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Temporal Negative Priming

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Negative priming provides one useful measure of attentional focus and cognitive control, requirements of most domains of life (driving, work, play, etc.). Until now, 2 types of negative priming have been identified: identity negative priming and location negative priming. These effects are of particular interest because individuals who have difficulty ignoring distraction (e.g., individuals with schizophrenia and attention-deficit disorder) exhibit reduced levels of negative priming. In the present experiments ($N = 187$), we report an entirely new type of negative priming based on when in time a target appears (temporal negative priming) rather than its identity or spatial location. Results indicate that responses to a target's temporal position were impaired when a distractor previously appeared at that same relative temporal position. In addition, temporal positioning was teased apart from response-based mechanisms and both were found to independently contribute to temporal negative priming. This result indicates that mechanisms of cognitive control trigger both response-based and memory-based processes.

Keywords: cognitive control, negative priming, temporal attention

An essential cognitive process is the ability to focus attention in the presence of distraction. Research over the past 50 years supports the conclusion that the negative priming task (originated by Dalrymple-Alford & Budayr, 1966, and later named negative priming by Tipper, 1985) provides a useful way of experimentally examining and measuring this cognitive control. A typical negative priming task involves the presentation of two consecutive displays called the *prime* and *probe*. Participants respond to a target on a prime trial while ignoring a distractor. Subsequently, the ignored

distractor might appear as the target for response on a probe trial. Results consistently show that responses are slower and less accurate on probe trials where the target previously appeared as a distractor (ignored repetition) relative to situations where the probe target had not previously been seen (control; see Fox, 1995; Frings, Schneider, & Fox, 2015; May, Kane, & Hasher, 1995, for reviews) and results may have implications for theories of cognitive control. In fact, negative priming tasks involve at least four of the situations that necessitate cognitive control, including response conflict, response inhibition, attentional control, and task switching (Abrahamse, Braem, Notebaert, & Verguts, 2016). In all of these domains people must successfully deal with conflict (response-based, attention-based, and/or task-based) and negative priming experiments may help to elucidate mechanisms that contribute to and maintain this control.

The negative priming effect may be especially important because its reduction is associated with situations involving impaired cognitive control, including (a) schizophrenia and schizotypic behaviors (Beech, Powell, McWilliam, & Claridge, 1989; see Frings et al., 2015, for a review since not all studies show these reductions), (b) attention-deficit/hyperactivity disorder (ADHD; Ossmann & Mulligan, 2003), (c) depression and dysphoria (Frings, Wentura, & Holtz, 2007; Goeleven, De Raedt, Baert, & Koster, 2006), (d) stress (Skosnik, Chatterton, Swisher, & Park, 2000), (e) Alzheimer's disease (Sullivan, Faust, & Balota, 1995), (f) sleep deprivation (Harrison & Espelid, 2004), (g) lack of exercise (Kamijo & Takeda, 2009), (h) recreational MDMA use (Dafters, 2006), and (i) cannabis use (Albertella, Le Pelley, & Copeland, 2016). In addition, different underlying brain areas have been associated with negative priming, the most notable being the dorsolateral prefrontal cortex (Egner & Hirsch, 2005). This is

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Todd A. Kahan developed the study concept and experimental design. Todd A. Kahan drafted the introduction and discussion while Melody R. Altschuler provided an initial draft of the methods and results for Experiment 1. Todd A. Kahan wrote the computer programs and Melody R. Altschuler created the experimental stimuli. Todd A. Kahan, Louisa M. Slowiaczek, and Melody R. Altschuler conducted the data analysis for Experiment 1 and Todd A. Kahan and Alexa C. M. Harrison conducted the analysis for Experiment 2. All authors were involved in revisions (though Todd A. Kahan and Louisa M. Slowiaczek played a larger role in this). Experiment 2 was conducted in partial fulfillment of Alexa C. M. Harrison's undergraduate honors thesis. Portions of the Experiment 1 data were presented at the 58th annual meeting of the Psychonomic Society, Vancouver, BC. The authors thank Kate Kerrigan, Hannah Pucker, Ariana Reichert, and Monica Xing for assistance in testing participants.

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important because the dorsolateral prefrontal cortex is implicated in schizophrenia (Callicott et al., 2000), depression (Grajny et al., 2016), and stress (Qin, Hermans, van Marle, Luo, & Fernández, 2009) and is hypothesized to play a significant role in both proactive and reactive control (Braver, 2012), further supporting the connection between this brain region, negative priming, and cognitive control.

Two different types of negative priming have been previously recognized—identity and location—and clinical populations who show a reduction in one type of negative priming may not show a reduction in the other. For example, some have argued that schizophrenia may be associated with reductions in location—but not identity—based negative priming (Hoenig, Hochrein, Müller, & Wagner, 2002). In identity-based negative priming participants respond to the target's identity on the prime (determining “what” was shown) while ignoring the identity of a superimposed or flanking distractor (Tipper, 1985). Reaction times (RTs) to identify the probe's target are slower if that item appeared as a distractor previously than situations in which the target was not previously ignored. In location-based negative priming participants respond to the target's spatial location on the prime (determining “where” the target appeared) while ignoring the location of a distractor (Tipper, Brehaut, & Driver, 1990). RTs to the probe's target location are slower if that location had previously been occupied by a distractor than situations in which the target's location was not previously ignored. Results across a variety of tasks indicate that these two types of negative priming are dissociable and may reflect different mechanisms.¹ For example, identity-based negative priming is reduced or eliminated with a working memory load (Engle, Conway, Tuholski, & Shisler, 1995), whereas location-based negative priming is not (Kahan, Oldak, & Lichtman, 2013). In addition, identity-based negative priming is sensitive to small changes in the spacing between the target and distractor (Fox, 1994) whereas location-based negative priming is less sensitive to these spacing manipulations (Chao & Yeh, 2005). In the current experiment, we ask whether a third type of negative priming might exist: temporal negative priming.

To investigate this, prime and probe trials unfolded over time and participants indicated when in the sequence a target was shown while ignoring a distractor that was presented during the prime sequence. All targets differed from the distractors to eliminate the possibility that effects reflect identity-based negative priming and all stimuli appeared in the same spatial location to eliminate the possibility that effects reflect location-based negative priming. The critical question was whether responses to the temporal position of the target on the probe are affected by the temporal position (and response) associated with the distractor from the prime trial. In addition, we manipulated the timing of events on the prime and probe to disentangle effects of temporal positioning from effects of the ignored response. A similar methodology was introduced by Neill and Kleinsmith (2016) in a spatial negative priming task to tease apart effects of spatial position from effects of the response. Across two experiments temporal negative priming is found and results indicate that both the temporal positioning and the response contribute to temporal negative priming. This new finding indicates that mechanisms of cognitive control generalize to when distractions appear in time.

Experiment 1

Method

Participants. Thirty-one students from Bates College and 30 students from Bowdoin College participated for extra credit in an introductory psychology course ($n = 61$). An additional 33 students from Bates College and 37 students from Bowdoin College ($n = 70$) participated in a preregistered replication through the Open Science Framework.² Although no prior research has examined temporal negative priming the sample size was determined on the basis of prior research on identity and location negative priming which has found both of these effects in experiments with sample sizes ranging between 16 and 30 participants (Chao, 2011). To help ensure adequate power a sample size that doubles these amounts was recruited.

Procedure. The presentation of stimuli and the recording of responses were controlled using E-prime software. The display resolution was set at 640×480 pixels and participants were seated approximately 60 cm away from the display.

Trials were presented in pairs containing a prime trial and a probe trial and participants completed 204 prime–probe pairs (i.e., 408 responses). The first four prime–probe pairs (8 responses) were treated as practice. Following practice participants completed four blocks of 50 prime–probe pairs with self-paced breaks given between blocks. The speed of events on the prime and probe trials were manipulated as was the positioning of targets and distractors.

On each prime trial, participants were shown 4 boxes one at a time in the center of the screen. These boxes contained an X, an O, or were left unfilled. At the end of the sequence of 4 boxes a question mark appeared and participants were instructed to press a key corresponding to the sequential position of the target (X) and to ignore the distractor position (O). The positioning of the target and distractor was randomly determined. Responses were made using the 1, 2, 3, and 4 keys on the keyboard to indicate if the target appeared in the first, second, third, or fourth sequential position, respectively. On each probe trial, participants were again shown 4 boxes one at a time in the center of the screen and the target's sequential position (X) was randomly determined. No distractor was presented on the probe trials, so the other three positions were empty (see Figure 1 for examples).

On both the prime and probe trials, the boxes were shown in either a fast or slow temporal sequence. During fast sequences, participants were shown in order: a fixation point (*) for 1 s, and then the first box, a blank screen, the second box, a blank screen, the third box, a blank screen, and the fourth box all for 250 ms. During slow sequences, the blank screen display between each box was extended to 750 ms. The research protocol for the experiments reported was approved by the institutional review board at both Bates and Bowdoin colleges.

Stimuli and conditions. By presenting the sequences at different speeds effects of temporal positioning could be separated from effects of the response. On some trials both the prime and probe were rapidly displayed (fast-fast temporal sequence) or slowly displayed (slow-slow temporal sequence). On other trials

¹ Causes of negative priming are discussed in the General Discussion.

² See https://osf.io/dmfj6/?view_only=e3dd74573e0343d29a5cf154b14b70cd.

Temporal Position/Response		Temporal Position				Response			
Prime	Probe	Prime	Probe	Prime	Probe	Prime	Probe	Prime	Probe
X		X		X		X		X	
O	X	O	X	O	X	O		O	X
							X		

Figure 1. Examples of critical prime-probe pairs. In each figure time flows downward and the prime trial appears to the left of the subsequent probe trial. A target (X) and distractor (O) appeared on the prime trial and only a target appeared on the probe trial. Larger gaps between boxes indicates greater delays (i.e., a slower rate of presentation). In these examples, the target on the probe trial (X) appears in a position where the temporal position and response had just been ignored (Temporal Position/Response), the temporal position had just been ignored (Temporal Position), or the response had just been ignored (Response).

the timing on the prime and probe mismatched (fast-slow or slow-fast temporal sequences). A similar methodology was originated by Neill and Kleinsmith (2016) where spatial distance, rather than speed, was manipulated in a location-based negative priming task.

The probe target could either (a) appear in the same temporal position as the prime target (Attended Position); (b) appear in the same temporal position as the prime distractor (Ignored Position); (c) require the same response as the prime target (Attended Response); (d) require the same response associated with the prime distractor (Ignored Response); or (e) hold none of these relationships (Unrelated). In addition, because the prime and probe were presented at different speeds the 10 experimental conditions (a through j below), which match the conditions of Neill and Kleinsmith (2016), were present here as well. Same-timing sequences (slow-slow and fast-fast) resulted in three condition types and in each of these temporal position and response are confounded (depicted on the far left of Figure 1): (a) Attended Position + Attended Response; (b) Ignored Position + Ignored Response; and (c) Unrelated Control. Different-timing sequences (fast-slow and slow-fast) resulted in seven condition types (depicted in the middle and right-hand side of Figure 1): (d) Ignored Position + Attended Response; (e) Attended Position + Ignored Response; (f) Ignored Position (different response); (g) Attended Position (different response); (h) Ignored Response (different position); (i) Attended Response (different position); and (j) Unrelated (including “position controls”).

Different-timing sequences resulted in two types of unrelated conditions (as was the case for Neill & Kleinsmith, 2016). On some unrelated trials, the probe target appeared at a temporal position that was possible on the prime (“position controls”) while on other unrelated trials the probe target appeared at a temporal position that was not possible on the prime. When assessing the effects of ignored position (condition f) only the position controls were used as a comparison since ignored position trials only arise when the target on the probe appears at a possible prime position. However, when assessing the effects of an ignored response (condition h), the unrelated trials were not limited in this way because ignored response trials are not dependent on the probe trial’s target appearing in a possible prime position.

Analyses focused on three critical comparisons, which are displayed in Figure 1. A comparison of conditions b and c in the fast-fast and slow-slow timing conditions shows the combined effects of an ignored position and ignored response on performance (see left-hand side of Figure 1). Here the temporal position and response are confounded. However, by examining conditions in which the prime and probe had different timing parameters the effects of temporal position and response can be teased apart. A comparison of conditions f and j (position controls) in the fast-slow and slow-fast timing conditions shows the effects of an ignored temporal position (see middle of Figure 1), whereas a comparison of conditions h and j in the fast-slow and slow-fast timing conditions shows the effects of an ignored response (see right-hand side of Figure 1). These comparisons, which are reported in the analyses that follow, were of a priori interest and match those reported by Neill and Kleinsmith (2016).

Results

In what follows, subscripts indicate which analyses were conducted on data from the first experiment ($n = 61$; reported with F_1 and t_1), and which analyses were conducted on data from the replication experiment ($n = 70$; reported with F_2 and t_2). Because the second experiment was a direct replication with no methodological changes, combined analyses ($N = 131$) are also reported ($F_{combined}$ and $t_{combined}$).³ RTs from trials in which participants did not correctly identify the prime target and probe target were discarded. These responses comprised 12.3% of the trials across participants in the first experiment and 10.75% of trials in the replication. The geometric mean RT and the percentage of errors were calculated for each condition for each participant (following the procedures of Neill, Lissner, & Beck, 1990). Data from the first experiment and replication show the same patterns but negative

³ When Todd A. Kahan presented these data at a recent conference an audience member asked that we analyze the data as a function of the location of the prime’s target relative to the distractor, because the distractor may have a greater impact when it precedes the target. A reviewer also asked that this analysis be reported on the combined set of data. We note that this analysis was not specified in our pre-registered replication (see Footnote 2) but we nonetheless report this following the main set of analyses.

priming effects only reach significance in the RT data in the initial experiment and negative priming effects only reach significance in error rates in the replication.

Effects of ignored position and response. RT data and error rates from situations in which temporal positioning and response were confounded are presented in Table 1 (conditions b vs. c). These data were analyzed in two separate 2 (prime-probe relation: ignored position/response vs. control) \times 2 (temporal sequence: fast-fast vs. slow-slow) repeated measures analysis of variance (ANOVA) for RTs and errors, respectively. In the RT data, a significant interaction was obtained between temporal sequence and prime-probe relation in the first experiment, $F_1(1, 60) = 6.74$, $p = .012$, $\eta_p^2 = .10$ and combined analysis, $F_{\text{combined}}(1, 130) = 6.81$, $p = .010$, $\eta_p^2 = .05$, but not the replication, $F_2(1, 69) = 1.09$, $p = .301$, $\eta_p^2 = .02$. No main effect of temporal sequence was observed, $F_1(1, 60) = .13$, $p = .716$, $\eta_p^2 = .00$; $F_2(1, 69) = 2.38$, $p = .127$, $\eta_p^2 = .03$; $F_{\text{combined}}(1, 130) = 0.67$, $p = .414$, $\eta_p^2 = .01$, or prime-probe relation, $F_1(1, 60) = .73$, $p = .396$, $\eta_p^2 = .01$; $F_2(1, 69) = .13$, $p = .724$, $\eta_p^2 = .00$; $F_{\text{combined}}(1, 130) = 0.20$, $p = .652$, $\eta_p^2 = .00$. To better understand the difference in the negative priming effects in the fast-fast and slow-slow conditions, two paired-samples t tests were conducted. Results from these t tests indicate no negative priming in the fast-fast condition, $t_f(60) = 1.19$, $p = .238$; $t_{\text{combined}}(130) = 1.60$, $p = .112$. However, there was robust temporal negative priming in the slow-slow condition, $t_f(60) = 2.49$, $p = .016$, $t_{\text{combined}}(130) = 2.19$, $p = .030$. Negative priming effects and 95% confidence intervals are shown in Figure 2.

The error data were also analyzed in the same 2×2 ANOVA. Results indicate a main effect of prime-probe relation in the replication, $F_2(1, 69) = 4.39$, $p = .040$, $\eta_p^2 = .06$, where participants made more errors on ignored repetition trials ($M = 5.5\%$) relative to control trials ($M = 4.2\%$), but this was not significant in the first experiment, $F_1(1, 60) = 0.27$, $p = .605$, $\eta_p^2 = .00$, or combined analysis, $F_{\text{combined}}(1, 130) = 3.03$, $p = .084$, $\eta_p^2 = .02$.

Table 1
Mean Reaction Times (RTs) and Proportion Errors (PEs) in the Fast/Fast and Slow/Slow Sequences of Experiment 1: Temporal Position Repetition Confounded With Response Repetition

Prime-probe relation	Temporal sequence				Marginal means	
	Fast/fast		Slow/slow		RT	PE
Experiment 1 (original)						
Ignored	311	.07	330	.05	320	.06
Unrelated	326	.06	301	.05	313	.06
Negative priming	-15	.01	29*	.00	7	0
Experiment 1 (replication)						
Ignored	288	.07	307	.04	300	.04
Unrelated	297	.05	302	.03	298	.05
Negative priming	-9	.02	5	.01	2	.01*
Experiment 1 combined						
Ignored	299	.07	318	.04	308	.06
Unrelated	311	.06	301	.04	306	.05
Negative priming	-12	.01	17*	.00	2	.01

Note. Positive difference values indicate negative priming.

* $p < .05$.

Also significant was the main effect of temporal sequence, $F_1(1, 60) = 5.58$, $p = .021$, $\eta_p^2 = .09$; $F_2(1, 69) = 15.76$, $p < .001$, $\eta_p^2 = .19$; $F_{\text{combined}}(1, 130) = 20.39$, $p < .001$, $\eta_p^2 = .14$. This demonstrates that error rates in the slow-slow conditions were lower than the fast-fast conditions. The interaction did not approach significance in the error rates.

Effects of ignored temporal position. RT data and error rates for situations in which effects of temporal position were isolated from effects of the response are shown in Table 2. These data were analyzed in a 2 (prime-probe relation: ignored repetition vs. control) \times 2 (temporal sequence: fast-slow vs. slow-fast) repeated measures ANOVA. For the RT data a significant main effect of prime-probe relation was found in Experiment 1, $F_1(1, 60) = 7.09$, $p = .010$, $\eta_p^2 = .11$ but not the replication or the combined analysis, $F_2(1, 69) = 0.03$, $p = .871$, $\eta_p^2 = .00$; $F_{\text{combined}}(1, 130) = 2.89$, $p = .091$, $\eta_p^2 = .02$. An interaction between temporal sequence and prime-probe relation was also found in the first experiment and combined analysis but not the replication, $F_1(1, 60) = 4.47$, $p = .039$, $\eta_p^2 = .07$; $F_2(1, 69) = 1.65$, $p = .204$, $\eta_p^2 = .02$; $F_{\text{combined}}(1, 130) = 5.79$, $p = .018$, $\eta_p^2 = .04$. To better understand how the temporal sequence affects negative priming, two paired-samples t tests were conducted. Results from these t tests indicate no negative priming in the fast-slow condition, $t_f(60) = .26$, $p = .800$; $t_{\text{combined}}(130) = 0.55$, $p = .586$. However, robust temporal negative priming was found in the slow-fast condition, $t_f(60) = 3.07$, $p = .003$; $t_{\text{combined}}(130) = 3.13$, $p = .002$. Together these data indicate that temporal negative priming occurs even in the absence of an ignored response (see Figure 2).

The accuracy data were also analyzed in the same 2×2 ANOVA. Here a main effect of prime-probe relation was found in the replication and combined analysis but not the first experiment, $F_1(1, 60) = 2.79$, $p = .100$, $\eta_p^2 = .04$; $F_2(1, 69) = 3.97$, $p = .050$, $\eta_p^2 = .05$; $F_{\text{combined}}(1, 130) = 6.44$, $p = .012$, $\eta_p^2 = .05$. These data confirm negative priming in the absence of an ignored response. None of the other effects reached significance.

Effects of ignored response. RT data and error rates for situations in which effects of an ignored response were isolated from effects of temporal position are shown in Table 3. These data were analyzed in a 2 (prime-probe relation: ignored repetition vs. control) \times 2 (temporal sequence: fast-slow vs. slow-fast) repeated measures ANOVA. Though the effect of prime-probe relation approached significance in the first experiment, $F_1(1, 60) = 3.93$, $p = .052$, $\eta_p^2 = .06$, this was not significant in the replication or the combined analyses, $F_2(1, 69) = 0.66$, $p = .420$, $\eta_p^2 = .01$; $F_{\text{combined}}(1, 130) = 0.84$, $p = .361$, $\eta_p^2 = .01$. None of the other effects were significant. These data indicate that response inhibition alone cannot explain temporal negative priming.

Error rates were analyzed in the same 2×2 ANOVA. Results showed a significant main effect of temporal sequence, $F_1(1, 60) = 4.48$, $p = .038$, $\eta_p^2 = .07$; $F_2(1, 69) = 4.25$, $p = .043$, $\eta_p^2 = .06$; $F_{\text{combined}}(1, 130) = 8.57$, $p = .004$, $\eta_p^2 = .06$. This main effect indicates that error rates in the fast-slow conditions were reduced relative to slow-fast conditions. None of the other effects approached significance.

Effects of target-distractor order. We also analyzed the data as a function of the ordering of the prime trial's distractor relative to the prime trial's target, the logic being that the distractor on the prime trial may have a greater impact when it precedes the target compared to situations in which it follows the target (see Footnote

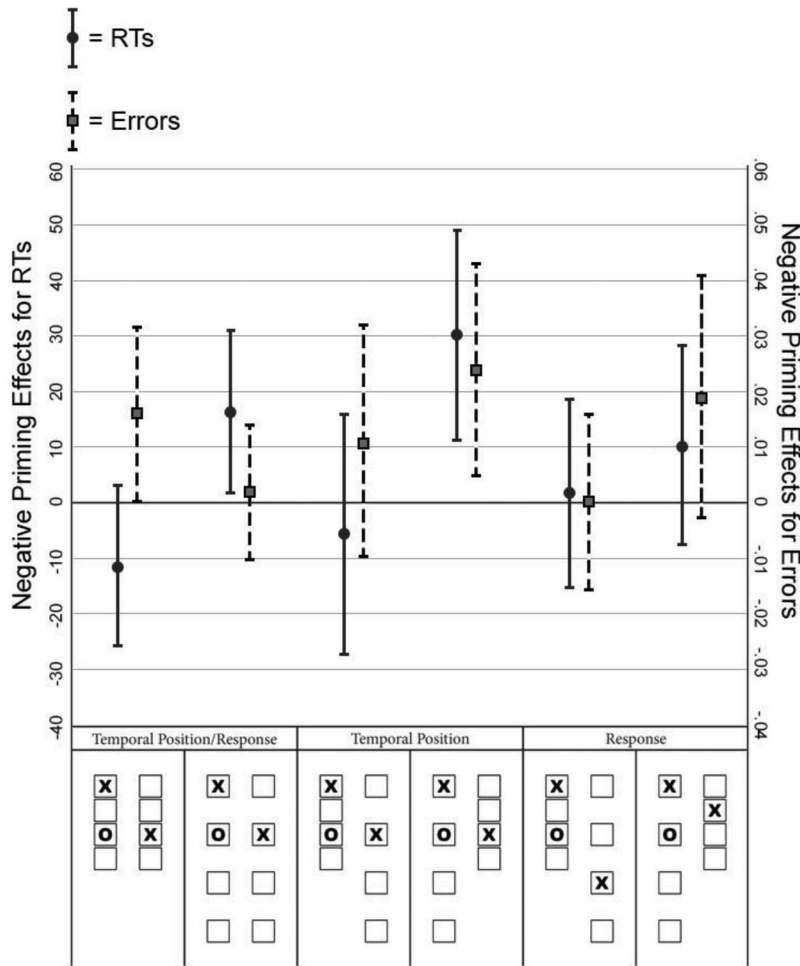


Figure 2. Negative priming effects in milliseconds (left axis) and proportion errors (right axis) in the combined Experiment 1 data for each critical prime-probe pair type. Error bars indicate the 95% confidence intervals. Positive values indicate negative priming.

3). When the distractor on the prime trial follows the target, it may be easier to ignore⁴ and as such may have a reduced impact on probe trial RTs and error rates. However, this analysis reduces the number of trials per condition in half, and many participants had missing cells in one or more conditions when the data were analyzed in this manner (this is reflected in the degrees of freedom for each analysis reported). For this reason, we follow the advice of a reviewer and report this analysis on the combined set of data. The data were analyzed as before but order was added as a repeated measures variable in a 2 (prime-probe relation: ignored position/response vs. control) × 2 (temporal sequence: fast-fast vs. slow-slow) × 2 (order: distractor before the target vs. distractor after the target) repeated-measures ANOVA. The same pattern of negative priming was found as was reported when order was not added to the analysis. Here we focus on the main effects and interactions with order. These results are shown in Table 4 and significant effects are highlighted in bold. As can be seen, target-distractor order moderated response-based negative priming (i.e., an interaction between target-distractor order and prime-probe relation) such that temporal negative priming was not significant

when the distractor followed the target ($M = -2$ ms difference between the ignored repetition condition and the control condition) but was significant when the distractor preceded the target ($M = 38$ ms difference between the ignored repetition condition and the control condition).

Experiment 2

Two sets of data are reported in Experiment 1 and although both show temporal negative priming the data differ in unexplained ways. In the first set of data temporal negative priming is obtained in RTs but not the accuracy rates ($n = 61$) yet in our direct replication temporal negative priming is significant in accuracy rates but not RTs ($n = 70$). Because of this it is not unreasonable to question whether temporal negative priming is a robust and

⁴ However, as pointed out by a reviewer the assumption that it will be easier to ignore a distractor when it appears after the target may not be correct, and attention to the distractor may also vary with presentation speeds.

Table 2

Mean Reaction Times (RTs) and Proportion Errors (PEs) in the Fast/Slow and Slow/Fast Sequences of Experiment 1: Temporal Position Repetition Without Response Repetition

Prime-probe relation	Temporal sequence					
	Fast/slow		Slow/fast		Marginal means	
	RT	PE	RT	PE	RT	PE
Experiment 1 (original)						
Ignored	356	.06	357	.08	357	.07
Unrelated	352	.04	306	.06	329	.05
Negative priming	-4	.02	51*	.02	28*	.02
Experiment 1 (replication)						
Ignored	339	.05	316	.06	327	.06
Unrelated	353	.04	305	.03	329	.04
Negative priming	-14	-.01	11	.03	-2	.02*
Experiment 1 combined						
Ignored	347	.05	335	.07	341	.06
Unrelated	353	.04	305	.04	329	.04
Negative priming	-6	.01	30*	.03	12	.02*

Note. Positive difference values indicate negative priming.

* $p < .05$.

reliable effect. For this reason, we conducted a second experiment examining temporal negative priming.

Prior research indicates that identity-based negative priming may increase if people attend to the distractor (Kahan, Mathis, & Jackson, 2002; MacDonald, Joordens, & Seergobin, 1999; but see Joordens, Betancourt, & Spalek, 2006, for data that indicate the increase in negative priming is not always significant, a point we return to in the General Discussion). For example, negative priming is larger if participants are presented with two words on the prime trial (e.g., "turtle" and "goat") and must pronounce the word that refers to the larger object (i.e., "goat") if on the probe trial (e.g., given "flea" and "turtle") the person must respond to the previously ignored word (i.e., turtle). This is found compared to a situation where selection is based on the color in which the word is printed rather than the word's referent (MacDonald et al., 1999). Similarly, in experiments conducted by Kahan et al. (2002), participants were presented with Stroop stimuli (i.e., color words printed in mismatching colors) and after making responses to the printed color of the prime and probe participants were occasionally asked to recall the distracting word from the prime. On some trials people were asked "What was the 1st word?" whereas on other trials they were told "Press the spacebar to continue." This procedure encouraged participants to attend to the distractor word on the prime. Kahan et al. (2002) reported 24 ms of identity-based negative priming when none of the trials asked participants to recall the prime word. However, 102 ms of negative priming was obtained when 12.5% of the trials asked for the prime word and 177 ms of negative priming was obtained when 87.5% of the trials asked for the prime word. It is possible that participants in Experiment 1 did not attend to the distractor and this may have been especially true when the distractor followed the target. To prevent this, participants in Experiment 2 were asked to indicate when the distracting letter "O" had been shown on 88% of the trials. By doing this, participants needed to attend to the distractor throughout the experiment.

Method

The method was identical to Experiment 1 in every detail (number of trials, types of stimuli, timing of trials, etc.) with only two differences. The first difference was that after a response was made to the probe, one of two displays randomly appeared and remained present until a response was given. The display chosen was randomly determined using nonequivalent weighting. On 88% of the trials participants were presented a display that read "When was the O?" in which case participants responded using the 1, 2, 3, or 4 keys. On the other 12% of trials, participants were presented with a display that read "Press the 8 key to continue." This key was chosen because it was easy to press with the little finger of the right hand while keeping the middle and index fingers positioned over the 1-4 keys. The 8 key was not available as a response option when participants were asked to indicate when the O had been shown and the 1-4 keys were not available as response options when participants were asked to press the 8 key.

The second difference was that at the end of the negative priming task participants were asked to indicate how often they ingest THC (whether through smoking marijuana, vaping, or consuming edibles). Choices of yearly, monthly, weekly, or daily were provided. If participants answered yearly, monthly, or weekly they were then asked a follow-up question of how many times they do this per year/month/week. From this we were able to estimate the number of days per year a person uses THC. Following this, participants were administered the 32-item Schizotypal Personality Questionnaire-Brief revised (updated [SPQ-BRU]; Davidson, Hoffman, & Spaulding, 2016). The THC questions and SPQ-BRU were administered so that we could determine if temporal negative priming correlates with these variables.

Results

We first analyzed performance judging when the distractor ("O") was shown. These results indicate that participants were able

Table 3

Mean Reaction Times (RTs) and Proportion Errors (PEs) in the Fast/Slow and Slow/Fast Sequences of Experiment 1: Response Repetition Without Temporal Position Repetition

Prime-probe relation	Temporal sequence					
	Fast/slow		Slow/fast		Marginal means	
	RT	PE	RT	PE	RT	PE
Experiment 1 (original)						
Ignored	342	.05	336	.09	339	.06
Unrelated	323	.05	317	.07	320	.06
Negative priming	19	.00	19	.02	19 [†]	.00
Experiment 1 (replication)						
Ignored	318	.05	307	.08	312	.06
Unrelated	331	.04	305	.05	318	.05
Negative priming	-13	.01	2	.03	-6	.01
Experiment 1 combined						
Ignored	329	.05	321	.08	325	.06
Unrelated	328	.05	311	.06	319	.05
Negative priming	1	.00	10	.02	2	.01

Note. Positive difference values indicate negative priming.

[†] $p = .052$.

Table 4
Effects of Target-Distractor Order on the Prime Trial in Experiment 1 Combined Set of Data

Effects of order	Reaction time data	Error data
Temporal position and response repetition		
Main effect of order	$F(1, 130) = .16, p = .692$	$F(1, 130) = 2.58, p = .111$
Order × Temporal Sequence	$F(1, 130) = .30, p = .588$	$F(1, 130) = 1.00, p = .318$
Order × Prime-Probe Relation	$F(1, 130) = 2.68, p = .104$	$F(1, 130) = 1.49, p = .225$
Order × Temporal Sequence × Prime-Probe Relation	$F(1, 60) = .21, p = .644$	$F(1, 60) = .44, p = .508$
Temporal position alone		
Main effect of order	$F(1, 129) = .63, p = .430$	$F(1, 129) = .02, p = .902$
Order × Temporal Sequence	$F(1, 129) = .08, p = .784$	$F(1, 129) = .00, p = .949$
Order × Prime-Probe Relation	$F(1, 129) = .00, p = .979$	$F(1, 129) = .49, p = .485$
Order × Temporal Sequence × Prime-Probe Relation	$F(1, 129) = 1.59, p = .209$	$F(1, 129) = .13, p = .909$
Response repetition alone		
Main effect of order	$F(1, 121) = 2.54, p = .114$	$F(1, 126) = .68, p = .411$
Order × Temporal Sequence	$F(1, 121) = 7.49, p = .007, \eta_p^2 = .058$	$F(1, 126) = .00, p = .975$
Order × Prime-Probe Relation	$F(1, 121) = 6.34, p = .013, \eta_p^2 = .050$	$F(1, 126) = 3.39, p = .068$
Follow-up tests		
Negative priming when distractor follows target	$t(129) = .20, p = .845$	
Negative priming when distractor precedes target	$t(129) = 3.12, p = .002$	
Order × Temporal Sequence × Prime-Probe Relation	$F(1, 121) = 1.25, p = .266$	$F(1, 126) = .09, p = .767$

Note. Main effects of order and interactions with order are shown and significant values are in bold.

to complete the task with accuracy ($M = .77$) much greater than expected by chance (.25), $t(55) = 24.44, p < .001$. In addition, RTs responding to the target on the probe trial were analyzed when responses to the prime trial and probe trial were correct, and accuracy rates were analyzed when the prime trial was responded to correctly. In instances where a participant had missing data in one or more conditions because of high error rates on the prime or probe, SPSS software omitted that person's data from the analysis (this is reflected in the degrees of freedom for each analysis reported).

Effects of ignored position and response. RT data and error rates from situations in which temporal positioning and response were confounded are presented in the top portion of Table 5 (conditions b vs. c) and negative priming effects are shown in Figure 3. These data were analyzed in a 2 (prime-probe relation: ignored position/response vs. control) × 2 (temporal sequence:

fast-fast vs. slow-slow) repeated measures ANOVA. None of the RT data reached significance (all p values $> .05$). For the error data the only effect that reached significance was a main effect of speed, $F(1, 55) = 5.88, p = .019, \eta_p^2 = .097$. This indicates that error rates were greater in the fast-fast sequence ($M = .12$) relative to the slow-slow sequence ($M = .09$). None of the other effects reached significance.

Effects of ignored temporal position. RT data and error rates for situations in which effects of temporal position were isolated from effects of the response are shown in the middle portion of Table 5 (conditions f and j). These data were analyzed in a 2 (prime-probe relation: ignored repetition vs. control) × 2 (temporal sequence: fast-slow vs. slow-fast) repeated measures ANOVA. For the RT data a main effect of prime-probe relation was found, $F(1, 51) = 10.30, p = .002, \eta_p^2 = .168$. RTs were slower in the ignored repetition condition ($M = 520$) relative to the control

Table 5
Mean Reaction Times (RTs) and Proportion Errors (PEs) in Experiment 2

Prime-probe relation	Temporal sequence					
	Fast/slow		Slow/fast		Marginal means	
	RT	PE	RT	PE	RT	PE
Temporal position and response repetition						
Ignored	497	.12	422	.08	459	.07
Unrelated	502	.12	481	.11	492	.05
Negative priming	-5	.00	-59	-.03	-33	-.02
Temporal position alone						
Ignored	516	.17	524	.14	520	.15
Unrelated	480	.15	435	.09	457	.12
Negative priming	36	.02	89	.05	63*	.03*
Response repetition alone						
Ignored	531	.08	559	.14	545	.11
Unrelated	466	.12	477	.13	472	.12
Negative priming	65	-.04	82	.01	73*	-.01

Note. Positive difference values indicate negative priming.
* $p < .05$.

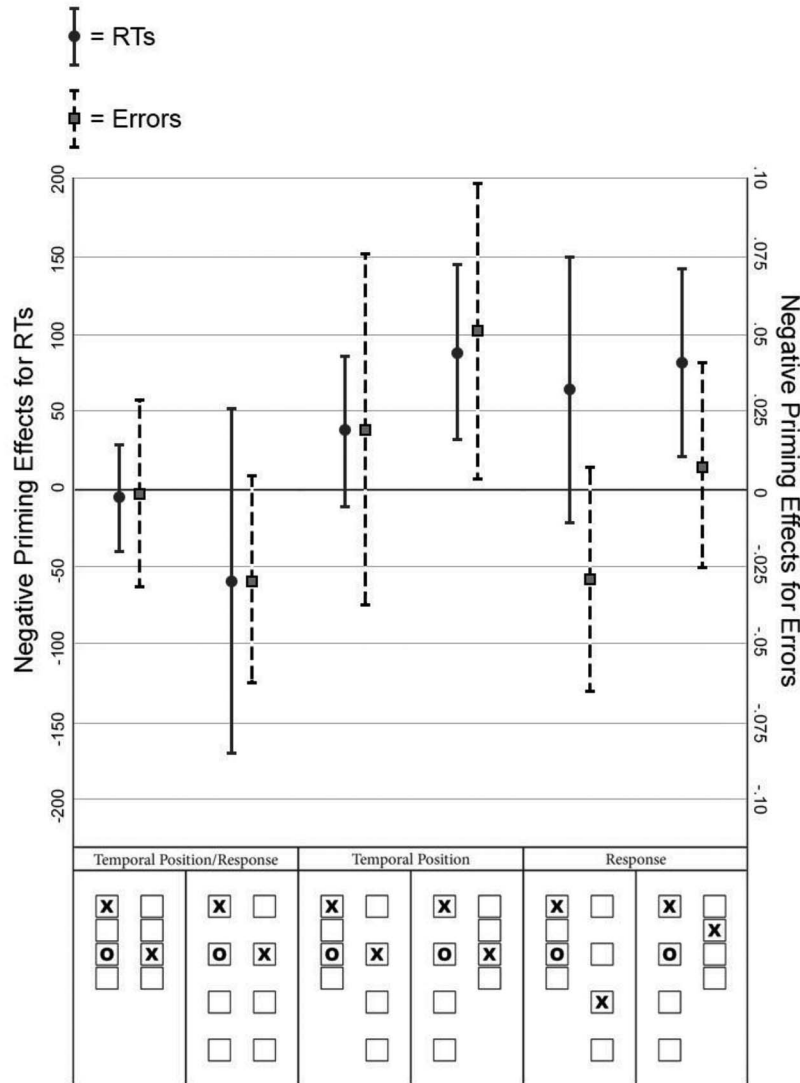


Figure 3. Negative priming effects in milliseconds (left axis) and proportion errors (right axis) in Experiment 2 for each critical prime-probe pair type. Error bars indicate the 95% confidence intervals. Positive values indicate negative priming.

condition ($M = 457$; 63 ms of negative priming). None of the other effects reached significance. For the error data, two main effects were obtained. The first was a main effect of speed, $F(1, 54) = 4.22$, $p = .045$, $\eta_p^2 = .072$, which indicates that error rates were greater in the slow-fast sequence ($M = .16$) relative to the fast-slow sequence ($M = .12$). The second was a main effect of prime-probe relation, $F(1, 54) = 5.35$, $p = .025$, $\eta_p^2 = .090$. Error rates were greater in the ignored repetition condition ($M = .15$) relative to the control condition ($M = .12$). Importantly, strong evidence of temporal negative priming was found in both RTs and error rates (see middle section of Figure 3).

Effects of ignored response. RT data and error rates for situations in which effects of an ignored response were isolated from effects of temporal position are shown in the bottom portion of Table 5. These data were analyzed in a 2 (prime-probe relation: ignored repetition vs. control) \times 2 (temporal sequence: fast-slow

vs. slow-fast) repeated measures ANOVA. For the RT data a main effect of prime-probe relation was found, $F(1, 54) = 7.39$, $p = .009$, $\eta_p^2 = .120$, which reveals a response-based component of temporal negative priming. Reaction times were slower in the ignored-repetition condition ($M = 545$) relative to the control condition ($M = 472$; see right-hand section of Figure 3). None of the other effects reached significance. For the error data a main effect of speed was observed, $F(1, 55) = 4.11$, $p = .047$, $\eta_p^2 = .070$, which indicates that error rates were lower in the slow-fast sequence ($M = .10$) relative to the fast-slow sequence ($M = .13$). None of the other effects reached significance.

Effects of target-distractor order. We also analyzed the data as a function of the ordering of the prime trial's distractor relative to the prime trial's target by adding order to the analyses in a 2 (order) \times 2 (prime-probe relation) \times 2 (temporal sequence) repeated-measures ANOVA. As was the case in Experiment 1 the

same pattern of negative priming effects was found as reported when order was not added to the analyses. Here we focus on main effects and interactions with order. The only main effects of order that were significant occurred in the RT and error data when temporal position and response were confounded (conditions b vs. c). This indicates that participants responded more rapidly and more accurately when the prime trial's distractor appeared before the target (RT $M = 440$; proportion error $M = .08$) relative to when the prime trial's distractor appeared after the target (RT $M = 494$; proportion error $M = .10$). These results are shown in the top portion of Table 6 and significant effects are highlighted in bold. In addition, there were two significant three-way interactions with order. Both of these interactions took the same form and were found in the error rate data when effects of the ignored temporal position (conditions f vs. j) or effects of the ignored response (conditions h vs. j) were examined. To better understand these interactions, separate 2 (prime-probe relation) \times 2 (order) ANOVAs were conducted on the fast-slow and slow-fast data. In the fast-slow condition an interaction between prime-probe relation and order was found and follow-up t tests show that temporal negative priming was significant when the distractor appeared after the target but no temporal negative priming was found when the distractor appeared before the target. However, in the slow-fast condition order did not moderate negative priming (i.e., there was no two-way interaction between order and prime-probe relation). These three-way interactions and follow-up tests are shown in the middle and bottom portion of Table 6.

Individual difference variables. Responses to the 32-item SPQ-BRU were summed. Responses to this measure are on a 5-point Likert scale making the possible range 0 to 160. In our sample the mean was 76 with a range of 42 to 109. Responses to the THC questions were also tallied to determine the number of times a person ingests THC during a year. In our sample, the mean number of days per year that participants used THC was 40 with a range of 0 to 365. Despite having a large range on both of these measures, neither was correlated with negative priming when

temporal position was confounded with response repetition, temporal position was isolated, or response repetition was isolated (all $ps > .13$). In addition to analyzing all of the data, we restricted the analysis to female participants because Albertella et al. (2016) reported that the relationship between negative priming and THC was only significant for women; yet here too none of the effects reached significance (all $ps > .13$). As such, we do not have evidence that temporal negative priming varies with schizotypy or THC use but note that correlation estimates are highly variable with small sample sizes (Schönbrodt & Perugini, 2013).

Discussion

Despite the fact that temporal negative priming varied across experiments and across conditions in sometimes unexpected ways (a point to which we return), performance was consistently worse in the ignored repetition condition relative to the control condition when temporal position was isolated from response-based mechanisms. In addition, this novel negative priming effect cannot be explained entirely by response-based inhibition (or a similar response-based mechanism). Though negative priming caused by a response-based mechanism does contribute to temporal negative priming when the distractor is made salient (in Experiment 1 this happened when the distractor preceded the target and in Experiment 2 this happened by requiring people to attend to the distractor's temporal position), it is not the sole cause of temporal negative priming because both experiments show a temporal component when effects of an ignored response are removed. As such, temporal negative priming must also reflect temporal position—time passed after the fixation—rather than ordinal position (1st, 2nd, etc.). This must be the case because in instances where temporal position was teased apart from the response, the distractor on the prime appeared in an ordinal position that did not match the ordinal position of the target on the probe. Despite this, negative priming emerges because of the shared temporal positioning (middle of Figures 2 and 3). This newly discovered neg-

Table 6
Effects of Target-Distractor Order on the Prime Trial in Experiment 2

Effects of order	Reaction time data	Error data
Temporal position and response repetition		
Main effect of order	$F(1, 53) = 16.44, p < .001$	$F(1, 54) = 5.50, p = .023$
Temporal Sequence \times Order \times Prime-Probe Relation	$F(1, 53) = .02, p = .897$	$F(1, 54) = .91, p = .345$
Temporal position alone		
Main effect of order	$F(1, 48) = 1.17, p = .285$	$F(1, 53) = 2.36, p = .130$
Temporal Sequence \times Order \times Prime-Probe Relation	$F(1, 48) = .77, p = .386$	$F(1, 53) = 8.89, p = .004$
Order \times Prime-Probe Relation for fast-slow data		$F(1, 53) = 6.56, p = .013$
Negative priming when distractor after target		$t(53) = 2.38, p = .021$
Negative priming when distractor before target		$t(54) = 1.25, p = .215$
Order \times Prime-Probe Relation for slow-fast data		$F(1, 54) = 2.37, p = .130$
Response repetition alone		
Main effect of order	$F(1, 40) = .08, p = .775$	$F(1, 48) = 1.80, p = .186$
Temporal Sequence \times Order \times Prime-Probe Relation	$F(1, 40) = 1.75, p = .193$	$F(1, 48) = 7.06, p = .011$
Order \times Prime-Probe Relation for fast-slow data		$F(1, 48) = 3.82, p = .056$
Negative priming when distractor after target		$t(54) = 2.11, p = .040$
Negative priming when distractor before target		$t(48) = 1.18, p = .245$
Order \times Prime-Probe Relation for slow-fast data		$F(1, 54) = 2.58, p = .114$

Note. Main effects and three-way interactions are reported as no other effects of order reached significance. Follow-up two-way interactions and t -tests are reported following significant three-way interactions. Significant values are in bold as was one follow-up test where $p = .056$.

ative priming effect cannot be attributed to the identity of the ignored item as the target identity on the probe trial (X) did not match the distractor's identity on the prime trial (O). Similarly, this effect cannot be attributed to the spatial location of the target on the probe trial because all stimuli were presented at the center of the screen. Instead, this effect reflects temporal positioning. Temporal negative priming effects in Experiments 1 and 2 are plotted in Figures 2 and 3, respectively.

To our knowledge this is the first report that attentional selection is affected by an ignored temporal position. One possibility is that the entire prime episode is encoded relative to a fixed starting point. This suggests that "episodes" may unfold over time and that attentional selection and cognitive control may be affected by shared temporal relationships with preceding episodes. Indeed, our data suggest that cognitive control is needed when making decisions about conflicting temporal events and that the successful resolution of this conflict can be achieved through the inhibition of distracting responses (or tagging of these responses as inappropriate) and through the tagging of events in episodic memory. We return to this point toward the end of the discussion where we draw connections between negative priming research and theories of cognitive control.

Error Protection

In a recent paper exploring spatial negative priming, Buckolz, Stoddart, Edgar, and Khan (2014) reported an effect they refer to as error protection. Error *protection* is the finding that participants take into account previous responses that resulted in an error and are more likely to respond in a way not previously associated with an error. To examine this, Buckolz et al. analyzed the types of errors participants made in spatial negative priming tasks. Rather than simply looking at overall error rates (which characterizes typical error analyses), the authors examined the types of errors that people made. They reported that when participants make an error responding to the target on the probe trial they are much less likely to respond with a keypress that had been associated with a distractor on the prime trial relative to a keypress that was not associated with a distractor on the prime trial (i.e., error protection). This analysis is especially clever because if errors are spurious, they should not pile up in predicted ways. However, if errors of one type are more likely than errors of another type then this provides additional information about the cognitive processes underlying those errors.

Because this type of analysis may provide additional information, we analyzed the types of errors that were made on unrelated trials (i.e., the control trials) in situations where temporal position was isolated from effects of the response. We did this for the original set of data ($n = 61$), the replication ($n = 70$), and Experiment 2 ($n = 56$). Though many participants had missing cells in this analysis, because they never made an error on the unrelated probe trial (reflected in the degrees of freedom), this analysis was still informative. When temporal position is isolated from effects of the response and an error is made, people are less likely to report that the target appeared at a point in time previously occupied by a distractor relative to a point in time that was not previously occupied by either a distractor or target, and this was true for the original set of data, $M = .10$ versus $M = .89$, $t(23) = 6.79$, $p < .001$, the replication, $M = .06$ versus $M = .77$,

$t(26) = 7.04$, $p < .001$, and Experiment 2, $M = .16$ versus $M = .60$, $t(16) = 2.58$, $p = .020$.

This result provides (a) independent evidence for temporal negative priming (since errors could have been distributed differently across conditions) and (b) converging evidence for temporal negative priming (this occurred in the original data, the replication, and Experiment 2). In addition, we believe this result may have theoretical significance since it makes more sense to us for an individual to tag the prime episode with something like "the target does not appear X ms following the fixation" rather than inhibiting a point in time on the prime, because that moment is in the past when the probe appears. As such, this tagging may be responsible for error protection rather than inhibition (an idea we return to in the next section).

Significance for Theories of Negative Priming

Numerous theories have been developed to help explain negative priming effects and these tend to fall into two broad classes, inhibition theories and memory theories. *Inhibition theories* suggest that selective attention to a target results in the active inhibition of the distractor's internal semantic representation (Tipper, 1985). Alternatively, *response inhibition theory* (Buckolz, Edgar, Kajaste, Lok, & Khan, 2012) is based on the idea that people actively inhibit the response associated with the distractor on the prime trial (rather than inhibition of a semantic representation). In each of these, responses to the target are slowed as a result of this inhibition. On the other hand, negative priming might reflect memory retrieval. For example, in *episodic retrieval theory* selective attention to the target results in the active tagging of the distractor as something to ignore (Neill & Mathis, 1998; Neill, Valdes, Terry, & Gorfein, 1992). If the probe triggers retrieval of this memory trace, then performance is impaired. Similarly, in *stimulus-response binding theory* (Mayr & Buchner, 2006), the prime episode contains the entire event of target, distractor, and response (Hommel, 1998) and it is the retrieval of the prime's response that causes negative priming. Finally, in *temporal-discrimination theory* (Milliken, Joordens, Merikle, & Seiffert, 1998), events are categorized as old or new and negative priming arises when people have difficulty categorizing a weakly familiar probe (which will happen on ignored repetition trials because the probe is only somewhat similar to the prime). A third possibility, somewhat distinct from inhibition or memory-based theories, is *feature mismatch theory* (Park & Kanwisher, 1994). According to this account, location-based negative priming arises because people have difficulty binding a target's features (X) to a spatial location where different features had just been bound (O). Although this theory has not received empirical support as contributing to location-based negative priming in visual tasks (Milliken, Tipper, & Weaver, 1994) or touch-based tasks (Frings, Mast, & Spence, 2014), it does appear to be the causal mechanism responsible for spatial negative priming in auditory tasks (Mayr, Buchner, Möller, & Hauke, 2011).

Here we report an altogether new class of negative priming. This temporal negative priming effect, like other forms of negative priming might have multiple causes and the data presented here provide some clues as to what those causes might be. First, temporal negative priming appears to reflect multiple mechanisms since there is both a response-based component and a time-based

component. The response-based component (in which people have difficulty responding with a keypress previously associated with a distractor) is consistent with *response inhibition theory* (Buckolz et al., 2012). However, this cannot be the entire cause of this effect because temporal negative priming also has a time-based component. We believe the time-based component of negative priming is more easily explained by memory-based theories than inhibition theories, because it makes little sense for people to form a mental representation of a point in time, which must immediately be inhibited. In this way our results are similar to those of DeSchepper and Treisman (1996), who reported long lasting identity-based negative priming of completely novel shapes. As is the case in that experiment it seems doubtful that people form a mental representation, in their case of a shape (or in our case a point in time) with the sole purpose of inhibiting that newly formed mental representation. Instead, it seems more likely that this reflects memory retrieval in which people recall information about what should be ignored. The specific mechanism(s) responsible for temporal negative priming await further scrutiny but it seems likely that response-based and memory-based mechanisms contribute to this effect.

Unforeseen Aspects of the Data

Temporal negative priming was significant in RTs in our first study, in error rates in our replication, and in both RTs and error rates in our second experiment. One possibility for this variability is that when error rates are high, negative priming is less robust in the RT data and negative priming may have been more robust had we pushed participants to maintain high accuracy rates (Neill & Westberry, 1987). Another possibility is that when attention is not directed at the distractor, as may have been the case in Experiment 1, temporal negative priming may be less robust. For this reason, we required participants to attend to the distractor's positioning in Experiment 2. As expected, negative priming in Experiment 2 was found in both RTs and error rates. This result matches others who report robust negative priming when participants attend to the distractor on the prime trial (Kahan et al., 2002; MacDonald et al., 1999). Indeed, memory-based theories of negative priming depend on the prime trial's distractor being encoded. For example, in Neill and Mathis's (1998) transfer-inappropriate processing account of negative priming the distractor is tagged as something to ignore and retrieval of this memory-trace impairs performance on the probe. Similarly, in Milliken et al.'s (1998) temporal-discrimination theory people categorize the probe as old or new on each trial and negative priming results when the probe is not easily categorized as being either old or new (which will happen on ignored repetition trials because the probe is only somewhat similar to the prime).

However, we point out that not every experiment finds an increase in the magnitude of negative priming when distractors are attended, rather than ignored. For example, Joordens et al. (2006) had participants respond to red digits while ignoring white digits (participants indicated if the red digit was less than or equal to 4 or greater than or equal to 5). In addition, some individuals needed to monitor the white distractors for the number 9 (or the letter p) and were instructed to press the space bar whenever this was shown. Other individuals were not required to monitor the white numerals. Negative priming was found for both groups and although the magnitude of negative priming was numerically greater for the

monitor-distractor group relative to the ignore-distractor group (36 ms vs. 19 ms), this difference was not significant. As such, we do not wish to claim that negative priming will certainly increase in magnitude when participants attend to the distractor. Instead, we point out that temporal negative priming was robust using this methodology and this result fits with theories of negative priming that are based on memory retrieval.

Another unexpected aspect of our data relates to the effects of target-distractor order. Though the influence of this factor in Experiment 1 matched our predictions, target-distractor order affected negative priming in unforeseen ways in Experiment 2. In Experiment 1, target-distractor order moderated the response-based component of temporal negative priming. Specifically, no response-based component was observed when the distractor followed the target but response-based negative priming was found when the distractor preceded the target. It is not altogether surprising that the distractor had a greater effect when it preceded the target as the distractor may receive relatively greater attention here (though see Footnote 4). However, the effects of target-distractor order were quite different in Experiment 2. When participants were required to attend to the distractor, we found greater response-based and time-based negative priming when the distractor followed the target and the prime was presented rapidly relative to when the distractor preceded the target and the prime was presented rapidly. When the prime presentation rate was slower, there was no effect of target-distractor order. This finding was unexpected but may indicate that the prime is more difficult to encode and remember with a fast presentation rate. Yet negative priming can still emerge if the distractor is closer in time to the probe (making it more temporally discriminable) and attention is directed to this distractor.

Finally, another peculiarity about the data was the finding that negative priming was not significant in situations where temporal positioning and response-based mechanisms were confounded in Experiment 2. At present, it is unclear why this was the case because the target appeared at both a point in time that was previously occupied by a distractor and required a response associated with a distractor. Because either of these variables, by themselves, would produce negative priming, it was somewhat surprising that the combined influence of these variables did not reach significance. The reason for this is unknown and awaits further testing.

Relation to Location-Based and Identity-Based Negative Priming

In many ways temporal negative priming appears to be more similar to location-based than identity-based negative priming because positioning—temporal or spatial—rather than identity affects performance. In fact, Neill and Kleinsmith (2016) reported that spatial negative priming was larger when the prime trial was more spread out in space (29 ms) than when the prime trial was more narrowly packed (12 ms). Here, we find the same pattern with temporal positioning: larger negative priming with slow relative to fast prime presentation rates in Experiment 1.

One critical difference between location-based negative priming and temporal negative priming is that in location-based negative priming the target on the probe trial appears at the exact same spatial location as the distractor on the prime trial, but in temporal

negative priming the prime and probe occupy different time periods.⁵ For this reason, the two negative priming effects appear to be quite distinct. Another difference is that in spatial negative priming the location of the target and distractor should have little effect since attention should be allocated equally to all spatial locations (i.e., whether the distractor appears to the left or right of the target) yet in temporal negative priming the positioning of the target and distractor does matter (i.e., whether the distractor appears before or after the target).

As already discussed, temporal negative priming, like other forms of negative priming, may have multiple causes and the time-based component of temporal negative priming must reflect similarities between the prime and probe episodes rather than inhibition of a specific moment in time (because the prime episode is in the past when the probe appears). It is an empirical question whether similarity between the prime and probe is based on the amount of time that has passed since the beginning of the trial, the onset time of the stimuli, offset times, and so forth. There are also ways in which temporal negative priming is similar to identity-based negative priming. For example, identity-based negative priming is more sensitive to the spatial proximity of target and distractor items than location-based negative priming (Chao & Yeh, 2005; Fox, 1994). Here we find that temporal negative priming is dependent upon the temporal spacing of the prime. However, in temporal negative priming, items more spread out (in time) give rise to negative priming whereas in identity-based negative priming more tightly packed items (in space) are needed.

Timing Manipulations and Negative Priming

Prior research has found that timing manipulations can affect negative priming. For example, Neill (1997) had participants identify a letter (A, B, C, or D) that was flanked by distracting letters. Identity based negative priming here is the finding that participants respond more slowly to previously ignored targets (e.g., the probe “BAB” preceded by the prime “ACA”) relative to situations in which the target on the probe trial had not just been ignored (e.g., the probe “BAB” preceded by the prime “DCD”). Importantly, Neill also manipulated whether the flanking letters appeared simultaneously with the target or had a 400-ms delay. Identity-based negative priming was much greater when the flanking letters from the prime matched the presentation rate of the flanking letters on the probe (both shown simultaneously with the target or both delayed) relative to when the flanking letters on the prime and probe had mismatched timing. These data suggest that timing manipulations can create a context that affects memory retrieval (and as such negative priming).

Other studies have also examined whether the time between the prime and probe affects identity or location-based negative priming. For example, negative priming may decrease as the delay between prime and probe increases (Neill & Westberry, 1987). Temporal manipulations may also influence negative priming by affecting memory retrieval (Neill, 1997; Neill et al., 1992). In our studies we did not examine the influence of temporal parameters on the magnitude of negative priming by manipulating the time between the prime and probe. It is possible that the time between the prime and the probe may affect temporal negative priming in ways similar to identity and location-based negative priming. For example, if the entire prime episode is encoded relative to a fixed

starting point then the time between prime and probe may affect negative priming by influencing the likelihood of prime retrieval. This possibility awaits future scrutiny.

Temporal Negative Priming and Cognitive Control

Cognitive control is often characterized as a contrasting and complementary component of learning where learning results in reflexive responses to environmental stimuli and cognitive control is engaged when the learned response is incorrect or should be avoided (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, 2012; but see Abrahamse et al., 2016, for an associative learning account of how cognitive control may develop). For example, a student might say aloud the answer to a question posed by a professor during office hours, but this response must be controlled during a lecture where the appropriate behavior involves raising a hand. As such, whenever people are in a situation where conflict is likely, whether that be response-based conflict, conflict related to attentional selection, or task-based conflict, cognitive control may be engaged and negative priming tasks exhibit all of these characteristics. In negative priming tasks, there are multiple response options available, some response is necessary whereas other responses must be prevented, there are demands on attention to select a target and ignore the distractor, and in some experiments task control is needed (e.g., Experiment 2 where the task required responding to the target and then responding to the distractor). In addition, cognitive control is also needed in prospective memory tasks where people must remember to perform an action at a later time (e.g., remembering to stop at the store on the way home from work; Strickland, Loft, Remington, & Heathcote, 2018). In identity-based and location-based negative priming, participants do not need to remember to respond to the target at a later point in time, because the target is on the screen when the response is needed, but in temporal negative priming prospective memory is necessary because the target is in the past when the cue for response is presented. One theoretical account of cognitive control that has been applied in all of these areas is the dual mechanisms of control framework (Braver, 2012), where cognitive control can be subdivided into proactive and reactive control.

Braver (2012, p. 106) described *proactive control* as occurring in a “sustained manner” where task goals are activated before the task begins and involves the ongoing maintenance of the proper attentional set. Reactive control on the other hand is characterized as occurring in a “just-in-time manner” and is triggered on a trial-by-trial basis by conflict. Maintenance of the overarching task is provided by proactive control while in-the-moment conflict triggers reactive control to remain vigilant, and each of these may be associated with different brain regions. Specifically, sustained activity in the lateral prefrontal cortex may help maintain proactive control and when conflict is detected (or is likely) the anterior cingulate cortex may signal the lateral prefrontal cortex to enhance reactive top-down control (Botvinick et al., 2001; Carter et al., 1998). The functional organization of the subregions of lateral

⁵ We thank Tram Neill for pointing this out and for also noting that this requires that we ignore rotation of the earth, revolution around the sun, and expansion of the universe (which is reasonable because these variables are not noticeable to participants).

prefrontal cortex that are involved in cognitive control are debated (Reynolds, O'Reilly, Cohen, & Braver, 2012) but include the dorsolateral prefrontal cortex a region that has also been implicated in both negative priming and episodic memory retrieval (Egner & Hirsch, 2005; Nee & Jonides, 2008; Rugg, Henson, & Robb, 2003). Perhaps this area is involved in both the tagging and retrieval of distracting events.

Cognitive control is predicted to be context specific and should arise in the absence of awareness (Abrahamse et al., 2016). In support of this, list-wide proportion-congruency effects have been found where Stroop interference is larger in mostly congruent lists, where proactive control is reduced, relative to mostly incongruent lists (Botvinick et al., 2001). This has also been found at the item level where greater Stroop interference is obtained for items that are more often congruent than incongruent (Blais, Robidoux, Risko, & Besner, 2007). In addition, as theories of cognitive control predict (Abrahamse et al., 2016), item-specific learning has been shown to occur outside awareness (Schmidt, Crump, Cheesman, & Besner, 2007). These results raise the interesting possibility that negative priming might be affected by list-wide congruency or item-specific congruencies. Perhaps negative priming will only emerge when control is needed and as such might be sensitive to item-specific learned associations that may operate outside awareness. These possibilities await further testing.

Temporal negative priming, unlike other forms of negative priming, involves prospective memory and may share similarities with other tasks that require prospective control. However we note that the cue to give a response is quite salient in the experiments reported here (i.e., the cue is a question mark occurring at the end of the sequence) and as such proactive control related to prospective memory may be relatively low (Bugg, McDaniel, & Einstein, 2013), whereas proactive control related to selection of the target, rather than the distractor, may be relatively high. Teasing apart the relative contribution of different sources of conflict awaits future testing.

Finally, one difference between temporal-negative priming and identity-based negative priming is that the target on the probe trial does not look like the distractor from the prime trial and for this reason we speculate that somewhat distinct brain regions may contribute to these two forms of negative priming. For example, in identity-based negative priming the target on the probe does look like the prior distractor and here Nee and Jonides (2008) found that regions in the occipital cortex may be involved in distractor inhibition, whereas the dorsolateral prefrontal cortex may be involved in episodic-retrieval. We speculate that the latter, but not the former, may contribute to temporal negative priming. Finally, we suppose that because cognitive control may impede some aspects of creativity (see Amer, Campbell, & Hasher, 2016), there may be an inverse relationship between temporal negative priming and groups who show enhanced creativity resulting from reduced control (e.g., older adults and individuals tested at off-peak times of day).

Conclusions

Negative priming provides a useful indicator of cognitive control as well as its impairment. Here we report an entirely new negative priming effect. Temporal negative priming is distinct from identity-based negative priming and location-based negative

priming and, although it shares some similarities with the latter (both involve the positioning of targets and distractors), the data indicate that different causal mechanisms may be at play. Whether temporal negative priming results from the same neural pathways that contribute to other negative priming effects and whether temporal negative priming would emerge if the timing of the prime and probe sequences were slowed further has yet to be determined. In addition, whether groups of individuals with impaired cognitive control exhibit temporal negative priming is not yet known. Temporal negative priming may be a transdiagnostic cognitive process that could help identify a mechanism for targeted interventions across diagnostic categories, as well as relate to individual differences in symptom severity, but this possibility awaits further testing. All that is known at this point is that THC use and variations in schizotypy—which have been associated with reduced levels of location-based and identity-based negative priming, respectively (Albertella et al., 2016; Beech & Claridge, 1987)—did not correlate with temporal negative priming here. It is also possible that temporal negative priming, unlike identity- or location-based negative priming, will be reduced for groups of individuals who have difficulty with temporal sequencing (e.g., patients with Korsakoff's Syndrome [Meudell, Mayes, MacDonald, Pickering, & Fairbairn, 1991] and Bálint's Syndrome [Malcolm & Barton, 2007]). In 50 years of research examining negative priming a great deal has been learned about the processes involved in selective attention and cognitive control. Here we report data that mark another milestone in this line of inquiry by providing empirical evidence for a third class of negative priming: temporal negative priming. We propose that this newly discovered negative priming effect may reflect mechanisms of cognitive control and that this control engages both response-based and memory-based mechanisms.

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