American Psychological Association

Journal of Experimental Psychology:
Human Perception and Performance

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0096-1523/18/$12.00

2018, Vol. 44, No. 12, 1946–1969
http://dx.doi.org/10.1037/xhp0000581

# Emotion-Specific Priming Effects With Marginally Perceptible Facial Expression Primes: Evidence From the "Leave-One-Out" Paradigm

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Priming studies investigating the processing of emotional faces under conditions of limited awareness have shown that people can extract more than just valence from masked faces. However, previous results have been inconsistent with regard to the degree of differentiation among negative expressions. Some results have suggested a *relevance* differentiation (i.e., anger differentiated from fear or sadness) and some have suggested differentiation by *arousal* (i.e., sadness differentiated from fear or anger); others have not suggested any differentiation beyond valence. It may even be possible that differentiation occurs down to the level of the *specific* emotion. To gain further insight into emotion differentiation under such conditions, we presented angry, fearful, and sad faces as masked primes in a response priming task with nontarget primes (i.e., primes and targets were from different stimulus sets). More important, in each of four experiments, only 2 of the prime emotions were used as target emotions in a binary emotion categorization task; that is, 1 prime emotion was left out as a target category. The relevance, arousal, and specificity hypotheses make contrasting predictions regarding (a) the presence or absence of focal priming effects (i.e., effects from prime emotions contained in the response set) and (b) the presence or absence of priming effects arising from the prime emotion left out from the response set. Results of conventional analysis of response times as well as diffusion model analyses were most compatible with the specificity hypothesis. However, the particular response set partially determined which information was extracted from masked primes. Results are interpreted in terms of an action-trigger account.

***Public Significance Statement***
What is the public health significance of this article? This study strongly suggests that briefly presented and masked emotional facial expressions (i.e., faces of which participants are at least subjectively unaware) are processed down to the level of the specific emotion.

*Keywords:* affective priming, emotion perception, nonconscious, facial expression, automatic processing

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The human cognitive-affective system is capable of processing affective or emotional information within a few hundred milliseconds, even under conditions of limited awareness (e.g., Draine & Greenwald, 1998; Klauer, Eder, Greenwald, & Abrams, 2007; Murphy & Zajonc, 1993; Wentura & Degner, 2010a). However, it is a widely shared assumption that this processing takes place on a rather global evaluative level, reflecting only the distinction between positivity and negativity. More detailed processing is assumed to be more time and capacity consuming. For example, the negativity of a facial expression is assumed to be automatically and nonconsciously detected, whereas the specific type of negativity (e.g., whether the facial expression is angry or fearful) can only be decoded by means of more effortful and time-consuming processes (see, e.g., Murphy & Zajonc, 1993).

Recently, this view has been challenged by studies using variants of the evaluative priming paradigm (Neumann & Lozo, 2012; Rohr, Degner, & Wentura, 2012; Rohr & Wentura, 2014; Wentura, Rohr, & Degner, 2017). In the original evaluative priming paradigm (Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Herring et al., 2013), participants categorize positive and negative targets based on valence. Targets are preceded by briefly presented primes, and typically, if valence of prime and target match, responses are faster and/or more accurate than in case of a nonmatch. This effect is also found with masked primes (i.e., primes that are presented very briefly and are then overwritten by a mask; such primes are only marginally perceptible; Draine & Greenwald, 1998; Klauer et al., 2007; Wentura & Degner, 2010a).

Neumann and Lozo (2012) reported evidence of a more specific processing of marginally perceptible primes. Presenting masked pictorial primes that elicited either disgust or fear, they found a congruency effect regardless of whether targets were pictures,

This article was published Online First October 29, 2018.
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We thank Ullrich Ecker for his helpful comments on an earlier version of this article and Andreas Voss for his support with the Monte Carlo simulations of the diffusion models. This research was supported by a grant from the German Research Foundation (DFG-WE 2284/9). All data and materials are openly accessible at osf.io/dxreu (Wentura & Rohr, 2018).
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words, or facial expressions (i.e., target responses were faster if prime and target emotions matched). In some of our previous studies using another variant of the evaluative priming paradigm (the emotion priming paradigm; Rohr et al., 2012; Wentura et al., 2017), we very briefly presented masked emotional facial expressions, followed by clearly perceivable emotional target faces or words (using four different emotions for both primes and targets: joy, anger, fear, and sadness); participants had to categorize the target emotion (Carroll & Young, 2005, introduced this paradigm with unmasked prime stimuli). This work yielded evidence that masked emotional faces can be differentiated at a more fine-grained level than just on the valence dimension.

However, the type of differentiation within the negative domain is not always the same. To foreshadow the discussion in the subsequent paragraphs, we have repeatedly found a differentiation between anger on the one hand and fear or sadness on the other hand (Rohr et al., 2012; Wentura et al., 2017). However, with a slight variation of the described paradigm, we have found a differentiation between anger or fear on the one hand and sadness on the other (Rohr, Degner, & Wentura, 2015; Rohr & Wentura, 2014). Both differentiations make theoretical sense (and were indeed predicted by influential emotion theories): The differentiation of anger versus fear or sadness corresponds to a difference in extractable behavioral relevance—angry faces (in frontal view) unequivocally signal behavioral relevance for an observer, which is not necessarily the case for fearful or sad faces (that signal primarily the negative emotional state of the expresser). By contrast, the differentiation of anger or fear versus sadness might correspond to the extractable arousal information—anger and fear are arguably more arousing emotions than sadness. Thus, further research is needed to clarify this inconsistency.

## Relevance: Anger Versus Fear or Sadness

Rohr et al. (2012) as well as Wentura et al. (2017) reported a total of four experiments using the masked emotion priming paradigm, with both primes and targets varying across joy, anger, fear, and sadness conditions, with categorization of the target emotion as the task. Apart from the expected congruency effect—overall faster responses in emotion-congruent compared with incongruent conditions—there was a Prime Emotion × Target Emotion interaction found in specific, prespecified contrasts. First, a significant interaction contrast of happy versus negative emotions suggested valence-specific processing of primes. Second, contrasts within the negative domain indicated processing beyond valence: while an interaction contrast of fear versus sadness was nonsignificant, a significant interaction contrast comparing anger with fear/sadness[1] was interpreted to reflect a "relevance principle," in line with several theoretical frameworks. As an angry face unequivocally signals behavioral relevance to the observer (i.e., the anger is directed at them), anger is seen primarily as an *other-relevant* emotional state. Sad or fearful faces, by contrast, predominantly signal a *possessor-relevant* emotional state, which is unequivocally negative for the signaler but carries only ambiguous implications for the observer (see Degner & Wentura, 2011; Peeters, 1983; Wentura, Rothermund, & Bak, 2000; Wentura & Degner, 2010a). Taking a slightly different perspective, Adams and Kleck (2003) likewise differentiated emotions within the negative domain but emphasized their behavioral impact in terms of approach and avoidance. They argued that joy and anger expressions are signals of approach for the perceiver, whereas fear and sadness are signals of avoidance.

The distinction of valence and relevance as two important facets of emotion processing is also emphasized in appraisal theories. Appraisal theories postulate that human beings constantly evaluate stimuli and events in their environment with regard to their significance for the individual along several dimensions (Ellsworth & Scherer, 2003; Moors, 2014; Scherer, 1984). These appraisals are assumed to take place automatically and to a large degree nonconsciously. Specifically, checks of novelty, valence (intrinsic pleasantness), and relevance (pertinence to one's well-being and survival) are assumed to occur immediately when encountering a stimulus (Ellsworth & Scherer, 2003).

## Arousal: Anger or Fear Versus Sadness

As mentioned above, with a slight variation of the emotion priming paradigm, we found a differentiation between anger or fear on the one hand and sadness on the other. This variation concerned the use of spatial frequency-filtered emotional faces (i.e., high- vs. low-frequency images) as primes in our paradigm (Rohr & Wentura, 2014). We will not elaborate on the theoretical background here, but we found the following pattern: Under conditions of relatively long and unmasked prime presentation, both high- and low-frequency primes triggered emotion-specific priming effects. However, with brief and masked prime presentations, we found a dissociation: high-frequency primes elicited a valence priming effect, whereas with low-frequency primes, we found significant contrasts between angry or fearful and sad faces. Given that the effects differentiated emotions along the arousal dimension, we argued that our results supported the notion that early and (possibly) nonconscious processing of emotional faces triggers what Russell (2003) termed "core affect," namely the "blend of hedonic (pleasure–displeasure) and arousal (sleepy–activated) values" that he considered the basis for the development of full-fledged emotions.

Comparable results were found in a slightly different paradigm, the "emotion misattribution procedure" (Rohr et al., 2015), a variant of the affective misattribution procedure (AMP; Payne, Cheng, Govorun, & Stewart, 2005). The AMP is similar to the evaluative priming paradigm, but seems to differ in basic processing requirements (for a review, see Payne & Lundberg, 2014). In the AMP, participants evaluate shortly presented *neutral* targets that are preceded by briefly presented prime stimuli. Typically, the evaluative categorization of the neutral targets is biased toward the valence of the primes: neutral targets are more often categorized as pleasant after positive primes and as unpleasant after negative primes.

[1] Methodologically, the three mentioned contrasts were a-priori specified orthogonal Helmert contrasts for the 4 (prime: happy, anger, fear, sad) × 4 (target: happy, anger, fear, sad) design. The first contrast is equivalent to the interaction in a 2 (prime: happy vs. anger/fear/sad collapsed) × 2 (target: happy vs. anger/fear/sad collapsed) analysis of the data; the second contrast is equivalent to the interaction in a 2 (prime: anger vs. fear/sad collapsed) × 2 (target: anger vs. fear/sad collapsed) analysis; the third contrast is equivalent to the interaction in a 2 (prime: fear vs. sad) × 2 (target: fear vs. sad) analysis.

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In our adaptation of the AMP, we presented masked emotional prime faces and used emotionally neutral faces as targets. Participants' task was to categorize this neutral expression with regard to emotion (they were told that the study investigated the processing of subtle emotional expressions). While happy and sad primes caused emotion-specific increases in response rates (i.e., the rate of happy [sad] target responses was significantly increased after happy [sad] primes), anger and fear primes significantly increased *both* anger and fear response rates to the same extent. Thus, we again found a result pattern consistent with an interpretation in terms of "core affect" (i.e., valence plus arousal; Russell, 2003).

The important point to emphasize here is that slightly different versions of the masked priming paradigm have provided corroborative evidence for priming effects that go beyond a simple positive/negative distinction. The type of differentiation within the negative domain, however, has varied across different variants of the priming paradigm: the priming paradigm using standard faces seemed to differentiate according to relevance, whereas the misattribution procedure and the priming paradigm using spatial frequency-filtered faces seemed to differentiate according to arousal.

## The Leave-One-Out Paradigm

To tackle this inconsistency, the present study introduces a variant of the emotion priming paradigm that we refer to as the "leave-one-out" paradigm. We present a series of experiments that used the three previously used negative facial expressions (i.e., anger, fear, and sadness) as primes, but only two emotions—varied across experiments—as target and response categories. Thus, one prime emotion is "left out"; hence the name of the paradigm. We devised this paradigm to mitigate some weaknesses and ambiguities associated with the emotion priming paradigm that uses multiple negative primes and targets. For example, it is not surprising that tasks with four alternative choices (e.g., Rohr et al., 2012) are associated with generally slower responses and increased error rates relative to standard binary tasks. Apart from such generic effects, the four-alternative choice version might also be particularly susceptible to strategy use. To illustrate, participants might deconstruct the task in a sequential manner: "If the target is positive, press the 'happy' key. If not, check if it is the negative emotion *x*; if it is, press the corresponding key. If not, try to differentiate between the two remaining emotions; then press the corresponding key." Such a sequential strategy might be associated with a decreasing influence of the prime emotion with each step of the cascade. Consequently, depending on what is *x*, different patterns of priming effects will emerge. It is, therefore, possible that primes are evaluated at the level of the specific emotion, but that this specificity does not shape the priming effects in the four-alternative choice version of the priming task because of a breakdown of the decision process into sequential binary decision steps. Of note, if this assumption holds, it undermines any alternative explanation deduced from emotion theories, as top-down effects would be a key factor even in the processing of marginally perceptible emotional stimuli (see, e.g., Kiefer & Martens, 2010, for top-down influences on nonconscious semantic priming). Reducing the number of target response categories to two in the leave-one-out paradigm reduces these issues of the four-alternative choice paradigm. As we will detail in the next section, the leave-one-out paradigm also allows for a clear differentiation between the relevance, arousal, and emotion-specificity hypotheses.

## The Leave-One-Out Paradigm as a Variant of Response Priming

The leave-one-out paradigm involves a binary choice as well as masked prime presentation, and can be considered a variant of the response priming paradigm. The response priming paradigm is commonly used to explore the processing of marginally perceptible stimuli; the focal characteristic is that primes can be described as either congruent or incongruent with the correct target response (for a differentiation from semantic priming designs, see, e.g., Ansorge, Kunde, & Kiefer, 2014; Wentura & Degner, 2010b). For example, in the above-mentioned evaluative priming paradigm, both positive and negative stimuli are presented as primes and targets. As targets have to be categorized according to their valence, primes can be considered congruent or incongruent with the target response (for other tasks, see, e.g., Dehaene et al., 1998; Draine & Greenwald, 1998; Greenwald, Draine, & Abrams, 1996; Klinger, Burton, & Pitts, 2000; Pohl, Kiesel, Kunde, & Hoffmann, 2010; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). The most straightforward explanation for congruency effects in *response priming* designs is to assume that the irrelevant prime's response-relevant feature (e.g., its valence) is nonintentionally processed to prepare a response (Schmidt, Haberkamp, & Schmidt, 2011; Wentura & Degner, 2010b; but see Ortells, Kiefer, Castillo, Megías, & Morillas, 2016). If the prime triggers the same response as the subsequent target, target responding is facilitated (i.e., faster responses and reduced likelihood of errors). If the prime triggers the alternative response, a conflict with the response triggered by the target ensues; this conflict increases the likelihood of an error, and resolution of the conflict slows down responses.

Studies in this domain differ in one fundamental aspect: namely, whether or not they use the same prime and target sets. Many studies draw primes and targets from the same stimulus set; this means that after a number of trials, the masked prime on any given trial will have already been categorized as a target in at least one preceding trial. In this case, priming effects can also be explained by stimulus-response bindings established during target categorization of the stimulus (Abrams & Greenwald, 2000; Damian, 2001); the assumption that the masked prime is processed up to the level necessary for the categorization is not needed. Other experiments—including the present ones—use nonoverlapping prime and target sets (e.g., Dell'Acqua & Grainger, 1999; Kiesel, Kunde, Pohl, & Hoffmann, 2006; Klauer et al., 2007; Koivisto & Rientamo, 2016; Naccache et al., 2005; Ortells et al., 2016; Pohl et al., 2010; Van den Bussche, Notebaert, & Reynvoet, 2009; Wentura & Degner, 2010a). Explaining how masked primes that do not appear as targets ("nontarget primes") can nevertheless cause priming effects requires a more elaborate theory than the assumption of simple stimulus-response bindings. Here, it seems inevitable to assume that masked primes are processed up to the level required for target categorization, which is typically a semantic level (e.g., Van den Bussche et al., 2009). One theory that is suitable to explain these effects, as well as a variety of other findings, is the action-trigger theory (Kunde, Kiesel, & Hoffmann, 2003, see also Kiesel, Kunde, & Hoffmann, 2008; see Neumann, 1990, for a precursor theory).

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The action-trigger theory proposes that participants create a set of action triggers, in an attempt to bypass the need for effortful semantic analysis on every single trial. For example, if the task is to categorize single digits as smaller or greater than 5, participants might create two action-trigger sets comprising all relevant digits (i.e., 1–4 and 6–9, respectively). Once these are established, a perceptual match between a target and an action trigger will suffice to trigger the appropriate response. According to this theory, response priming effects are caused by a perceptual match between the prime and an action trigger. Thus, even if a specific stimulus is not included in the target set, it can act as a nontarget prime if it is part of the action-trigger set (e.g., if only the target digits 1, 4, 6, and 9 are used, the digits 2 and 3, as well as 7 and 8, could be in the action-trigger set and, thus, serve as nontarget primes; Kunde et al., 2003). Thus, action-trigger theory provides an elegant explanation for priming effects caused by primes that were never presented for categorization; it does not assume elaborate processing of the masked prime itself.

However, in its original form, action-trigger theory cannot easily explain how nontarget primes from one of two broad target categories (e.g., positive vs. negative words, Klauer et al., 2007; animals vs. nonanimals, Van den Bussche et al., 2009; large vs. small objects, Pohl et al., 2010) cause priming effects. To account for these results, Kiesel et al. (2006) suggested that action triggers can be established at the level of semantic categories. Of course, that assumption acknowledges that masked primes can be processed beyond the perceptual level (see Van den Bussche et al., 2009).

Thus, to explain priming effects in a leave-one-out paradigm that uses primes and targets from broad emotional stimulus categories, one might need to assume some kind of processing beyond a simple stimulus-response binding. However, several additional factors influence whether primes are processed to a categorical level or not. Most important for the present context was a finding by Pohl et al. (2010), who used an object-size task (". . . smaller or larger than a shoebox?"). If the target set comprised only animals, only nontarget *animal* primes caused priming effects, but not *object* primes. If, however, the target set comprised both objects and animals, primes from both categories caused priming effects. This suggests that participants' task framing is important for the processing of the primes.

What does this mean for the leave-one-out paradigm and our research question? If the task is to categorize, for example, anger versus sadness expressions, then any feature that discriminates between angry and sad faces might be used by participants to solve the task. First of all, angry and sad faces are distinct schematic facial expressions, and a match to a mentally represented template might be sufficient to discriminate between the two (i.e., action triggers for the internal templates of angry and sad expressions would be set). Furthermore, it is plausible that affective connotations contribute to the distinction, and that action triggers are formed based on specific emotion aspects or categories. These connotations might be emotion-specific; however, as outlined above, easy-to-process features might be used for categorizations that are discriminative enough for the task at hand but not emotion-specific. For example, anger and sadness might be discriminated by arousal; alternatively, they might be discriminated on the basis of what we earlier termed relevance signals.

This implies that from the priming effects in the leave-one-out paradigm, we can infer which features were used for the task—because depending on which features are used for the task, primes should be more or less confusable. If, for example, the relevance signal is used in the anger or sadness task, fear primes should mimic sadness primes. If, however, arousal is used, fear primes should mimic anger primes. Finally, if an emotion-specific signal (e.g., a combination of arousal or relevance) is used, fear primes should be neutral with regard to the target response. Thus, by conducting several experiments with different negative emotions, we aimed to clarify which features are used across different target emotions, and whether these features are automatically processed in the left-out prime as well.

## Overview

We conducted four experiments, all using the three prime emotion categories of fear, anger, and sadness. In each experiment, only two of these emotion categories were used as target and response categories (i.e., anger, sadness in Experiment 1a; anger, fear in Experiment 1b; fear, sadness in Experiments 1c and Experiment 2). For each experiment, we calculated the focal priming effect, that is, the difference in RTs (and errors) between prime-target congruent conditions and incongruent conditions (defined as cases where prime and target mismatch but both represent active target categories). Note that such focal priming effects would already constitute evidence for priming effects caused by nontarget primes (see above), because (a) prime and target sets were distinct and (b) targets were semiprofile views whereas primes were frontal views (thus, preventing a simple perceptual matching of primes and targets).

In addition, we calculated two further priming effects ("left-out priming effects" from hereon) for each experiment. To this end, one prime category was replaced with the left-out prime category in the calculation of priming effects. This allowed us to test whether the left-out prime category mimics one of the focal prime categories. To elucidate: In Experiment 1a, anger and sadness were the focal categories; fear was the left-out category used as a prime but not a target or response category. The focal priming effect is given by the RT difference of *As* (read: anger targets primed by sadness primes) and *Sa* collapsed (i.e., the incongruent conditions) minus *Aa* and *Ss* collapsed (i.e., the congruent conditions). The left-out priming effects are given, first, by *Af* and *Sa* collapsed minus *Aa* and *Sf* collapsed (i.e., sadness is replaced by fear) and, second, by *As* and *Sf* collapsed minus *Af* and *Ss* collapsed (i.e., anger is replaced by fear).

Let us assume that there will be a significant focal priming effect, and let us assume—for the sake of the argument—that this focal priming effect is caused by a *relevance* signal that is triggered by anger primes but not fear and sadness primes. In this case, the first left-out priming effect should be similar to the focal priming effect, whereas the second left-out priming effect should be null. Alternatively, let us assume that the focal priming effect is caused by an *arousal* signal that is triggered by anger and fear primes but not sadness primes. In this case, the first left-out priming effect should be null, whereas the second left-out priming effect should be similar to the focal priming effect. Finally, if the focal priming effect is based on *specificity*, that is, emotion-specific prime evaluation, then fear primes should not bias the target categorization process—that is, they should neither slow down target processing as much as an incongruent target-category prime, nor speed up processing as much as a congruent prime. Therefore, both left-out priming effects should be roughly half the size of the focal priming effect because in both cases, only half the congruent and incongruent conditions are effective (i.e., those conditions with target-category primes). In terms of the effect calculations, this means that the minuend will contain only one not two prime-target incongruent elements and the subtrahend will contain only one not two prime-target congruent elements; the minuend will, thus, be smaller and the subtrahend greater, resulting in a difference reduction.

Figure 1 depicts the specific hypotheses for the priming effects in the three experiments according to the three hypotheses (i.e., relevance, arousal, and specificity hypotheses). Specifically, Figure 1A shows the expected patterns of priming effects across experiments if processing of masked primes can only convey the presence or absence of a *relevance* signal. The pattern expected in Experiment 1a was already detailed above. For Experiment 1b (i.e., anger and fear as target and response categories; sadness left out), we would expect exactly the same priming effect pattern as in Experiment 1a, because according to the relevance hypothesis, fear and sadness are interchangeable categories. For Experiment 1c, however, no priming effects would be expected at all, because the target categories (fear and sadness) cannot be distinguished by relevance.

Figure 1B shows the hypothesized pattern if the arousal hypothesis is true, that is, processing of masked primes can only convey the presence or absence of an *arousal* signal. In this case, anger and fear play interchangeable roles. Therefore, if one of these emotions is contrasted with the nonarousing category sadness and the other is left out (Experiments 1a and 1c), we would expect focal priming effects as well as a priming effect based on the left-out category and sadness, but no left-out priming effect based on the contrast of the two arousing emotion categories anger and fear. If, however, sadness is left out (i.e., Experiment 1b), no priming effects would be expected at all, because the target categories fear and anger cannot be distinguished by arousal.

Finally, Figure 1C illustrates the pattern of expected priming effects if all three categories of primes are processed at the level of specific emotion. In this case, only those primes that match one of the target categories would bias the target response. That is, we would expect focal priming effects in all experiments because all conditions that enter into the effect calculations would contribute. In this case, left-out category primes could not bias target responses because either an emotion type is triggered that is not among the target categories, or the left-out primes do not trigger any process because only target-category primes have this capability. In this scenario, the calculation of left-out priming effects is based half on effective (i.e., focal) primes and half on ineffective primes (i.e., the left-out category). Therefore, the two priming effects that are (partly) based on the left-out prime category should be roughly half the size of the focal priming effects.

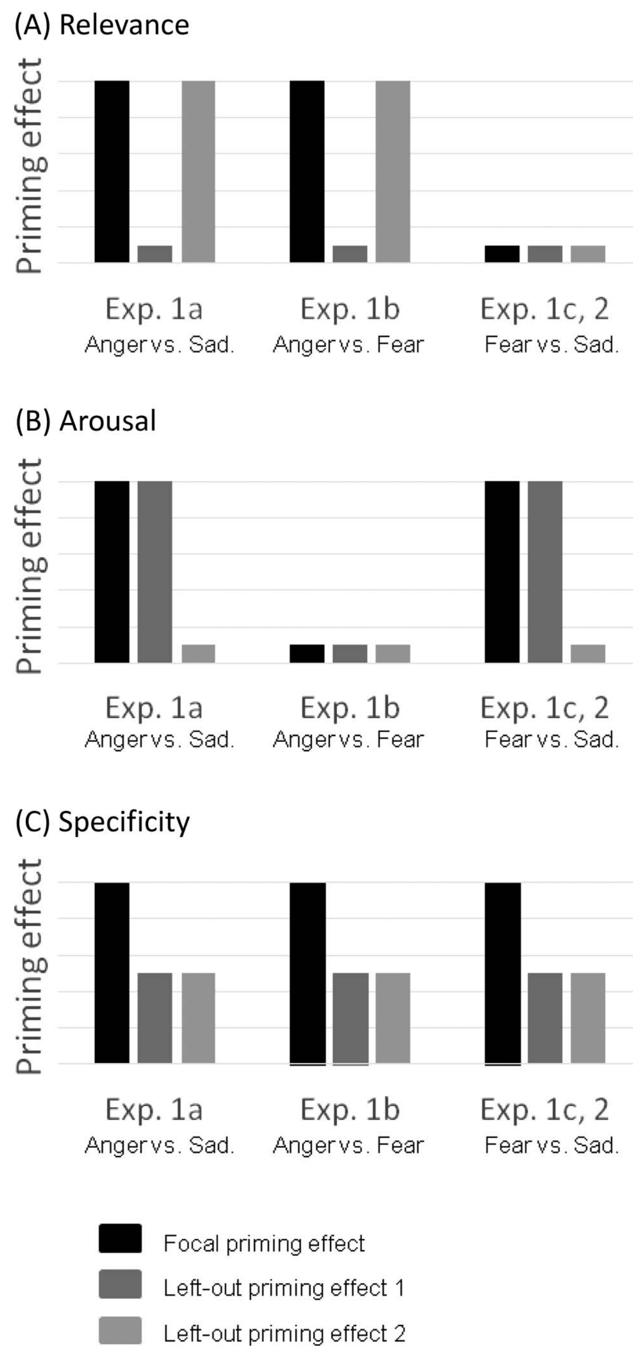


*Figure 1.* Schematic illustration of priming effects for the three experiments predicted by the three hypotheses. (The focal categories of each experiment are mentioned in the captions; left-out priming effect 1 [2] results if the focal prime emotion mentioned left [right] in the caption is replaced by the left-out primed category).

In addition to conventional statistics, we conducted diffusion-model analyses (Ratcliff, 1978; Voss, Rothermund, & Voss, 2004; Voss, Nagler, & Lerche, 2013) to corroborate the claim that priming effects are primarily based on response priming processes (Voss, Rothermund, Gast, & Wentura, 2013). These models make use of the full distribution of RTs associated with correct and incorrect responses to estimate a set of parameters that can be related to cognitive processes. Most important in the present context, Voss, Rothermund, et al. (2013) applied diffusion-model analyses to response priming (evaluative priming) and semantic priming (i.e., associated prime-target pairs) paradigms, and found a response priming "signature" in the model parameters.

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The basic idea of diffusion models is that the overall response time can be decomposed into a decisional and a nondecisional part. The decisional process in a binary choice task is characterized by continuous information sampling from a (potentially biased) starting point $z$. Through this continuous sampling process, evidence is accumulated until one of the two response criteria is met and a decision is made; this process is characterized by a drift rate $\nu$ (the slope of the evidence-accumulation process).[2] The parameter $t_0$ captures all nondecisional components of the response generation process. These processes may include predecisional (encoding) as well postdecisional (response) processes.

Voss, Rothermund, et al. (2013) argued that an account of evaluative priming effects in terms of response competition would predict that evaluative priming effects should be associated with a lower nondecision time $t_0$, whereas associative priming effects should be associated with larger drift rates ($\nu$). This was indeed what the authors found: Evaluative priming variations (i.e., whether targets were congruently or incongruently primed) consistently caused variations in $t_0$, whereas associative priming variations (i.e., whether targets were primed by an associatively related or unrelated prime) consistently caused variations in $\nu$. That is, presenting the prime "bread" briefly before the target "butter" in a lexical-decision task influences the information-accumulation process; the slope of the drift process is steeper. This does not hold if "murder" precedes "cockroach" in an evaluative decision task. The information-accumulation process triggered by "cockroach," which eventually leads to an internal decision "negative," is not influenced by the prime. However, the process of transforming the decision into an overt response is influenced by the prime, presumably by the prime evoking some response preparation (i.e., facilitative preparation of the correct response, as in the example, or preparation of the incorrect response in case of a target-incongruent prime).

For the emotion priming paradigm, the same considerations apply. The leave-one-out version of the emotion priming paradigm with its binary decision task is structurally equivalent to the evaluative decision task. Hence, it is the most plausible a priori hypothesis that we will find effects on the nondecision parameter ($t_0$), in line with the findings of Voss et al. (2013) for the evaluative priming task. However, it is conceivable that encoding facilitation processes do contribute as well. This is most apparent if we assume for a moment—counterfactually—that both prime and target faces would be presented in frontal view. In case of congruency, two emotion-prototypical expressions presented in brief succession might be integrated into a kind of "mental morph" that could be efficiently matched to the corresponding mental schema for the given emotion. Such a process might result in different drift rates for congruent and incongruent prime-target pairs. While we tried our best to preclude such perceptually based effects by presenting targets in half-profile views, we applied the diffusion model to more objectively assess potential encoding facilitation, and bolster the response priming interpretation of the emotion priming effects.

## Experiment 1

In this section, we report three experiments—Experiments 1a, 1b, and 1c—that all follow the same procedure and used the same priming conditions and materials. The only feature that was varied across experiments was the choice of the two target categories.

### Method

**Participants.** For all three experiments, we recruited nonpsychology undergraduate students from Saarland University, who participated for a remuneration of €8. All participants had normal or corrected-to-normal vision. In Experiment 1a, sample size was $N = 48$ (21 women, 27 men; age $Md = 22$ years, range: 18–29). In Experiment 1b, sample size was $N = 63$ (36 women, 27 men; age $Md = 23$ years, range: 18–34). In Experiment 1c, sample size was $N = 59$ (41 women, 18 men; age $Md = 23$ years, range: 19–34). Three further participants were excluded from analyses (two in Experiment 1b, one in Experiment 1c) because of extremely high error rates (i.e., greater than 40%).

For power calculations, we used the relevance priming effects (i.e., anger vs. sadness/fear) found in our previous studies using the emotion priming paradigm (Rohr et al., 2012; Wentura et al., 2017) as an anchor. The mean effect across four experiments was $d_Z = 0.33$. When planning the present series of experiments, we assumed that the binary choice task should produce less noise than the four-alternative choice task; moreover, the number of trials entering into a specific priming effect in the present experiments was larger than in the previous experiments. With power 1-$\beta$ = .80 ($\alpha$ = .05, one-tailed), the sample size of $N = 48$ (as in Experiment 1a) allowed us to detect effects of $d_Z = 0.36$. However, for Experiments 1b and 1c, we returned to the more conservative assumption of $d_Z = 0.33$ because both the relevance and arousal hypotheses predicted null effects for the focal comparisons (see Figure 1). To detect an effect of $d_Z = 0.33$ with power 1-$\beta$ = .80 ($\alpha$ = .05, one-tailed), a sample size of $N = 59$ is needed. Power calculations were done with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007).

**Design.** For all three experiments, we used a 3 (prime emotion: anger vs. sadness vs. fear) × 2 (target emotion: negative emotion 1 vs. negative emotion 2) design with both factors varied within-participants. In Experiment 1a (fear left out), the target emotions were anger and sadness. In Experiment 1b (sadness left out), the target emotions were anger and fear. Finally, in Experiment 1c (anger left out), the target emotions were fear and sadness.

**Materials.** We used the same stimuli as in our previous research (Rohr et al., 2012). Face stimuli were obtained from the Karolinska Directed Emotional Faces database (KDEF; Lundqvist, Flykt, & Öhman, 1998). To avoid perceptual priming effects, prime pictures depicted frontal views of the faces, whereas target pictures depicted semiprofile views. All images were set to a size of 200 × 200 pixels (approximately 63 × 63 mm). Primes were four angry, fearful, and sad expressions, respectively, all displayed by the same four individuals (2 men, 2 women). Prime faces were framed by a gray oval, leaving only the facial features visible and masking unrelated distracting features (e.g., hair). Targets were 10 angry, fearful, and sad expressions, respectively, displayed by another 10 individuals (5 men, 5 women). For the direct test of prime sensitivity (see Procedure), the profile views of the same individuals displaying neutral expressions were used as target stimuli. The masking picture was created by converting one addi-

[2] Figure C1 in Appendix C illustrates the diffusion model.

tional neutral face into a spatially quantized face mask, resulting in a face-like image with unidentifiable characteristics (Bachmann, Luiga, & Põder, 2005).

**Procedure.** Participants were seated at individual computers, separated by partition walls. The experiment was implemented in E-Prime (Version 1.2) on standard PCs with 17″ CRT monitors with a refresh rate of 85 Hz (i.e., minimum presentation duration was 11.8 ms); all instructions were given on the computer screen. Participants were informed that portrait images would be presented on the computer screen and that their task was to identify their emotional expressions. The two response options (out of "anger," "fear," and "sadness," depending on experiment) were assigned to the "S" and "Ö" keys of a German QWERTZ keyboard (corresponding to the "S" and ";" keys on a QWERTY keyboard) and marked with blue stickers. Assignment of emotions to response keys was counterbalanced across participants. Reminders of the response options were displayed in the left and right lower corners of the screen throughout the experiment. The beginning of a trial (see Figure 2) was signaled by a black fixation cross that was presented in the center of the gray screen for 306 ms. It was followed by the sequence of a forward mask presented for 106 ms, the prime presented for 24 ms (i.e., two refresh cycles), and the backward mask presented for 35 ms (i.e., three refresh cycles). The mask was directly overwritten by the target. The target remained on screen for a maximum of 500 ms but disappeared as soon as a response was given. We instructed participants to make fast but correct decisions and to respond before a deadline of 1,500 ms post target onset. In case of late responses, participants received feedback on the screen (i.e., "PLEASE RESPOND").

Initially, there were two blocks of 20 practice trials each; these trials contained no primes (i.e., the mask was presented instead of the prime). During practice, participants received error feedback in case of incorrect target responses (i.e., "ERROR!" appeared on the screen for 500 ms). In the main experiment, participants completed four blocks of 60 trials each (i.e., there were 240 priming task trials in total). Each block comprised 10 subblocks of six trials each, implementing the basic 2 (target emotion) × 3 (prime emotion) design. Each subblock presented six different prime and target stimuli, drawn randomly from the lists. Target repetitions at subblock borders were prevented.[3]

Subsequently, participants were given a funneled debriefing procedure to obtain a subjective measure of prime awareness. Participants were asked increasingly specific questions to explore their subjective awareness of primes (e.g., "Did you notice a flicker preceding the clearly visible portrait images?"; "Did you notice anything in the flicker? If so, what did you notice?").

Finally, participants completed the direct test of prime sensitivity, in which they were instructed to categorize the emotional expressions of the prime faces using the identical response keys as in the previous task, plus the space key for the third left-out emotion. Participants were informed that response time was irrelevant in this part of the experiment, and they were asked to do their best to discriminate the masked primes. To familiarize them with the new response key assignment, they were given 12 practice trials, in which each prime was shown once. The direct test also comprised 240 trials, and all presentation parameters were identical to the priming task, with the exception that target faces had neutral expressions and remained on the screen until a response was given.

## Results

All the data is openly accessible at osf.io/dxreu (Wentura & Rohr, 2018). We report all measures, manipulations, and exclusions for our studies. The mean RTs of correct trials served as the dependent variable of interest. Trials with RTs below 200 ms or RTs greater than 1.5 interquartile ranges above the third quartile with respect to the (experiment-wise) sample distribution of RTs were discarded (Tukey, 1977; see also Rohr et al., 2012; this led to exclusion of 4.7% of trials in Experiment 1a; 4.2% in Experiment 1b; 4.6% in Experiment 1c). Mean error rate was 10.8% ($SD$ = 5.5) in Experiment 1a; 16.4% ($SD$ = 7.9) in Experiment 1b; and 9.4% ($SD$ = 5.2) in Experiment 1c. Mean RTs and error rates are reported in Table 1.

**Response times.** As explained in detail above, for descriptive purposes we calculated three priming indices for each experiment (see Figure 3A): One priming index denotes the focal priming effect, that is, the priming effect resulting from the two emotion categories used as primes and targets. The remaining two priming indices (i.e., the left-out priming indices) result from contrasting each of the focal prime conditions with the left-out prime category.

We ran a 3 (prime emotion: left-out emotion vs. focal emotion 1 vs. focal emotion 2) × 2 (target emotion: focal emotion 1 vs. focal emotion 2) multivariate analysis of variance (MANOVA) for repeated measures (see O'Brien & Kaiser, 1985) with RTs as the dependent variable for each experiment. However, for reasons of conciseness we will solely report the interaction results in the main text (see Appendix A for a table including the main effect tests). In addition to the overall interaction test (with 2 $df_N$), we report two a priori orthogonal Helmert contrasts that answer two essential questions: (a) Is there a significant focal priming effect? This question is answered by the second Helmert interaction contrast, which is equivalent to the interaction test in the reduced 2 (prime emotion: focal emotion 1 vs. focal emotion 2) × 2 (target emotion: focal emotion 1 vs. focal emotion 2) ANOVA. (b) Is there a significant difference between the two left-out priming effects? This question is important because both the relevance and the arousal hypothesis predict significant differences between the left-out priming effects in two of three experiments (see Figure 1), whereas the specificity hypothesis predicts equal-sized left-out priming effects in all three experiments. The question is answered by the first Helmert interaction contrast, which is equivalent to the interaction in a 2 (prime emotion: left-out emotion vs. focal emotions collapsed) × 2 (target emotion: focal emotion 1 vs. focal emotion 2) ANOVA (i.e., this interaction contrast also corresponds to testing the difference between the two left-out priming effects as depicted in Figure 3A). As this analogy is not self-evident, we present the derivation in the Appendix B. Note that the two contrasts are independent; this would not hold if all three priming effects (i.e., the focal and the two left-out effects) were tested for deviation from zero, because the conditions entering into the calculation of the priming indices always have some overlap. (Nevertheless, for the sake of completeness and transparency, we report simple $t$ tests for the two left-out priming effects as well.)

[3] In Experiments 1b and 1c, a side effect of the algorithm preventing target repetitions was that some participants had an additional incomplete 11th sub-block in one or two blocks. Thus, these participants had between 40 and 42 trials per condition (instead of 40 for all conditions).

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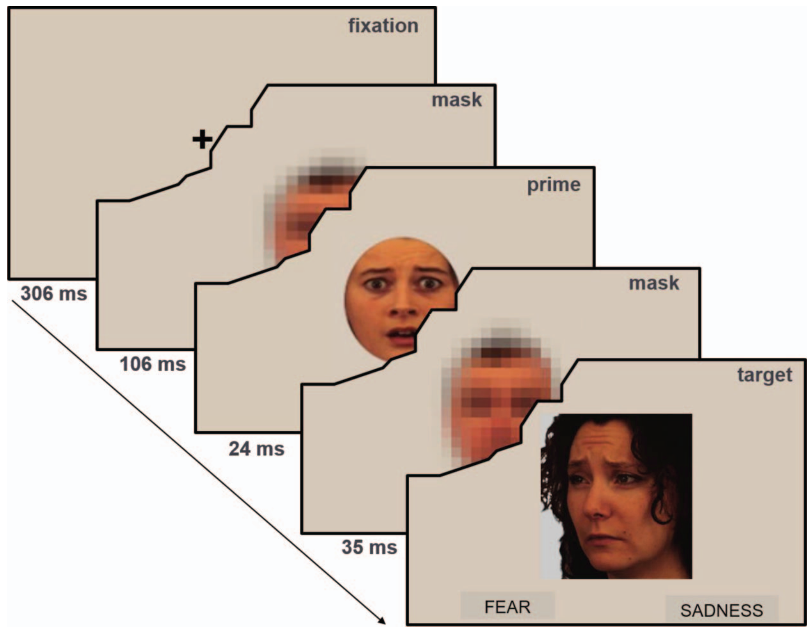


*Figure 2.* Schematic depiction of a priming trial (with the target task of Experiment 1c). See the online article for the color version of this figure.

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In Experiment 1a (fear left out), a 3 (prime emotion: fear vs. anger vs. sadness) × 2 (target emotion: anger vs. sadness) MANOVA for repeated measures with RTs as the dependent variable yielded a significant interaction effect, $F(2, 46) = 7.86$, $p = .001$, $\eta_p^2 = .255$. As expected, the second Helmert interaction contrast for the focal priming effect (i.e., anger vs. sadness; answering question [a] above) was significant, $F(1, 47) = 15.90$, $p < .001$, $\eta_p^2 = .253$ ($d_Z = 0.58$). The left-most bar referring to Experiment 1a in Figure 3A shows this effect. The first Helmert interaction contrast (fear vs. anger/sadness), testing whether the two left-out priming effects significantly differ (thus, answering question [b] above) was not significant, $F(1, 47) = 1.21$, $p = .277$, $\eta_p^2 = .025$. Figure 3A shows the two effects (the second and third bar referring to Experiment 1a). The priming effect based on sadness versus fear (with fear replacing anger in the focal formula) was associated with $t(47) = 1.18$, $p = .243$; the priming effect based on anger versus fear (with fear replacing sadness in the focal formula) was associated with $t(47) = 2.78$, $p = .008$.

In Experiment 1b (sadness left out), a 3 (prime emotion: sadness vs. anger vs. fear) × 2 (target emotion: anger vs. fear) MANOVA for repeated measures with RTs as the dependent variable was run; the overall interaction test just missed the criterion of significance, $F(2, 61) = 2.84$, $p = .066$, $\eta_p^2 = .085$. However, as expected a priori, the second Helmert contrast (anger vs. fear) was significant, $F(1, 62) = 5.75$, $p = .020$, $\eta_p^2 = .085$ ($d_Z = 0.30$). The left-most bar referring to Experiment 1b in Figure 3A shows this focal priming effect. The first contrast (sadness vs. anger/fear) was not significant, $F < 1$, indicating no difference between the left-out priming effects (see Figure 3A). The priming effect based on fear versus sadness (with sadness replacing anger in the focal formula) was associated with $t(62) = 1.41$, $p = .161$; the priming effect based on anger versus sadness (with sadness replacing fear in the focal formula) was associated with $t(62) = 1.13$, $p = .261$.

In Experiment 1c (anger left out), a 3 (prime emotion: anger vs. fear vs. sadness) × 2 (target emotion: fear vs. sadness) MANOVA for repeated measures with RTs as the dependent variable yielded the expected interaction, $F(2, 57) = 17.30$, $p < .001$, $\eta_p^2 = .378$. The second Helmert contrast (fear vs. sadness) was significant, $F(1, 58) = 35.16$, $p < .001$, $\eta_p^2 = .377$ ($d_Z = 0.77$). The left-most bar referring to Experiment 1c in Figure 3A shows this focal priming effect. The first Helmert contrast (anger vs. fear/sadness) was not significant, $F(1, 58) = 2.05$, $p = .158$, $\eta_p^2 = .034$. Figure 3A shows the two effects. The priming effect based on sadness versus anger (with anger replacing fear in the focal formula) was associated with $t(58) = 2.21$, $p = .031$; the priming effect based on

Table 1
*Mean Response Times in Milliseconds and Error Rates (in Parentheses; in %) as a Function of Prime Emotion, Target Emotion, and Experiment*

| Target | Prime: Fear | Prime: Anger | Prime: Sadness |
|---|---|---|---|
| Experiment 1a (fear left out) | | | |
| Anger | 583 (14.6) | **568 (10.8)** | **581 (13.9)** |
| Sadness | 589 (8.8) | **588 (9.3)** | **581 (7.4)** |
| Experiment 1b (sadness left out) | | | |
| Anger | **537 (16.2)** | **530 (14.5)** | 533 (14.9) |
| Fear | **551 (17.9)** | **553 (17.4)** | 551 (17.1) |
| Experiment 1c (anger left out) | | | |
| Fear | **513 (11.6)** | 515 (12.9) | **520 (12.1)** |
| Sadness | **512 (8.5)** | 497 (5.6) | **494 (5.7)** |
| Experiment 2 (anger left out) | | | |
| Fear | **515 (11.2)** | 523 (12.3) | **520 (11.3)** |
| Sadness | **514 (8.0)** | 504 (6.2) | **499 (6.7)** |

*Note.* The conditions that constitute the focal priming effect are presented in bold type.

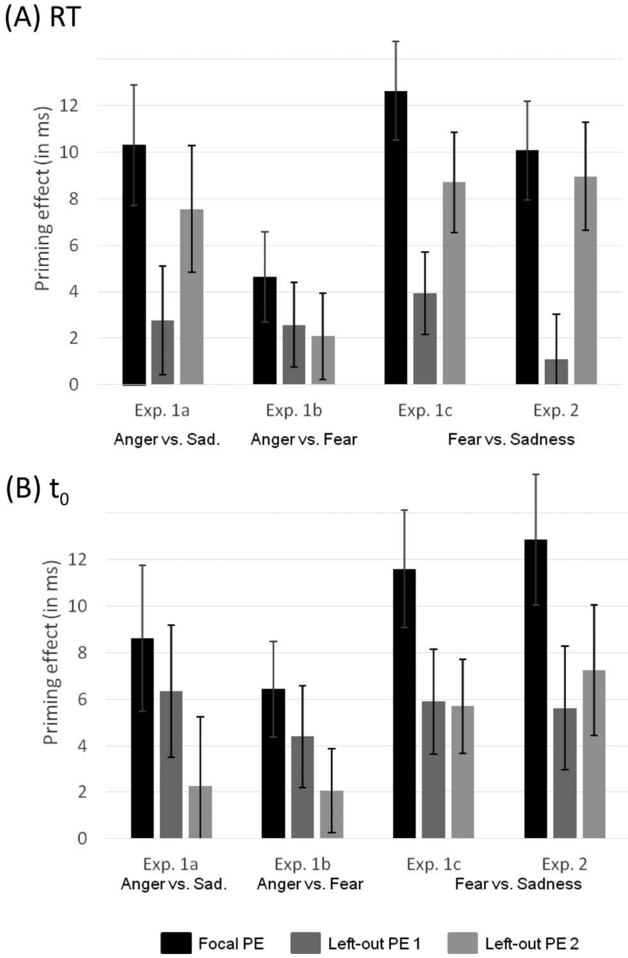


*Figure 3.* Priming effects for focal and left-out priming conditions (Experiments 1a–c and 2; whiskers are *SE*s; focal priming effects in black; left-out priming effect 1 [2] results if the focal prime emotion mentioned left [right] in the caption is replaced by the left-out primed category).

fear versus anger (with anger replacing sadness in the focal formula) was associated with $t(58) = 4.04$, $p < .001$.

Additionally, we conducted an across-experiments analysis by rearranging the conditions to a 3 (prime emotion: left-out emotion vs. focal emotion 1 vs. focal emotion 2) × 2 (target emotion: focal emotion 1 vs. focal emotion 2) design. A 3 (prime emotion) × 2 (target emotion) × 3 (experiment) MANOVA for repeated measures with experiment as a between-participants factor yielded a significant Prime × Target interaction, $F(2, 166) = 26.00$, $p < .001$, $\eta_p^2 = .239$, which was significantly moderated by experiment,[4] $F(4, 334) = 2.73$, $p = .029$, $\eta_p^2 = .032$.

The second Helmert contrast corresponding to the focal priming effect was significant, $F(1, 167) = 52.31$, $p < .001$, $\eta_p^2 = .239$ ($d_Z = 0.55$). It was moderated by experiment $F(2, 167) = 3.79$, $p = .025$, $\eta_p^2 = .043$. As the focal priming effect was significant in all experiments, we were faced with an ordinal interaction. Indeed, the focal priming effect was significantly smaller in Experiment 1b than in Experiment 1c, $F(1, 120) = 7.72$, $p = .006$ (i.e., $p < .05/3$ according to Bonferroni-Holm adjustment, which we adopted for these post hoc comparisons), $\eta_p^2 = .060$. The two remaining comparisons were not significant, $F(1, 109) = 3.20$, $p = .076$, $\eta_p^2 = .029$ (Experiment 1a vs. Experiment 1b), and $F < 1$ (Experiment 1a vs. Experiment 1c).

The first Helmert contrast, which tests for the difference between the two left-out priming effects, was not significant, $F(1, 167) = 2.17$, $p = .143$, $\eta_p^2 = .013$; it was not further moderated by experiment, $F < 1$.[5]

**Error rates.** Additionally, we analyzed error rates (see Table 1) to see whether there were any results at odds with the RT data. Inferential statistics from the MANOVAs can be found in Appendix A. To give a brief synopsis, Experiments 1a and 1c yielded significant overall interactions, Experiment 1b did not (see Appendix). Basically, these significant interactions were based on significant second Helmert contrasts, $F(1, 47) = 11.48$, $p = .001$, $\eta_p^2 = .196$ ($d_Z = 0.49$) for Experiment 1a, $F(1, 58) = 7.87$, $p = .007$, $\eta_p^2 = .119$ ($d_Z = 0.37$) for Experiment 1c. Both indicated a typical focal priming effect (i.e., fewer errors in congruent compared with incongruent conditions; see Table 1). The first Helmert contrast in Experiment 1a was not significant, $F(1, 47) = 2.39$, $p = .129$, $\eta_p^2 = .048$. Deviating from the RT analysis, the first Helmert contrast of Experiment 1c was significant, $F(1, 58) = 8.05$, $p = .006$, $\eta_p^2 = .122$. The priming effect contrasting anger with fear was significantly larger than the priming effect contrasting anger with sadness. This can be easily seen in Table 1, as the error rates were very similar across anger and sadness prime conditions.

**Diffusion model analyses.** RT distributions of the two response categories (e.g., anger vs. sadness in Experiment 1a) were entered into diffusion-model analyses using the *fast-dm-30* program (Voss & Voss, 2007; Voss, Voss, & Lerche, 2015). Parameter values were estimated individually for each participant. Drift rates ($v$) and nondecisional RT constants ($t_0$) were estimated separately for the different Prime × Target types. Finally, the relative starting point ($z_r$) was estimated for the different prime types; however, we did not expect starting point differences since the prime type does not predict the upcoming target type (see, e.g., Imhoff, Lange, & Germar, 2018, for a meaningful modulation of $z_r$). The three parameters that were allowed to vary between prime types ($t_0$, $v$, $z_r$) were entered in separate repeated-measurement analyses. Evaluation of model fit (as well as other details of the analyses) can be found in Appendix C. To foreshadow, as expected based on the evaluative priming results by Voss and colleagues (2013), we found clear-cut results for the nondecisional parameter $t_0$—that are essentially in line with the RT analyses reported

[4] For the three-way interaction, we report the $F$-approximation associated with the Pillai-Bartlett trace criterion (Olson, 1976).

[5] The across-experiments analysis has a slight ambiguity because we can assign the focal categories to the roles "focal emotion 1" (*fe1*) and "focal emotion 2" (*fe2*) in different ways, with the consequence that one emotion always has a split assignment (e.g., in the reported analysis anger is always *fe1* and sadness *fe2*, whereas fear is *fe1* for Experiment 1c and *fe2* for Experiment 1b. This ambiguity has no consequences for the overall test of the focal priming effect (i.e., Helmert contrast 2, and its moderation by experiment), but for the left-out priming effect (i.e., Helmert contrast 1, HE 1). The two alternative assignments yielded (a) $F < 1$ for HE 1 ($F(2, 167) = 1.71$, $p = .185$, $\eta_p^2 = .020$ for HE 1 × Experiment) and (b) $F(1, 167) = 2.65$, $p = .105$, $\eta_p^2 = .016$ for HE 1 ($F < 1$ for HE 1 × Experiment).

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above—and (almost) no significant results for drift rate ($v$) and relative starting point ($z_r$).

Table 2 shows the mean estimates for nondecision time $t_0$. In Experiment 1a (fear left out), a 3 (prime emotion: fear vs. anger vs. sadness) × 2 (target emotion: anger vs. sadness) MANOVA for repeated measures with $t_0$ as the dependent variable yielded a significant interaction, $F(2, 46) = 4.15$, $p = .022$, $\eta_p^2 = .153$. As expected, the second Helmert interaction contrast for the focal priming effect (i.e., anger vs. sadness) was significant, $F(1, 47) = 7.54$, $p = .009$, $\eta_p^2 = .138$ ($d_Z = 0.40$). Figure 3B shows this effect. The first Helmert interaction contrast (fear vs. anger/sadness), testing whether the two left-out priming effects significantly differ, was not significant, $F < 1$. The priming effect based on sadness versus fear (with fear replacing anger in the focal formula) was associated with $t(47) = 2.23$, $p = .030$; the priming effect based on anger versus fear (with fear replacing sadness in the focal formula) was associated with $t(47) = 0.76$, $p = .452$ (see Figure 3B).

In Experiment 1b (sadness left out), a 3 (prime emotion: sadness vs. anger vs. fear) × 2 (target emotion: anger vs. fear) MANOVA for repeated measures with $t_0$ as the dependent variable yielded a significant interaction, $F(2, 61) = 4.84$, $p = .011$, $\eta_p^2 = .137$. The second Helmert contrast (anger vs. fear) was significant, $F(1, 62) = 9.83$, $p = .003$, $\eta_p^2 = .137$ ($d_Z = 0.40$; see focal priming effect in Figure 3B). The first contrast (sadness vs. anger/fear) was not significant, $F < 1$, indicating no difference between the left-out priming effects. The priming effect based on fear versus sadness (with sadness replacing anger in the focal formula) was associated with $t(62) = 2.02$, $p = .048$; the priming effect based on anger versus sadness (with sadness replacing fear in the focal formula) was associated with $t(62) = 1.14$, $p = .260$ (see Figure 3B).

In Experiment 1c (anger left out), a 3 (prime emotion: anger vs. fear vs. sadness) × 2 (target emotion: fear vs. sadness) MANOVA for repeated measures with $t_0$ as the dependent variable yielded the expected interaction, $F(2, 57) = 10.45$, $p < .001$, $\eta_p^2 = .268$. The second Helmert contrast (fear vs. sadness) was significant, $F(1, 58) = 21.06$, $p < .001$, $\eta_p^2 = .266$ ($d_Z = 0.60$; see Figure 3B). The first Helmert contrast (anger vs. fear/sadness) was not significant, $F < 1$. The priming effect based on sadness versus anger (with anger replacing fear in the focal formula) was associated with $t(58) = 2.62$, $p = .011$; the priming effect based on fear versus anger (with anger replacing sadness in the focal formula) was associated with $t(58) = 2.82$, $p < .007$ (see Figure 3B).

Additionally, we conducted an across-experiments analysis by rearranging the conditions to a 3 (prime emotion: left-out emotion vs. focal emotion 1 vs. focal emotion 2) × 2 (target emotion: focal emotion 1 vs. focal emotion 2) design. A 3 (prime emotion) × 2 (target emotion) × 3 (experiment) MANOVA for repeated measures with experiment as a between-participants factor yielded a significant Prime × Target interaction, $F(2, 166) = 18.60$, $p < .001$, $\eta_p^2 = .183$, which was not significantly moderated by experiment, $F < 1$.

The second Helmert contrast corresponding to the focal priming effect was significant, $F(1, 167) = 36.51$, $p < .001$, $\eta_p^2 = .179$ ($d_Z = 0.46$). It was not significantly moderated by experiment $F(2, 167) = 1.12$, $p = .328$, $\eta_p^2 = .013$. The first Helmert contrast, which tests for the difference between the two left-out priming effects, was not significant, $F < 1$; it was not further moderated by experiment, $F < 1$.[6]

Table 3 shows the mean absolute-value estimates for the drift parameter $v$.[7] In Experiment 1a, a 3 (prime emotion) × 2 (target emotion) MANOVA for repeated measures yielded a nonsignificant interaction, $F(2, 46) = 1.13$, $p = .332$, $\eta_p^2 = .047$ ($F(1, 47) = 1.35$, $p = .252$, $\eta_p^2 = .028$ for the first Helmert contrast; $F(1, 47) = 1.64$, $p = .207$, $\eta_p^2 = .034$ for the second Helmert contrast). In Experiment 1b, a 3 (prime emotion) × 2 (target emotion) MANOVA for repeated measures also yielded a nonsignificant interaction, $F < 1$ ($F < 1$ for both Helmert contrasts). In Experiment 1c, again, a 3 (prime emotion) × 2 (target emotion) MANOVA for repeated measures yielded a nonsignificant interaction, $F(2, 57) = 1.28$, $p = .286$, $\eta_p^2 = .043$ ($F(1, 58) = 2.60$, $p = .112$, $\eta_p^2 = .043$ for the first Helmert contrast; $F < 1$ for the second contrast). Thus, by and large and as expected, the primes did not moderate the drift rates.

However, despite the nonsignificance of these results, the drift-rate analyses did yield one specific finding worth noting (see Table 3). Namely, the two left-out priming effects in Experiments 1a and 1c, which are based on the prime contrast anger versus fear, were numerically positive with a potentially nontrivial mean/*SE* ratio. Indeed, an across-experiments analysis showed this priming effect to be associated with $F(1, 105) = 4.31$, $p = .040$, $\eta_p^2 = .043$ ($d_Z = 0.20$; $F < 1$ for the moderation by experiment).

Finally, we allowed for prime-specific relative starting points ($z_r$; see Table 4) in the diffusion analyses. As expected, a 3 (prime

Table 2
*Mean Nondecisional Parameter Estimates (t0) in Milliseconds as a Function of Prime Emotion and Target Emotion, and Priming Effects Based on t0 (SEs in Parentheses)*

| | Prime | | |
|---|---|---|---|
| Target | Fear | Anger | Sadness |
| Experiment 1a (fear left out) | | | |
| Anger | 442 | **434** | **445** |
| Sadness | 470 | **467** | **461** |
| Experiment 1b (sadness left out) | | | |
| Anger | **423** | **416** | 420 |
| Fear | **432** | **437** | 433 |
| Experiment 1c (anger left out) | | | |
| Sadness | **418** | 406 | **401** |
| Fear | **411** | 411 | **417** |
| Experiment 2 (anger left out) | | | |
| Sadness | **413** | 406 | **397** |
| Fear | **403** | 411 | **413** |

*Note.* Fast-dm analyzes RTs in second units and returns $t_0$ parameters accordingly (see, e.g., Voss, Nagler, & Lerche, 2013). For convenience, we multiplied the original $t_0$ values by 1,000. The *SD*s of the 2 × 3 $t_0$ mean values ranged from 55–68 (Experiment 1a), 50–61 (Experiment 1b), 52–68 (Experiment 1c), and 58–72 (Experiment 2). The conditions that constitute the focal priming effects are presented in bold type.

[6] This result—that is, that the test for a difference between the two left-out priming effects as well as the moderation of this effect by experiment were associated with $F < 1$—held for all assignments of focal categories to the roles "focal emotion 1" and "focal emotion 2" (see Footnote 5).

[7] Drift rates are positive for one response category and negative for the other response category. Accordingly, estimated drift rates are positive for one target category and negative for the other target category.

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Table 3
*Mean Absolute Values of Drift-Rate Parameter Estimates (v) as a Function of Prime Emotion and Target Emotion, and Priming Effects Based on (Absolute) v (SEs in Parentheses)*

| | Prime | | | Priming effect ($v$)[a] | | |
|---|---|---|---|---|---|---|
| Target | Fear | Anger | Sadness | Foc | $Lo_1$ | $Lo_2$ |
| Experiment 1a (fear left out) | | | | | | |
| Anger | 2.53 | **2.91** | **2.69** | .14 | −.03 | .17 |
| Sadness | 2.68 | **2.72** | **2.77** | [.11] | [.09] | [.12] |
| Experiment 1b (sadness left out) | | | | | | |
| Anger | **2.74** | **2.77** | 2.75 | −.03 | .01 | −.04 |
| Fear | **2.09** | **2.18** | 2.18 | [.09] | [.09] | [.09] |
| Experiment 1c (anger left out) | | | | | | |
| Sadness | **3.81** | 4.05 | **3.92** | .04 | −.11 | .15 |
| Fear | **2.79** | 2.73 | **2.83** | [.09] | [.08] | [.10] |
| Experiment 2 (anger left out) | | | | | | |
| Sadness | **3.73** | 3.89 | **3.67** | −.09 | −.11 | .02 |
| Fear | **2.66** | 2.77 | **2.77** | [.11] | [.10] | [.09] |

*Note.* The *SD*s of the 2 × 3 $v$ mean values ranged from .68–.98 (Experiment 1a), .86–1.06 (Experiment 1b), .92–1.09 (Experiment 1c), and .92–1.16 (Experiment 2); the *SD*s of the three $z_r$ mean values ranged from .056–.078 (Experiment 1a), .061–.063 (Experiment 1b), .065–.069 (Experiment 1c), and .065–.069 (Experiment 2). The conditions that constitute the focal priming effects are presented in bold type.
[a] Focal priming effect (Foc) = mean(absolute $v$ of incongruent cells) − mean(absolute $v$ of congruent cells); $Lo_1$, $Lo_2$: left-out priming effects; For $Lo_1$ ($Lo_2$), the left-out prime category replaces the left (right) focal category in calculating the priming effect. Differences between $v$ columns and priming effect columns are because of rounding.

emotion: left-out vs. focal 1 vs. focal 2) MANOVA for repeated measures with $z_r$ as the dependent variable yielded nonsignificant results for all experiments, all $F < 1$, except $F(2, 46) = 1.13$, $p = .331$, $\eta_p^2 = .047$ for the overall test in Experiment 1a; $F(1, 47) = 1.95$, $p = .170$, $\eta_p^2 = .040$ for the first Helmert contrast in Experiment 1a; and $F(1, 62) = 1.82$, $p = .182$, $\eta_p^2 = .029$ for the second Helmert contrast in Experiment 1b.

**Subjective prime awareness.** In Experiment 1a, only four out of the 48 participants spontaneously made a reference to the prime images. During the funneled debriefing, an additional six participants referred to other face-like images, and three further participants referred to the pixelated face-like mask. In Experiment 1b, four participants (out of 63) spontaneously referred to face primes; four additional participants mentioned blurry or pixelated images. In the debriefing, 14 participants claimed to have recognized something in the flickering, but only eight participants referred to emotional faces as content. The other participants mentioned "a neutral face," "a blurry head," or other unspecified content. Similarly, in Experiment 1c, eight participants (out of 59) spontaneously mentioned images appearing before the targets. In the debriefing, 22 participants claimed to have perceived something in the flickers; however, only 14 participants made clear reference to faces when questioned about what they had perceived. Other comments were "a flickering," "it seemed as if the program ran through several images until it stopped at one," or "I think something like faces or schematic faces, but I could not recognize them."

Table 4
*Mean Relative Starting Point Estimates ($Z_R$) as a Function of Prime Emotion and Experiment; Threshold Separation a and SDs of $T_O$ as a Function of Experiment*

| | $z_r$ | | | | |
|---|---|---|---|---|---|
| Experiment | Fear | Anger | Sadness | $a$ | $st_0$ |
| Experiment 1a (fear left out) | .452 | .462 | .471 | .878 | .174 |
| Experiment 1b (sadness left out) | .474 | .461 | .471 | .793 | .170 |
| Experiment 1c (anger left out) | .472 | .478 | .478 | .783 | .157 |
| Experiment 2 (anger left out) | .488 | .485 | .472 | .809 | .150 |

*Note.* The *SD*s of the three $z_r$ mean values range from .056–.078 (Experiment 1a), .061–.063 (Experiment 1b), .065–.069 (Experiment 1c), and .065–.069 (Experiment 2). Parameters $a$ and $st_0$ were held constant across conditions. The *SD*s of the $a$ mean values were .108 (Experiment 1a), .114 (Experiment 1b), .116 (Experiment 1c), and .105 (Experiment 2); the *SD*s of the $st_0$ mean values were .050 (Experiment 1a), .045 (Experiment 1b), .054 (Experiment 1c), and .048 (Experiment 2).

**Objective prime awareness.** Mean response frequencies in the direct test are listed in Table 5. Cohen's κ served as an overall index of prime awareness (Cohen, 1960). Kappa is zero if the sum of the frequencies in the diagonal cells corresponds to the expected value derived from the table marginals (i.e., chance performance); κ is one if the observed relative frequencies along the diagonal are one (i.e., perfect recognition). Mean values of κ were $\kappa = .21$ ($SD = .18$) for Experiment 1a, $\kappa = .13$ ($SD = .17$) for Experiment 1b, and $\kappa = .19$ ($SD = .18$) for Experiment 1c. All were significantly above zero, all $|ts|(47–62) > 6.00$, $ps < .001$. (The difference between experiments missed the criterion of significance, $F(2, 167) = 2.99$, $p = .053$, $\eta_p^2 = .035$.) That is, prime awareness in the direct test was better than chance.

To ascertain whether or not the priming results depend on prime awareness (as assessed by the direct test), we regressed the focal priming difference of each participant on κ (Experiments 1a to 1c combined; see Figure 4). The intercept of this regression can be interpreted (with some caution; see, e.g., Klauer, Greenwald, & Draine, 1998) as an estimate of priming when the index of direct prime awareness equals zero (Greenwald, Klinger, & Schuh, 1995, applied this rationale to subliminal priming). The intercept of the

Table 5
*Mean Response Frequencies (SDs in Parentheses) in the Direct Prime Recognition Test*

| Response | Prime | | |
|---|---|---|---|
| | Fear | Anger | Sadness |
| Experiment 1a (fear left out) | | | |
| Fear | **37.9 (16.9)** | 12.5 (7.8) | 12.1 (8.9) |
| Anger | 27.5 (13.8) | **27.1 (14.1)** | 19.8 (11.9) |
| Sadness | 14.6 (8.2) | 40.4 (15.7) | **48.0 (16.7)** |
| Experiment 1b (sadness left out) | | | |
| Fear | **34.9 (17.9)** | 17.2 (11.8) | 17.7 (12.3) |
| Anger | 26.4 (13.0) | **23.6 (12.5)** | 20.3 (10.2) |
| Sadness | 18.7 (12.9) | 39.2 (14.8) | **42.0 (15.7)** |
| Experiment 1c (anger left out) | | | |
| Fear | **34.8 (19.1)** | 11.4 (11.9) | 10.2 (10.4) |
| Anger | 31.2 (18.5) | **25.7 (17.8)** | 20.5 (17.1) |
| Sadness | 14.0 (10.7) | 42.9 (19.0) | **49.3 (19.3)** |
| Experiment 2 (anger left out) | | | |
| Fear | **26.1 (14.5)** | 16.3 (11.1) | 17.2 (11.5) |
| Anger | 30.1 (14.7) | **22.2 (14.1)** | 20.0 (13.0) |
| Sadness | 23.9 (16.6) | 41.5 (16.1) | **42.7 (16.0)** |

*Note.* The diagonal in bold font indicates the mean frequencies of correct prime detection; columns add to marginals of 80 (i.e., the number of trials per condition).

regression was indeed significant, $b_0 = 6.15$, $t(167) = 3.51$, $p < .001$. Moreover, priming effects slightly increased with increasing awareness, as shown by the significant slope, $b_1 = 17.30$, $t(167) = 2.44$, $p = .016$.[8]

Inspection of Table 5 shows that (a) prime awareness does not seem to be equal across the three emotions, and (b) the numbers in the nondiagonal cells do not seem uniformly distributed. To address the first point, we calculated the unbiased hit rates (corrected for chance; $H_{Uc}$) for each emotion (Wagner, 1993). The (uncorrected) unbiased hit rate is simply the product of two relative frequencies: the observed frequency in a given diagonal cell divided by the corresponding row marginal and the same frequency divided by the corresponding column marginal. It is zero if the frequency is zero; it is one if the given stimulus type is always correctly identified and the corresponding response category is always correctly applied. To correct for chance responding, we subtracted the expected relative frequency derived from the marginals, such that a $H_{Uc} = 0$ denotes random responding (Wagner, 1993). The range of corrected unbiased hit rates was $H_{Uc} = .13–.19$ (*SD*s = .13–.19), $|ts|(47–62) > 8.07$, $ps < .001$, $d_Z = 1.01–1.16$, for sadness, and $H_{Uc} = .18–.24$ (*SD*s = .25–.32), $|ts|(47–62) > 5.55$, $ps < .001$, $d_Z = 0.70–0.92$, for fear. Thus, sadness and fear primes were clearly categorized above chance level, as all tests were significant (applying Bonferroni-Holm adjustment). This did not hold for anger: although the corrected unbiased hit rate in Experiment 1a was significantly above zero, $H_{Uc} = .04$ ($SD = .11$), $t(47) = 2.57$, $p = .013$ (i.e., $p < .05/3$, applying Bonferroni-Holm correction), $d_Z = 0.37$, the mean values of Experiments 1b and 1c failed to reach significance, $H_{Uc} = .02$ ($SD = .07$), $t(62) = 1.75$, $p = .085$, $d_Z = 0.22$, for Experiment 1b, and $H_{Uc} = .02$ ($SD = .09$), $t(57) = 1.40$, $p = .167$, $d_Z = 0.18$, for Experiment 1c.

With regard to the second point (i.e., the nonuniform distribution of nondiagonal cell frequencies), we can descriptively state that a fear prime is rarely categorized as sad, and that anger and sadness primes are rarely categorized as fearful. However, confusions between fear and anger responses arose for fear primes, and confusion between anger and sadness responses arose for anger and sadness primes.

## Discussion

In three experiments with different left-out prime emotions (i.e., fear in Experiment 1a, sadness in Experiment 1b, anger in Experiment 1c), we found the following results: the focal priming effect was significant in each experiment; this is the conventional priming effect based on the two prime emotions that also formed the response set. This result is noteworthy in itself because it adds to the small number of studies reporting response priming effects with marginally perceptible primes that are nontarget primes (i.e., prime stimuli that are never categorized in the target task, as primes and targets are drawn from different sets; see above). The two left-out priming effects—that is, the priming effects calculated by replacing either the first or the second focal prime emotion with the prime emotion that was not part of the response set—were not significantly different from each other.

The diffusion model analyses clearly corroborate the claim that the processes involved in the leave-one out paradigm map onto the processes involved in response priming (Voss, Rothermund, et al., 2013): Only the nondecisional parameter $t_0$ was affected by the Prime × Target interaction; there was (almost) no evidence for a moderation of drift rate (or the relative starting point). Moreover, analyses of the $t_0$ parameter corroborated the RT analyses: There were significant focal priming effects and no statistically reliable difference between left-out priming effects. Note that even the slight imbalance in focal priming effects in the RT analyses (i.e., that the effect in Experiment 1b was significantly smaller than the effect in Experiment 1c) was absent in the analyses of $t_0$.

There was, however, one obvious divergence between the analyses of RTs and $t_0$, relating to the variations in left-out priming effects. For RTs, the left-out priming effects based on the anger versus fear contrast (i.e., the right-most bars in Figure 3A for Experiments 1a and 1c, respectively) were relatively large. This asymmetry vanished (Experiment 1c) or reversed (Experiment 1a) in the analyses of the $t_0$ parameter. Of potential interest to readers, the exploratory results from the drift rate analysis showed that the anger versus fear contrast of RTs in Experiments 1a and 1c was mirrored in the drift parameter. We will return to this issue in the General Discussion.

By and large, the pattern of mean response times and the $t_0$ parameter is in line with the assumption that primes are involuntarily categorized at the level of the specific emotion: primes that belong to the task-relevant response set facilitate the target decision in case of prime-target congruence, and/or impede the target decision in case of incongruence. By contrast, the left-out prime behaves like a neutral prime.

[8] The same results (i.e., significant intercept as well significant slope) emerged in a regression analysis following the improved method proposed by Klauer, Draine, and Greenwald (1998), which accounts for measurement error in the predictor (i.e., direct test performance) that biases the intercept test.

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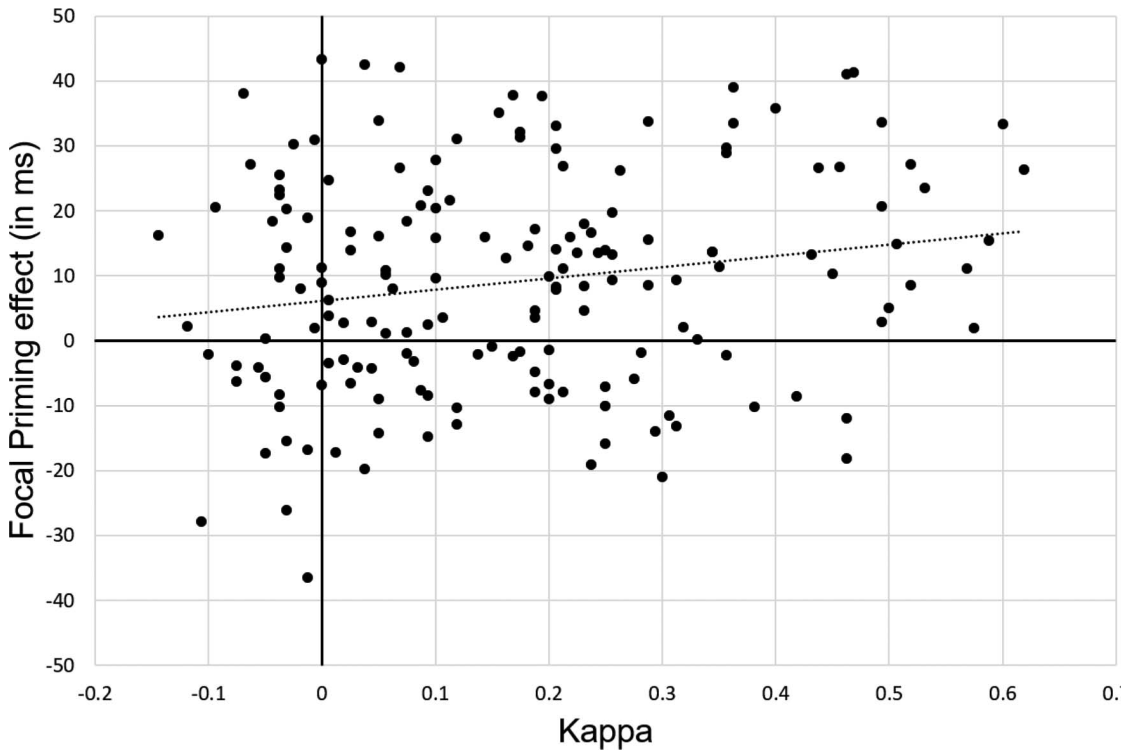


*Figure 4.* Focal priming difference (in milliseconds) plotted against direct effect (κ; Experiments 1a to 1c).

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Although direct prime awareness was relatively low in Experiments 1a to c, we aimed to replicate Experiment 1c with prime presentation parameters that should reduce prime awareness even further, to make sure that the observed pattern of findings can be observed under nonconscious processing conditions.

## Experiment 2

### Method

**Participants.** We recruited nonpsychology undergraduate students from Saarland University, who participated for a remuneration of €8. All participants had normal or corrected-to-normal vision. Sample size was $N = 60$ (38 women, 22 men; age $Md = 23$ years, range: 18–30).

**Design, materials, and procedure.** Design, materials, and procedure were identical to Experiment 1c, apart from the following changes: The refresh rate of the CRT monitors was now 100 Hz. The forward mask was presented for 100 ms, the prime was presented for 20 ms (i.e., 2 refresh cycles), and the backward mask was presented for 30 ms (i.e., 3 refresh cycles). Thus, prime duration was reduced from 24 to 20 ms, and the prime-target onset asynchrony was reduced from 59 to 50 ms.

### Results

Outlier criteria were identical to Experiment 1 (5.2% of all trials excluded). Mean error rate was 9.3% ($SD = 6.4$). Mean RTs and errors rates are reported in Table 1.

**Response times.** As in Experiment 1, for descriptive purposes we calculated three priming indices for each experiment (see Figure 3A). With regard to inferential statistics (see again Appendix A for main effects), a 3 (prime emotion: anger vs. fear vs. sadness) × 2 (target emotion: fear vs. sadness) MANOVA for repeated measures with RTs as the dependent variable yielded the expected interaction, $F(2, 58) = 11.65$, $p < .001$, $\eta_p^2 = .287$. The second Helmert interaction contrast (fear vs. sadness) was significant, $F(1, 59) = 22.33$, $p < .001$, $\eta_p^2 = .275$ ($d_Z = 0.61$). Figure 3A shows this focal priming effect. In contrast to Experiment 1c, the first Helmert interaction contrast (anger vs. fear/sadness) was significant as well, $F(1, 59) = 4.50$, $p = .038$, $\eta_p^2 = .071$. Figure 3A shows the two effects. The priming effect based on sadness versus anger (with anger replacing fear in the focal formula) was associated with $t(59) = 0.57$, $p = .573$; the priming effect based on fear versus anger (with anger replacing sadness in the focal formula) was associated with $t(59) = 3.86$, $p < .001$.

Additionally, we calculated a 3 (prime emotion: anger vs. fear vs. sadness) × 2 (target emotion: fear vs. sadness) × 2 (experiment: Experiment 1c vs. Experiment 2) MANOVA for repeated measures with RTs as the dependent variable, with experiment as a between-participants variable. The analysis yielded a significant Prime × Target interaction, $F(2, 116) = 28.64$, $p < .001$, $\eta_p^2 = .331$, which was not significantly moderated by experiment, $F < 1$. The second Helmert contrast was significant, $F(1, 117) = 56.76$, $p < .001$, $\eta_p^2 = .327$ ($d_Z = 0.69$), indicating a focal priming effect. The contrast was not moderated by experiment, $F < 1$. The first Helmert contrast was also significant,

$F(1, 117) = 6.41$, $p = .013$, $\eta_p^2 = .052$, indicating a difference between the two left-out priming effects; the contrast was not further moderated by experiment, $F < 1$.

**Error rates.** The analysis of error rates (see Table 1 for the descriptive statistics and Appendix A for the MANOVA results) yielded the following picture. The overall interaction just missed the criterion of significance (see Appendix A). The second Helmert contrast was not significant, $F(1, 59) = 1.28$, $p = .263$, $\eta_p^2 = .021$ ($d_Z = 0.15$), although the observed numerical differences were in the direction of a typical focal priming effect (see Table 1). The first Helmert contrast (anger vs. fear/sadness) was significant, $F(1, 59) = 4.90$, $p = .031$, $\eta_p^2 = .077$. As in Experiment 1c, the priming effect with anger replacing sadness was significantly larger than the priming effect with anger replacing fear.

**Diffusion-model analyses.** Diffusion-model analyses were conducted in the same way as for Experiments 1a to 1c. To foreshadow, results were largely comparable with those obtained in the preceding experiments. Table 2 shows the mean estimates for the nondecisional parameter $t_0$. A 3 (prime emotion: fear vs. anger vs. sadness) × 2 (target emotion: anger vs. sadness) MANOVA for repeated measures with $t_0$ as the dependent variable yielded a significant interaction, $F(2, 58) = 10.34$, $p < .001$, $\eta_p^2 = .263$. As expected, the second Helmert interaction contrast for the focal priming effect (i.e., anger vs. sadness) was significant, $F(1, 59) = 21.04$, $p < .001$, $\eta_p^2 = .263$ ($d_Z = 0.59$; see Figure 3B). The first Helmert interaction contrast (fear vs. anger/sadness), testing whether the two left-out priming effects significantly differed, was not significant, $F < 1$. The priming effect based on sadness versus anger (with anger replacing fear in the focal formula) was associated with $t(59) = 2.11$, $p = .039$; the priming effect based on fear versus anger (with anger replacing sadness in the focal formula) was associated with $t(59) = 2.58$, $p = .012$ (see Figure 3B).

An across-experiments analysis comparing Experiments 1c and 2 yielded a significant Prime × Target interaction, $F(2, 116) = 20.81$, $p < .001$, $\eta_p^2 = .264$, which was not significantly moderated by experiment, $F < 1$. The second Helmert contrast was significant, $F(1, 117) = 41.91$, $p = .008$, $\eta_p^2 = .264$ ($d_Z = 0.60$), indicating a focal priming effect. The contrast was not moderated by experiment, $F < 1$. The first Helmert contrast was not significant, $F < 1$; the contrast was not moderated by experiment, $F < 1$.

Table 3 shows the absolute-value estimates for the drift rate parameter $\nu$. A 3 (prime emotion) × 2 (target emotion) MANOVA for repeated measures with absolute $\nu$ as the dependent variable yielded a nonsignificant interaction, $F < 1$; both Helmert contrasts were likewise nonsignificant, $F < 1$. An across-experiments analysis comparing Experiment 1c and 2 yielded a nonsignificant Prime × Target interaction, $F(2, 116) = 1.62$, $p = .202$, $\eta_p^2 = .027$, which was not significantly moderated by experiment, $F < 1$. The second Helmert contrast was nonsignificant, $F < 1$ ($F < 1$ for the moderation by experiment). The first Helmert contrast also missed the criterion of significance, $F(1, 117) = 3.13$, $p = .080$, $\eta_p^2 = .026$ ($F < 1$ for the moderation by experiment). Thus, as expected, by and large we found no moderation of drift rates by the primes.

Exploratory follow-up analyses to the first Helmert contrast showed that the left-out priming effect for anger versus sadness was numerically negative, $F(1, 117) = 2.85$, $p = .094$, $\eta_p^2 = .024$ ($F < 1$ for the moderation by experiment), whereas the left-out priming effect for anger versus fear was numerically positive, $F(1, 117) = 1.65$, $p = .202$, $\eta_p^2 = .014$ ($F < 1$ for the moderation by experiment). Potentially more elucidating were follow-up analyses comparing the drift rates regarding anger versus fear/sadness for the two response modes. For the sadness response, drift rates were significantly larger for anger than for fear or sadness combined, $F(1, 117) = 4.24$, $p = .042$, $\eta_p^2 = .035$ ($F < 1$ for the moderation by experiment); for the fear response, there were no differences, $F < 1$ ($F < 1$ for the moderation by experiment).

Table 4 shows prime-specific relative starting points ($z_r$). As expected, a MANOVA for repeated measures yielded a nonsignificant overall result, $F < 1$ ($F < 1$ for the first Helmert contrast; $F(1, 59) = 1.64$, $p = .206$, $\eta_p^2 = .027$ for the second Helmert contrast).

**Subjective prime awareness.** Only four participants (out of 60) spontaneously mentioned face-like images; nine further participants mentioned a flickering or pixelated faces before the actual target. In the debriefing, 19 participants claimed to have detected something in the flickering. Again, the majority of participants were unsure and made reference to "something pixelated, maybe a face" or similar; only seven participants mentioned other face images.

**Objective prime awareness.** Mean response frequencies in the direct test are listed in Table 5.[9] Mean κ was $\kappa = .07$ ($SD = .13$), which is still above zero, $t(56) = 4.08$, $p < .001$. Thus, prime awareness in the direct test was again better than chance. However, the comparison with Experiment 1c showed a significant reduction of prime awareness in Experiment 2, $t(103.0) = 3.89$, $p < .001$, $d = .74$ (Figure 5).

We regressed the focal priming difference on κ (see Figure 4). The intercept of the regression was significant, $b_0 = 6.96$, $t(55) = 2.91$, $p = .005$, as was the slope coefficient, $b_1 = 35.70$, $t(54) = 2.14$, $p = .037$.[10] Moreover, restricting the analysis of the priming effect to participants with κ values that do not deviate significantly from zero ($n = 37$) still yielded a significant priming effect, $t(36) = 2.46$, $p = .019$, $d_Z = 0.40$.

We calculated the unbiased hit rates (corrected for chance; $H_{Uc}$) for each emotion (Wagner, 1993). Corrected unbiased hit rates were $H_{Uc} = .07$ ($SD = .09$), $t(56) = 6.14$, $p < .001$, $d_Z = 0.81$, for sadness, and $H_{Uc} = .09$ ($SD = .18$), $t(56) = 3.95$, $p < .001$, $d_Z = 0.52$, for fear. Thus, as in Experiments 1a through 1c, sadness and fear were clearly categorized above chance level, as all tests were significant (applying Bonferroni-Holm adjustment). Again, this did not hold for anger: the corrected unbiased hit rate was $H_{Uc} = -.01$ ($SD = .06$), $t(56) = -0.727$, $p = .471$, $d_Z = 0.10$.

## Discussion

By and large, Experiment 2 replicated the results found in Experiment 1c. However, there were two noteworthy aspects: First, as expected given the shorter prime duration, direct detection performance was significantly reduced compared with Experiment 1c. However, this reduction was *not* accompanied by a reduction

[9] For three participants, direct test data were incomplete because of a technical failure.

[10] Results from the improved regression analysis approach proposed by Klauer, Draine, and Greenwald (1998) cannot be reported because the *SE*s could not be computed due to a singular Fisher information matrix. This can happen if the direct measure reflects mostly measurement error variance (for a discussion see Klauer, Draine, & Greenwald, 1998).

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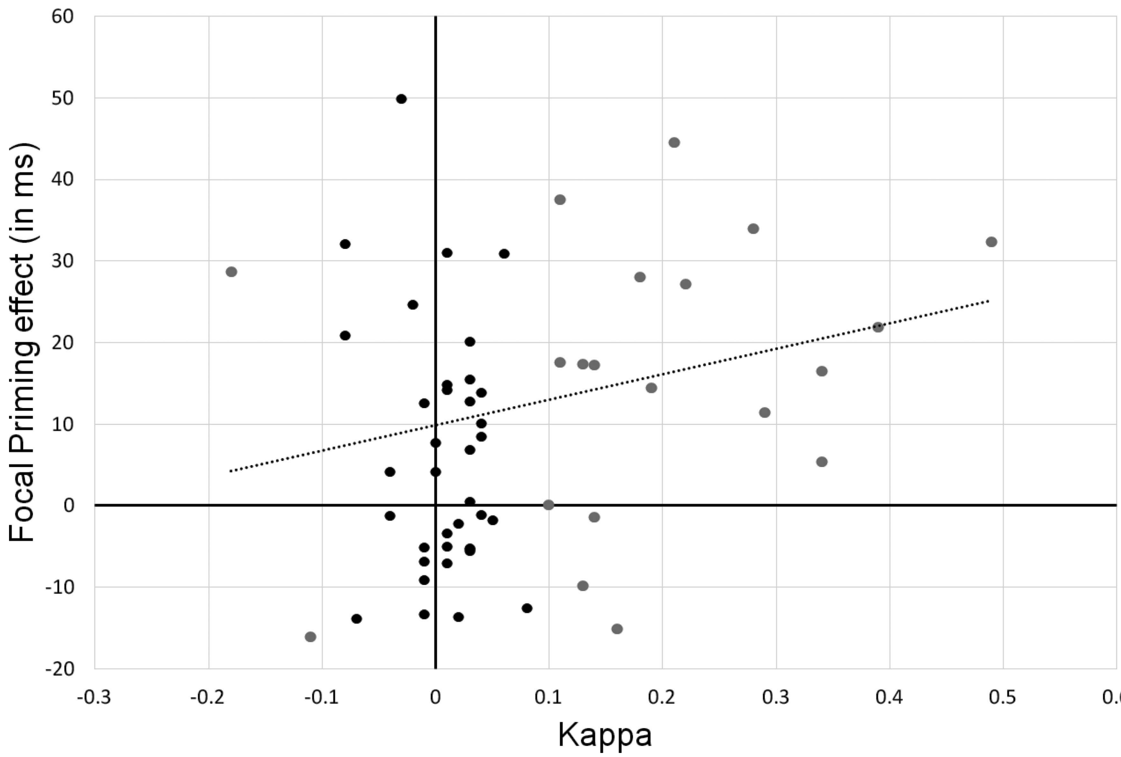


*Figure 5.* Focal priming difference (in milliseconds) plotted against direct effect (κ; Experiment 2; filled circles represent participants with κ values that do not deviate significantly from zero).

of priming. Of course, this is not a double dissociation (i.e., an experimental manipulation that has opposite effects on the priming effect and direct test performance), which would have strongly suggested a contribution of unconscious processes (see Schmidt & Vorberg, 2006). It is nevertheless noteworthy that small changes to prime presentation duration clearly altered direct test performance while not affecting the priming effect.

Second, Experiments 1c and 2 both yielded an interesting inconsistency between dependent variables. On the one hand, the two left-out priming effects differed significantly in terms of RTs and error rates: The left-out priming effect based on the contrast anger versus fear was significantly greater than zero, whereas the effect based on anger versus sadness was not. On the other hand, the left-out priming effects based on the $t_0$ parameter were of almost exactly the same size in both experiments. The drift-rate analyses—despite yielding nonsignificant results—potentially shed some light on this puzzle: The only result from these analyses that came close to significance was the comparison of the left-out priming effects in the across-experiments analysis. As noted in the Results section, this was because of increased drift rates for the sadness response after anger priming. We will return to this issue in the General Discussion.

## General Discussion

In four experiments, we tested the specificity of processing of masked negative facial expressions in a priming paradigm. The general backdrop for this work was provided by research on masked response priming effects with so-called nontarget primes (i.e., primes never presented for target categorization) drawn from potentially large sets. Hitherto, only few studies have demonstrated such effects (Dell'Acqua & Grainger, 1999; Kiesel et al., 2006, 2007; Koivisto & Rientamo, 2016; Naccache et al., 2005; Wentura & Degner, 2010a).

Therefore, the first thing to note is that we consistently found focal priming effects in our four experiments. That is, if participants categorized two negative emotional expressions A and B, responses in prime-target congruent trials (i.e., A-A, B-B) were always faster than responses in incongruent trials (i.e., A-B, B-A). Diffusion-model analyses corroborated the notion that these focal priming effects reflect response priming. In line with the evaluative priming analyses of Voss, Rothermund, et al. (2013), we found the focal priming effects (almost) exclusively in nondecision time ($t_0$) and not in drift rate (or relative starting point). In the present context, this result is remarkable for a second reason. As outlined in the Overview section, in a priming paradigm that uses perceptually similar primes and targets, two emotion-congruent expressions presented in brief succession might be integrated into a morphed representation that can be more efficiently matched to the corresponding mental schema for the given emotion. Such a process might result in different drift rates for congruent and incongruent prime-target pairs. By and large, our results yielded no support for this rather trivial explanation (also, note again that we presented targets in half-profile views to preclude such perceptually based effects from the outset).

Thus, our results mesh well with the broader literature on masked nontarget primes drawn from potentially large sets: Prim-

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ing effects seem to arise if primes match the action-trigger set for efficient target processing. This suggests that—contrary to the original action-trigger account (Kunde et al., 2003)—action triggers can be established at a rather abstract level (e.g., "small" vs. "large" animals, see Pohl et al., 2010). Of course, this view then includes the assumption that masked stimuli can be processed online up to this abstract level.

Apart from providing evidence for the existence of masked priming effects with negative emotional expressions, the aim of this study was to investigate how much information can be extracted from masked primes—especially because our earlier studies had yielded an inconclusive picture (Rohr et al., 2012, 2015; Rohr & Wentura, 2014; Wentura et al., 2017). To this end, we devised the leave-one-out paradigm, based on the following rationale: A target task involving the discrimination of two emotions, such as an anger versus sadness discrimination task, can be solved by using any information that discriminates the two expressions. Apart from perceptual schemata, this set of features might include the (relative) presence or absence of arousal, or the presence or absence of a relevance signal (i.e., anger is negative in an other-relevant manner; sadness is negative in a possessor-relevant manner; see above). Of course, emotional expressions might also convey emotion-specific information that can be used for target discrimination.

Our earlier research (Rohr et al., 2012, 2015; Rohr & Wentura, 2014; Wentura et al., 2017), however, seemed to suggest that a relevance signal was extracted in some contexts, and an arousal signal in others. We now argue that if a certain, briefly presented and masked emotional expression A is only processed with regard to a characteristic shared with another emotional expression B, then A should mimic B in terms of the resulting priming pattern. If, for example, the processing of anger is differentiated from the processing of fear or sadness only by the relevance signal, then fear and sadness expressions should elicit equivalent priming patterns. Thus, if targets are angry and sad faces, and the task is to classify the target accordingly, we should have observed not only an anger versus sadness priming effect, but also an anger versus fear priming effect (and no fear vs. sadness effect). If targets are fear and sadness expressions, there should be no priming effect at all.

The fact that we found focal priming effects in all experiments is at odds with both the pure-relevance and the pure-arousal hypotheses, namely that *either* a relevance *or* an arousal signal is extracted from a masked prime: Both hypotheses predicted a null effect for one focal priming effect—the relevance hypothesis predicted a null effect in the anger-out experiment (Experiment 1c), and the arousal hypothesis predicted a null effect in the sadness-out experiment (Experiment 1b).[11] The consistent occurrence of focal priming effects is more compatible with either (a) emotion-specific processing of the primes or (b) the assumption that an arousal or relevance signal is extracted from the primes *dependent on the target task*.

According to the relevance and arousal hypotheses, we also expected very specific patterns for the left-out priming effects (see Figure 1A and B). Basically, if we assume that using the relevance signal is helpful in a given task *and* the relevance signal can be extracted from a masked prime (i.e., in Experiments 1a and 1b), fear and sadness primes should mimic each other. If we assume that using the arousal signal is helpful in a given task *and* the arousal signal can be extracted from a masked prime (i.e., in Experiments 1a and 1c), fear and anger primes should mimic each other. Finally, according to the specificity hypothesis, priming effects should be based on the emotion-specific signal, and the left-out prime should not bias the response process. As a consequence, the left-out priming effects should be roughly half the size of the corresponding focal priming effects, as one of the effective primes (i.e., one of the focal prime categories) is replaced by a neutral prime (i.e., the left-out prime category) in the formula for calculating the priming effect (see Figure 1C).

As the consistent occurrence of focal priming effects presents a challenge for pure-relevance as well as pure-arousal hypotheses, we need to consider a modified perspective, namely that *both* relevance and arousal signals might be used in a given task if they can contribute to the discrimination of target categories. Such a perspective would be compatible with recent studies in the field showing that those features that are used to discriminate target categories are extracted from masked primes (e.g., Pohl et al., 2010). Experiment 1a (anger vs. sadness) is ambiguous in this regard because the target categories could be discriminated on the basis of either relevance or arousal. In Experiment 1b (anger vs. fear), the arousal signal was not useful because it did not allow discrimination between the target categories. The relevance signal was potentially useful, but reliance on relevance would imply that the left-out priming effect with sadness replacing fear should be similar in magnitude to the focal priming effect, whereas the left-out priming effect with sadness replacing anger should be roughly zero. We did not observe such a pattern: For RTs, there was no significant difference between the two left-out priming effects and both effects were nonsignificant (that was presumably because of the fact that the focal effect was rather small in this experiment). For the $t_0$ parameter of the diffusion model, there was clearly no significant difference between the two left-out priming effects; although one left-out priming effect was significant and the other was not, the observed pattern was reversed relative to the prediction derived from the relevance hypothesis. In Experiment 1c (fear vs. sadness), the relevance signal was not useful because it did not allow discrimination between target categories. Here, the arousal signal was potentially useful, but reliance on arousal would imply that the left-out priming effect with anger replacing fear should be similar in magnitude to the focal priming effect, whereas the left-out priming effect with anger replacing sadness should be roughly zero. Again, our results were not compatible with this expectation: For RTs, even though there was a significant difference between the two left-out priming effects (for Experiment 2 and for Experiment 1c/2 combined), the observed pattern was reversed relative to the prediction derived from the arousal hypothesis. For the $t_0$ parameter, the two left-out priming effects were numerically almost identical, and both effects were significant.

[11] One might argue that the considerably smaller focal priming effect (in the RT analysis) in Experiment 1b (compared with Experiments 1a and 1c) fits (a weak version of) the arousal hypothesis. However, anger and fear primes (i.e., primes related to the more arousing emotions) were consistently differentiated from one another in Experiments 1a and 1c. This is clearly at odds with the arousal hypothesis. Moreover, significant differences in the focal priming effects were not found in the analyses of $t_0$.

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The obvious question at this point is whether the specificity hypothesis is compatible with the results. Focusing for a moment exclusively on the $t_0$ parameter, the pattern of effects comes very close to what is expected based on the specificity hypothesis: First, we observed focal priming effects that were significant in all experiments and that—despite some numerical variability—were not significantly different between experiments. Second, the left-out priming effects were not significantly different in any of the experiments. In fact, in two out of the four experiments (Experiments 1c and 2), they were numerically almost identical. In the other two experiments (Experiments 1a and 1b), there was a slight imbalance insofar as one left-out priming effect was significant and the other one was not. However, as argued earlier, the observed pattern does not fit with any of the other hypotheses. Moreover, it is not clear whether the two focal priming categories are equally effective; if this is not the case, the partitioning of the focal priming effect with the aid of a neutral condition (i.e., the left-out prime) will necessarily be a bit uneven. Finally, it should be kept in mind that for statistical reasons, such partitioning of an overall priming effect will not always be perfectly balanced at the level of the specific experiment.

If we focus exclusively on the RT analyses, we are faced with the fact that the contrast anger versus fear consistently produced a significant left-out priming effect (in Experiments 1a, 1c, and 2) whereas the remaining left-out priming effects did not significantly deviate from zero (except the anger vs. sadness priming effect in Experiment 1c, which, however, did not replicate in Experiment 2). Correspondingly, the anger-out experiments (i.e., Experiments 1c and 2) yielded evidence that the two left-out priming effects differed from each other.

In other words, anger (or fear) primes mimicked sadness primes with regard to the RT priming effects if fear (or anger) targets had to be discriminated from sadness targets. There are three possible lines of interpretation, two of which seem rather implausible. The first is to ask (a) which features are shared by anger and sadness expressions if fear is the countertarget category to sadness; and (b) which features are shared by fear and sadness expressions if anger is the countertarget category to sadness. While the answer to question (b) is "possessor-relevant negativity" (i.e., the absence of a relevance signal), the answer to question (a) remains elusive.

The second line proceeds from the assumption that anger and fear are incompatible in the sense that the presence of one emotion indicates the absence of the other. If so, it might be that the action-trigger schema associated with the sadness response category includes an anger template (in case of fear as the second response category) or a fear template (in case of anger as the second target category). It is, however, not easy to explain why a nontarget category would be included in the generation of action triggers. Nevertheless, if one adopts this perspective, the general assumption of emotion-specific processing of masked primes can be upheld.

The third and most parsimonious line of interpretation is to assume an asymmetry regarding the ease with which masked primes release an action trigger. Concretely, it can be assumed that a masked sadness prime will not be processed up to the level needed for triggering the corresponding response. Thus, according to this assumption, sadness primes act like neutral primes (as does the left-out prime, if we adopt the specificity hypothesis). In this case, the focal priming effects found in Experiment 1a (i.e., anger vs. sadness) and Experiments 1c and 2 (i.e., fear vs. sadness) are primarily based on action-trigger releases by anger and fear primes, respectively, causing facilitation and interference in congruent and incongruent trials, respectively. Sadness primes as well as the left-out primes do not contribute to the priming effects. If we adopt this interpretation, we arrive at a slightly modified version of the specificity hypothesis: Masked anger and fear primes but not sadness primes are processed up to level of the specific emotion if they are target categories.

However, to integrate RT and diffusion-model analyses, we need to take into account the analyses of the drift-rate parameter ($v$). By and large, these analyses yielded nonsignificant results with regard to the Prime × Target interaction. However, regarding the most striking divergence between RT and $t_0$ results—the imbalance of left-out RT priming effects in Experiments 1c and 2 versus the almost perfect balance for the corresponding $t_0$ priming effects (see Figure 3B)—the drift-rate analyses are elucidating. We can see that conditions with anger primes and sadness targets are associated with the largest drift toward the sadness decision boundary. Thus, for as yet unknown reasons, angry faces seem to accelerate the information-accumulation process if a sadness target is presented. Notably, this is a process that can be separated from the response-priming process. Interestingly, in the direct prime recognition test of our experiments, we see an increased rate of sadness responses after anger primes, which might indicate perceptual confusability.

Taken together, we can conclude, with some caution, that the results are most compatible with the specificity hypothesis. This is most clearly corroborated by the analyses of the $t_0$ parameter. However, we acknowledge that our support for the specificity hypothesis rests on two pieces of evidence from the $t_0$ analyses—the presence of focal priming effects and the absence of differences between left-out priming effects—one of which relates to the acceptance of a null hypothesis, which is problematic in a frequentist hypothesis-testing framework.[12] Yet, even if we base our interpretation solely on the RT (and error) analyses, we argue that a slightly modified version of the specificity hypothesis (i.e., the version that assumes sadness primes are ineffective even if sadness is a target category) provides the most plausible explanation.

Finally, concurrently focusing on both $t_0$ and RT analyses suggests that the RT results potentially reflect a mixture of processes: the robust response priming process (indicated by $t_0$) on the one hand, and a secondary process that is (a) not yet robustly substantiated (i.e., the drift-rate results are equivocal) and (b) not well understood (i.e., it seems to produce a confusion of anger and sadness primes) on the other hand. Thus, while our study answers some questions, it also stipulates further research into this issue. It may well be that emotional stimuli, and especially faces, trigger several different processes that feed into priming effects to varying degrees.

To again take a step back, our results mesh well with the emerging literature on masked response priming effects with non-

[12] However, we note that a Bayesian analysis, jointly taking into account all experiments, yielded a Bayes factor in favor of the null hypothesis of $BF_{01}$ = 13.01. This can be considered strong evidence according to Jeffreys (1961; see also Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011).

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target primes. If participants' task requires discrimination of two target categories, masked primes that can be classified as easily as the targets themselves produce robust response priming effects. These effects do not occur at the level of specific stimulus processing because (a) the prime set is distinct from the target set, and (b) the potential set of action triggers on the concrete-stimulus level is too large to activate on demand. Hence, it seems that masked negative facial expressions are processed at the level of the specific emotion, at least under conditions where differentiating two of the emotion categories are task-relevant and, thus, response-related processes play a role. This holds even for the left-out prime category, because otherwise it should have mimicked one of the target emotions. Note that this does not necessarily mean that the left-out category is actively processed up to its category level, and then acts like a neutral prime because its category is not among the response categories. Rather, we argue that the action-trigger hypothesis (Kunde et al., 2003; also see Kiesel et al., 2008) provides a more plausible explanation of our results. Adopting this account, participants develop appropriate release preconditions for the two response alternatives on the basis of representations of the emotional target expressions. Thus, if anger and fear are the target categories, participants build action-trigger schemata on the basis of features that differentiate anger and fear expressions. If a stimulus matches such an action trigger, the corresponding response tendency is released. Masked priming effects are then explained by primes matching an action trigger, thereby releasing a response tendency that either facilitates the adequate target-related response or interferes with it. Within this framework, the left-out prime category does not elicit any priming because it simply does not match any of the active action triggers. Nevertheless, the action triggers must be emotion-specific enough to preclude a match of the left-out prime with any of them.

One question the present data cannot answer in this regard is whether the action triggers are specified as (affectively neutral) facial expression schemata or as (affect-connoted) emotion schemata. The former implies that participants solve the task by matching the target face to a perceptual schema. Primes are processed accordingly and will trigger responses to the extent that a prime matches one of the two expression schemata. Alternatively, participants might (solely or additionally) use rudimentary affective responses to solve the task: For example, an anger expression elicits a feeling of threat with a clear source (i.e., the angry person); a fearful face elicits a feeling of threat with no clear source and, therefore, conveys insecurity; a sad face may elicit a hint of sadness in the observer because of emotional contagion. If this is the case, primes might trigger responses accordingly. It is up to further research to discriminate between these alternatives (e.g., by using primes that are reduced to emotionally expressive parts of the face but do not convey the complete emotional expression; see, e.g., Horstmann & Bauland, 2006, for a comparable approach in a visual search paradigm).

In addition to the action-trigger account, we should briefly note that Ortells and colleagues (2016) recently argued that masked priming effects in response priming designs might be (partially) caused by target encoding facilitation processes instead of response interference processes. They provided evidence for this claim by showing that priming effects were larger for strongly semantically related prime-target pairs (e.g., dog—cat) than for weakly related pairs (e.g., cow—cat) in an animal versus body part categorization task. This result cannot be easily reconciled with the action trigger account since for response-based processes the strength of the relationship within the response-congruent condition should not play a role. For the discussion of the present experiments, this difference is not decisive since both theories allow for the assumption of categorical processing of masked primes. It would, however, be worthy to explore priming by masked emotional faces in a task that precludes an explanation in terms of response preparation or interference.

Finally, we are faced with two questions: Why did we not find specificity effects in previous experiments? And why did different paradigms produce distinct patterns of differentiation within the negative domain?

## The Emotion-Priming Paradigm

Rohr et al. (2012) as well as Wentura et al. (2017) used the four-alternative choice task with joy, anger, fear, and sadness as prime and target categories. Apart from a valence effect, we found that anger was differentiated from both fear and sadness, whereas the latter two prime emotions were not differentiated. A post hoc interpretation is that the four-alternative choice task may be overtaxing, in that not all four response categories are actively supported by corresponding action triggers. At least one category (per participant) might be a kind of passive rest category, which is selected only if no action trigger is matched by the incoming stimulus. If one assumes that anger is most consistently associated with an action trigger, one would obtain the results reported: Anger versus fear or sadness would produce a priming effect; fear versus sadness would not. Thus, a modified version of the relevance assumption might be maintained.

Earlier theorizing (see Rohr et al., 2012) assumed that masked primes are processed based on relevance, and that the other-relevant negativity of anger primes triggers an anger response that either matches the appropriate response to the target or not. Hence, a distinction between fear and sadness was not possible. Now, given the backdrop of the present experiments, we can assume that prime processing is (a) more flexible, but also (b) more restricted than initially assumed. Re (a): Processing is more flexible because all pairs in our set of negative emotional expressions produced a focal priming effect. Therefore, whatever features contribute to the differentiation of two target categories, it seems that the processing of the masked facial expressions involves—at least to some extent—the processing of those features, thus, causing priming effects. In other words, a differentiation along the relevance dimension (i.e., anger vs. fear or sadness) is not an obligatory consequence of the processing of masked facial expressions.

Re (b): Prime processing is more restricted than initially assumed because the relevance distinction must be task-relevant to affect the processing of masked faces. This may not always be the case, although the relevance distinction may be task-relevant in many contexts (among them the four-alternative choice task used in Rohr et al., 2012). Also, anger might be quite salient when the task involves categorization of clearly visible negative emotions, as in the present study. Admittedly, we already know of one case where this assumption does not hold, because we did not find a relevance differentiation when using frequency-filtered primes (Rohr & Wentura, 2014), even though all other experimental parameters were comparable with Rohr et al. (2012). This discrepancy cannot be clarified on the basis of the present results.

## The Emotion Misattribution Procedure

As noted above, we also obtained discrepant results (i.e., results different from the priming results) with an emotion misattribution procedure (Rohr et al., 2015). In that case, sadness was differentiated from anger and fear (that were not separable). Note that the misattribution task differs from the priming task in at least two aspects. First, the misattribution task does not have the character of a speeded response time task with its pressure to produce a fairly good performance. Second, the target expressions used in the misattribution task are emotionally neutral. Both features make it unlikely that action triggers are established in the same way as in the priming paradigm. However, even if we presume strong similarities between the two paradigms, the divergence in results can easily be explained given the insights from the present study. The most-often chosen response category in the misattribution experiments was the sadness category. That is, there was a bias to interpret the neutral target stimuli as sad faces. Thus, implicitly the distinction between sadness and the other (negative) emotions might have played a bigger role than the distinction between anger and fear. Note that in the present experiments, whenever sadness was one of the response categories (i.e., in Experiments 1a, 1c, and 2), focal priming effects were especially pronounced.

A final note addresses the question of whether or not the observed effects were based on nonconscious processes. We have discussed this issue elsewhere (Wentura et al., 2017) and will, thus, only briefly elaborate on the issue here. In the present experiments, we did not establish conditions that completely precluded the awareness of primes, as demonstrated by the direct test results. Thus, we cannot entirely rule out that only trials in which primes were (partly) recognized caused the priming effects (see, e.g., Lähteenmäki, Hyönä, Koivisto, & Nummenmaa, 2015, for such an argument; but see Schmidt, 2015). However, demonstrating priming effects with a zero-awareness criterion is not the only means to provide evidence for nonconscious processing. Schmidt and Vorberg (2006) suggested testing for double dissociations, that is, for experimental manipulations that have opposite effects on masked priming effects and direct tests (see Wentura et al., 2017, with regard to the present paradigm). We do not have a double dissociation here. Of note, however, is the contrast of Experiment 1c and 2 in the present article. The slight changes in the prime presentation parameters led to a considerable decrease in awareness, without affecting the priming effect.

## Conclusions

In conclusion, we found robust masked priming effects with marginally perceptible emotional facial expressions (angry, fearful, and sad). These effects occurred at the level of the specific emotion, whenever the emotions were task-relevant. Consistent with this result, a third nontask-relevant prime category ("left-out primes") was generally not confused with the primes of the task-relevant categories. Overall, the results are compatible with the theory of action triggers (Kiesel et al., 2006; Kunde et al., 2003).

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# Appendix A

## MANOVA Results

Table A1

*Results of The 3 (Prime) × 2 (Target) MANOVAs for the Dependent Variables RT, Errors, and Diffusion Model Parameters $t_0$ and $v$*

| Effect | *df* | RT | | | Error | | | $t_0$ | | | (absolute) $v$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *F* | *p* | $\eta_p^2$ | *F* | *p* | $\eta_p^2$ | *F* | *p* | $\eta_p^2$ | *F* | *p* | $\eta_p^2$ |
| Experiment 1a | | | | | | | | | | | | | |
| Prime | 2,46 | 6.10 | .004 | .210 | 2.13 | .130 | .085 | 2.12 | .131 | .084 | 2.58 | .087 | .101 |
| Target | 1,47 | 5.38 | .025 | .103 | 17.64 | <.001 | .273 | 43.66 | <.001 | .482 | <1 | | |
| Prime × Target | 2,46 | 7.86 | .001 | .255 | 6.13 | .004 | .210 | 4.15 | .022 | .153 | 1.13 | .332 | .047 |
| Experiment 1b | | | | | | | | | | | | | |
| Prime | 2,61 | <1 | 1.33 | .272 | .042 | <1 | <1 | | | | | | |
| Target | 1,62 | 21.84 | .001 | .260 | 2.25 | .139 | .035 | 13.19 | <.001 | .175 | 26.83 | <.001 | .302 |
| Prime × Target | 2,61 | 2.84 | .066 | .085 | <1 | 4.84 | .011 | .137 | <1 | | | | |
| Experiment 1c | | | | | | | | | | | | | |
| Prime | 2,61 | 2.84 | .066 | .085 | 2.39 | .101 | .077 | 8.10 | <.001 | .221 | <1 | | |
| Target | 1,58 | 16.97 | .001 | .226 | 29.19 | <.001 | .335 | 1.46 | .231 | .025 | 94.54 | <.001 | .620 |
| Prime × Target | 2,57 | 17.30 | .001 | .378 | 6.82 | .002 | .193 | 10.45 | <.001 | .268 | 1.28 | .286 | .043 |
| Experiment 2 | | | | | | | | | | | | | |
| Prime | 2,58 | 3.29 | .044 | .102 | <1 | 2.00 | .144 | .065 | 1.00 | .559 | .020 | | |
| Target | 1,59 | 19.03 | .001 | .244 | 27.11 | <.001 | .315 | 1.17 | .284 | .019 | 90.54 | <.001 | .605 |
| Prime × Target | 2,58 | 11.65 | .001 | .287 | 2.97 | .059 | .093 | 10.34 | <.001 | .263 | <1 | | |

*Note.* MANOVA = multivariate analysis of variance.

(*Appendices continue*)

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## Appendix B

### The Test for Differences Between the Two "Left-Out" Priming Effects

In each experiment, we calculated 3 (prime emotion) × 2 (target emotion) multivariate analysis of variances (MANOVAs) for repeated measures (see O'Brien & Kaiser, 1985), as reported in the Results sections. In addition to the overall interaction test (with 2 $df_N$), for each analysis we report two a priori orthogonal Helmert contrasts addressing the two essential questions: (a) Is there a significant focal priming effect? (b) Is there a significant difference between the two additional "left-out" priming effects? This paragraph serves to elucidate this regularity:

Specifically, the first Helmert contrast for the prime factor contrasts the left-out prime category with the pooled focal prime conditions, whereas the second Helmert contrast compares the focal prime conditions while ignoring the left-out prime condition. Thus, the second Helmert contrast is equivalent to the interaction in a reduced a 2 (prime emotion: focal 1 vs. focal 2) × 2 (target emotion: focal 1 vs. focal 2) ANOVA for repeated measures. The first Helmert contrast (left out vs. focal 1/focal 2) tests whether the two left-out priming effects significantly differ. We exemplify the logic with Experiment 1a (fear out): The focal priming difference is given by:

$$(As + Sa) - (Aa + Ss), \qquad (1)$$

where the first letter refers to the target emotion, and the second letter refers to the prime emotion (e.g., "As" should be read as "mean RT for anger targets primed by sadness primes").

As can be seen, the incongruent conditions (first parenthesis) are tested against the congruent conditions.[13] If the mean of (1) is significantly greater than zero, there is evidence for a focal priming effect.

The first left-out priming effect ("Does a fear prime mimic an anger prime?") is given by:

$$(As + Sf) - (Af + Ss) \qquad (2)$$

The second left-out priming effect ("Does a fear prime mimic a sadness prime?") is given by:

$$(Af + Sa) - (Aa + Sf). \qquad (3)$$

Note that difference (1) is the sum of differences (2) and (3). If the mean of (2) is comparable with the mean of (1), but the mean of (3) is null, the pattern best fits the arousal hypothesis. If the mean of (3) is comparable with the mean of (1), but the mean of (2) is null, the pattern best fits the relevance hypothesis. If (2) and (3) are comparable in size, the pattern best fits the specificity hypothesis. Thus, a test that compares difference (2) with difference (3) is best-suited to decide between hypotheses. This test is equivalent to the first Helmert interaction contrast of the 3 (prime emotion: fear vs. anger vs. sadness) × 2 (target emotion: anger vs. sadness) analysis, as can be easily shown: The first Helmert contrast compares fear with anger and sadness collapsed. Thus, the interaction contrast tests whether the difference between RTs to sad targets and angry targets, both primed by fear, deviates from the corresponding difference where targets are primed by sadness or anger:

$$(Sf - Af) - ((Ss + Sa)/2 - (As + Aa)/2). \qquad (4)$$

Multiplying by 2 and removing parentheses gives:

$$Sf + Sf - Af - Af - Ss - Sa + As + Aa. \qquad (5)$$

Recombining the terms results in

$$((As + Sf) - (Af + Ss)) - ((Af + Sa) - (Aa + Sf)). \qquad (6)$$

As can be seen, this is exactly the difference between the first and the second left-out priming effect (see above [2] and [3]).

[13] Normally, one would compare the means (and not the sums) of the congruent and incongruent conditions. Of course, this does not matter for the inferential statistics. Discarding the divisions by 2 makes the following exposition a bit easier to follow.

(*Appendices continue*)

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# Appendix C

## Diffusion-Model Analyses

We used the *fast-dm-30.2* program (Voss & Voss, 2007; Voss et al., 2015) and the Kolmogorov–Smirnov statistic as the optimization criterion (see, e.g., Voss et al., 2013, for recommendations). Outlier elimination corresponded to the one used for the conventional analyses (i.e., RTs below 200 ms or RTs greater than 1.5 interquartile ranges above the third quartile with respect to the experiment-wise sample distribution of RTs were discarded). The only, marginal difference was that error-related RTs (that are included in the diffusion-model analyses) were kept in the distribution of RTs used for calculation of the outlier criteria.

RT distributions relating to the two response categories were entered in diffusion-model analyses (e.g., anger vs. sadness in Experiment 1a; see Figure C1). Parameter values were estimated individually for each participant. Drift rates ($v$), and nondecisional RT constants ($t0$) were estimated separately for the different Prime × Target types. Note that Voss and colleagues (2013) chose the alternative way of defining the upper criterion as "correct response" and the lower criterion as "error response." This conceptualization allowed them to reduce the overall number of parameter estimations to only two values per parameter, namely the estimates for congruent versus incongruent prime-target pairs instead of estimates for four (i.e., 2 [prime valence] × 2 [target valence]) different conditions. However, for the evaluation of the left-out prime condition, the standard conceptualization seemed more appropriate. Note that for the focal prime variation, the two conceptualizations are essentially equivalent.

Finally, the relative starting point ($z_r$) was estimated for the different prime types. However, we did not expect differences here since prime type did not objectively predict the subsequent target type. Threshold separation ($a$) was held constant between conditions, following Voss et al. (2013). The remaining parameters were either held constant between conditions (*SD* of $t0$; $st0$) or were set to zero (*SD*s of $z_r$, and $v$; $sz_r$, $sv$), following recommendations by Voss et al. (2015). Version *fast-dm-30.2* has a further parameter $p$ (percentage of guessing responses). Because very large trial numbers are needed to estimate $p$, it is recommended to set $p$ to zero for most standard applications (Voss, 2018).

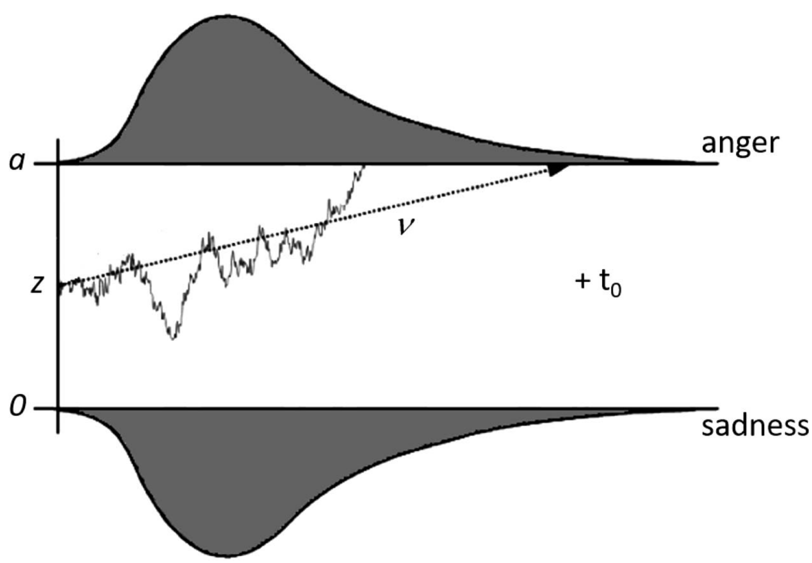


*Figure C1.* Illustration of the basic diffusion model. The noisy diffusion process starts from $z$ and is driven by a constant drift ($v$). If the path passes the upper (a) or lower threshold (0), the decision process stops. The overall response time is the sum of the duration of the diffusion process and all nondecisional components ($t_0$). The example response alternatives are provided for illustration purposes (Experiment 1a).

(*Appendices continue*)

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Table C1
*Model Fit of the Diffusion-Model Parameters*

| | Fit | | | Monte Carlo simulation | | | |
|---|---|---|---|---|---|---|---|
| | | | | .01 | | .05 | |
| Experiment | Min | Mean | *SD* | cfit | #bfm | cfit | #bfm |
| Experiment 1a (fear left out) | .213 | .704 | .163 | .130 | 0 | .308 | 2 (4%) |
| Experiment 1b (sadness left out) | .271 | .662 | .170 | .178 | 0 | .388 | 7 (11%) |
| Experiment 1c (anger left out) | .183 | .653 | .191 | .092 | 0 | .368 | 7 (12%) |
| Experiment 2 (anger left out) | .278 | .716 | .156 | .144 | 0 | .332 | 1 (2%) |

*Note.* Fit = Probabilities of the Kolmogorov-Smirnov statistic, that is, measures of deviance of the empirical RT distributions from the predicted RT distributions. The table shows the minimum value for a given experiment (Min), the mean, and the *SD*. The right-most columns refer to the fit-value distributions of Monte Carlo simulations (see text for further explanation). Cfit is the fit value that marks the 1% quantile (.01) or 5% quantile of simulated fit values; #bfm (number of bad fitting models) denotes the number of participants with fit values below these criteria.

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Table C1 (left panel) shows descriptive statistics regarding the estimated fit values, that is, probabilities of the Kolmogorov–Smirnov statistic, which is a measure for deviances of the empirical RT distributions from the predicted RT distributions. Although the fit values should be interpreted with caution (see Voss et al., 2015), it is noteworthy that the fit indicators met conventional criteria for all participants. A more elaborate model evaluation used Monte Carlo simulation, proceeding as follows (see Voss, 2018; Voss et al., 2015): In Step 1, a total 1,000 parameter sets were drawn from a multidimensional normal distribution defined by the covariance matrix of the estimated parameter values. In Step 2, for each of the 1,000 parameter sets, one data set was simulated, using the *construct-sample* tool of *fast-dm* (Voss, 2018). In Step 3, the simulated data sets were entered into a diffusion-model analysis with the same settings used for the analysis of the empirical data. The distribution of fit indices was then used for evaluation of the empirical models. Table C1 shows that using an alpha level of .01 (i.e., using the 1% quantile of the simulated fit indices as a cut-off; see, e.g., Germar, Albrecht, Voss, & Mojzisch, 2016), none of the 230 participant data sets were associated with a bad fitting model (#bfm); using an α level of .05, 17 of the 230 data sets (7.4%) were associated with a bad fitting model. These values correspond roughly with the findings of Voss and colleagues (2013) for evaluative priming. Notably, excluding the participants with bad fitting models yielded almost the same results as those obtained with the full sample. Thus, overall model fit can be considered good.

Received October 6, 2017
Revision received June 28, 2018
Accepted July 3, 2018 ■