieval was implied (and also demonstrated), for "NoGo" trials without a prime response, prime-response retrieval was assumed to be eliminated (which was also demonstrated).

trials and is supposed to slow down responding. The authors do not directly address the negative priming error effect but it seems self-evident that an increased difficulty in probe distractor suppression should also increase the probability of selecting the wrong probe distractor stimulus. Note, that this error type is modeled in the prime-response retrieval model (see Figure 6-1, p. 64) as the probability of committing a probe stimulus confusion error given no correct response had been made. In terms of a multinomial modeling strategy, the hypothesis derived from the model by Houghton and Tipper (1994) would be that the probability of a probe stimulus confusion error should be larger in the ignored repetition than in the control condition, that is, the model with the restriction that $psc_{IR} = psc_{C}$ should not fit the data. Instead, psc_{IR} should be larger than psc_{C}. The data of Experiments 2 and 3 as well as to the data of the "Go" and the "NoGo" condition of Experiment 4 were reanalyzed. For all four cases, psc_{IR} was descriptively *smaller* than psc_{C} eliminating the necessity to perform a formal model test. Thus, the error data collected over three experiments do not provide any evidence for a prediction derived from Houghton and Tipper's (1994) neural network model of selective attention. However, this analysis only demonstrates that distractor inhibition is not reflected in the specific error data. This analysis does *not* provide any evidence against inhibition as an underlying mechanism of negative priming in reaction times.

11.4 Future Perspectives in (Auditory) Negative Priming Research

So far, there is empirical evidence for prime-response retrieval. However, it is not clear at what stage of information processing the mechanism operates. The retrieved prime response might interfere with response selection in that the prime response hampers the selection among response alternatives. This may take time, which would explain a negative priming reaction time effect, but it may also lead to the wrong response selection every so often, which would account for the error effect of negative priming. Another possibility is conceivable: Retrieved prime responses might always be selected first and transferred to response preparation. Motor response preparation might take place up to overt execution of the wrong response in some of the cases which would explain the error effect. But in most of the trials, the task-inappropriateness of the selected response alternative would be detected *before* the overt response had been carried out. As a consequence, response preparation would have to be cancelled, corrected, and re-programmed with the correct response alternative. This would take time, which explains the reaction time negative priming effect.

Although the differences between these two modes of functioning are subtle, there is a possibility of differentiating between them by help of electrophysiological measures. The deployment of lateralized readiness potentials (LRPs) seems to be a suitable methodology. Before the strategy to test between the two modes of functioning can be explained, the rationale of LRPs has to be illustrated first.

LRPs are supposed to be indicators of motor response preparation generated in motor areas (Coles et al., 1995). Like ERPs they are based on EEG measurement at the scalp. But for LRPs, only electric activity over the motor cortex is of relevance (i.e. C4′ over the right motor cortex and C3′ over the left motor cortex). Activity at these positions is measured time-locked to the onset of the overt response (e.g., a button press). Typical for motor preparation is an asymmetric topography: Electric activity is stronger over the motor cortex on the side contralateral to the (hand) movement. For example, a preparation of the right hand movement is accompanied by a stronger negative activation over left motor cortex than over right motor cortex. The negative activation increases up to the point of response execution. LRPs are computed as follows

Equation (12):

$$LRP = \left[Mean\left(C4' - C3'\right)_{left-hand\ movement} + Mean\left(C3' - C4'\right)_{right-hand\ movement} \right] / 2.$$

As can be seen from Equation 12, the LRP expresses the mean activation difference between the contralateral and the ipsilateral (relative to movement side) motor cortex. A response preparation that is correct from the beginning is reflected in a monotonically rising negative LRP. However, if initially the wrong response hand had been prepared and this preparation has to be cancelled before execution and re-preparation has to be initiated for the other hand, this can be seen in a temporary positivity in the LRP (for an example, see Heil et al., 2000). This positivity reflects the transient preparation of the wrong response hand devoid any overt sign of movement with this hand.

The reflection of the wrong response preparation is a property of the LRP that can be exploited to test whether response slowing in ignored repetition trials is indeed the result of retrieving and preparing the inappropriate prime response. Imagine a negative priming task as in Experiment 1 with two response categories (such as animal and music instrument) that are assigned to the left and right index finger button. Imagine further, that there is always a response category change (from animal to music instrument or vice versa) between prime and probe for the critical ignored repetition and their control trials. This implies that the prime response would always be the incorrect response in the probe.

If response slowing in ignored repetition trials is indeed the result of retrieving and preparing the inappropriate prime response, the transient LRP positivity reflecting preparation of the wrong response hand should be found in ignored repetition trials. In contrast to this, there should be no transient LRP positivity for the control trials because no prime response will be retrieved, and, consequently, no prime response will be prepared.

A wrong response hand preparation in ignored repetition but not in control trials would confirm that prime-response retrieval affects processing up to the late stage of response preparation. Note that this would also implicate that the prime-response retrieval mechanism is a mechanism that affects not only errors rates (as has been shown in Experiment 4) but also reaction times in correct trials because only correct trials can be analysed via LRPs and because a re-preparation automatically takes additional time. If no indication of wrong response hand preparation in correct response trials can be found, this favors interpretation of prime-response retrieval taking place at an earlier stage in information processing, as is the response selection stage. The above testing strategy would clarify at what level of information processing in the probe the retrieved prime response interferes.

Another aspect is the question of whether the prime response retrieval mechanism depends on the motor execution of the prime response. Possibly, the retrieval of the actually executed motor program of the prime response is crucial for initiating interference with task-appropriate probe processing. Alternatively, the interference effect due to prime response retrieval operates not on the procedural motor program of a response but on an abstract response information. As an example, imagine the typical prime situation of Experiment 2 or 4, where participants heard the prime target sound of a frog and were to respond by pressing the upper button with their right middle finger. In this case, an abstract response information would be “respond with frog” whereas the procedural response information is the whole motor program that activates and moves the right middle finger to press the upper button. In Experiment 4, participants were informed *before* the presentation of the prime display whether they should respond (“Go”) or not (“NoGo”). It is very likely that participants in “NoGo” trials did not select and prepare any prime response because they knew in advance that this was unnecessary. Therefore, neither an abstract nor a procedural prime response information should exist as part of the prime episode. An experimental setup to differentiate between the two possibilities would be similar to the setup of Experiment 4. But instead of telling participants before the prime presentation whether they would have to respond or not, they could be informed just *after* they had been exposed to the prime display but *before* an overt response execution. These “NoGo” trials could be mixed with “Go” trials in which a prime response would have to be executed. For the “Go” trials, both an abstract as well as a procedural prime response information should exist. For the “NoGo” trials, only an abstract prime response can be generated because its overt execution will be prevented. For this experiment, the same multinomial testing strategy that was used in Experiment 2, 3, and 4 may be applied. If the prime-response retrieval mechanism depends on the existence of the procedural memory of the prime response, one would expect that prime response retrieval errors should only be increased for the ignored repetition trials relative to the control trials in the “Go” condition. In contrast, if prime-response retrieval can work on abstract response information, prime response retrieval errors should be increased for the ignored repetition trials in the “Go” as well as in the “NoGo” condition.

Throughout this paper, the issue of similarity in negative priming mechanisms between the visual and auditory modality has been repeatedly addressed. So far, there is little empirical evidence for assuming that auditory and visual negative priming function entirely differently (but see Mondor et al., in press). The data reported here supported the similarity assumption in that evidence for a prime-response retrieval mechanism was provided in both the visual and auditory modality. However, the mechanism seemed stronger in the auditory than in the visual domain. Whether this was due to differences in experimental variables such as task difficulty between Experiment 2 and 3 or whether the prime-response retrieval mechanism is generally stronger in the auditory domain cannot be judged from the restricted amount of evidence reported here. To this end, prime-response retrieval analyses using the multinomial modeling approach should be undertaken for a row of auditory and visual negative priming experiments with varying experimental variables such as task difficulty, stimulus material, and timing.

A further possibility of comparing the nature of negative priming mechanisms in the two modalities consists of analyzing ERPs across modalities. A transfer of the auditory negative priming paradigm of Experiment 1 into the visual domain appears promising. If the auditory negative priming ERP correlate represented a modality-independent central processing stage, then a similar pattern of data should be observed in the auditory and in the visual domain. In contrast, differential ERP effects would be expected if ERP correlates of negative priming reflected modality-specific processes.

In sum, the work presented in this paper opens up numerous links to future research. What appears particularly appealing in the outlined research program is the broad variety of tools—classical reaction time studies, ERPs, LRPs, and multinomial modeling—that is now available for unfolding the characteristics and underlying mechanisms of the negative priming phenomenon. The author beliefs that—in the long run—a multimethod approach yields a greater understanding for the phenomenon of interest.

12 References

Banks, W. P., Roberts, D., & Ciranni, M. (1995). Negative priming in auditory attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 1354-1361.

Batchelder, W. H., & Riefer, D. M. (1990). Multinomial processing models of source monitoring. *Psychological Review, 97*, 548-564.

Bertelson, P. (1965). Serial choice reaction-time as a function of response versus signal-and-response repetition. *Nature, 206*, 217-218.

Broadbent, D. E. (1958). *Perception and communication*. Elmsford, NY, US: Pergamon Press Inc.

Buchner, A., Erdfelder, E., & Vaterrodt-Plünnecke, B. (1995). Toward unbiased measurement of conscious and unconscious memory processes within the process dissociation framework. *Journal of Experimental Psychology: General, 124*, 137-160.

Buchner, A., & Mayr, S. (2004). Auditory negative priming in younger and older adults. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 57A*, 769-787.

Buchner, A., & Mayr, S. (2005). Evidence for episodic retrieval in auditory negative priming. *Manuscript submitted for publication*.

Buchner, A., & Steffens, M. C. (2001). Auditory negative priming in speeded reactions and temporal order judgements. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 54A*, 1125-1142.

Buchner, A., Zabal, A., & Mayr, S. (2003). Auditory, visual, and cross-modal negative priming. *Psychonomic Bulletin & Review, 10*, 917–923.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*, 215-222.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Coles, M. G., & Rugg, M. D. (1995). Event-related brain potentials: an introduction. In M. D. Rugg & M. G. Coles (Eds.), *Electrophysiology of mind: Event related brain potentials and cognition* (pp. 1-26). London: Oxford University Press.

Coles, M. G., Smid, H. G., Scheffers, M. K., & Otten, L. J. (1995). Mental chronometry and the study of human information processing. In M. D. Rugg & M. G. Coles (Eds.), *Electrophysiology of mind: Event related brain potentials and cognition* (pp. 86-131). London: Oxford University Press.

Curran, T., & Cleary, A. M. (2003). Using ERPs to dissociate recollection from familiarity in picture recognition. *Cognitive Brain Research*, *15*, 191-205.

Curran, T., & Dien, J. (2003). Differentiating amodal familiarity from modality-specific memory processes: An ERP study. *Psychophysiology*, *40*, 979-988.

Dalrymple-Alford, E. C., & Budayr, B. (1966). Examination Of Some Aspects Of The Stroop Color-Word Test. *Perceptual and Motor Skills*, *23*, 1211-1214.

Eimer, M. (1993). Effects of attention and stimulus probability on ERPs in a Go/Nogo task. *Biological Psychology*, *35*, 123-38.

Erdfelder, E. (2000). *Multinomiale Modelle in der kognitiven Psychologie* (Habilitationsschrift). Bonn: Philosophische Fakultät der Rheinischen Friedrich-Wilhelms-Universität in Bonn.

Erdfelder, E., & Buchner, A. (1998). Decomposing the hindsight bias: A multinomial processing tree model for separating recollection and reconstruction in hindsight. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 387-414.

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments and Computers*, *28*, 1-11.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica*, *101*, 267-91.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2002). Inhibition-related ERP components: Variation with modality, age, and time-on-task. *Journal of Psychophysiology*, *16*, 167-175.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin and Review*, *2*, 145-173.

Fox, E., & de Fockert, J. W. (1998). Negative priming depends on prime-probe similarity: Evidence for episodic retrieval. *Psychonomic Bulletin and Review*, *5*, 107-113.

Frings, C. (2005). *Verstärkte Reaktionszeitvorteile von Distraktor-zu-Distraktor-Wiederholung im Negativen Priming - Klare Gegenevidenz zur Temporal Discrimination Theory*. Paper presented at the TeaP - 47. Tagung experimentell arbeitender Psychologen, Universität Regensburg.

Fuster, J. M. (1997). *The prefrontal cortex. Anatomy, physiology, and neuropsychology of the frontal lobe* (3rd ed.). Philadelphia, PA: Lippincott-Raven.

Gamboz, N., Russo, R., & Fox, E. (2002). Age differences and the identity negative priming effect: An updated meta-analysis. *Psychology and Aging*, *17*, 525-530.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 163-169.

Haxby, J. V., Courtney, S. M., & Clark, V. P. (1998). Functional magnetic resonance imaging and the study of attention. In R. Parasuraman (Ed.) *The attentive brain* (pp. 123-142). Cambridge, MA, US: The MIT Press.

Healy, D., & Burt, J. S. (2003). Attending to the distractor and old/new discriminations in negative priming. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 56A*, 421-443.

Heil, M., Osman, A., Wiegelmann, J., Rolke, B., & Hennighausen, E. (2000). N200 in the Eriksen-task: Inhibitory executive process? *Journal of Psychophysiology, 14*, 218-225.

Hintzman, D. L. (1988). Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychological Review, 95*, 528-551.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics, 6*, 65-70.

Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory mechanisms of attention, memory, and language* (pp. 53-112). San Diego, CA: Academic Press.

Houghton, G., & Tipper, S. P. (1998). A model of selective attention as a mechanism of cognitive control. In J. Grainger & A. M. Jacobs (Eds.), *Localist connectionist approaches to human cognition. Scientific psychology series* (pp. 39-74). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Houghton, G., Tipper, S. P., Weaver, B., & Shore, D. I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition, 3*, 119-164.

Hu, X., & Batchelder, W. H. (1994). The statistical analysis of engineering processing tree models with the EM algorithm. *Psychometrika, 59*, 21-47.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a Go/No-go task. *Electroencephalography and Clinical Neurophysiology, 82*, 477-482.

Johnston, W. A., Dark, V. J., & Jacoby, L. L. (1985). Perceptual fluency and recognition judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*, 3-11.

Kane, M. J., Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Connelly, L. S. (1994). Inhibitory attentional mechanisms and aging. *Psychology and Aging, 9*, 103-112.

Kane, M. J., May, C. P., Hasher, L., Rahhal, T., & Stoltzfus, E. R. (1997). Dual mechanisms of negative priming. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 632-50.

Kopp, B., Mattler, U., Goertz, R., & Rist, F. (1996). N2, P3 and the lateralized readiness potential in a nogo task involving selective response priming. *Electroencephalography and Clinical Neurophysiology*, *99*, 19-27.

Kopp, B., Rist, F., & Mattler, U. (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology*, *33*, 282-294.

Leimkuhler, M. E., & Mesulam, M. M. (1985). Reversible go-no go deficits in a case of frontal lobe tumor. *Annals of Neurology, 18*, 617-9.

Liotti, M., Woldorff, M. G., Perez, R., III, & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*, 701-711.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*, 492-527.

Lowe, D. G. (1979). Strategies, context, and the mechanism of response inhibition. *Memory and Cognition*, *7*, 382-389.

Marcel, T. (1980). Conscious and preconscious recognition of polysemous words: Locating the selective effects of prior verbal context. In R. Nickerson, S. (Ed.) *Attention and performance VIII* (pp. 259-276). Hillsdale, NJ.

Markela-Lerenc, J., Ille, N., Kaiser, S., Fiedler, P., Mundt, C., & Weisbrod, M. (2004). Prefrontal-cingulate activation during executive control: Which comes first? *Cognitive Brain Research*, *18*, 278-287.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin*, *118*, 35-54.

Mayr, S., Niedeggen, M., Buchner, A., & Orgs, G. (2004). The level of reaction time determines the ERP correlates of auditory negative priming. *Manuscript submitted for publication*.

Mayr, S., Niedeggen, M., Buchner, A., & Pietrowsky, R. (2003). ERP correlates of auditory negative priming. *Cognition*, *90*, 11-21.

Metzler, C., & Parkin, A. J. (2000). Reversed negative priming following frontal lobe lesions. *Neuropsychologia*, *38*, 363-379.

Milliken, B., Joordens, S., Merikle, P. M., & Seiffert, A. E. (1998). Selective attention: A reevaluation of the implications of negative priming. *Psychological Review*, *105*, 203-229.

Mondor, T. A., Breau, L. M., & Milliken, B. (1998). Inhibitory processes in auditory selective attention: Evidence of location-based and frequency-based inhibition of return. *Perception and Psychophysics*, *60*, 296-302.

Mondor, T. A., Leboe, J. P., & Leboe, L. C. (in press). The role of selection in generating auditory negative priming. *Psychological Bulletin*.

Moore, C. M. (1994). Negative priming depends on probe-trial conflict: Where has all the inhibition gone? *Perception and Psychophysics*, *56*, 133-147.

Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, *229*, 782-784.

Myers, J. L., & Well, A. D. (1995). *Research design and statistical analysis*. Mahwah, N.J.: Erlbaum.

Münte, T., Urbach, T. P., Duüzel, E., & Kutas, M. (2000). Event-related brain potentials in the study of human cognition and neuropsychology. In F. Boller, J. Grafman, & G. Rizzolatti (Eds.), *Handbook of neuropsychology* (2nd ed.) (pp. 139-235). Amsterdam: Elsevier.

Neill, W. T. (1977). Inhibitory and facilitatory processes in selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *3*, 444-450.

Neill, W. T. (1978). Decision processes in selective attention: Response priming in the Stroop Color-Word task. *Perception and Psychophysics*, *23*, 80-84.

Neill, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 1291-3105.

Neill, W. T., & Valdes, L. A. (1992). Persistence of negative priming: Steady state or decay? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 565-576.

Neill, W. T., & Valdes, L. A. (1996). Facilitatory and inhibitory aspects of attention. In A. F. Kramer (Ed.) *Converging operations in the study of visual selective attention* (pp. 77-106). Washington, DC, US: American Psychological Association.

Neill, W. T., Valdes, L. A., & Terry, K. M. (1995). Selective attention and the inhibitory control of cognition. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 207-261). San Diego, CA: Academic Press.

Neill, W. T., Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 993-1000.

Neill, W. T., & Westberry, R. L. (1987). Selective attention and the suppression of cognitive noise. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 327-334.

Nelson, H. E. (1976). A modified card sorting test sensitive to frontal lobe defects. *Cortex*, *12*, 313-324.

Neumann, E., & DeSchepper, B. G. (1991). Costs and benefits of target activation and distractor inhibition in selective attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 1136-1145.

Näätänen, R., & Picton, T. W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, *24*, 375-425.

Näätänen, R., Sams, M., Alho, K., & Paavilainen, P. (1988). Frequency and location specificity of the human vertex N1 wave. *Electroencephalography and Clinical Neurophysiology*, *69*, 523-531.

Park, J., & Kanwisher, N. (1994). Negative priming for spatial locations: Identity mismatching, not distractor inhibition. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 613-623.

Pashler, H. E. (Ed.) (1998a). *Attention*. Hove, England: Psychology Press.

Pashler, H. E. (1998b). *The psychology of attention*. Cambridge, MA, US: The MIT Press.

Pashler, H. E., & Baylis, G. C. (1991). Procedural learning: II. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 33-48.

Perret, E. (1974). The left frontal lobe of man and the suppression of habitual responses in verbal categorical behaviour. *Neuropsychologia*, *12*, 323-330.

Pfefferbaum, A., Ford, J. M., Weller, B. J., & Kopell, B. S. (1985). ERPs to response production and inhibition. *Electroencephalography and Clinical Neurophysiology*, *60*, 423-434.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3-25.

Riefer, D. M., & Batchelder, W. H. (1988). Multinomial modeling and the measurement of cognitive processes. *Psychological Review*, *95*, 318-339.

Rothermund, K., Wentura, D., & De Houwer, J. (in press). Retrieval of incidental stimulus-response associations as a source of negative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

Rothkegel, R. (1999). AppleTree: A multinomial processing tree modeling program for Macintosh computers. *Behavior Research Methods, Instruments and Computers*, *31*, 696-700.

Rugg, M. D. (1987). Lexical contribution to nonword-repetition effects: Evidence from event-related potentials. *Memory and Cognition*, *15*, 473-481.

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. *Memory and Cognition*, *18*, 367-379.

Rugg, M. D. (1995). ERP studies of memory. In M. D. Rugg & M. G. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 132-170). Oxford: Oxford University Press.

Rugg, M. D., & Allan, K. (2000). Memory retrieval: an electrophysiological perspective. In M. S. Gazzaniga (Ed.) *The new cognitive neurosciences*. Cambridge, MA: The MIT Press.

Rugg, M. D., & Coles, M. G. (Eds.). (1995a). *Electrophysiology of mind: Event-related brain potentials and cognition*. Oxford: Oxford University Press.

Rugg, M. D., & Coles, M. G. (1995b). The ERP and cognitive psychology: conceptual issues. In M. D. Rugg & M. G. Coles (Eds.), *Electrophysiology of mind: Event related brain potentials and cognition* (pp. 27-39). London: Oxford University Press.

Rugg, M. D., & Doyle, M. C. (1992). Event-related potentials and recognition memory for low- and high-frequency words. *Journal of Cognitive Neuroscience*, *4*, 69-79.

Rugg, M. D., & Doyle, M. C. (1994). Event-related potentials and stimulus repetition in direct and indirect tests of memory. In H. J. Heinze, T. F. Muente, & G. R. Mangun (Eds.), *Cognitive Electrophysiology* (pp. 124-148). Boston, MA: Birkhaeuser.

Rugg, M. D., Doyle, M. C., & Melan, C. (1993). An event-related potential study of the effects of within- and across-modality word repetition. *Language and Cognitive Processes*, *8*, 357-377.

Scharf, B. (1998). Auditory attention: The psychoacoustical approach. In H. Pashler (Ed.) *Attention* (pp. 75-117). Hove, England: Psychology Press.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General*, *117*, 34-50.

Spence, C. J., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 555-574.

Spence, C. J., & Driver, J. (1997). Audiovisual links in exogenous covert spatial orienting. *Perception and Psychophysics*, *59*, 1-22.

Steel, C., Haworth, E. J., Peters, E., Hemsley, D. R., Sharma, T., Gray, J. A., Pickering, A., Gregory, L., Simmons, A., Bullmore, E. T., & Williams, S. C. R. (2001). Neuroimaging correlates of negative priming. *Neuroreport*, *12*, 3619-3624.

Stolz, J. A., & Neely, J. H. (2001). Taking a bright view of negative priming in the light of dim stimuli: Further evidence for memory confusion during episodic retrieval. *Canadian Journal of Experimental Psychology*, *55*, 219-230.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643-662.

Stuss, D. T., Toth, J. P., Franchi, D., Alexander, M. P., Tipper, S., & Craik, F. I. M. (1999). Dissociation of attentional processes in patients with focal frontal and posterior lesions. *Neuropsychologia*, *37*, 1005-1027.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 37A*, 571-590.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 54A*, 321-343.

Tipper, S. P., Brehaut, J. C., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 492-504.

Tipper, S. P., & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 37A*, 591-611.

Tipper, S. P., & Driver, J. (1988). Negative priming between pictures and words in a selective attention task: Evidence for semantic processing of ignored stimuli. *Memory and Cognition, 16*, 64-70.

Tipper, S. P., Weaver, B., Cameron, S., Brehaut, J. C., & Bastedo, J. (1991). Inhibitory mechanisms of attention in identification and localization tasks: time course and disruption. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 681-92.

Tulving, E. (1983). *Elements of episodic memory*. Oxford: Oxford University Press.

West, R., & Alain, C. (1999). Event-related neural activity associated with the Stroop task. *Cognitive Brain Research, 8*, 157-164.

West, R., & Alain, C. (2000). Effects of task context and fluctuations of attention on neural activity supporting performance of the Stroop task. *Brain Research, 873*, 102-111.

Wilding, E. L., Doyle, M. C., & Rugg, M. D. (1995). Recognition memory with and without retrieval of context: An event-related potential study. *Neuropsychologia, 33*, 743-767.

Zabal, A., & Buchner, A. (in press). Normal auditory negative priming in schizophrenic patients. *Quarterly Journal of Experimental Psychology*.

Hiermit erkläre ich, dass ich die hier vorgelegte Dissertation eigenständig und ohne unerlaubte Hilfe angefertigt habe. Die Dissertation wurde in der vorgelegten oder in ähnlicher Form noch keiner anderen Institution eingereicht. Ebenso versichere ich, dass bisher keine erfolglosen Promotionsversuche meinerseits stattgefunden haben.

Düsseldorf, den 03.06.2005

(Susanne Mayr)