

Resisting recently acted-on cues: Compatibility of Go/NoGo responses to response history modulates (frontal P3) event-related potentials

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Abstract

Using event-related potentials to investigate compatibility between past and present cue–response interactions, an experiment combined elements of selective-attention and Go/NoGo tasks. In the selective-attention part of each trial, participants responded to one of two visible numerical digits. Immediately afterward, in the Go/NoGo part of each trial, one of the same two digits appeared, with participants required to press the corresponding key on Go trials and to withhold responding on NoGo trials. Higher-amplitude anterior P3 responses on NoGo than on Go trials emerged when participants withheld responding to a recently selected cue but were greatly diminished when participants withheld responding to a recently ignored cue. The findings suggest that episodic traces of past Go/NoGo responses guide future action decisions, such that increased response control is needed to overcome bias to respond to recently acted-on NoGo cues.

Descriptors: Go/NoGo, P3, Episodic retrieval, Categorization, Event-related potentials, Action control, Cognitive control

Goal-directed action entails following rules or intentions despite the frequent presence of goal-incompatible information. Decades of behavioral and neurophysiological research have examined how compatibility between intentions and environmental cues impacts action control (e.g., Freitas, Liberman, & Higgins, 2002; Leung, Skudlarski, Gatenby, Peterson, & Gore, 2000; MacLeod, 1991; McCarthy & Donchin, 1981; West, 2003). In a related vein, research in cognitive neuroscience recently has begun to examine another kind of compatibility, that between one's current actions and one's own action history (for reviews, see Fecteau & Muñoz, 2003; Schacter, Dobbins, & Schnyer, 2004). What cognitive and neurophysiological processes facilitate responding to cues differently from how one has responded to them in the past? The current work addressed this question in the context of a basic aspect of response control, deciding whether or not to act.

Response control has been studied extensively with the Go/NoGo task, in which the participant makes overt or covert responses (“Go”) to a particular stimulus and withholds re-

sponses (“NoGo”) to another stimulus (e.g., Pfefferbaum, Ford, Weller & Kopell, 1985; Simson, Vaughan & Ritter, 1977). Recent research has examined the effects of the local and global context of generating versus withholding responses on brain function during Go/NoGo tasks, in both fMRI studies (Durstun et al., 2002) and electrophysiological studies (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). However, no previous research—behavioral or neurophysiological—of which we are aware has examined the impact of compatibility between past and present Go/NoGo responses to particular stimuli, as when one must withhold responding to a particular stimulus for which one recently generated a response. Despite the lack of extant work on this topic, examining the impact of cue-specific Go/NoGo responses on future responses appears important to explaining how, and when, information pertaining to one's action history is incorporated into current action decisions.

More specifically, the current investigation tested whether episodic-retrieval accounts of learning (Logan, 1988) and categorization (Nosofsky & Palmeri, 1997) can help explain Go/NoGo electrophysiological responses. Logan's instance theory proposes that each episode (“instance”) of behavior generates a separate episodic trace that is stored in memory. In this sense, encoding of behavior–environment interactions is said to be obligatory, in that separate traces of each instance of behavior (even if those instances are identical to one another) are generated. Cued retrieval of episodic traces also is said to be obligatory, in that encountering a stimulus cues all traces associated with it,

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with the most recently created traces retrieved most rapidly. Neuroimaging data supporting these assumptions come from evidence of reductions in cortical activity as a function of response-specific prior interactions with cues (Dobbins, Schnyer, Verfaellie, & Schacter, 2004). Moreover, activation of the dorsolateral prefrontal cortex (DLPFC) often has been linked to episodic memory retrieval (e.g., Lepage, Ghaffar, Nyberg, & Tulving, 2000; Shallice et al., 1994). Accordingly, the finding that responding to a recently ignored color word increases DLPFC activation has been interpreted as consistent with the view that particular interactions with a stimulus (e.g., ignoring it) generate episodic traces that are retrieved at subsequent stimulus presentations (Egner & Hirsch, 2005; see also Neill, 1997; Rothermund, Wentura, & De Houwer, 2005; cf. Tipper, 2001). Finally, responding to a recently ignored auditory tone was associated with a late-positive electrophysiological signal often linked to episodic retrieval of “old/new” stimulus information (Mayr, Niedeggen, Buchner, & Pietrowsky, 2003), a finding also interpreted to suggest that responses to a stimulus generate action records that are retrieved upon subsequent stimulus presentations.

Response History, Response Control, and NoGo P3 Event-Related Potentials

Following an episodic-retrieval account, then, instances of responding (“Go”) or withholding responding (“NoGo”) to a particular cue should generate action records that are retrieved upon subsequent exposures to the cue, thus impacting future Go/NoGo decisions. A cue responded to recently should prompt more rapid retrieval of instances of having responded to the cue than of having withheld responding to it, thus biasing one’s present action decision in favor of generating a response (for more extensive discussion of exemplar-based decision making, see Nosofsky & Palmeri, 1997). In contrast, a cue ignored recently should prompt more rapid retrieval of instances of having withheld responding to the cue than of having responded to it, thus biasing one’s present action decision in favor of withholding a response. Following this reasoning, recently acted-on NoGo cues, by prompting the (task-inappropriate) Go response, should require a greater degree of response control than recently ignored cues, which are assumed to prompt the (task-appropriate) NoGo response.

Which brain responses will change as a function of the above hypothesized changes in task demands for response control? Among the most studied phenomena in psychophysiology is the P3 component, an endogenous late-positive component of the event-related potential (Sutton, Braren, Zubin, & John, 1965). Characterized in terms of amplitude, latency, and scalp topography, this component has proved an important predictor of numerous cognitive and behavioral phenomena (for reviews, see Donchin & Coles, 1988; Nieuwenhuis, Aston-Jones, & Cohen, 2005). In Go/NoGo tasks in particular, one important correlate of response control appears to be the finding of higher amplitude P3 responses at fronto-central electrodes, peaking between 300 and 700 ms, when participants enact NoGo relative to Go responses (i.e., the NoGo P3; Fallgatter & Strik, 1999). Given its distinct association with response suppression rather than response generation, and given its source localization to frontal brain areas associated with executive control (e.g., lateral orbitofrontal cortex; Bokura, Yamaguchi, & Kobayashi, 2001), the NoGo P3 may be interpreted as functionally related to response-control processes, including assessing and suppressing off-task

responding (see also Kok, Ramautar, De Ruiter, Band, & Ridderinkhof, 2004).

Other lines of reasoning, however, suggest alternative functional characterizations of the NoGo P3. One intriguing study contrasted event-related potentials (ERPs) in a typical Go/NoGo task in which participants generated a motor response to a frequent stimulus but withheld responding to an infrequent stimulus, to ERPs in two types of oddball tasks, a silent-count oddball task, in which participants silently counted occurrences of an infrequent stimulus but not a frequent stimulus, and a conventional oddball task, in which participants generated a motor response for an infrequent stimulus but not a frequent stimulus (Salisbury, Griggs, Shenton, & McCarley, 2004). The critical finding was that prominent anterior P3 effects emerged not only on NoGo responses relative to motor responses but also on silent-count responses relative to motor responses. To the extent that a silent-count response can be considered an active response, then, the finding that silently counting and withholding responses equally increases the amplitude of anterior P3 responses raises the possibility that anterior P3 responses may reflect brain processes other than response control. However, humans may have an overlearned tendency to respond actively to targets rather than to silently count them; if so, prominent anterior P3 responses on silent-count oddball tasks relative to motor-response oddball tasks could reflect increased response control, in which the assumedly overlearned tendency to respond actively must be rejected in favor of the silent count. Although speculative, this interpretation would appear to suggest that further work is needed to assess the functional relationship between NoGo P3 responses and response control.

The NoGo P3 also has been viewed to occur too late to relate causally to response control (Falkenstein, Hohnsbein, & Hoormann, 1999). However, as has been argued with respect to whether the P3 more generally can be considered to index causes rather than only consequences of action, it is important to note that P3 latency typically is measured at the component’s peak, whereas it would appear equally reasonable to measure it according to alternative criteria, such as onset, that occur much earlier (Nieuwenhuis et al., 2005). Moreover, concerning Go/NoGo responses in particular, withholding responding is required throughout the *entire* response window, not only at the *specific timepoint* at which a Go response might be generated, suggesting that withholding a response may be a longer duration brain event than is generating a response. For these reasons, the latency of the NoGo P3 appears insufficient to assess its functional role in response control.

An alternative strategy of assessing the functional role of the NoGo P3 in response control is to test whether the NoGo P3 is particularly pronounced when response-control processes are particularly engaged. Support for this hypothesis is emerging from studies contrasting Go/NoGo responses among distinct subject populations. Boys diagnosed with attention deficit hyperactivity disorder, whose propensity for response control is greatly diminished, exhibit diminished (lower amplitude) NoGo P3 responses relative to matched control participants (Fallgatter et al., 2004). Similarly, children of alcoholics, who are presumed to be at increased genetic risk of diminished ability to inhibit inappropriate responses, also exhibit diminished NoGo P3 responses relative to matched control participants (Kamarajan et al., 2005). Likewise, Parkinson’s disease patients, whose symptoms include compromised executive control, exhibit lower amplitude NoGo P3 responses relative to matched controls (Bokura, Yamaguchi,

& Kobayashi, 2005). In the latter study, moreover, individual differences on a measure of set-switching and inhibitory function (the Wisconsin Card-Sorting Task) correlated positively with amplitude of NoGo P3 responses. Further supporting the specificity to response control of the above findings, in each of studies reviewed above, differences between populations of interest emerged only with respects to NoGo responses (i.e., Go P3 responses did not differ between clinical and control groups). Finally, developmental data also highlight the functional association of the NoGo P3 with response control, in that, relative to adults, 9-year-old children demonstrate higher impulsivity scores as well as lower amplitude NoGo P3 responses (Jonkman, Lansbergen, & Stauder, 2003). Taken together, these findings across different subject populations are consistent with the view that NoGo P3 responses relate functionally to response control.

Besides comparing members of preexisting populations that vary in propensity to exert response control, manipulating situational demands on response control can be a powerful means of assessing particular neural processes' functional role in response control. Following this tract, a recent investigation showed that NoGo P3 responses are greatly enhanced when the response one must suppress is being enacted, in real time, by a study participant seated beside oneself (Sebanz, Knoblich, Prinz, & Wascher, 2006). This finding suggests that fronto-central NoGo P3 responses index neural processes functionally related to response control, in that suppressing highly accessible actions performed simultaneously by a study coparticipant should be expected to recruit a considerably greater degree of response control than suppressing actions for which situational cues do not prompt action generation.

Following the general strategy of manipulating situational demands for response control in Go/NoGo tasks, the present study tested whether participants' own response histories would modulate their NoGo P3 responses. As discussed above from an episodic-retrieval perspective, recently acted-on NoGo cues, by prompting the (task-inappropriate) Go response, should require a greater degree of response control than should recently ignored cues, which are assumed to prompt the (task-appropriate) NoGo response. Accordingly, we hypothesized that larger NoGo P3 effects will emerge when withholding a response to a recently selected cue than when withholding a response to a recently ignored cue. Support for this hypothesis would (1) support interpreting fronto-central NoGo P3 brain responses as functionally related to response control, while (2) providing the first evidence of how and when past Go/NoGo responses to particular cues impact future ones. Toward these ends, we conducted an experiment combining elements of selective-attention and Go/NoGo tasks. In the selective-attention part of each trial, participants responded to one of two visible numerical digits. Immediately afterward, in the Go/NoGo part of each trial, one of the same two digits appeared, with participants required to press the corresponding key on Go trials and to withhold responding on NoGo trials.

Method

Participants

Thirteen undergraduates, with normal or corrected-to-normal vision, received course credit for participating in the experiment. Data from two additional subjects were unusable due to insufficient (under 50%) artifact-free trials.

Experimental Task

The experimental task combined selective-attention and Go/NoGo components. First, in the *selective-attention* part of each trial, participants viewed two digits (drawn from the set: [1, 2, 3, and 4]), each in a different color (either yellow or light blue, with a black background maintained throughout the experiment). Participants used a four-button response box to press the key corresponding to whichever one of the two digits appeared in a particular target color (i.e., yellow or blue, with the target color counterbalanced across participants and constant, for each participant, across trials). Participants were instructed to hold the response box in their hands (like holding gaming devices) and to use their left thumb to press the "1" and "2" keys and their right thumb to press the "3" and "4" keys. The stimuli remained on the screen until participants responded (97.13% of responses occurred in 1000 ms or faster). After this initial response, a 500-ms pause ensued, in which the screen was blank. Next, in the *Go/NoGo* part of each trial, one of the same two digits participants had viewed immediately previously (in the selective attention part of the trial) appeared again, but in white font, and encased in either a circle or a square. Participants responded (by pressing the corresponding key on the response pad) to digits encased in one of the two shapes (e.g., the circle) and withheld responses to digits encased in the other of the two shapes (e.g., the square, with the target shape counterbalanced across participants and constant, for each participant, across trials). Go/NoGo stimuli remained visible until participants responded or until 1200 ms had transpired, at which point the next trial began. No feedback was provided during the experimental blocks. The intertrial interval was 1000 ms.

Thus, as exemplified in Figure 1, there were four compound types of (equiprobable) trials: Go/Selected, in which participants responded to a recently selected stimulus; Go/Ignored, in which participants responded to a recently ignored stimulus; NoGo/Selected, in which participants withheld responding to a recently selected stimulus; and NoGo/Ignored, in which participants withheld responding to a recently ignored stimulus. There were 30 presentations of each compound trial type. All possible combinations of digit identity (i.e., 1, 2, 3, 4), digit color (i.e., yellow, blue), and digit placement (i.e., left of center, right of center) were included in equal proportions throughout the experiment, and trials were presented in randomized order.

Procedure

The experiments were conducted in a dark, sound-attenuating chamber, with participants seated comfortably in a reclining chair, approximately 61 cm from a flat-panel LCD computer monitor. The stimuli were 5.08 cm high by 5.08 cm wide ($4.76^\circ \times 4.76^\circ$ visual angle). Participants were instructed to remain as still as possible and to minimize eyeblinks throughout the experiment. A short training block, with trial-by-trial feedback, acclimated participants to the task.

Electrophysiological Recording

The EEG was recorded continuously using a 64-channel electrode cap (Neuroscan Inc., Sterling, USA). All recordings were performed using a fronto-central electrode as ground, and electronically linked mastoid electrodes as reference. The horizontal EOG was monitored from electrodes at the outer canthi of the eyes, and the vertical EOG was monitored from electrodes above and below the orbital region of the left eye. Impedances for all electrodes were kept below 10 K Ω . The EEG and EOG signals

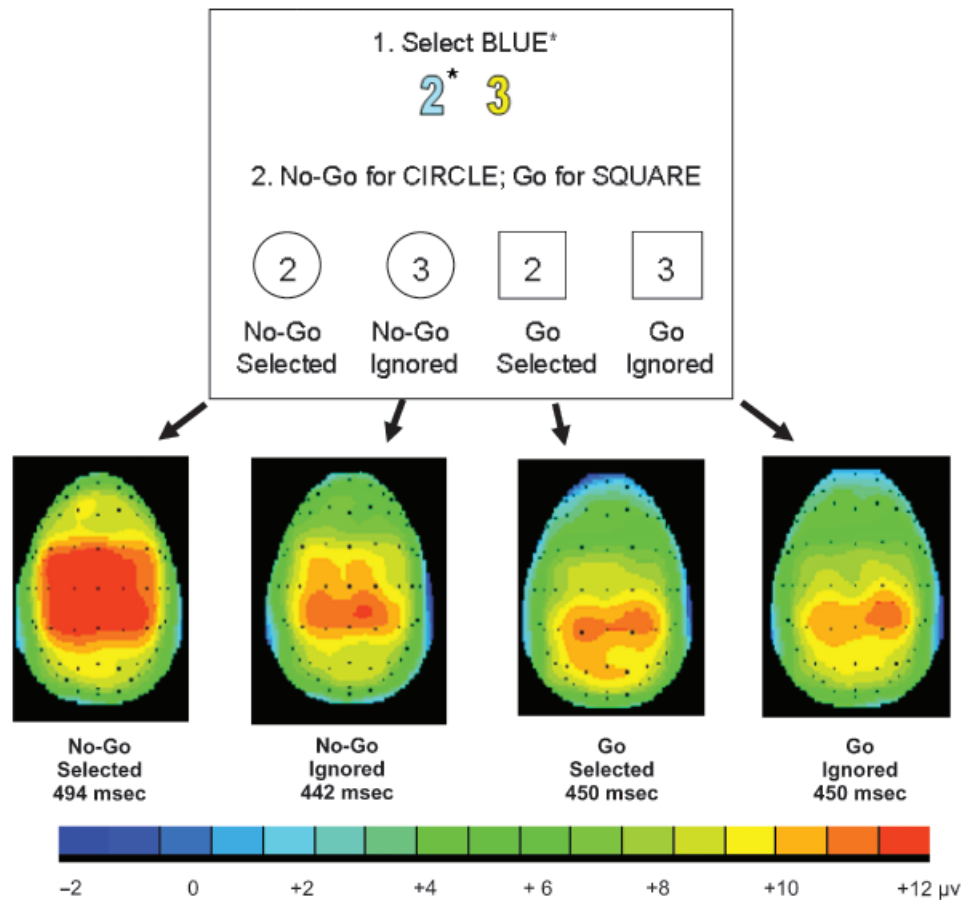


Figure 1. Experimental design (top panel) and 64-channel topographical voltage maps (bottom panel) across the scalp at time points corresponding to the maximal amplitude of the P3 component at electrode FCZ, across the four experimental conditions.

were digitized at 1000 Hz and were amplified with a gain of 500. The filter bandpass was 0.01–30 Hz. To eliminate EOG artifact, trials with EEG voltages exceeding $\pm 100 \mu\text{V}$ were rejected from the average. Artifact rejection and averaging were done off-line. Approximately 20% of the trials were excluded due to artifacts.

ERP Analysis and Statistics

Individual ERP averages were created for each stimulus category. ERP epochs began 100 ms prior to Go/NoGo stimulus onset and continued for 900 ms thereafter (ERP epochs also were collected on the selection part of each trial, but those data were not analyzed). Peak amplitude between 300 and 700 ms was designated as the P3 component. Peak amplitude was measured relative to the prestimulus baseline. As shown in Figure 1, topographical maps (based on all 62 channels) at the time point of maximum P3 amplitude at electrode FCZ were taken to present scalp distribution. Statistical analyses reported below are based on data from all 62 channels. Consistent with past research that has used 64-channel electrode caps to investigate electrophysiological Go/NoGo P3 responses (e.g., Kamarajan et al., 2005), prior to conducting statistical analyses, individual electrodes were grouped into the six regions: frontal (AF7, AF3, FP1, FPZ, FP2, AF6, AF8, F7, F5, F3, F1, FZ, F2, F4, F6, F8), central (FC5, FC3, FC1, FCZ, FC2, FC4, FC6, C5, C3, C1, CZ, C2, C4, C6), parietal (CP3, CP1, CPZ, CP2, CP4, P3, P1, PZ, P2, P4), Left Temporal (FT7, T7, TP7, CP5, P7, P5), right temporal (FT8, T8, TP8, CP6, P8, P6), and occipital (PO7, PO5, PO3,

POZ, PO4, PO6, PO8, O1, OZ, O2). The Greenhouse–Geisser correction was used for all comparisons with more than two within-subject levels (Greenhouse & Geisser, 1959).

Results

Behavioral Results

Accuracy (proportion of correct responses) was high across all parts of the experiment, including the selection component of all trials ($M = 0.985$, $SD = 0.012$), the Go/Selected trials ($M = 0.987$, $SD = 0.034$), the Go/Ignored trials ($M = 0.951$, $SD = 0.055$), the NoGo/Selected trials ($M = 0.997$, $SD = 0.009$), and the NoGo/Ignored trials ($M = 0.987$, $SD = 0.046$). Accuracy was lower on Go/Ignored than on Go/Selected trials, $t(12) = 2.50$, $p < .05$, $\eta_p^2 = .11$. There was no significant difference in accuracy between NoGo/Selected and NoGo/Ignored trials, $t < 1$.

Turning next to response times, 1.41% were not analyzed due to subject errors, and an additional 3% of the most extreme scores (> 1000 ms) were not analyzed. Responses on the selective-attention component of the task required an average of 649.38 ms ($SD = 62.28$). Most relevant, Go responses to recently selected digits ($M = 555.01$ ms, $SD = 61.78$) were, on average, 62.35 ms faster than were Go responses to recently ignored digits ($M = 617.36$ ms, $SD = 72.46$). This behavioral difference indicates that performance on the selective-attention task significantly impacted performance on the subsequent Go trials of the

Go/NoGo part of the task, $t(12) = 5.34$, $p < .001$, $\eta_p^2 = .49$. To understand the impact of selective attention on performance on the NoGo trials (for which there are no valid response times), we turn next to analyses of electrophysiological responses.

ERP Waveforms

Figure 2 shows grand-average ERP waveforms for each experimental condition. Consistent with previous evidence that inserting choice into the Go response greatly attenuates the NoGo N2 effects (Smid, Fiedler, & Heinze, 2000), visual inspection of the waveforms indicates no difference in prominence of N2 re-

sponses to NoGo cues relative to Go cues in the current four-choice Go/NoGo task (for more general discussion of differences between N2 and P3 NoGo effects, see the Discussion section). Most relevant to our investigation is the P3 component, which, at anterior electrodes, appears more prominent on NoGo relative to Go trials.

Overall Go/NoGo Anterior P3 Effect

Turning first to analysis of overall Go/NoGo anterior P3 effects, a 2 (Go vs. NoGo) \times 6 (Region: frontal, central, parietal, left-temporal, right-temporal, occipital) ANOVA yielded a

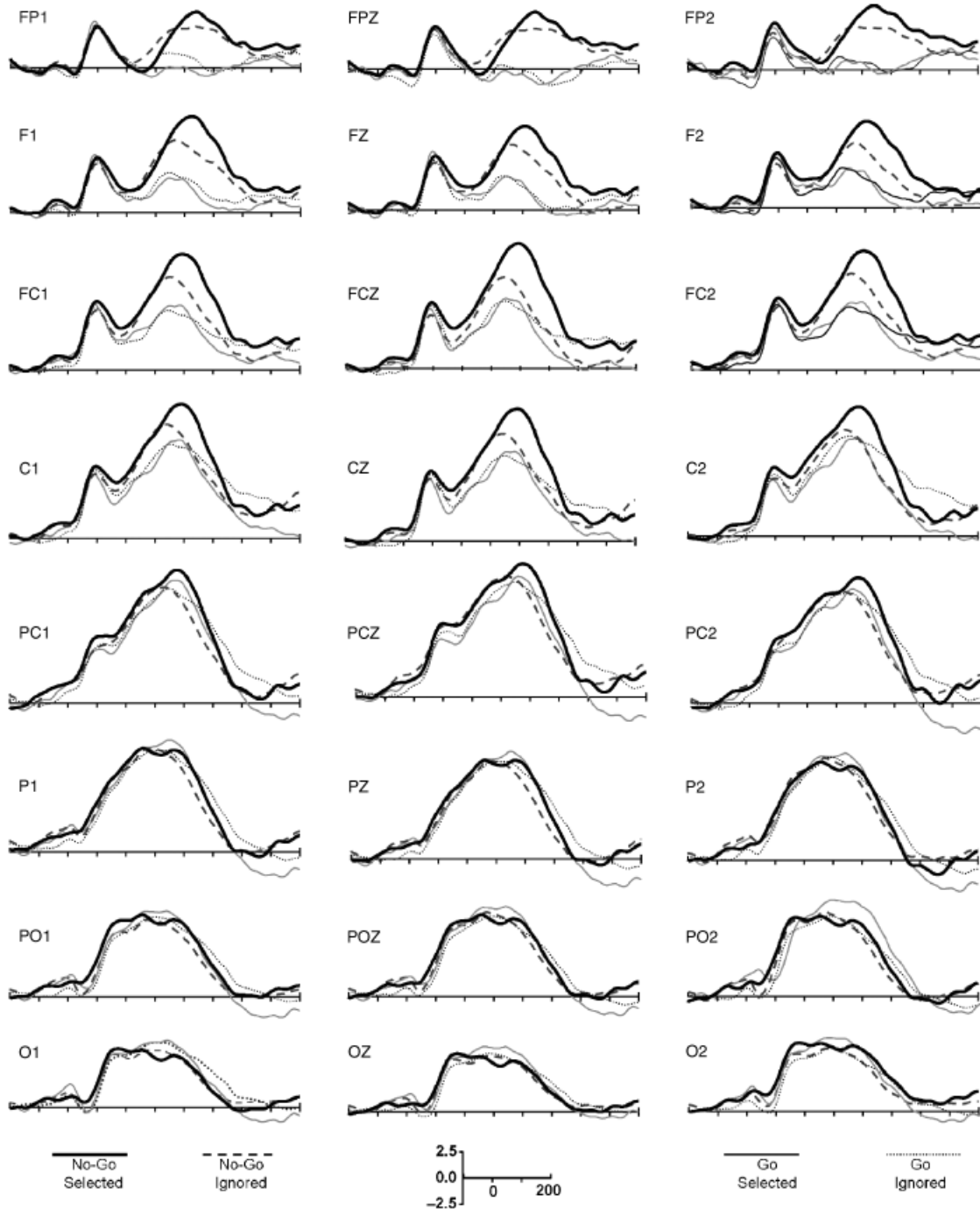


Figure 2. Grand-average waveforms ($N = 13$) for Go and NoGo P3 to cues that had been selected or ignored during the (immediately previous) selective-attention part of each trial.

significant effect of Go/NoGo, $F(1,12) = 5.17$, $p < .05$, $\eta_p^2 = .30$, a significant effect of Region, $F(5,60) = 7.81$, $\varepsilon = .32$, $p < .01$, $\eta_p^2 = .39$, and a significant Go/NoGo \times Region interaction, $F(5,60) = 8.01$, $\varepsilon = .40$, $p < .01$, $\eta_p^2 = .40$. Clarifying the nature of this interaction, P3 amplitude was higher on NoGo trials than on Go trials at electrodes in the frontal region (difference $M = 3.11 \mu\text{V}$, $SD = 3.17$, $t[12] = 3.53$, $p < .01$) and the central region (difference $M = 2.40 \mu\text{V}$, $SD = 2.66$, $t[12] = 3.25$, $p < .01$), but not at any other regions, all $ts < 1.48$, $ps > .16$. Replicating past work, then, higher amplitude P3 responses, at fronto-central electrode locations only, accompanied NoGo relative to Go trials.

Go/NoGo Response-History Effect

Most relevant to the current investigation, we next examined the moderating impact of the selective-attention manipulation (see Table 1 for corresponding descriptive statistics). In a 2 (Selective Attention: selected vs. ignored) \times 2 (Go/NoGo) \times 6 (Region: frontal, central, parietal, left-temporal, right-temporal, occipital) ANOVA, the above reported Go/NoGo \times Region interaction was moderated further by the selective-attention manipulation, yielding a significant three-way interaction, $F(5,60) = 3.76$, $\varepsilon = .41$, $p < .05$, $\eta_p^2 = .24$. This result means that the NoGo P3 effect was significantly different when participants responded to a previously ignored cue from when they responded a previously selected cue.

Accordingly, we next separately analyzed responses in the Selected and Ignored conditions. On Selected trials, in a 2 (Go/NoGo) \times 6 (Region: frontal, central, parietal, left-temporal, right-temporal, occipital) ANOVA, there was a significant effect of Go/NoGo, $F(1,12) = 5.53$, $p < .05$, $\eta_p^2 = .32$, which was moderated by Region, $F(5,60) = 10.62$, $\varepsilon = .38$, $p < .001$, $\eta_p^2 = .47$. This interaction reflects that fact that, when responding to recently selected cues, P3 amplitude was higher on NoGo trials than on Go trials at electrodes in the frontal region and the central region, but not at any other regions (see left side of Table 1). In contrast, on Ignored trials, in a 2 (Go/NoGo) \times 6 (Region: frontal, central, parietal, left-temporal, right-temporal, occipital) ANOVA, there was no significant main effect of Go/NoGo, $F(1,12) = 1.74$, $p > .21$, nor was there a significant Go/NoGo \times Region interaction, $F(5,60) = 2.04$, $\varepsilon = .31$, $p > .14$. This absence of significant main and interactive effects indicates that, in terms of the overall data pattern (see right side of Table 1), the NoGo P3 effect did not reach conventional levels of statistical significance on Ignored trials.

Further illustrating that recently selected stimuli evoke more prominent fronto-central NoGo P3 effects than do recently

ignored stimuli, P3 amplitude was significantly higher on NoGo/Selected trials than on NoGo/Ignored trials at electrodes in the frontal region (difference $M = 1.54 \mu\text{V}$, $SD = 2.48$, $t[12] = 2.25$, $p < .05$) and the central region (difference $M = 2.12 \mu\text{V}$, $SD = 3.41$, $t[12] = 2.24$, $p < .05$), but not at any other regions, all $ts < 1.16$, $ps > .27$.

Discussion

Behavioral habits long have been assumed to impact many aspects of the quality of life (e.g., Aristotle, 1997; James, 1906), in that, as confirmed in modern experiments, habitual experiences with particular stimuli and responses come to activate behavioral goals (Aarts & Dijksterhuis, 2000) and to modulate activity engagement (Freitas & Higgins, 2002). Accordingly, understanding how previous cue-response interactions impact future ones is an issue of practical as well as conceptual significance. In the present experiment, participants' Go/NoGo response histories modulated their electrophysiological responses. Fronto-central NoGoP3 effects emerged when participants withheld responding to a recently selected cue but were attenuated greatly when participants withheld responding to a recently ignored cue. These results support interpreting fronto-central NoGo P3 responses as functionally related to response control, in that, from the perspective of episodic-retrieval views of learning and priming (Logan, 1990), recently acted-on NoGo cues, by prompting the (task-inappropriate) Go response, should instigate a greater need for response control than should recently ignored cues, which are assumed to prompt the (task-appropriate) NoGo response. More broadly, then, deviating from cue-specific response histories appears to instigate relatively extensive response-control processes, and aversion to these processing costs may help underlie behavioral consistency and the resulting perpetuation of human habits across time.

Withholding a response to a recently respond-to stimulus (on NoGo/Selected trials) entails generating a different response on the present trial (e.g., NoGo, when viewing "2") than on the immediately previous trial (e.g., select "2," not "1"). Accordingly, the present results might be viewed to reflect conflict between temporally contiguous motor programs rather than conflict between present behavioral aims and retrieved instances of behavior. However, responses on Go/Ignored trials also entail generating a different response on the present trial (e.g., Go/press "1") than on the immediately previous one (select "2," not "1"). Accordingly, because anterior P3 differences between Ignored and Selected trials emerged only on NoGo responses, simple

Table 1. Mean Amplitude (in Microvolts) of Go and NoGo P3 Responses (Standard Error of the Mean in Parentheses) to Cues That Had Been Selected or Ignored during the (Immediately Previous) Selective-Attention Part of Each Trial

Electrode groupings	Recently attended cues			Recently ignored cues		
	NoGo	Go	Difference	NoGo	Go	Difference
Frontal	8.59 (1.78)	4.72 (1.35)	3.87** (1.05)	7.05 (1.76)	4.70 (1.49)	2.35* (1.07)
Central	11.90 (1.46)	8.66 (1.04)	3.24** (0.99)	9.77 (1.51)	8.22 (1.26)	1.56 (1.03)
Left-temporal	7.97 (0.93)	7.26 (0.88)	0.71 (0.71)	7.73 (0.97)	6.99 (0.90)	0.75 (0.92)
Right-temporal	8.40 (0.87)	7.55 (0.74)	0.84 (0.62)	7.68 (0.81)	6.96 (0.82)	0.72 (0.89)
Parietal	11.96 (1.02)	11.27 (0.88)	0.69 (0.73)	11.17 (1.16)	10.07 (1.07)	1.10 (1.06)
Occipital	8.66 (0.77)	8.84 (0.71)	-0.18 (0.54)	8.24 (0.88)	7.55 (0.67)	0.69 (1.00)

Note. See text for definition of electrode groupings.

** $p < .01$.

* $p < .05$.

conflict between temporally contiguous motor programs appears unable to explain the results. In a related vein, because the present work found stronger evidence of NoGo P3 effects when participants withheld responding to a recently selected cue than when they withheld responding to a recently ignored cue, these results do not appear to reflect only an absence of overlapping motor potentials on NoGo relative to Go trials (e.g., Salisbury et al., 2004). Both NoGo/Selected and NoGo/Ignored responses, by entailing the withholding of motor responses, should facilitate an absence of overlapping motor potentials, but only the former response elicited a robust NoGo P3 effect, consistent with a response-control account of the NoGo P3.

It might appear simplest, methodologically, to study only Go/NoGo responses and to examine responses to particular stimuli that serve conflicting roles on successive trials (e.g., when responding to “2” on trial $n-1$ and then withholding a response to “2” on trial n). As reviewed earlier, however, neurophysiological NoGo effects typically are more pronounced following Go trials than following NoGo trials (Durstun et al., 2002; Nieuwenhuis et al., 2003). Thus, examining only Go/NoGo trials as a function of whether response cues for the same stimulus are the same or different across consecutive trials would conflate effects of local context (of generating vs. withholding responses in general) with effects of how one recently responded to a particular cue. By interspersing within each trial a selection task (on which a response always is generated) and a Go/NoGo task, the present design ensures that an active response precedes every Go/NoGo response. Thus, the present task holds constant the local context of generating versus withholding responses while varying only whether particular cues have been selected or ignored.

NoGo N2, NoGo P3, and Component Processes of Response Control

Consistent with findings that clinical patients that vary in ability to exert response control also vary concomitantly in the amplitude of their NoGo P3 responses (Bokura et al., 2005; Fallgatter et al., 2004; Kamarajan et al., 2005), the present results support interpreting NoGo P3 responses as related functionally to response control. Thus far, however, we have discussed response control in broad terms. Moreover, it is well established that, relative to Go responses, NoGo responses often produce a fronto-central negative deflection (NoGo N2) peaking between 200 and 300 ms after stimulus presentation (e.g., Pfefferbaum et al., 1985; Simson et al., 1977). Whether reflecting pure response inhibition (Jodo & Kayama, 1992) or, rather, the detection of conflict between the generation versus suppression of a particular response (e.g., Donkers & Van Boxtel, 2004; Nieuwenhuis et al., 2003), the N2 often observed in Go/NoGo tasks appears to relate functionally to response control. Accordingly, integrating NoGo N2 and NoGo P3 findings appears necessary for a comprehensive account of response control (see also Luu & Tucker, 2002).

On the bases of the presently reported findings and of previous findings, one important functional distinction appears to be that NoGo N2 effects are more likely than NoGo P3 effects to emerge when the (erroneous) Go response already has begun to be enacted by the time the participant is cognizant of the NoGo cue. Supporting this general interpretation, lateralized readiness potentials to produce the wrong response predict increases in the size of the NoGo N2 (Kopp, Mattler, Goertz, & Rist, 1996; Smid et al., 2000) but not the NoGo P3 (Kopp et al., 1996), suggesting the sensitivity of the NoGo N2, but not the

NoGo P3, to the actual beginnings of the enactment of erroneous responses. Further informative are comparisons between single-response and choice-based Go/NoGo tasks. Participants are less likely to begin responding before receiving NoGo cues in choice-based tasks (where the appropriate response for a given trial is not known before stimulus presentation) than in single-response tasks (where the same response is given on all trials). Smid and colleagues (2000) manipulated whether Go responses required choice (in a two-choice Go/NoGo task) or not (in a single-response Go/NoGo task), and found markedly smaller NoGo N2 effects in the two-choice condition relative to the no-choice condition. Similarly, in the present study, we observed no differences in N2 amplitude, but substantial differences in anterior P3 amplitude, between Go and NoGo responses on a four-choice Go/NoGo task. Thus, the NoGo N2, but not the NoGo P3, appears to be diminished greatly when choice is inserted into the Go response, such that beginning to execute the (incorrect) Go response prior to receiving the NoGo cue is less likely.

Whereas NoGo N2 responses may relate broadly to signaling that erroneous responses *already have been set in motion*, NoGo P3 may relate broadly to *forestalling a response* while evaluating potentially conflicting response-related information. Go/NoGo responses require categorical processing (i.e., “is this an event requiring a response or not?”), irrespective of whether they culminate in “Go” or a “NoGo” decisions. Importantly, however, on NoGo trials exclusively, the actor must resist generating the Go response in order to allow this processing to run its course. When situational or retrieved cues press for conflicting response decisions, heightened response control may be needed to monitor and stave off responding until an action decision is reached. In the present experimental design, for example, withholding responding to a NoGo cue for which one recently generated a response requires abstaining from responding while integrating conflicting information from different sources (i.e., retrieved instances of having responded to the cue vs. symbolically communicated “do not respond” instructions). Accordingly, whereas central-posterior P3 responses increase in amplitude as a function of the extent of cognitive processing needed to form a categorical decision (Azizian, Freitas, Parvaz, & Squires, 2006; Azizian, Freitas, Watson, & Squires, 2005; see also Kok, 2001), anterior P3 responses on Go/NoGo tasks may reflect the additional recruitment of frontal brain structures that monitor and forestall generating the Go response until categorical-decision processes are able to run their course.

Response Priming in Go/NoGo Tasks

The present discussion also appears relevant to previous studies of response priming in Go/NoGo tasks, in which stimuli compatible with the Go response are presented to participants prior to the actual Go/NoGo cue. Kopp and colleagues (1996) showed that priming Go responses increased the size of the NoGo N2 but not the NoGo P3. Seemingly in direct contrast, Bruin, Wijers, and van Stavern (2001) found that priming Go responses increased the size of the NoGo P3 but not the NoGo N2. Consistent with the logic that neural processes related to response control should be particularly evident when task demands for response control are particularly high (i.e., as when the Go response has been primed on a NoGo trial), each of these findings was presented as evidence against attributing a response-control function to the particular component (NoGo P3 or NoGo N2, respectively) not impacted by Go priming in each particular study. However, it is interesting to note that, in the Kopp et al.

study, the primes were flanker stimuli that consisted of the same symbols that served as the Go cues, whereas in the Bruin et al. study, the primes were morphologically distinct from the Go signals. Moreover, in the Bruin et al. study, the primes (which informed participants of response possibilities) disappeared 700 ms prior to onset of the Go/NoGo signal, whereas in the Kopp et al. study, the flanker primes were presented just before (100 ms) and concurrently with the Go/NoGo signal. Thus, subjects in the Kopp et al. study may have experienced the task as a stop-signal task, in that they may have begun generating a response to the first symbol (which was identical to the Go signal), but then have had to rescind the response if a NoGo (i.e., “stop”) signal appeared. Consistent with this interpretation, a large N2 also emerged on Go trials in which the flankers were incompatible (e.g., left-pointing triangle) with the Go signal (e.g., right-pointing triangle). Thus, beginning to execute the wrong response, whether on Go or NoGo trials, appeared to elicit a large N2 (Kopp et al., 1996), much as a large N2 typically is elicited in stop-signal tasks when the subject already has committed to executing a response and then is signaled not to do so (e.g., Ramautar, Kok, & Ridderinkhof, 2006). Following these con-

siderations, one can hypothesize that response priming will enhance NoGo N2 responses when such priming leads to the precursors of actual response execution, whereas response priming will enhance the NoGo P3 when such priming biases the actor toward subsequently categorizing cues as events requiring a response, such that the participant needs to forestall generating the Go response until the conflicting information can be evaluated.

Conclusion

In summary, the present study found evidence of a NoGo P3 effect, of higher amplitude anterior P3 responses on NoGo than on Go trials, which was present when participants were cued by a previously selected stimulus but was greatly diminished when participants were cued by a previously ignored stimulus. These findings are consistent with the hypotheses that (1) episodic traces of past Go/NoGo responses to particular stimuli help guide future Go/NoGo decisions and (2) NoGo anterior P3 effects are particularly pronounced when response-control processes are particularly engaged.

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