

Negative Priming as a Memory Phenomenon

A Review of 20 Years of Negative Priming Research

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Abstract. Reactions to recently ignored stimuli are slowed down or more error prone when compared to reactions to control stimuli. This so-called negative priming effect has been traditionally investigated in the area of selective attention. More recent theory developments conceptualize the negative priming effect as a memory phenomenon. This review presents four models to explain the phenomenon as well as their essential empirical evidence. The review also considers several negative priming characteristics – that is stimulus modality, prime selection and prime response requirement, probe interference, stimulus repetition, aging and thought disorders, and physiological correlates. On these bases, it is concluded that only the distractor inhibition and the episodic retrieval models have survived empirical testing so far. Whereas evidence has increased that negative priming clearly obeys memory retrieval principles, the distractor inhibition model has lost much of its persuasiveness within recent years.

Keywords: selective attention, negative priming, episodic retrieval model, distractor inhibition model

The negative priming effect manifests itself in slowed-down and/or more error-prone reactions to a stimulus that had to be ignored previously (see Figure 1 for an example). Traditionally, this phenomenon has been investigated in the area of selective attention research. The original (and still popular) explanation of this phenomenon has been the distractor inhibition model (Tipper, 1985, 2001; Tipper & Cranston, 1985) according to which distractors are actively inhibited, thereby facilitating the selection of the target. When a previous distractor becomes the subsequent target responding is hampered due to the residual inhibition.

Given this, a review on negative priming may seem unexpected in a volume on memory research. However, theory development within the past 15 years brought up alternative models that conceptualize negative priming as a memory phenomenon, as will be explicated below. We will see that even the distractor inhibition mechanism is now seen within an integrative account comprising selection and memory processes. Conceiving negative priming as a memory phenomenon is plausible given that the negative priming paradigm has an innate temporal dimension. If something that happened in the past, such as the processing of a prime distractor, influences the later processing of the probe target, some form of memory must be involved.

This article has two parts. First, theories of the negative priming phenomenon shall be summarized briefly. Second, we review those areas of negative priming research in which extensive research within the past few years suggests conclusions that differ from those reached in earlier reviews (Fox, 1995; May, Kane, & Hasher, 1995; Tipper, 2001).

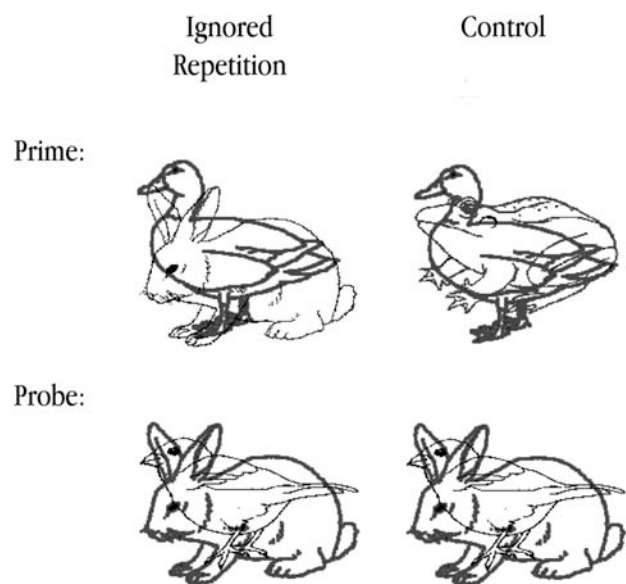


Figure 1. Example of a prime and a probe display for an ignored repetition (left) and a parallel control trial (right). The task is to name the animal printed in gray bold face. Usually participants respond more slowly and/or more error-prone to the rabbit in the probe when it had been the animal to be ignored in the prime (ignored repetition) than when it had not been presented in the previous trial (control). The negative priming effect is defined as the reaction time difference between the probe response in ignored repetition and control trials (pictures taken from Snodgrass & Vanderwart, 1980).

Theories of Negative Priming

Four main theoretical approaches have been proposed to explain the negative priming phenomenon. The distractor inhibition model (Tipper, 1985) has been modified since its first version (Houghton & Tipper, 1994; Tipper, 2001; Tipper & Cranston, 1985). Episodic retrieval (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) has been presented as the main antagonist of the inhibition view although more recent publications were aimed at integrating the two models (May, Kane, & Hasher, 1995; Tipper, 2001). The feature mismatch hypothesis (Park & Kanwisher, 1994) has been mainly discussed as an explanation of negative priming for tasks in which participants have to respond to a stimulus location and not to a stimulus identity. The temporal discrimination model (Milliken, Joordens, Merikle, & Seiffert, 1998) constitutes the most recent theoretical proposal.

Distractor Inhibition Model

Negative priming was originally interpreted as a mandatory aftereffect of a selection process. Tipper (1985) assumed that within the preattentive processes of scene analysis, meaningful and well-learned objects are categorically represented, and representations of to-be-ignored objects are inhibited as part of the process of target selection. When such a representation becomes task relevant in the following probe, access to the inhibited representation is hampered, which slows down responding. Tipper and Cranston (1985) modified this initial version by assuming that the process translating the distractor representation into a response code is inhibited rather than the distractor representation per se.

Further progress in theory development has been achieved by Houghton and Tipper's neural network model of the dynamics of selective attention (1994; 1998; Houghton, Tipper, Weaver, & Shore, 1996). Active inhibition of distracting information is seen as a central mechanism in the selection process that coordinates the interaction between parallel perceptual processes and goal-directed serial behavior. Preattentively activated object features are bound together forming unified representations that are 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. An internal template specifies the momentary target stimulus features. For goal-directed behavior, the externally activated object representations matching the internal target specification have to be selected. This is done by a self-regulatory feedback system with self-excitatory feedback loops for target properties and self-inhibitory feedback loops for nontarget properties. As a consequence, the activation of ignored (distractor) stimuli is reduced relative to an attended (target) stimulus. The activation difference between target and distractor represen-

tations facilitates the binding of the target object's parameters into the current action scheme.

The reduced activation of distractor representations does not fall below resting level as long as there is bottom-up excitation during the permanent external input. 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 the resting level. The post-offset inhibitory rebound causes the negative priming effect. If the distractor is again presented as a target while the internal representation is still suppressed (as in the probe of an ignored repetition trial), re-establishment of the target representation takes more time before it can dominate the new probe distractor representation that has an initial activation advantage. Consequently, reactions to the target are slowed down in an ignored repetition trial.

Episodic Retrieval Model

Logan's instance theory of automatization (Logan, 1988) 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. Each episode contains information about the stimulus as well as the given response. Performance in a task can be accomplished either by analytically computing a response or by directly retrieving the response from previous encounters with the same stimulus from memory. The faster of the two routes determines responding.

Against this theoretical backdrop Neill and Valdes (1992) argued that negative priming is the result of retrieving the prime episode when exposed to the probe stimulus. A probe target that is similar or identical to the prime distractor serves as retrieval cue to the prime episode. Part of the retrieved episode is the do-not-respond information tied to the prime distractor. This response information conflicts with the requirement to respond to this stimulus in the probe episode. Resolving this conflict is time consuming, hence the negative priming effect.

The successful retrieval of the prime episode is a necessary precondition for the effect to occur. Negative priming should thus depend on factors influencing the probability of successful episodic retrieval. The more probable episodic retrieval, the larger should be 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). These studies were originally intended to determine how long the negative priming effect persists over time. The experimental results were very heterogeneous. Neill and Westberry (1987) and Neill and Valdes (1992) found decreases of negative priming with increasing prime-probe RSI, but studies by Tipper, Weaver, Cameron, Brehaut, and Bastedo (1991) and by Hasher, Stoltzfus, Zacks, and Rypma (1991) revealed

no influence of the prime-probe RSI on the size of the negative priming effect. These empirical inconsistencies could not be explained by RSI differences. 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. Whenever 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 a comparison of two experiments (Hasher et al., 1991). A RSI manipulation between subjects or even between experiments implies that the RSI is of fixed length throughout the whole experiment.

Neill and Valdes (1992) argued that the retrieval probability of the recent episode does not depend on the prime-probe RSI per se 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 implies 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 preced-

ing episode (for an illustration, see case (a) in Figure 2). Successful retrieval of the task-inappropriate prime episode, in turn, is a necessary precondition for the negative priming effect to occur. 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 $n-2$ is short, the prime display $n-1$ should be poorly discriminable from the episode before (see case (b) in Figure 2). Retrieval probability would, in turn, be reduced.

Neill, Valdes, Terry, and Gorfein (1992) indeed found that negative priming was largest when the ratio of preprime-prime RSI/prime-probe RSI was 4000/500 ms, and smallest for a ratio 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. For between-subject 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, respectively) regardless of the size of the prime-probe RSI. 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 result. Negative priming should depend only on the RSI between prime and probe¹.

Further evidence in support of the episodic retrieval model comes from studies in which the contextual similarity be-

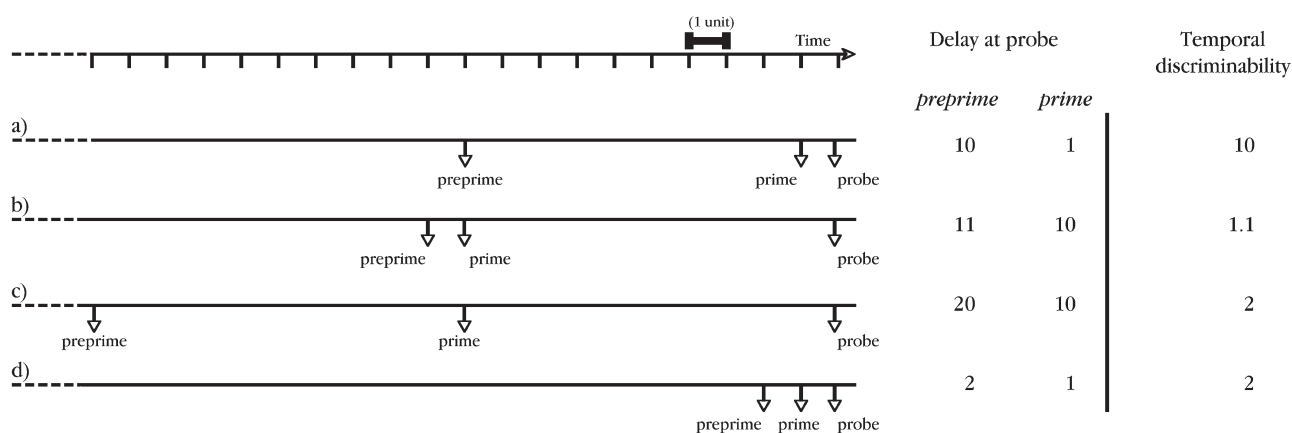


Figure 2. Depicted are the preprime-prime and prime-probe RSI on a time bar. Cases (a) to (d) demonstrate all four possible combinations of long and short intervals. To make the idea of temporal discriminability clear, RSI is varied as either a 1-time-unit interval or a 10-time-unit interval. The temporal 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.

¹ Note that, within an inhibition account, one could perhaps add the assumption that inhibition is of limited capacity and needs a refractory delay to recover. Given this, inhibition after a short preprime-prime interval could be less efficient than after a long preprime-prime interval. Note, however, that this supplementary assumption is incompatible with available data and thus cannot be used to explain variations in negative priming as a function of the preprime-prime interval. First, negative priming is just as large after a long preprime-prime plus a long prime-probe interval as it is after a short preprime-prime plus a short prime-probe interval (Experiment 1B, Mayr & Buchner, 2006). Second, prime reactions after short preprime-prime intervals should be slower and more error-prone than after long preprime-prime intervals, but this is not the case (Experiment 1A and 1B, Mayr & Buchner, 2006).

tween the prime and probe displays was varied (Fox & de Fockert, 1998; Neill, 1997; Stolz & Neely, 2001), and the size of the negative priming effect increased as a function of the prime-probe contextual similarity. For instance, Fox and de Fockert (1998) varied the intensities of letters adjacent to a target in a letter identification task. In ignored repetition trials, an adjacent prime distractor letter became the probe target. Intensities of the adjacent letters could be either bright or dim, equivalent for prime and probe (bright-bright or dim-dim) or not (bright-dim or dim-bright). Negative priming was larger when intensities matched between prime and probe, regardless of whether they were bright or dim.

The original episodic retrieval theory (Neill & Valdes, 1992) assumes that the retrieved prime distractor is associated with some form of nonresponse information. Alternatively, the response associated with the prime target could be retrieved in ignored repetition trials. When retrieved, this response would be inappropriate and lead to a conflict when responding to the probe target (Mayr & Buchner, 2006; Rothermund, Wentura, & De Houwer, 2005). In standard negative priming tasks in which participants need to name or identify (features of) the targets, the probe response is different from the prime response. 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.

The prime-response variant of the episodic retrieval theory allows deriving a unique prediction about the relative frequencies of the different probe error types. Simply put, if the prime-response variant has any validity, then incorrect repetitions of the prime response as a reaction to the probe target should be overrepresented in the error rates of ignored repetition trials compared to control trials. Mayr and Buchner (2006) tested this prediction with a four-alternative identification task in which every stimulus required a unique response. The prime-response variant was confirmed for both the visual and the auditory domain in that participants responded more often with the former prime response to ignored repetition probes compared to control probes.

Feature Mismatch Hypothesis

Park and Kanwisher (1994) proposed that the negative priming effect was the result of interference due to a feature mismatch between prime and probe displays. 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, participants identify, by a speeded keypress, which of four pre-defined positions is occupied by a target symbol (e.g., O). One other position is occupied by a distractor symbol (e.g., +; see Figure 3 for an illustration). In ignored repetition trials the probe target appears at the same location as the prime distractor. Response times are typically slower for ignored repetition than for control trials in which the probe target appears in a previously unoccupied location. Tipper,

	Ignored Repetition		Control	
Prime:	<u>O</u>	–	<u>O</u>	–
	–	±	±	–
Probe:	–	±	–	±
	–	<u>O</u>	–	<u>O</u>

Figure 3. 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.”

Brehaut, and Driver (1990) interpreted the effect as the result of an inhibition in the selection and execution of a response to the prime target’s spatial location. Park and Kanwisher (1994) suggested instead that negative priming occurred as the result of a prime-to-probe mismatch in the binding of the symbol identity to the location.

The feature mismatch model may provide a viable explanation of the emergence of location negative priming, but it is not an adequate explanation of negative priming when the selection is based on identity. For instance, Tipper and Cranston (1985, Experiment 4) changed the target selection criterion between prime and probe (naming the red letter in the prime, naming the green letter in the probe), thus avoiding a color-to-identity mismatch (as the analog to an identity-to-location mismatch in a spatial localization task) between prime and probe. Nevertheless, negative priming was found which is inconsistent with the feature mismatch model. Many other experiments have since confirmed this result (Buchner & Mayr, 2004; Buchner & Steffens, 2001; Buchner, Steffens, & Berry, 2000; Buchner, Zabal, & Mayr, 2003; Mayr & Buchner, 2006; Mayr, Niedeggen, Buchner, & Orgs, 2006; Mayr, Niedeggen, Buchner, & Pietrowsky, 2003).

Temporal Discrimination Model

The temporal discrimination model proposed by Milliken et al. (1998) is based on the assumption that negative priming is caused at the moment of response formation during the probe. If the probe target is categorized as new, a moderately fast response is generated on the basis of perceptual analysis, as in the episodic retrieval model. This is the case for control trials with probe targets unrelated to the prime stimuli. When the prime target is repeated as the probe target it is quickly categorized as old, leading to a response that is very fast because it can simply be retrieved from

memory. A probe target in an ignored repetition trial is ambiguous in that respect. It is familiar due to its appearance in the prime. This prevents a quick categorization as new. It is, however, insufficiently familiar to be categorized as old. Resolving this ambiguity takes time, which slows down reactions in ignored repetition trials.

Support for the model according to Milliken et al. (1998) comes from experiments in which brief single masked prime words were presented, followed by two interleaved probe words, one of which had to be named. Significant negative priming was found, that is, a relative slow-down when the prime was repeated as the probe target compared to trials where the prime stimulus was different from the probe target. According to Milliken et al., selection against a distractor did not take place in the prime displays because the prime target required no response. Instead one should assume that a briefly presented irrelevant prime stimulus is only marginally processed. When repeated as the probe target, this stimulus is ambiguous. Its faint familiarity prevents a categorization as new but is not enough to lead to an "old" response. In this sense briefly presented single primes were said to be functionally similar to the typical prime distractors that are presented for longer durations but that are not fully processed.

However, an obvious possibility is that participants selected against the single prime stimulus or the display as a whole. After all, responses to the prime had to be withheld. Instead of selective inhibition this implies that the representation of the single prime was suppressed. In terms of episodic retrieval this would mean that a do-not-respond tag was attached to the single prime. In this way, 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. Their participants saw two prime words, but no prime response was required. However, a secondary task ensured that participants attended to the primes. In the following probe display, a red word had to be named while ignoring a green word. For ignored repetition trials, the temporal discrimination model predicts a quick "old" categorization and, hence, a very fast response. From the point of view of episodic retrieval, the prime stimuli of trials without a prime response should have been associated with a nonresponse information, which should slow down responding when the stimulus was repeated as the probe target. The results were in line with the episodic retrieval model. The results are also compatible with an inhibition model assuming that withholding a prime response is analogous to selecting against a distractor in producing inhibition.

Further evidence against the temporal discrimination model has recently been provided by Frings and Wühr (2007). They found a response speed-up for a condition in which prime and probe distractors were the same. Both inhibition as well as episodic retrieval models can explain this reaction time decrease whereas the temporal discrimi-

nation model would predict a response slow-down or a null effect for this condition. We may thus conclude that the temporal discrimination model is based on evidence entirely explicable by both the distractor inhibition and the episodic retrieval models and that there is even empirical evidence against the model.

Conclusion

Of the four accounts of the negative priming phenomenon that were analyzed two stand on shaky ground. The feature mismatch hypothesis cannot be considered an adequate account for identity negative priming. The temporal discrimination model lacks convincing empirical support and faces mounting empirical counter evidence.

With respect to the two remaining models, distractor inhibition and episodic retrieval, evidence exists that favors one model over the other. For example, the influence of temporal discriminability of the prime episode relative to the preceding episodes is more easily accommodated by episodic retrieval (Neill et al., 1992) than by inhibition. The same is true for evidence showing that the effect increases when the contextual similarity between prime and probe is increased (Fox & de Fockert, 1998; Neill, 1997; Stolz & Neely, 2001; but see Wong, 2000). Additionally, recent evidence for the prime-response retrieval variant of the episodic retrieval model (Mayr & Buchner, 2006) cannot be explained within an inhibitory model. However, the existence of semantic negative priming effects (e.g., an ignored picture of a cat delaying the response to an attended picture of a dog, cf. Tipper, 1985) is more easily accounted for by an inhibition model. An inhibition model is usually 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. However, a big problem for the distractor inhibition model is that evidence that has traditionally been counted in favor of inhibitory processes must be re-evaluated in the light of more recent findings. Specifically, it has previously been assumed that certain special populations such as children, the elderly, or schizophrenic patients can be characterized by a reduced efficacy of inhibitory processes (Hasher et al., 1991; Hasher & Zacks, 1988; May et al., 1995). This should translate into reduced negative priming for these populations. However, as we will show further on, more recent evidence contradicts this assumption, creating problems for the distractor inhibition model.

It may or may not be a coincidence that proponents of an inhibitory deficit theory of cognitive aging (which fits particularly well with the distractor inhibition concept) such as May et al. (1995) and Kane, May, Hasher, Rahhal, and Stoltzfus (1997) have proposed that both inhibitory processes and memory retrieval can be the source of neg-

ative 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. A context assumed to trigger the retrieval of previous episodes is the presentation of the probe stimuli under difficult perceptual conditions (such as degradation or limited exposure time). Here participants are thought to retrieve the prime episode to aid the current probe target identification. Negative priming in this situation should then be caused by retrieving the task-inappropriate (non)response information attached to the prime distractor.

The account just described assumes mutual exclusiveness of processes in that the negative priming effect is either caused by inhibition or by episodic retrieval. Tipper (2001), in contrast, 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 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).

Characteristics of Negative Priming

In this section, we will have a closer look at some of the characteristics of the negative priming phenomenon about which knowledge has changed since the earlier reviews of Fox (1995), May et al. (1995), and Tipper (2001). These characteristics comprise stimulus modality, prime selection and prime response requirement, probe interference, stimulus repetition, aging and thought disorders, and physiological correlates.

Stimulus Modality

The overwhelming amount of negative priming research has used visual stimulus materials, but negative priming has also been reported for the auditory modality, using human voices (Banks, Roberts, & Ciranni, 1995), natural sounds (Buchner & Mayr, 2004; Buchner & Steffens, 2001; Mayr & Buchner, 2006; Mayr et al., 2006; Mayr et al., 2003; Zabal & Buchner, 2006), and artificial sounds (Mondor, Leboe, & Leboe, 2005). Usually, an auditory negative priming task is implemented by presenting two sounds dichotically, one to the right and one to the left. A preceding

cue – such as a short click – signals the to-be-attended side. Participants have to identify or categorize the attended sound. After their reaction, a click indicates the to-be-attended probe side. Again probe sounds are presented and the target has to be responded to.

Banks et al. (1995) argued that auditory attentional selection is not supported by a peripheral selection mechanism comparable to shifting fixation in the visual modality. Instead, auditory attention has to be almost entirely based on central selection mechanisms. Based on this consideration, Banks et al. (1995) predicted stronger negative priming effects in the auditory than in the visual modality. In one study that measured negative priming in both modalities within the same experimental task (Buchner, Zabal, & Mayr, 2003), auditory negative priming was indeed larger when comparing the absolute differences in reaction times between the ignored repetition and control conditions. However, standardized effect sizes did not differ much between modalities.

Apart from this, negative priming in the auditory and visual modalities seems to follow the same principles. The temporal discriminability of the prime episode at the time of the probe display has been found to be positively related to the size of the negative priming effect in both the visual (Neill et al., 1992, see paragraph on episodic retrieval) and the auditory modality (Mayr & Buchner, 2006). Additionally, experimental evidence favoring the variant of the episodic retrieval model in which the prime-response is involved in the slow-down of responses has also been supported for both the visual and the auditory domain (Mayr & Buchner, 2006; Rothermund et al., 2005).

In contrast to episodic retrieval, feature mismatch does not seem to explain identity negative priming in any of the two modalities. It has long been known that negative priming is not reduced or absent when the prime distractor changes a visual feature in the probe such as color (Tipper & Cranston, 1985). Analogously, the size of the negative priming effect is independent of whether or not the ignored prime sound is presented at the same or at a different location (i.e., ear) in the probe display (Banks et al., 1995; Buchner & Mayr, 2004; Buchner & Steffens, 2001).

Additionally, negative priming has been found *across* modalities, such as from spoken single-digit numbers to visually presented digits (Driver & Baylis, 1993). However, this auditory-to-visual negative priming effect was only observed for a subgroup of participants who were “unaware” of the ignored repetition contingency. Buchner et al. (2003) found crossmodal negative priming irrespective of a prime-to-probe change from audition to vision and vice versa. In this study an additional congruence between negative priming in both modalities was revealed, in that negative priming was observed only if the attended and the ignored primes required different responses. Cross-modal negative priming implies that the underlying processes operate on abstract, amodal stimulus representations, that operations on representations in one modality automatically activate features in other modalities, or both.

Prime Selection and Prime Response Requirement

Theories of negative priming differ in their predictions as to what aspects of the prime display and prime processing are necessary preconditions for negative priming to appear. The distractor inhibition and the episodic retrieval models differ from the feature mismatch and temporal discrimination accounts in assuming that selection against a distractor is a necessary prerequisite. At first sight, testing whether selection against a distractor is indeed necessary for negative priming to occur seems to be a reasonable strategy to differentiate between models. However, manipulating the prime selection process is rather difficult to accomplish. Typically, researchers varied whether participants were or were not to respond to the prime. There are two problems with this approach. First, manipulating the overt response requirement confounds selection against a distractor with the activation of premotor and motor components. Second, we do not know what processes operate when overt responding is to be prevented. For instance, participants may nevertheless select one prime stimulus against another prime stimulus, or they may select against the whole prime display. Consequently, if negative priming is found in experiments in which there is no overt prime selection requirement, this will never be evidence against the distractor inhibition or episodic retrieval theory.

Table 1 presents a selection of studies investigating the role of prime selection and prime response for negative priming. Given the above considerations, the published studies can be categorized into two groups. First, there are some studies that tried to selectively manipulate the response requirement but left the prime processing as similar as possible to a normal prime trial (see "Response requirement manipulations"). Second, there is a rather heterogeneous group of studies that primarily investigated the importance of prime selection. The prime selection requirement in these studies was manipulated by either presenting single primes very briefly (and, by implication, by instructing against a prime response) or by instructing participants either to ignore or not to respond to the prime target. In both cases, no prime response was required, and the uncertainty as to how the prime was processed is large. In a subgroup of these studies, attentional prime processing was difficult or even unlikely (see "No selection & attentional processing unlikely"). In the remaining studies primes could be attentionally processed but either had to be ignored or a response was to be avoided (see "No selection & attentional processing likely").

Several conclusions can be drawn from these studies. First, regardless of whether the prime was presented very briefly ("No selection & attentional processing unlikely") or far above threshold ("No selection & attentional processing likely") or whether it had to be necessarily processed but not responded to ("Response requirement manipulations"), negative priming has been found in the bigger part

of these studies. Second, the few exceptions to this fact fall in one of the following categories: (a) the percentage of ignored repetition trials was extremely large (75%) so that participants must have been hit on this prime-to-probe contingency (Milliken, Lupianez, Debner, & Abello, 1999, Experiment 1 & 2), or (b) the prime stimulus had to be silently read, that is, it had in fact to be responded to (Milliken et al., 1998, Experiment 4) – actually, this is more similar to a prime target processing situation for which positive priming is usually found than to a prime distractor processing –, or (c) participants became aware of the prime-to-probe contingency (Frings & Wentura, 2005, Experiment 2), probably due to the fact that the stimulus repetition probability in ignored repetition trials was way above chance. In sum, negative priming does not seem to depend on a prototypical "attend and respond to target, ignore distractor" prime selection situation. However, as mentioned above, the interpretation of this finding in favor of certain negative priming models must remain ambiguous because it is always possible (in fact, even plausible) that instead of selecting against a particular distractor stimulus participants simply selected against the entire prime display.

Probe Interference

It has been known for quite some time that the negative priming effect depends on the presence of distractor stimuli in the probe display (e.g. Lowe, 1979; Milliken et al., 1998; Moore, 1994; Tipper & Cranston, 1985). For example, Lowe (1979) found a negative priming effect with Stroop stimuli 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.

These findings have usually been counted as evidence in favor of episodic retrieval. If negative priming effects were the consequence of prime distractor suppression alone, properties of the probe display should not be of any influence. By contrast, the episodic retrieval model can easily account for this effect. A switch from a two-stimulus prime display to a single-probe display is a clear context change, as a consequence of which the probability of successful episodic retrieval of the prime is reduced.

Attempts exist to account for this phenomenon within a modified inhibition approach. In their so-called response-blocking model, Tipper and Cranston (1985) assumed that participants were 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 due to the inhibitory response block between the activated distractor representation and the overt response. 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, but the activated distractor representation facilitates re-

Table 1. Studies investigating the role of prime selection and prime response requirement for negative priming. Experiments are characterized with respect to task, manipulation/procedure, prime instructions, trial type percentages (percentage of trials in each experimental condition), set size (number of different stimuli the experimental trials are composed of), and results. All studies included a probe display with distractor interference (abbreviations: AR = attended repetition, C = control, II = Ignored prime becomes ignored probe, IR = ignored repetition, NP = negative priming, PP = positive priming)

	Task	Manipulation/ procedure	Prime instructions	Trial type percentages	Set size	Results
<i>No selection & attentional processing unlikely:</i>						
Milliken, Joordens, Merikle, & Seiffert (1998)	Exp. 2A	Word naming	Single prime (33 ms)	No instruction (most people do not report stimulus)	50–50% IR–C	12 NP
	Exp. 2B	Word naming	Single prime (33 ms)	(see Exp. 2A)	33–67% IR–C	12 NP
	Exp. 2C	Word naming	Single prime (33 ms)	(see Exp. 2A)	50–50% IR–C	12 NP
Frings & Wentura (2005)	Exp. 1	Word naming	Single prime with a) 39 ms vs. b) 300 ms presentation time (block-wise)	a) Attend location b) Ignore stimulus	50–50% IR–C	12 a) NP b) NP
	Exp. 2	Word naming	Single prime (28 ms) of same color as either probe target or distractor	Attend location	50–50% IR–C	12 NP for unaware subjects, PP for aware subjects
<i>No selection & attentional processing likely:</i>						
Healy & Burt (2003)	Exp. 3	Word naming	Two prime distractors (900 ms)	Attend to prime words (response required only if consonant string in prime)	25–25% IR–C (50% trials with consonant string in prime)	12 NP
	Exp. 4	Word naming	Two prime distractors (1200 ms)	Attend to prime words, (response required only if nonword in prime)	25–25% IR–C (50% trials with nonword in prime)	12 NP
Milliken & Joordens (1996)	Exp. 1	Word naming	Two prime distractors (100 ms), prime and probe differ in color	No instruction	50–25–25% IR–II–C	4 NP
	Exp. 2	Word naming	Two prime distractors (100 ms), probe target of same color as primes	No instruction	50–25–25% IR–II–C	4 NP
Milliken, Joordens, Merikle, & Seiffert (1998)	Exp. 4	Word naming	Single prime (200 ms)	Group a) Read silently Group b) Ignore	50–50% IR–C	12 a) PP b) NP
Milliken, Lupianez, Debner, & Abello (1999)	Exp. 1	Stroop color naming	Single white prime word (200 ms)	No instruction	Group a) 25–75% IR–C Group b) 75–25% IR–C	4 Group a) NP Group b) PP
	Exp. 2	Stroop color naming	Single white prime word (57 ms), additional SOA manipulation is omitted	No instruction	Group a) 25–75% IR–C Group b) 75–25% IR–C	4 Group a) NP Group b) PP
Mondor, Leboe, & Leboe (2005)	Exp. 2	Sound identification	Single prime (250 ms)	No instruction	25–25–50% IR–II–C	4 NP

	Task	Manipulation/ procedure	Prime instructions	Trial type percentages	Set size	Results	
<i>Response requirement manipulations:</i>							
Mayr (2005)	Exp. 4	Sound identification	Two primes (300 ms) with vs. without response depending on preceding cue	Attend to prime (in 25% of trials control question to prime target)	25–25–50% IR–AR–C	4	NP for trials with and without response, NP larger for trials with prime response
Verbruggen, Liefvooghe, Szmalc, & Vandierendonck (2005)	Exp. 1	Letter identification	Two primes (150 ms) with vs. without response depending on stop signal after stimulus	Simple stop signal appears after stimulus presentation	50–50% IR–C	4	NP for trials with prime response (trials without stop signal & responded trials despite stop signal), tendency of PP for trials without prime response
	Exp. 2	Letter identification	Two primes (150 ms) with vs. without response depending on stop signal after stimulus	Selective stop signal appears after stimulus presentation (stop if response with right/left hand)	50–50% IR–C	4	NP regardless of prime response

sponding as was found in probes without selection requirement. Whereas this explanation is entirely post-hoc, Houghton and Tipper's (1998) neural network model of inhibition provides for a model-immanent explanation of why negative priming should be reduced without probe interference. Stimulus representations win competitions for access to the response system based on their relative activation advantages. A probe target representation with a reduced activation level due to previous inhibition will take longer to reach the critical activation difference relative to the probe distractor, causing a negative priming effect. In the case of a single probe, no competition between stimulus representations takes place, consequently, no negative priming is found. Note that this model cannot explain why negative priming is sometimes inverted into a facilitatory effect.

However, it seems that attempts to explain a lack of single-probe negative priming within existing negative priming models were in vain. Frings and Wentura (2006) have recently demonstrated that these effects can be explained by simply assuming that, for single-probe displays, it is particularly easy to learn that the prime distractor frequently becomes the probe target. The learned prime-to-probe contingencies may be used to support fast responding by preferentially preparing a probe response based on the prime distractor even before the probe is presented. The bottom line of Frings and Wentura's work is that nonexistent negative priming in single-probe displays does not demand for special assumptions within any negative priming model. Which properties will facilitate the detection of prime-to-probe contingencies? First, single-probe displays

require fewer processing resources. Hence, more resources are left to detect prime-to-probe contingencies. Second, the more ignored repetition trials are included, the more likely they will be detected. Third, ignored repetition trials become all the more salient, the more prominent they are in the experimental context. Stimulus set size is a relevant factor with respect to this point. Chance presentation probability of a stimulus is $1/\text{set size}$, that is, for example, $1/4$ for a set size of 4. However, if there are 50% ignored repetition trials (which is the case quite often), the probability that the distractor becomes the subsequent target is no longer $1/4$, but $1/2$. The situation is worse for larger set sizes. For instance, for a set size of 12 the probability for distractors to become targets increases from $1/12$ to $1/2$ – a probability increase by a factor of 6. With a large proportion of ignored repetition trials and in addition a large stimulus set size, reduced negative priming, no negative priming, or even a facilitatory effect should be found with single probes or nonconflict probes in general.

Table 2 summarizes studies that tested the influence of probe interference on the negative priming effect. The studies are characterized, among other things, by trial type percentages and stimulus set size. It is interesting to focus on those experiments that reported, at least for one condition, *positive priming* in single or nonconflict probe trials (Lowe, 1979, Experiment 3 & 4; Milliken et al., 1998, Experiment 3; Milliken et al., 1999, Experiment 3 & 4; Neill & Kahan, 1999, Experiment 1A, 1B, & 2; Tipper & Cranstoun, 1985, Experiment 3). In the two experiments by Lowe there was an extremely high percentage of trials including repetition (87.5%) which might have pushed people to pay

Table 2. Studies investigating the role of probe interference for negative priming. Experiments are characterized with respect to task, manipulation/procedure, trial type percentage, set size, and results. Unless otherwise noted, all studies included a prime display with distractor interference (abbreviations: AR = attended repetition, C = control, IR = ignored repetition, NP = negative priming, PP = positive priming)

	Task	Manipulation/procedure	Trial type percentage	Set size	Results	
<i>Identity Priming:</i>						
Lowe (1979)	Exp. 3	Stroop color naming	Colored patches in probes	Group a) 12.5–75–12.5% IR–AR–C Group b) 12.5–25–62.5% IR–AR–C	4	Group a) PP Group b) no NP
	Exp. 4	Stroop color naming	Colored patches, random letters or Stroop words in probes	12.5–75–12.5% IR–AR–C	4	NP for words, PP for patches, effect for random letters: NP when in combination with words, PP when in combination with patches
Milliken & Joordens (1996)	Exp. 3	Word naming	No prime response required, single probes	50–50% IR–C	4	No NP
Milliken, Joordens, Merikle, & Seiffert (1998)	Exp. 3	Word naming	Single prime (33 ms) without response, single probes	50–50% IR–C	12	PP
Milliken, Lupianez, Debner, & Abello (1999)	Exp. 3	Stroop color naming	Single prime (57 ms) without response, no probe interference [additional manipulation of SOA omitted]	25–75% IR–C	4	PP
	Exp. 4	Stroop color naming	Single prime (57 ms) without response, probe interference vs. no interference (randomized)	25–75% IR–C	4	PP for no interference probes, no NP for interference probes
Moore (1994)	Exp. 1	Letter identification	Pure and mixed blocks with vs. without probe distractors	Random trial generation [trial type percentages not unambiguously determinable]	4	NP for trials with distractors, no NP for trials without distractors (irrespective of block type)
	Exp. 2	Letter identification	Pure and mixed blocks with response-associated vs. response-neutral probe distractors	Random trial generation [trial type percentages not unambiguously determinable]	4	NP for trials with response-associated distractors, NP for trials with response-neutral distractors only in mixed blocks
	Exp. 3	Letter identification	Pure and mixed blocks with colored distractor probe letters vs. strings	Random trial generation [trial type percentages not unambiguously determinable]	4	NP for trials with colored letter distractors, NP for trials with colored string distractors only in mixed blocks
	Exp. 4	Letter identification	Pure and mixed blocks with colored distractor probe letters vs. random-dot distractors	Random trial generation [trial type percentages not unambiguously determinable]	4	NP for trials with colored letter distractors, no NP for trials with random-dot distractors (irrespective of block type)
	Exp. 5	Letter identification	Mixed blocks with probe distractors vs. without distractors vs. distractor-only trials	Random trial generation [trial type percentages not unambiguously determinable]	4	NP for trials with and without distractors

	Task	Manipulation/procedure	Trial type percentage	Set size	Results	
Neill & Kahan (1999)	Exp. 1A	Word naming	Single prime (33 ms), probe with vs. without distractors (randomized), no prime instruction	50–50% IR–C	12	PP for trials without distractors, NP for trials with distractors
	Exp. 1B	Word naming	(Replication of Exp. 1A)	50–50% IR–C	12	PP for trials without distractors, smaller PP for trials with distractors (participants probably tried to identify masked words)
	Exp. 2	Word naming	Single prime (200 ms), Probe with vs. without distractors (randomized), no prime instruction	50–50% IR–C	12	PP for trials without distractors, smaller PP for trials with distractors
Neill & Westberry (1987)	Exp. 1	Stroop color word identification	Colored conflict words vs. nonconflict strings in probes [additional manipulation of strict vs. lax accuracy instructions]	Random trial generation with approx. 8% IR conflict, C conflict, C nonconflict trials and 4% IR nonconflict trials	4	NP irrespective of probe conflict for strict accuracy instructions, tendency of PP for lax accuracy instructions
	Exp. 2	Stroop color word identification	Colored words vs. strings in probes [additional manipulation of RSI]	Random trial generation with approx. 8% IR conflict, C conflict, C nonconflict trials and 4% IR nonconflict trials	4	NP irrespective of probe conflict [but no NP for longest RSI]
Tipper & Cranston (1985)	Exp. 3	Letter naming	Probe with vs. without distractors (between subjects)	50–50% IR–C	12	NP for trials with distractors, PP for trials without distractors
<i>Localization Priming:</i>						
Tipper, Brehaut, & Driver (1990)	Exp. 5	Target localization	No distractors in probes	33–33–33% IR–C–only-target primes	4	No NP
Neill, Terry, & Valdes (1994)		Target localization	Probe with vs. without distractor	25–25–50% IR–AR–C	4	NP with and without distractors, smaller NP for trials with distractors

attention to the prime-to-probe contingencies. In the studies by Milliken et al. (1998, Experiment 3), Tipper and Cranston (1985, Experiment 3), and Neill and Kahan (1999, Experiment 1A, 1B, & 2), the percentage of ignored repetition trials was very large (50%) and so was the stimulus set (12). These numbers imply that the percentage of trials with prime distractor repetition (50%) was six times larger than the chance level of 8.3%. Finally, in the two experiments by Milliken et al. (1999, Experiment 3 & 4) the task was very easy and included only a single nonresponse prime which was nonmasked. Obviously, this very simplistic task must have facilitated the detection of prime-to-probe contingencies even in the probe trials *with* distractors, as a consequence of which no negative priming appeared for interference probes in their Experiment 4. In sum, it appears that at least the positive priming effects in nonconflict trials reflect strategy effects that need not be explained within a theory of negative priming.

Stimulus Repetition

Malley and Strayer (1995) showed that negative priming can be modulated by stimulus repetition. When every stimulus appeared only within one single experimental trial, negative priming was not observed. A negative priming effect was found when stimuli were drawn from a limited set of 16 words and were repeated frequently throughout the experiment. This finding has been replicated (e.g., Kramer & Strayer, 2001; Strayer & Grison, 1999; Waszak, Hommel, & Allport, 2005).

Following Malley and Strayer (1995), distractor suppression seems to come into effect only if the distractors are highly activated stimulus representations. From the view of the distractor inhibition model, only highly activated distractors are likely to interfere with responding and therefore have to be suppressed. In contrast to this, novel stimuli of a low activation level will hardly interfere with

current target selection and response execution and therefore do not have to be suppressed. Strayer and Grison (1999) additionally argued that the episodic retrieval model can only predict increased negative priming with stimulus repetition when the repetitions take place in the role of the (task-inappropriate) distractor stimulus, but not the (task-appropriate) target stimulus. They reported evidence of increased negative priming with target but not distractor repetition (Strayer & Grison, 1999, Experiment 3a and 3b) which seemed to be consistent with distractor inhibition but not with episodic retrieval.

However, several findings are incompatible with the above explanation. DeSchepper and Treisman (1996; see also Treisman & DeSchepper, 1996) found negative priming for novel shapes presented only within one single experimental trial, and what is more, this negative priming effect was extremely robust, lasting across 200 intervening trials and a temporal delay of up to a month. Similarly, Buchner, Steffens, and Berry (2000) observed negative priming with faces as stimuli even though each face occurred in only one single experimental trial. Furthermore, Hauke, Mayr, Buchner, and Niedeggen (2007) showed that negative priming *increased* with the number of distractor repetitions before the probe.

So far, the reasons for this conflicting set of results are unclear. However, the original explanation of the relation between stimulus repetition and negative priming in terms of a distractor inhibition model now seems premature.

Aging and Thought Disorders

Earlier reviews (Fox, 1995; May et al., 1995) of the negative priming literature concluded that special populations such as elderly people, children, and schizophrenic patients show reduced or no identity negative priming at all. May et al. (1995) interpreted the age-dependent decrease or loss in negative priming as an expression of the inhibitory inefficacy that presumably characterizes cognitive functioning in old age according to the inhibitory deficit theory (Hasher & Zacks, 1988). In contrast, location negative priming seemed to be spared in the elderly. This dissociation was interpreted as showing that identity and location negative priming were based on different underlying inhibitory mechanisms with different developmental gradients. May et al. even suggested a possible link to neurophysiological pathways, such as the ventral, occipitotemporal pathway specialized in processing identity information and the dorsal, occipitoparietal pathway specialized in processing spatial information. The former was supposed to be responsible for inhibitory processes in identity negative priming, whereas the latter was thought to be involved in suppression in spatial negative priming situations.

However, the empirical situation has changed completely since then. A growing body of evidence has been published demonstrating that negative priming can in fact be found in all of the special populations just mentioned. With

regard to aging, a meta-analysis (Verhaeghen & De Meersman, 1998) revealed that older adults show both identity and location negative priming, however the effect was smaller than in young adults. An update to this meta-analysis by Gamboz, Russo, and Fox (2002) revealed no difference at all between young and old adults in the size of the negative priming effect in identity tasks. Similarly, a recent study revealed that children do indeed show negative priming, and that they show it to the same degree as young, healthy adults (Pritchard & Neumann, 2004). Finally, the third population of major interest in negative priming research has been schizophrenic patients. Again, none of the more recent studies reveals differences between schizophrenics and healthy controls in the size of identity negative priming (Moritz, Jacobsen, Mersmann, Kloss, & Andresen, 2000; Moritz et al., 2001; Zabal & Buchner, 2006).

What was the problem with these earlier studies? First, the frequently reported results of significant negative priming in young adults, but no negative priming in, say, the elderly can be expected for a purely methodological reason. Response times in older adults are longer overall and also more variable than responses in young adults (typically a very homogeneous set of university students). It is easy to show that this fact alone selectively reduces the size of the standardized negative priming effect for the group of older participants, and, hence, the probability of finding a statistically significant negative priming effect for this group; the problem is particularly grave due to the fact that the sample sizes in that type of research are often quite small (for more detail, see Buchner & Mayr, 2004). Second, a publication bias may have existed such that experiments finding the “typical” dissociation pattern were more easily published than those showing no group difference or even a reversed pattern (no negative priming in young adults, but an effect in the elderly, see Buchner & Mayr, 2004) simply because only the “typical” dissociation findings are consistent with inhibitory deficit theory whereas other patterns would have to appear either uninteresting or even equivocal. A third relevant variable is that participants in the “special populations” may have difficulties identifying the stimuli in the first place, as a consequence of which negative priming can of course not be expected. For instance, Moritz et al. (2001) investigated this possibility for the case of schizophrenic patients. The patients showed normal negative priming under easy stimulus presentation conditions, but showed reduced negative priming under the most difficult presentation conditions (100 ms presentation time and a post-mask).

In sum, recent evidence shows that negative priming is not reduced or eliminated for special populations with a presumed “inhibitory deficit.” This is a problem for distractor inhibition models because reduced negative priming in older adults, children, and schizophrenic patients has typically been counted in favor of these models. This unique supportive evidence is now missing.

Table 3. Studies investigating ERP correlates of negative priming. Studies are characterized with respect to task and ERP findings (abbreviations: C = control, IR = ignored repetition)

	Task	ERP findings
<i>Identity priming:</i>		
Ceballos, Nixon, & Tivis (2003)	Same-different task with novel objects	Increased P300 amplitude in IR relative to C; delayed P300 in IR relative to C
Gibbons (2006)	4AFC number identification	No ERP effects; very early LRP positivity in IR relative to C
Gibbons, Rammsayer, & Stahl (2006)	4AFC number identification	No ERP effects; no LRP effects
Heil & Rolke (2004)	Lexical decision	Reduced N400 in IR and semantic IR relative to C
Kathmann, Bogdahn, & Endrass (2006)	4AFC number identification	Increased P3 amplitude (290 – 450 ms) in IR relative to C
Mayr, Niedeggen, Buchner, & Orgs (2006)	2AFC categorization (auditory)	Reduced late positive complex (LPC, 550 – 730 ms) in IR relative to C at parietal positions, this effect increased with reaction time level
Mayr, Niedeggen, Buchner, & Pietrowsky (2003)	2AFC categorization (auditory)	Reduced late positive complex (LPC, 300 – 600 ms) in IR relative to C particularly expressed at parietal positions
Wagner, Baving, Berg, Cohen, & Rockstroh (2006)	Lexical decision	Reduced N400 in IR and semantic IR relative to C (only for control subjects, not for schizophrenic patients); increased late positive complex (LPC, 500 – 700 ms) in IR relative to C
<i>Location priming:</i>		
Gibbons (2006)	4AFC number localization	Enhanced posterior N2 in IR relative to C; increased frontopolar N440 in IR and in inverted condition (target-to-distractor & distractor-to-target) relative to C; no LRP effects
Gibbons, Rammsayer, & Stahl (2006)	4AFC number localization	Reduced parietal P1-N1 amplitude in IR relative to C; reduced P300 in IR relative to C; no LRP effects
Kathmann, Bogdahn, & Endrass (2006)	4AFC x/o localization	Reduced P1-N1 amplitude in IR relative to C; delayed P3 in IR relative to C
Ruge & Naumann (2006)	4AFC x/o localization	Reduced contralateral posterior N1 in IR relative to C; enhanced contralateral N2pc in IR relative to C (only for sustained attention); enhanced posteriorly distributed N2 in IR relative to C

Physiological Correlates

Research on the psychophysiological correlates of the negative priming effect is still sparse. The available evidence with respect to electroencephalographic measures – to which we want to restrict our review – is summarized in Table 3.

The prefrontal cortex has been proposed as the locus of a central inhibition mechanism (Fuster, 1997). Consistent with this assumption, frontally located electrophysiological components have been found in other paradigms associated with inhibitory processes of executive control (Eimer, 1993; Falkenstein, Hoormann, & Hohnsbein, 2002; West & Alain, 2000). Therefore, if negative priming is indeed caused by a distractor inhibition process, expecting a frontal activation correlate seems obvious (Mayr et al., 2006; Mayr et al., 2003). With regard to alternative predictions, distractor inhibition has also been related to early components reflecting suppressed sensory processing, whereas slower components have been associated with stimulus evaluation and memory-related processes (Kathmann,

Bogdahn, & Endrass, 2006). Gibbons, Rammsayer, and Stahl (2006) predicted early components reflecting visual analysis (such as P1 and N1) to be sensitive if feature mismatch was a valid explanation of negative priming. No ERP specific predictions have been formulated from the temporal discrimination point of view. As the above outline already indicates, the various models do not seem to provide clear-cut and testable predictions of what to expect as an ERP correlate of negative priming. Some correlates are compatible with more than one theory, different correlates can be consistent with a single theory. As a consequence, testing theories of negative priming on the basis of ERP findings seems difficult, at least at present. In the following summary we therefore present ERP correlates without drawing conclusions for or against any theory.

If effects were found at all in identity priming studies they were very small and rather late in time² Three studies of various tasks found an increased P3 (Ceballos, Nixon, & Tivis, 2003; Kathmann et al., 2006) or a so-called late positive complex (Wagner, Baving, Berg, Cohen, & Rockstroh, 2006) in the ignored repetition compared to the con-

² We will only mention those findings that have been reported in more than one study.

control condition. Similar in time range but not polarity of components, the two auditory negative priming experiments available to date (Mayr et al., 2006; Mayr et al., 2003) found a relatively more negative late positive complex in the ignored repetition condition compared to two control conditions. Two studies that used a lexical decision task found small reductions in the N400 component in the ignored repetition condition and the semantic ignored repetition condition (Heil & Rolke, 2004; Wagner et al., 2006). However, this component is rather the correlate of a detected prime-probe repetition than a specific correlate of negative priming given that N400 reductions are usually found while presenting probe words associated with or identical to prime words irrespective of attentional allocation (Heil & Rolke, 2004). In sum, ERP correlates of identity negative priming were not related to sensory processes but rather to late processes of stimulus evaluation. Frontally located correlates were not observed in any of the studies.

With regard to the location priming experiments, the situation turns out to be somewhat different. All studies have found early sensory components specific for the ignored repetition condition, that is, a reduced parietal P1-N1 amplitude (Gibbons et al., 2006; Kathmann et al., 2006), a reduction in N1 and an enhancement in N2pc contralateral to the presentation side (Ruge & Naumann, 2006) as well as N2 enhancement (Gibbons, 2006; Ruge & Naumann, 2006). Two studies additionally found effects in the P3 time range (Gibbons et al., 2006; Kathmann et al., 2006). However, in none of the localization-task studies care was taken to exclude (or manipulate) feature mismatch as the source of ERP effects. Taking into account that location-identity mismatches are an important factor in location priming (Park & Kanwisher, 1994), the early sensory ERP components that were reported might be the correlate of a detected mismatch.

So far, the studies currently available have not brought up a clear picture of the electrophysiological correlates of negative priming. This may be due to the small number of existing studies, the variety of the tasks applied, and the diversity of the experimental manipulations used.

Conclusions

We tried to present the theoretical accounts, as well as the empirical state of affairs, of the negative priming phenomenon. Of the models currently available only distractor inhibition and episodic retrieval have survived empirical testing so far. Traditionally, distractor inhibition has been the more popular model of the two. Its dominance to this very day becomes particularly evident in contexts where negative priming tasks are applied as pure measurement tools of inhibitory control without questioning this interpretation. In such contexts, episodic retrieval is often only an also-ran, if mentioned at all (see, e.g., Dimitrov et al., 2003; Vitkovitch, Bishop, Dancy, & Richards, 2002; C.I. Wright

et al., 2005; Wright, McMullin, Martis, Fischer, & Rauch, 2005). The predominance of the distractor inhibition model can be traced back to the fact that this model came into play at the same moment at which the phenomenon itself received a saucy name which is itself not neutral but suggests a particular explanatory construct. In addition, some of the empirical “facts” about the nature and the causal factors of the negative priming phenomenon were traditionally counted as support of the distractor inhibition model, but as this review has shown a number of these earlier conclusions have been premature. For example, the presumed reduction or elimination of negative priming in special populations – such as the elderly, schizophrenic patients, or children – turned out to be the result of methodological artifacts or of very basic processing deficiencies in these populations (Buchner & Mayr, 2004; Moritz et al., 2001). The knowledge that these special populations do not suffer from an “inhibitory deficit” is a severe problem for the distractor inhibition model because inhibitory deficits in association with reduced negative priming has traditionally been counted as support for this model (see May et al., 1995).

The assumption that negative priming depends on the presence of probe interference is another “fact” which turned out to be wrong. Instead, prime-to-probe contingency learning is probably easier for probes without interference, particularly under certain experimental conditions (Frings & Wentura, 2006), as a consequence of which simple response strategies can readily explain findings of no negative priming or even response facilitation in single-probe trials. This finding weakens the response-blocking variant of the distractor inhibition model combined with the assumption of a flexible “selection state” (Tipper & Cranston, 1985). The idea that responses to distractor stimuli are blocked, but that the blocking can be abandoned in situations without a need for selection has been turned to account for positive priming effects in single probe trials. Given that probes without interference do not imply positive priming effects, this model has no additional explanatory value.

We also presented evidence that negative priming does not depend on highly activated distractor representations. From the view of the distractor inhibition model only highly activated distractors are likely to interfere with responding and therefore have to be suppressed (see Malley & Strayer, 1995; Strayer & Grison, 1999). As a consequence, findings of negative priming with nonrepeated (and thus not highly activated) stimuli weaken the distractor inhibition approach.

In sum, the more recent empirical findings weaken rather than strengthen the distractor inhibition model. At the same time, new empirical findings have been accrued that selectively support the episodic retrieval model to explain the negative priming effect. The influence of temporal discriminability of the prime episode relative to the preceding episodes can readily be accounted for by episodic retrieval but not by inhibition (Mayr & Buchner, 2006; Neill et al.,

1992). Episodic retrieval is also more adequate than distractor inhibition in explaining why the effect increases when the contextual similarity between prime and probe is increased (Fox & de Fockert, 1998; Neill, 1997; Stolz & Neely, 2001). Overall, the negative priming phenomenon obeys general memory retrieval principles, which is not explicable from a distractor inhibition point of view. Additionally, results from experiments designed to test the prime-response retrieval variant of the episodic retrieval model (Mayr & Buchner, 2006; Rothermund et al., 2005) cannot be explained within an inhibition model.

What can be inferred from this review? First, within the past decade distractor inhibition lost much of its persuasiveness. Second, negative priming clearly obeys memory retrieval principles. Third, the question whether we need an integrated approach of inhibition and memory retrieval as proposed by Tipper (2001) is still open. Whereas the importance of memory retrieval processes has been proven, more evidence is needed to show the necessity of an additional inhibitory process. Last but not least, research within more than 20 years has shown that the negative priming phenomenon is even more omnipresent and robust than we had thought. It can be found regardless of which population we measure and what prime and probe settings we implement, as long as we keep in mind general basic principles of experimental design and statistical analysis.

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