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Sequential processing in an auditory equiprobable Go/NoGo task with variable interstimulus interval

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ABSTRACT

A recent series of studies of the auditory equiprobable Go/NoGo task, using fixed interstimulus intervals (ISIs), proposed a processing schema relating observed event-related potential (ERP) components to sequential processing stages. However, it has been demonstrated that attention and ERP components can be affected by the predictable rhythmic timing of fixed ISIs. Hence the aim of the current study was to test the robustness of that processing schema with an unpredictable arrhythmic variable ISI. EEG was recorded from 30 university students at 30 scalp sites in an unwarned auditory equiprobable Go/NoGo task using a variable ISI. Following our previous studies, Go and NoGo ERP components were derived using temporal principal components analysis (PCA). Of the unrestricted Varimax-rotated factors, seven were identifiable as components based on their topography, polarity, and latency: two subcomponents of the N1 (N1-1, and processing negativity, PN), P2/N2b, N2c/P3a, P3b, and two subcomponents of the slow wave (SW-1 and SW-2). These components showed Go/NoGo effects comparable to those previously noted with fixed ISI, supporting the proposed processing schema. The Late Positivity (LP) component, previously speculated to mark cortical deactivation after processing the NoGo stimulus, was not present in the sequence of components. In its absence, activity underlying the observed sustained P300/late positive complex may be involved in processing temporally-uncertain stimuli.

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1. Introduction

The auditory equiprobable Go/NoGo task requires a response to Go (or target) stimuli, while a physical response is not required to NoGo (standard or non-target) stimuli. Given its 50/50 probability, event-related potentials (ERPs) can be averaged with maximal efficiency for both Go and NoGo processing streams (Barry and De Blasio, 2013). This has proven useful in our EEG/ERP dynamics studies that need large numbers of robust ERPs for subdivision in terms of prestimulus EEG phase or amplitude (e.g., Barry and De Blasio, 2012; Barry et al., 2010, 2014c; De Blasio and Barry, 2013a,b). For example, Barry et al. (2014c) subdivided each subject's Go and (separately) NoGo trials on the basis of EEG phase (e.g., in the alpha band) at stimulus onset, using four phase divisions. Adequate trials were available to form reliable Go and NoGo ERPs at each phase quartile — an outcome difficult to achieve with (say) a 20% Go/NoGo task of normal duration. The defining characteristic of the task, its equal probability of Go and NoGo stimulus presentations, positions it midway between the traditional Go/NoGo task (stimulus probability: Go > NoGo) and the auditory oddball (stimulus probability: NoGo > Go). Although these more extreme tasks have been widely investigated in the literature, there is no overarching theoretical linkage between them. Hence we have been exploring the processing stages involved in the auditory equiprobable Go/NoGo task, in order to illuminate the processing involved in this and the more extreme tasks — the traditional Go/NoGo and the oddball.

Based on the observed sequence of temporal principal components analysis (PCA)-derived ERP components, Barry and De Blasio (2013) suggested a processing schema for both Go and NoGo streams in the task. At stimulus onset, N1-1 reflects initial stimulus discrimination processing, and processing negativity (PN) and P2 are indicative of further sensory processing. Completion of stimulus categorisation is further marked by differences in N2 topography, leading to two distinct processing chains. For Go, the effortful motor-response to the Go stimulus is associated with a centroparietal P3b and a subsequent large frontally negative and parietally positive Slow Wave (SW). For the NoGo stimulus, the processing is associated with a frontocentral P3a and a large Late Positivity (LP). The LP was first reported by Barry and De Blasio (2013) as a novel diffuse component to NoGo, peaking temporally after the SW at 654 ms. They posited that the LP enhancement for NoGo, taken together with its uniform scalp distribution, suggests a broad cortical deactivation marking the end of stimulus processing. It is larger in NoGo as active processing ceases earlier in the processing chain than with Go. Since then, four other studies (all using physically linked ears as a reference) have reported PCA-derived LP components showing comparable topography, peak latencies, and explained variance, supporting Barry and De Blasio's (2013) interpretation (Barry and De Blasio, in press; Barry et al., 2014a,b,c).

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Recently, Barry and De Blasio (in press) have reconceptualised the processing schema, with Barry and De Blasio's (2013) P2 and N2 now identified as a P2/N2b complex and N2c, respectively. Further, Barry and De Blasio (in press) have proposed that early components such as P1 and N1-3 (that are not consistently observed) mark initial sensory processing and/or feature analysis (as defined by Kok, 1997) in order to determine whether attentional resources are worth allocating to the stimulus. The subsequent Go N1-1 enhancement signals the beginning of relevant stimulus identification, and PN confirms this with a greater lateral hemispheric negativity for Go (Näätänen and Picton, 1987). Following on from the early components, categorisation of the stimulus into "Go" and "NoGo" processing streams is flagged by the P2/N2b complex. The Go chain is marked by the P2, a subsequent posterior N2c (Folstein and van Petten, 2008), P3b (Barry and Rushby, 2006), and a large SW, reflecting effortful processing in response to preparation and execution of the button press to Go. In the NoGo chain, there is a frontal N2b (Huster et al., 2013), frontocentral P3a (Barry and Rushby, 2006) and a diffuse LP.

The studies that developed this processing schema examined the auditory equiprobable Go/NoGo task with a fixed interstimulus interval (ISI). However, it has been illustrated that manipulating the physical parameters of the ISI alters ERP waveforms (Polich, 1990; Polich and Bondurant, 1997). While these studies used varied conditions of fixed ISI lengths, research indicates that predictability of time intervals affects ERPs (Doherty et al., 2005; Lange, 2009). It is well documented that explicit information predicting stimulus onset can be used to focus ttention voluntarily to a relevant point in time (Lange, 2013), a phenomenon known as temporal orienting. In the case of fixed ISIs, attention can be oriented to the regularity in the rhythmic timing of stimulus presentations. Use of arrhythmic variable ISIs has been shown to be less predictive. A number of studies have reported greater accuracy for judgement of time intervals with expected time points compared to uncertain time points (Boltz, 1993; Large and Jones, 1999). Doherty et al. (2005) and Lange (2009) assessed stimulus temporal expectancy effects on peak-picked ERPs by holding the temporal probability constant between fixed and variable ISI conditions using Go/NoGo tasks. They found N1 to be enhanced and P300 attenuated for the variable ISI condition. Scalp distributions were found to be largely stable over ISI conditions with reported topographical features matching those of Barry and De Blasio (2013) and Barry et al. (2014a,b,c), although with Doherty et al.'s (2005) use of a visual Go/NoGo task, N1 was distributed parietally. Additionally, Doherty et al. (2005) reported a P300 latency shift, with the fixed ISI P300 peaking substantially earlier than the variable ISI P300.

In light of the stimulus temporal uncertainty effects on ERP waveforms elicited by ISI variability, the current study examined the robustness of the processing schema when employing a variable ISI. Not only is this important in developing the processing schema in this equiprobable task, but also the findings should be relevant to overlapping tasks such as the traditional Go/NoGo and auditory oddball tasks. Based on the reviewed research it is hypothesised that first, sequential processing should be broadly comparable with the results of Barry and colleagues because of the similar behavioural outcomes. ERP components: N1-1, PN, P2/N2b, N2c, P3, and SW are likely be found (in this sequence), showing Go/NoGo differential effects that resemble those reported previously (Barry and De Blasio, 2013, in press; Barry et al., 2014a,b,c). Second, following Doherty et al. (2005), temporal uncertainty of stimulus occurrence is anticipated to delay the P300. In order to assess this we identify and compare the latencies of the P300 peaks for the variable (present study) and fixed (Barry and De Blasio, 2013) ISI datasets, with the former expected to show substantial increases. Third, if the LP marks the early cessation and deactivation of NoGo processing, it is predicted that it will not occur in the sequence of components here, due to the unpredictability of the next stimulus occurrence requiring sustained engagement with the task.

2. Methods

2.1. Participants

Thirty University of Wollongong students participated in the current study as one means of meeting a course requirement. The sample consisted of 15 males and 15 females, aged 18–49 ($M = 22.5$, $SD = 6.7$) years, and all were right handed as defined by the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were screened for serious head injuries, psychiatric conditions, neurological disorders and periods of unconsciousness. Participants abstained from caffeine and tobacco for a minimum of 2 h prior to testing and none consumed alcohol or other psychoactive substances within 12 h. All participants provided written informed consent as approved by the institutional ethics committee.

2.2. Electrophysiological recording

Continuous EEG was recorded from 30 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) and the right ear (A2), using a cap with tin electrodes. The left ear (A1) was used as a reference and the cap was grounded by an electrode positioned midway between Fp1, Fp2, and Fz. Additional tin cup electrodes recorded EOG activity from under and above the left eye for vertical eye movements, and from the outer canthus of each eye for horizontal movements. Impedance was less than 5 kΩ for EOG, EEG, and reference electrodes. EOG and EEG signals were amplified 500 times, and sampled from 0 to 70 Hz by a Neuroscan Synamps2 EEG system at a rate of 1000 Hz.

2.3. Procedure and task

Participants completed two resting conditions, eyes-open and eyes-closed, and then visually tracked a small square alternating horizontally, then vertically, on the screen. Subsequently, participants were instructed to blink each time the stimulus, now remaining stationary, changed colour. This brief calibration task was used to facilitate the later post-processing of EEG data to correct for eye movements and blinks using Croft and Barry's (2000) EOG correction software. After EEG/EOG calibration, participants completed an unwarned auditory equiprobable Go/NoGo task, receiving two blocks of 300 tones (each 80 ms in duration, including 15 ms rise and fall times) binaurally through headphones at 60 dB SPL with a brief rest between blocks. The stimulus onset asynchrony (SOA) was varied randomly between 1.0 and 1.5 s, with 50% of the tones at 1000 Hz and the other 50% at 1500 Hz, presented in random order. Participants were instructed to respond to the target Go tone as quickly and accurately as possible with a button press using their dominant (right) hand and to not respond to the non-target NoGo tone. The target Go tone frequency was balanced between subjects.

2.4. Data extraction and processing

Recorded EEG data were corrected for ocular artefacts using Croft and Barry's (2000) EOG correction software. The EOG-corrected data were digitally re-referenced to linked ears and low-pass filtered (zero phase shift, 30 Hz, 24 dB/Octave) using Neuroscan software (Compumedics, Version 4.5). Single trial epochs were extracted and those containing incorrect responses (omission of button press to Go, button press to Go exceeding a reaction time of 600 ms, and commission errors of button press to NoGo) were excluded from analysis. A 100 ms pre-stimulus baseline-correction followed by an artefact rejection at ±100 μV was applied. ERPs were derived by averaging the accepted trials for Go and NoGo, separately for each presentation block.

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