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Research Report

Prime retrieval of motor responses in negative priming: Evidence from lateralized readiness potentials

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In two experiments using a sequential prime–probe design we analyzed whether distractors repeated as targets retrieve the former prime response, although the prime response had to be withheld until after probe responding. Following Gibbons and Stahl (2008), we applied the lateralized readiness potential (LRP) as a measure for the retrieval of compatible or incompatible motor activation from the prime. When targets retrieved episodes containing the same response hand, the LRP onset occurred earlier, whereas when targets retrieved episodes containing the other response hand, the LRP onset was delayed. This data pattern supports prime-response retrieval theories of negative priming (Mayr and Buchner, 2006; Rothermund, De Houwer, and Wentura, 2005). In addition, the results show that executing a prime response is not a precondition for stimulus–response bindings.

1. Introduction

When humans ignore a distracting stimulus while reacting to a target stimulus, the response to the target and possibly both stimuli present during responding are integrated into one stimulus–response episode. Upon later presentation, both stimuli can also retrieve the whole episode including the response (Frings et al., 2007; Hommel, 2005). In selection tasks, in which participants react to targets accompanied by distractors, such binding and retrieval processes have been discussed as a source for the negative priming (NP) effect (Gibbons, 2009; Gibbons and Stahl, 2008; Mayr and Buchner, 2006; Rothermund et al., 2005). NP (Tipper, 1985; for reviews see Fox, 1995; Neill, 2007; Tipper, 2001) refers to the finding that, if a distractor from a prime display becomes the target in the subsequent probe display, then a person's response to this target will be impaired in terms of latency and/or accuracy of their response (Dalrymple-Alford and Budayr, 1966). There is now a consensus amongst researchers that NP taps selective control mechanisms. Nevertheless, the exact nature of these control processes is still a topic of heated debate. A coarse-grained taxonomy of NP theories differentiates between inhibition- (Houghton and Tipper, 1994; Tipper, 1985) and retrieval-based accounts (Mayr and Buchner, 2006; Milliken et al., 1998; Neill, 2007; Rothermund et al., 2005). In this article, we focus on the most recent variant of retrieval accounts, namely the Stimulus–Response- (Rothermund et al., 2005) or Prime-Response-Retrieval (Mayr and Buchner, 2006) theory.

In a nutshell, this theory assumes that NP is caused by the fact that perceiving a target activates memory traces associated with that particular stimulus. When a distractor is repeated as the target, the last memory trace of the current probe target stimulus contains the response to the former prime target, and it is this response information that interferes with a person's ability to respond quickly and accurately to the current target (as

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long as the response changes between prime and probe displays; this is, however, always the case in the conditions relevant for computing the NP effect).

Gibbons and Stahl (2008) yielded evidence for prime response retrieval in NP tasks by measuring the lateralized readiness potential (LRP; Gratton et al., 1988). The LRP is obtained by subtracting activity over the motor cortex ipsilateral to the responding hand from contralateral activity. By that means, the time course of hand specific motor activation during the interval between stimulus presentation and response execution can be monitored. Typically, in a two-choice reaction time task with left and right-hand responses the LRP remains close to zero until about 300–400 ms post-stimulus, then turns into a sharp-rising negativity that peaks shortly after the overt response, and returns to baseline within some 100 ms. Gibbons and Stahl applied the logic of prime response retrieval as measured by the LRP to a four-choice reaction time task in which four stimuli were mapped on four responses. In fact, they argued that because LRPs are always hand-specific, retrieval of the prime-response should be analyzed with respect to hand shifts between prime and probe displays. In particular, when a probe target requires a response with a finger of the right (left) hand, while it retrieves a prime response with a finger of the left (right) hand, the wrong hand (irrespective of the actual finger) would be pre-activated. Of course, analytic probe processing will activate the correct hand in parallel but the interference from the retrieved episode will hamper the correct response generation. This would lead to an early *positivity* in the LRP and could be measured as a delayed onset of LRP negativity. In contrast, when a probe distractor requires a response with a finger of the right (left) hand, while it also retrieves a prime response with a finger of the right (left) hand, the correct hand (irrespective of the actual finger) would be pre-activated, and in turn facilitate the correct hand in parallel with analytic probe processing. This would lead to an early *negativity* in the LRP which is reflected in earlier LRP onset. In a nutshell, Gibbons and Stahl (2008) observed data that exactly matched these predictions. Importantly, the modulation of the LRP onset due to hand shifts is exclusively predicted by theories assuming prime response retrieval. Even other episodic-retrieval theories (e.g., Neill, 1997) – least the inhibition theory – cannot explain this data pattern.

However, a closer look at the data of Gibbons and Stahl (2008) reveals some irritating details of the observed LRPs. For example, the (uncorrected, original) probe LRP onset started very early at around 100 ms post-stimulus. With respect to the LRP literature, even in a localization task with spatially congruent stimulus–response mapping, which is much easier than the present flanker task, hand preparation starts not earlier than around 200 ms (e.g., Osman et al., 1992). In addition, in Gibbons and Stahl's (2008) conditions in which the response hand repeated from the prime to the probe, uncorrected probe LRPs had an unusual positive-only characteristic. The authors attributed these findings partially to the fact that residual activation from the executed prime response had an impact on probe LRPs. This idea was supported by a strong LRP negativity at around probe display onset, relative to a baseline preceding prime display onset. Although a correction procedure to remove this activation was developed by Gibbons and Stahl (2008), it complicates the analysis of sequential responses with the LRP considerably, and this may explain why only a few respective studies have been published so far (see also Jentzsch and Sommer, 2002) Yet, since the theoretical argument put forward by Gibbons and Stahl (2008) differentiates between alternative theories on the NP effect (and distractor processing in general), we thought it prudent to replicate their results within a design that might hedge against residual prime response activation. In particular, we instructed our participants to withhold their prime response until after the probe response. That is, participants had to select a prime target against a prime distractor and knew that the respective response had to be executed only after the probe response. Thus, the prime distractor should be still bound into an episode containing the (not executed) prime response. Repeating the distractor as the probe target should nevertheless lead to retrieval of this episode including a then incompatible albeit not executed response. Obviously, we assume here that retrieval of prime responses does not require that the prime response is actually executed. In this regard, it should be noted that Mayr et al. (2009) recently argued against prime response retrieval in tasks without an executed prime response — at least when behavioral data, particularly error rates, are analyzed. We will discuss our data with respect to their study in detail in the General Discussion.

To ensure that standard NP can be found when prime responses are withheld until after probe responding, we first tested our procedure with a behavioral control experiment (Experiment 1), in which we conducted the typical conditions of an NP experiment, namely repeating the prime distractor as the probe target (ignored repetition; IR), repeating the prime target as the probe target (attended repetition; AR), and a control condition (C) with no stimulus repetitions between prime and probe. Note that others have used quite a similar variant of the NP task, in which no prime responses had to be given (e.g., Milliken et al., 1998; Neumann and DeSchepper, 1991) or in which the prime response had to be given after the probe response (e.g., Ortells et al., 2001). Yet, due to the fact that participants had to withheld their prime response until responding to the probe display, one might argue that the working-memory load during probe processing was somewhat harder than is usual for NP. It is noteworthy that in some previous studies the magnitude of NP effects has been found to be influenced by working-memory load in that NP diminished when the working-memory load increased (e.g., Engle et al., 1995; but see Frings and Spence, 2011). Thus, it seems important to ensure that the standard NP effect would emerge in the variant of the NP task as used here. After the behavioral control experiment, we replicated this experiment while EEG was continuously recorded (Experiment 2). We predict that in trials with a hand shift between primes and probes the repeated distractor retrieves the wrong response hand and thereby causes a delayed LRP onset. In contrast, in trials without a hand shift between primes and probes the repeated distractor retrieves the correct response hand, which should cause earlier LRP onset. In the same vein, the behavioral NP effect might also be modulated by hand shifts. As a consequence of the pre-activation of the wrong or correct response hand, reaction times to the probe target might be slowed down or facilitated. The latter might overshadow or compensate the interference from repeating the prime distractor as the probe target.