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Linking components of event-related potentials and autonomic measures of the orienting reflex

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ABSTRACT

This study examined autonomic measures and event-related potentials (ERPs) associated with elicitation and habituation of the basic Orienting Reflex (OR). Subjects received 16 innocuous tones with intensity alternating between 60 and 80 dB, at long inter-stimulus intervals. There was no stimulus-related task, so we could examine the effects of stimulus novelty and intensity in the absence of task demands. Cardiac, respiratory, peripheral vasoconstriction, and electrodermal measures were recorded, as well as continuous EEG. Single-trial ERPs were obtained, and components extracted by Principal Components Analysis were examined for potential response fractionation in the central indices of stimulus processing. The predicted fractionation of autonomic measures was obtained: cardiac deceleration showed no systematic change with intensity or trials, respiratory pause showed a substantial main effect of trials but no intensity effects, peripheral vasoconstriction showed intensity but no trials effects, and electrodermal responses showed substantial main effects of trials and intensity. A range of intensity and novelty effects were obtained in components identified as the N1, P3a, P3b, Novelty P3, and the classic Slow Wave. The different stimulus–response profiles of the ERP components are discussed in relation to the autonomic response profiles within the context of a sequential processing theory of OR elicitation.

1. Introduction

The orienting reflex (OR) was brought to prominence in Western Psychophysiology by Evgeni N. Sokolov's publications in the 1960s. Sokolov focused on three major attributes of the stimulus event — novelty, intensity, and significance. His work characterising the OR employed a range of physiological measures such as electrodermal activity, respiratory pause (RP), blood volume changes (peripheral vasoconstriction, PVC; and cephalic vasodilation, CVD), EEG alpha desynchronisation, pupil dilation, and eye movements (Sokolov, 1963a, b). Sokolov conceptualised the OR as a unitary reflex, suggesting that responses in different measures similarly reflect variation in stimulus parameters. This tempting picture of a monolithic integrated response complex elicited by stimulus variation undoubtedly contributed to the enormous swell of research that followed. Unfortunately, 50 years of investigation has disconfirmed this unitary theory, in that a range of commonly-used physiological measures fail to covary with stimulus parameters (e.g., Siddle and Heron, 1977).

Our early parametric studies (e.g., Barry, 1977a,b) examined the influence of intensity, novelty, and significance, using heart rate (HR) deceleration, PVC, CVD, RP, electrodermal activity, and EEG alpha desynchronisation as dependent measures. All these measures (except the phasic HR response — not available to Sokolov) were broadly compatible with those used by Sokolov. The results displayed response fractionation: different response patterning in different measures. HR deceleration and CVD did not vary with trials or intensity. PVC was sensitive to intensity, but not stimulus repetition. EEG alpha desynchronisation and RP showed response decrement across trials, but were not affected by stimulus intensity. Only electrodermal activity (equivalent to the modern skin conductance response, SCR) matched the phasic OR pattern expected from Sokolov's work: decrement with stimulus repetition, and sensitivity to stimulus intensity and significance.

Subsequent work (e.g. Barry and James, 1981a,b) demonstrated the reliability of these four different patterns over stimulus intensity and novelty, and led to Preliminary Process Theory (PPT), the only extant OR theory that can accommodate this complex response patterning. PPT incorporates three preliminary processes evaluating the stimulus' physical characteristics (its onset, novelty, and intensity). The final outputs of this sequential processing interact to produce the OR to indifferent (or non-significant) stimuli (Barry, 1996, 2006, 2009). Additional processing is required if there is a stimulus-related task, or if the stimulus has other significance for the individual, but these are beyond the scope of the present study.

We have recently become interested in integrating central indices of stimulus processing, exemplified in the event-related potential (ERP), into PPT. In the light of the largely-autonomic basis of PPT

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development, in most of these studies we included SCR as a model OR measure. We started with a focus on the P300 or Late positive Complex (LPC), following Donchin et al. (1984). Rushby et al. (2005) averaged responses across 15 trains of stimuli presented with an 8 s interstimulus interval (ISI), and reported across-train response decrement in both SCR and LPC, and larger responses in both measures to 80 compared to 50 dB tones. Rushby et al. (2005) also used Principal Component Analysis (PCA) to separate the LPC into its subcomponents. Although Simons et al. (2001) had argued that two previously-reported subcomponents, P3a (Squires et al., 1975) and Novelty P3 (nP3) (Courchesne et al., 1975), were identical. Rushby et al. (2005) found four distinguishable subcomponents identified as P3a, P3b, nP3, and the classic frontal-negative/posterior-positive Slow Wave (SW). All four subcomponents showed decrement over trials, but only P3a and P3b showed stimulus intensity effects, our first evidence of PPT-like response fractionation in the ERP.

Rushby and Barry (2009) built on a serendipitous observation made during data processing in a study of EEG differences between eyes-open and -closed conditions using alternating 2-min epochs (Barry et al., 2007). We found that clear single-trial ERPs occurred to tones used to signal eye-opening or -closing. Thus, rather than averaging across trains of stimuli, Rushby and Barry (2009) reported SCRs and single-trial peak-picked ERPs to 12 tones presented with 2-min ISI. There was no clear evidence of decrement over trials in the P1, N1, P2, N2, or LPC. The 500 ms poststimulus epoch was also submitted to PCA, and components identified as N1, N2, P3a, P3b, and nP3, were identified. P3a, P3b, and nP3 occurred in the same temporal order as in Rushby et al. (2005), and a significant decrement over trials was apparent for nP3.

Subsequent studies from our lab have continued exploration of trial effects using single-trial ERPs and including SCRs as the "gold-standard" OR index. For instance, Steiner and Barry (2011) examined peak-picked LPCs from a dishabituation paradigm with a varying ISI of 5–7 s. Both SCR and LPC showed significant response decrement, recovery, and dishabituation. In addition, Barry et al. (2011) measured eye-turning towards an unexpected laterally-presented tone using an ISI of 50–70 s, together with HR deceleration, SCR and single-trial ERPs. Behavioural orienting and SCR decremented over trials; HR deceleration did not. Peak-picked N1 and LPC measures showed no main effects of trial. Separate PCAs were carried out in relation to N1 (0–200 ms) and LPC (200–700 ms). N1 subcomponents (Näätänen and Picton, 1987) identified as Component 1 and Component 3 showed no main effect of trials, but a subcomponent identified as Processing Negativity (PN) showed a substantial reduction over trials. PCA identified a number of LPC subcomponents: P3a, P3b, nP3, and SW, in the same temporal order as our previous PCA studies, followed by an additional late SW2. Of these LPC subcomponents, only nP3 showed a main effect of trials. In another study, MacDonald et al. (2012) presented subjects with 16 tones alternating in intensity between 60 and 80 dB, at 50–70 s ISI, and examined trials and intensity effects in a number of autonomic and central measures. As expected, HR deceleration showed no trials or intensity effects, respiratory pause decremented over trials but was insensitive to intensity, and SCR decremented over trials and was larger to 80 than 60 dB stimuli. Peak-picked N1 and LPC were larger for 80 than 60 dB, but showed no main effects of trials.

These studies from our laboratory have tried to link autonomic and central measures in the OR context, and have found evidence for response fractionation in the central measures, thus broadly reflecting a core aspect of PPT. But the results are not entirely consistent in regard to the observed trials effects, despite significant SCR decrement in each study. Peak-picked LPC decrement was found by Rushby et al. (2005) and Steiner and Barry (2011), but not by Rushby and Barry (2009), Barry et al. (2011), or Macdonald et al. (2012). Of our three studies using PCA to separate the LPC into its subcomponents, decrement over trials was found for P3a, P3b, nP3 and SW by Rushby et al. (2005), and for nP3 alone by Rushby and Barry (2009) and Barry et al. (2011). In only one study was a decrementing non-LPC component or subcomponent obtained: Barry et al. (2011) uniquely found a PN that decremented over trials.

Only a small number of these studies manipulated intensity, but in all of those, significant intensity effects were obtained in SCR. Parallel effects in peak-picked components were found for LPC in Rushby et al. (2005), and for N1 and LPC in MacDonald et al. (2012). Similar intensity effects had been noted in N1 and LPC by Lawrence and Barry (2009) in a non-SCR study of the effects of counting. Intensity effects were also noted in P3a and P3b (with an inverse effect for SW) by Rushby et al. (2005).

The current study extended our autonomic/central focus by building on the trials/intensity investigation of Macdonald et al. (2012). The same paradigm presenting alternating 60 and 80 dB tones was used with a larger number of participants. We also added PVC as the PPT index of stimulus intensity processing, and implemented PCA to identify the major post-stimulus components in the ERP, and to separate the subcomponents of the LPC. Based on the autonomic antecedents of PPT, it was predicted that a substantial HR deceleration would not be affected by trials or intensity, respiratory pause would decrement over trials but show no intensity effect, PVC would show an intensity effect but no trials effect, and SCR would reflect both trials and intensity. In relation to ERP components, we predicted that N1 would reflect stimulus intensity, but not trials, and nP3 would show decrement over trials, but no intensity effect. We expected P3a and P3b to reflect stimulus intensity, but, in light of the results surveyed above, no prediction of trials effects could be made. Finally, we had no firm expectations of trials or intensity effects in SW.

2. Methods

2.1. Participants

Twenty-eight university students participated in an experimental session as one means of fulfilling a course requirement (ages 19–44, mean 23.3 years; 17 females; 24 right-handed). After the procedure was explained, written consent was obtained in accordance with a protocol approved by the joint South East Sydney and Illawarra Area Health Service/University of Wollongong Human Research Ethics Committee. Participants completed a demographic/screening questionnaire, and only those with normal hearing participated. Individuals with a history of seizures, psychiatric illness or severe head injury were excluded, as were those currently taking psychoactive drugs.

2.2. Procedure

After attachment of transducers, participants were seated in a dimly-lit, sound attenuated, air-conditioned testing booth with a fixation cross displayed on a computer monitor at a distance of 1.5 m. They were instructed that they would occasionally hear sounds over the headphones, but that there was no task in relation to them. They were asked to focus their eyes on the fixation cross on the monitor screen, try not to move or blink, and to stay relaxed.

Stimuli were alternating 1000 Hz tones at 60 and 80 dB intensity, each with a duration of 50 ms (15 ms rise/fall times) and a random, variable ISI of 50–70 s, presented via circumaural stereo headphones. Start intensity (60 or 80 dB) was counterbalanced between subjects. Participants received either 16 or 17 tones in the paradigm to reduce group expectations about the series. The first 16 tones were used for analysis, yielding 8 trials at each intensity.