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Effects of inter-stimulus interval on skin conductance responses and event-related potentials in a Go/NoGo task

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ABSTRACT

Skin conductance responses (SCRs) to NoGo stimuli have been found to be smaller than to Go stimuli, possibly due to their diminished task relevance. These findings have been obtained at inter-stimulus intervals (ISI) that were unusually short for SCR recordings. Therefore, we tested whether the same findings would also hold at longer ISIs. Simultaneously, effects of ISI duration on the NoGo-N2 and-P3 components of event-related brain potentials (ERPs) were assessed. Go and NoGo stimuli were equiprobable while ISI varied between 2, 5, and 8 s. Although increasing the ISI-enhanced SCR amplitudes in general, it did not modulate the attenuation of the response to NoGo relative to Go stimuli. When considered as difference between NoGo and Go conditions, neither the NoGo-N2 nor the NoGo-P3 was affected by ISI variation. Together, these data confirm the feasibility of co-registering ERPs and SCRs.

1. Introduction

Psychophysiological variables like event-related potentials (ERPs) or skin conductance responses (SCRs) are informative about different cognitive and emotional processes. Recently, there is increasing interest in registering several variables simultaneously, in order to concurrently assess indicators of several processes. However, different psychophysiological variables have specific time courses and recovery times. Therefore, ERP paradigms normally employ short inter-stimulus intervals (ISIs), around 1 s, whereas autonomic variables such as the SCR have traditionally been studied at longer ISIs of 6–60 s, allowing for full recovery of these sluggish responses. The apparent need for long ISIs for slow response systems is often considered as an impediment for co-registration with faster variables, possibly causing distortions in the variable for which suboptimal ISIs are used. Assessing the feasibility of co-registering SCRs and ERPs in a Go/NoGo paradigm was a main aim of the present study.

Several recent studies have recorded SCRs at short ISIs in the Go/NoGo task. Thus, Barry and Rushby (2006) have found evidence for the feasibility of using the SCR as indicator for the orienting reflex (OR) in a Go/NoGo paradigm with short 1.1-s ISI (see also Rushby et al., 2005). They showed enhanced SCR amplitudes for Go as compared to NoGo stimuli and explained these SCR differences in the context of Solokov's orienting reflex theory (1963) and Maltzman's (1990) distinction between "voluntary" and "involuntary" ORs. NoGo trials were considered as indifferent stimuli, evoking a basic involuntary OR. In contrast, Go trials, which require a behavioural response, were considered as significant stimuli, involving a voluntary OR. According to these assumptions, the significant Go stimuli involve some extra processing as compared to the indifferent NoGo stimuli (Barry and Rushby, 2006).

In line with these results, a recent study by Schacht et al. (in press) showed differences in SCR amplitudes to Go and NoGo stimuli, using 2-s ISIs. Schacht et al. hypothesized that rare NoGo trials represent "conflict" situations (e.g., Nieuwenhuis et al., 2003), where a prepotent response tendency has to be inhibited. Thus, they might induce an arousal response reflected in enhanced SCRs. SCRs to rare NoGo stimuli were indeed larger than those to frequent Go stimuli. However, when stimulus frequency was controlled for, that is when Go and NoGo trials were equiprobable, SCRs to NoGo trials were attenuated relative to Go trials. This result was interpreted as a consequence of reduced task relevance for NoGo as compared to Go stimuli in the 50/50 condition. Therefore, the larger SCRs to rare NoGo relative to frequent Go stimuli might reflect the OR for rare events overriding the relevance effect. Alternatively, one might expect these Go/NoGo differences in the 50/50 condition to be due to a refractory effect associated with the short ISI. Thus, it is conceivable that at short ISIs SCRs are diminished especially for NoGo stimuli and, hence, the results might not generalize to long ISI situations. In order to empirically address this question, we conceived the present experiment. A Go/

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NoGo task with equiprobable Go and NoGo stimuli was realized at three levels of ISI (2, 5, and 8 s), while both SCRs and ERPs were recorded.

If enhanced SCR amplitudes for Go trials are attributable to the "task relevance" of Go stimuli (e.g., Schacht et al., in press), as opposed to the refractory period of a slow variable, then this effect should also appear at longer ISI. Therefore, enhanced SCR amplitudes for Go stimuli should be elicited at all ISI levels. Further, we predicted overall larger SCR amplitudes for long ISIs, due to the refractory effect. Finally, if the effects of ISI variation and stimulus type (Go/NoGo) are additive, this would indicate an independence of the Go/NoGo and the refractoriness effects.

As a further issue, two characteristic ERP components have been reliably observed in the Go/NoGo paradigm. Around 300 ms after stimulus onset, Go stimuli elicit larger positivities than NoGo stimuli at posterior electrodes, whereas NoGo stimuli elicit enhanced positivities at more anterior sites (e.g., Bruin and Wijers, 2002; Bruin et al., 2001; Tekok-Kilic et al., 2001). Prior to these P3 components, a negative-going N2 component appears to NoGo trials at latencies around 200–300 ms after stimulus onset (e.g., Bekker et al., 2004; Bokura et al., 2001; Bruin and Wijers, 2002; Eimer, 1993; Falkenstein et al., 1999; Kok, 1986). The posterior Go-P3 has been considered to reflect updating of working memory contingent upon stimulus evaluation (see Polich, 2007, for a review). On the other hand, the anterior NoGo-P3 and the NoGo-N2 have been often suggested to reflect top-down inhibition mechanisms (e.g., Falkenstein et al., 1999; Kok, 1986; Kopp et al., 1996), and – with respect to the NoGo-N2 – conflict monitoring processes (e.g., Nieuwenhuis et al., 2003; van Veen and Carter, 2002).

Interestingly, there are almost no data on how these NoGo-specific ERP components are affected by varying ISIs. To our knowledge, the only pertinent study is by Nakata et al. (2005), who used somatosensory stimuli while varying the ISIs from 1 to 6 s. With increasing ISI, the peak latency of a negative-going component between 140 and 210 ms – measured as difference between NoGo and Go trials – was delayed, whereas its amplitude was unaffected by the ISI. This short latency is quite untypical for NoGo-N2 components and besides, effects of different ISIs on the NoGo-P3 were not reported. Such effects might be expected, considering that ISI has clear effects on the P3 component in other contexts. For instance, studies using the oddball paradigm have shown enhanced P3 amplitudes with increasing ISIs, using somatosensory stimuli (e.g., Nakajima and Imamura, 2000; Polich et al., 1991), as well as auditory stimuli (e.g., Gonsalvez and Polich, 2002; Polich, 1990a,b). These effects have been interpreted in terms of decreased refractoriness with increasing ISIs, but apparently, it has not been systematically investigated in Go/NoGo ERP components in modalities other than the somatosensory. Hence, in the current Go/NoGo experiment we expected larger amplitudes for visual ERPs associated with increases in the ISI.

2. Method

2.1. Participants

Twenty-two healthy students (10 women, mean age = 25.9 years) participated in this experiment. Data of two others had to be rejected because the EEG data contained too many artifacts. All participants apart from three were right-handed (according to Oldfield, 1971). They signed informed consent to the study and were rewarded with a small amount of money or course credits. The experiment was performed in accordance with the ethical standards from the 1964 Declaration of Helsinki.

2.2. Stimuli

Stimuli consisted of the capital letters "M" or "W" in font Trebuchet MS size 76, which were presented in white on a dark grey background at 80-cm distance from the participant's eyes. For half of the subjects M served as Go and W as NoGo stimulus, and vice versa for the other half.

2.3. Procedure

Each trial started with a white fixation cross in the middle of the screen. After 900 ms the cross turned yellow for 200 ms. Then a letter appeared for 100 ms, followed by a blank screen. The time until the start of the next trial varied according to the ISI condition. It was either 800, 3800, or 6800 ms, resulting in ISIs of 2, 5, or 8 s, ordered randomly. To one of the letters participants had to press a button with the index finger of their dominant hand (Go condition) but should refrain from responding to the other letter (NoGo condition). Letters were presented equiprobably and in random order. The assignment of letter to response condition was counterbalanced across participants. The session started with an instruction screen followed by a practice block with 20 trials (half Go). The session was divided into two blocks, with a 5-min break in between.

2.4. Psychophysiological recordings and data analyses

Recording took place in an electrically shielded and sound attenuated chamber with constant ambient light. The EEG signal was obtained from 30 tin electrodes, referenced to the left mastoid. The electrodes (Fp1, Fp2, Fz, F3, F4, F7, F8, FC5, FC6, Cz, C3, C4, CP5, CP6, T7, T8, Pz, P3, P4, P7, P8, P9, P10, O1, O2, PO7, PO8) were placed within a cap. In addition, electrodes were placed on the right mastoid, as well as above and below the eyes in order to record the electrooculogram (EOG). ECI electrode gel (Expressive Constructs Inc., Worcester, MA) was used as electrolyte. Recording was done with a sampling rate of 250 Hz. Electrode impedance was kept below 5 kΩ. All channels were amplified with a bandpass of 0.05–70 Hz.

Offline, the continuous EEG recording was divided into 1200-ms segments, starting 200 ms before stimulus onset, and transformed to average reference. ERPs were calculated for these segments, considering only trials with correct responses. The prestimulus baseline was established 200 ms before stimulus onset. Blink and eye movement artifacts were removed with BESA software. Epochs were classified according to stimulus type (Go, NoGo), and the interval between the response eliciting stimulus and the preceding stimulus (ISI: 2, 5, or 8 s), resulting in 6 conditions with 35 trials on each.

Skin conductance responses were recorded simultaneously with the EEG using a Coulbourn Model S21–22 constant voltage (0.5 V) skin conductance coupler. Two Ag/AgCl electrodes (diameter 1.0 cm) were placed on the thenar and hypothenar eminences of the non-dominant hand. The skin conductance coupler was calibrated prior to each session to detect activity in the range of 0–40 μs. Off-line, the continuous SC recording was segmented into 17-s epochs, starting 8.2 s before stimulus onset. Prestimulus baseline was established 200 ms before stimulus onset. According to our previous study (Schacht et al., in press) and with respect to the time window where SCRs were maximal, SCR mean amplitudes were calculated between 2.5 and 3 s. Epochs were classified according to the same criteria as for ERPs.

Statistical analyses of dependent variables (RTs, error rates, ERPs and SCRs) were performed by repeated measures analyses of variance (ANOVA), involving the factor ISI (2, 5, and 8 s) and stimulus type (Go vs. NoGo). In case of ERP mean amplitudes, first, an overall ANOVA was conducted, including all electrodes (25 levels). In addition, two separate ANOVAs were calculated, considering only midline electrodes (3), or the factors hemisphere (2), and electrode (11), respectively.

3. Results

3.1. Performance

Performance data of one participant were lost due to technical reasons; therefore the corresponding analyses were conducted on 21 participants. Mean correct reaction times (RTs) for Go stimuli were 369.8 ms (S.D. = 1.2), and did not differ between ISI conditions, $F < 1$. On average, there were 3.5% of false alarm (FA) responses for NoGo trials, which did not differ between ISI conditions, $F(2,40) = 1.4$, $p = .25$ (see also Table 1).

3.2. Skin conductance responses

Averaged SCRs and their mean amplitudes in the 2.5–3.0 s interval are presented in Fig. 1A. ANOVA showed significant effects of stimulus type, $F(1,21) = 3.6$, $p < .05$ (one-tailed), and ISI, $F(2,42) = 2.9$, $p < .05$ (one-tailed), which did not interact, $F < 1$.