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Neurophysiological responses to gun-shooting errors

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ABSTRACT

The present study investigated the neural responses to errors in a shooting game – and how these neural responses may relate to behavioral performance – by examining the ERP components related to error detection (error-related negativity; ERN) and error awareness (error-related positivity; Pe). The participants completed a Shooter go/no-go task, which required them to shoot at armed targets using a gaming gun, and avoid shooting innocent non-targets. The amplitude of the ERN and Pe was greater for shooting errors than correct shooting responses. The ERN and Pe amplitudes elicited by incorrect shooting appeared to have good internal reliability. The ERN and Pe amplitudes elicited by shooting behaviors also predicted better behavioral sensitivity towards shoot/don't-shoot stimuli. These results suggest that it is possible to obtain online brain response measures to shooting responses and that neural responses to shooting are predictive of behavioral responses.

1. Introduction

The ability to detect and process errors is important in our lives, as this allows us to appropriately respond to and learn from them. A considerable amount of research in cognitive neuroscience has been dedicated to understanding how our brains respond to errors, and how these brain responses predict behavior. In the present research, we were interested in examining errors related to gun-shooting. Because shooting errors can result in harming another person, people should therefore be motivated to be accurate in their shooting decisions. However, shooting behavior is relatively understudied in neuroscience, with basic questions still being unexplored. For example, can shooting a target elicit measurable brain responses? Would these neural responses be related to behavioral responses?

The present study aimed to investigate these questions using a shooting paradigm. Specifically, we wanted to establish, from a methodological angle, whether reliable neural responses to shooting errors can be produced in a novel Shooter go/no-go task. As well, we wanted to examine whether the neural responses to shooting errors may be related to behavioral task performance. We examined two event-related potential (ERP) components that are integral to the detection and processing of errors: error-related negativity (ERN) and error-related positivity (Pe) (e.g., Hajcak, 2012; Falkenstein et al., 2000).

1.1. ERN and Pe

The ERN is a negative-going waveform occurring approximately 50–100 ms after a response is made (Gehring et al., 1993). Consistently elicited by incorrect responses across different types of tasks, the ERN is believed to reflect the neural system for performance monitoring (Gehring et al., 2012). Originating in the ACC (Dehaene et al., 1994), it is thought to reflect the detection and monitoring of conflict, error, and uncertainty (Botvinick et al., 2001; Holroyd and Coles, 2002; Ridderinkhof et al., 2004; Yeung et al., 2004). Increasing evidence also suggests that the ERN may be sensitive to the affective and motivational significance of errors (Hajcak, 2012; Legault and Inzlicht, 2013; Riesel et al., 2012). For example, individuals who experience more negative affect or for whom errors are more aversive tend to produce greater ERN responses to errors (Hajcak et al., 2004; Riesel et al., 2012). On the other hand, if people are given the opportunity to reduce their error-related anxiety (e.g., by misattributing their arousal to a benign source), they show reduced ERN amplitudes compared to those not given such an opportunity (Inzlicht and Al-Khindi, 2012). Thus, in addition to error detection and monitoring, the ERN may also reflect the affective relevance of errors.

In contrast, the Pe is a positive-going waveform that occurs approximately 200 to 400 ms post-response (Overbeek et al., 2005). While debates still exist surrounding the exact functional significance and interpretation of the Pe, a prominent view is that the Pe is associated with the awareness of errors (Nieuwenhuis et al., 2001; Overbeek et al., 2005). Unlike the ERN, Pe responses appear to be elicited only after perceived errors, which suggests that this component is involved in processes related to the actual awareness or conscious recognition of errors (Nieuwenhuis et al., 2001). Evidence suggests that in addition to the ACC, the Pe is also generated from the posterior cingulate–

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precuneus, a region that is associated with post-error processing, as well as self-awareness (O'Connell et al., 2007). It has also been suggested that the Pe may reflect a special type of the P3b component that is associated with the motivational significance of an error (Overbeek et al., 2005).

In sum, while both the ERN and Pe are elicited by error responses, they are believed to reflect separate aspects of error processing (Falkenstein et al., 2000; Overbeek et al., 2005). The ERN is thought to be involved in error detection and is associated with affective responses towards errors, whereas the Pe is thought to be reflective of conscious error awareness and recognition.

1.2. Neural responses to gun shooting

In the present study, we investigated the neural correlates in response to shooting a gaming gun at stimuli targets. Shooting a gun, both in real life and in a video game setting, can be a highly motivating task. Shooting accuracy has socially relevant consequences, and therefore people should want to avoid incorrectly shooting somebody, as doing so may result in harming an innocent person. To our knowledge, there has been very little research examining the neural responses to gun-shooting behaviors. There is preliminary evidence suggesting that the ability to distinguish between targets in a shooting task is related to P200 and N200 amplitudes (Correll et al., 2006). Other work using go/no-go tasks in which participants responded with a gaming gun has found that errors of commission (i.e., incorrect responding on no-go trials) elicited greater ERN and Pe amplitudes (Bediou et al., 2012).

However, the past research was limited in that they either did not investigate error-related neural responses to shooting mistakes (e.g., Correll et al., 2006), or only made use of simplistic stimuli (e.g., different colored shapes) as shooting targets (e.g., Bediou et al., 2012). Our research aimed to extend on past work by examining the neural responses to errors in a Shooter-type go/no-go task, which used more realistic shooting targets (i.e., armed versus unarmed people), in addition to trigger-pulling response methods. By using more complex shooting targets such as images of people holding guns (compared to simple shapes or letters), as well as requiring the participants to respond via shooting a gaming gun at the targets (compared to using button or key presses), this task then incorporates elements commonly found in real-life shooting or gaming situations. Thus, methodologically, the paradigm of the present study is more realistic to real-life shooting or gaming behaviors compared to traditional tasks (e.g., Flanker, Stroop), and may offer greater external validity in task design. Furthermore, by establishing the reliability of the amplitudes of the ERN/Pe obtained in the present Shooter task, it would allow this task to be a valid measure for future neuroscience research into shooting errors.

1.3. Present research

We examined the neural responses to shooting errors using a Shooter go/no-go paradigm, which instructed the participants to pull the trigger on a gaming gun to shoot armed targets, but to avoid shooting unarmed non-targets. This Shooter task simulates more real-life gaming or even shooting behaviors in both the task design (i.e., using images of individuals holding a gun) and response requirement (i.e., pulling a trigger on a gaming gun to “shoot” a target and to withhold pulling the trigger when seeing non-targets).

We suspect that one of the central characteristics of gun shooting is cognitive conflict (Botvinick et al., 2001), and that incorrectly shooting a non-target should elicit conflict and negative affect. We therefore hypothesize that errors in shooting responses should elicit greater ERN and Pe responses than accurate shooting.

2. Method

2.1. Participants

The participants were 53 first-year psychology undergraduate students (35 males) at the University of Toronto Scarborough, who participated for course credits. The participants' mean age was 19.22 years ($SD = 2.72$ years). Data from 14 participants were excluded from analyses due to low error rate (i.e., fewer than six errors; Olvet and Hajcak, 2009; $n = 6$), equipment/software malfunction ($n = 3$), and poor recording quality (i.e., high artifact rate; $n = 5$),[1] leaving a total of 39 participants for analyses.

2.2. Materials

2.2.1. Shooter go/no-go task

A Shooter go/no-go task was constructed based on the design of the shooter task used by Correll et al. (2002). This task resembled a video game, in which a series of stimuli images were presented on the computer screen. Each image consisted of a male target superimposed on a background. The male target was shown to be either holding a gun (black or silver colored) or a similarly colored harmless object (e.g., camera, wallet, cell phone, soda can). The task made use of 20 different target models (10 White males, 10 African–American males[2]). Each target model appeared four times in the task, twice holding guns and twice holding harmless objects. Thus, there were a total of 40 different images of targets holding guns (20 images with White males, 20 with African–American males), and 40 images of targets holding harmless objects (20 images with White males, 20 with African–American males; for further details regarding specifications of the background and target images, see Correll et al., 2002).

The participants were instructed to shoot (“go”) targets holding a gun, but to withhold from shooting (“no-go”) non-targets holding a harmless object. Shooting responses were made by pulling the trigger on a G-Mate-PC/USB gaming gun, and don't-shoot responses were made by withholding the pulling of the trigger. The gaming gun was hand-held freely by the participant for the duration of the task, which usually lasted around 10 minutes. The participants were instructed to hold the gun as naturally and comfortably as they could, while ensuring that the gun is pointed at the computer screen. Participants were given breaks between each block of the task, during which they could relax.

A total of 300 trials were used in the task (240 shoot, 60 don't-shoot), separated into six blocks of 50 trials each. The number of shoot and don't-shoot trials were identical in each block (40 shoot, 10 don't-shoot). The shoot and don't-shoot stimuli images were randomized, although the task specified an equal number of White and African–American targets for both the shoot and don't-shoot trials for each block. This 80:20 go to no-go ratio was used, in order to ensure that the go responses will become habitual, whereas the no-go responses will need to be suppressed. A practice session consisting of 20 trials, using different stimuli images than the actual task, preceded the 300 trials.

Each trial began with a fixation cross that appeared onscreen from between 300 to 600 ms. The image stimulus then appeared for 600 ms, during which the participants could make the shoot/don't-shoot response. The image disappeared from the screen either after 600 ms has passed without any responses from the participant, or after a shoot response was made. Finally, a blank screen was presented

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[1] The somewhat high number of participants excluded due to poor ERP recording quality was attributed to the recording amplifier experiencing technical difficulties. However, these exclusions were made a priori before examining the data statistically, and are not selective exclusions.

[2] The original Shooter task was used by Correll et al. (2002) to examine differential responses to White and African–American targets. However, the current study was unable to examine the role of ethnicity, due to the low number of participants who made sufficient number of errors per target-race category.