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Evidence for aversive withdrawal response to own errors

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ABSTRACT

Recent model suggests that error detection gives rise to defensive motivation prompting protective behavior. Models of active avoidance behavior predict it should grow larger with threat imminence and avoidance. We hypothesized that in a task requiring left or right key strikes, error detection would drive an avoidance reflex manifested by rapid withdrawal of an erring finger growing larger with threat imminence and avoidance. In experiment 1, three groups differing by error-related threat imminence and avoidance performed a flanker task requiring left or right force sensitive-key strikes. As predicted, errors were followed by rapid force release growing faster with threat imminence and opportunity to evade threat. In experiment 2, we established a link between error key release time (KRT) and the subjective sense of inner-threat. In a simultaneous, multiple regression analysis of three error-related compensatory mechanisms (error KRT, flanker effect, error correction RT), only error KRT was significantly associated with increased compulsive checking tendencies. We propose that error response withdrawal reflects an error-withdrawal reflex.

1. Introduction

Over the past thirty years research has shed light on a brain mechanism for performance monitoring capable of assessing the accuracy of actions as they unfold (Gehring, Liu, Orr, & Carp, 2012). This mechanism is so fast that it allows the brain to arrest (Hochman, Wang, Milner, & Fellows, 2015a; Roger, Nunez Castellar, Pourtois, & Fias, 2014), and correct (Hochman, Wang, Milner, & Fellows, 2015b; Rodriguez-Fornells, Kurzbuch, & Munte, 2002) the error response before it is completed. In the long run it shapes reinforcement learning (Sambrook & Goslin, 2015). Recent model suggests that these cognitive aspects of the mechanism do not tell the whole story (Hajcak & Foti, 2008; Inzlicht & Al-Khindi, 2012; Weinberg et al., 2016). The affective or motivational model postulates that because errors have a devastating potential, performance monitoring considers errors an inner threat (Critchley, Tang, Glaser, Butterworth, & Dolan, 2005; Hajcak, McDonald, & Simons, 2004). As a result, error-detection gives rise to defensive motivation prompting protective reflexes. The motivational view of error detection is supported by series of studies using various methodologies. One line of work links electrophysiological and behavioral error-detection indices with various pathologies associated with increased reaction to threat (see (Weinberg et al., 2016) for a review). Other studies show that error commission is followed by modulations in autonomic nervous system (ANS) activity (Aarts, De Houwer, & Pourtois, 2012, 2013), (see Weinberg et al., 2016 for a review) and that errors induce augmented blink reaction to a startle-reflex probe (Hajcak & Foti, 2008).

As aforesaid, the motivational view of performance monitoring predicts that error detection would drive defensive reflexes aimed at reducing the inner-threat represented in the ongoing error (Weinberg et al., 2016). However, supporting evidence such as post-error ANS activity changes, post-error increased reaction to a startle-reflex probe and associations of anxious personality characteristics with elevated reaction to error commission may all reflect post-error vigilance elevation aimed at preventing future errors. To our knowledge, no study so far has demonstrated an active defensive reflex aimed at reducing the impact of the ongoing error. Recent study (Low, Weymar, & Hamm, 2015), portrays the dynamics of defensive responses to threatening stimulus acting on motor output. According to Low (Low et al., 2015), defensive mechanisms grow larger with threat imminence, and shift from defensive attentive frizzing to an active avoidance reflex as function of the opportunity to avoid threat. Ecological errors often involve continuous movements allowing just quick enough withdrawal reflex to tone down the error devastating impact. For example, an absent-minded driver pressing the accelerator would reduce collision impact owing to quick reflexive withdrawal of the erring foot. Therefore, unlike defensive reactions to exogenous threat (Low et al., 2015), error commission might always give rise to an active withdrawal reflex, growing larger with threat imminence and the opportunity to avoid threat.

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In Experiment 1, we hypothesized that in a two-choice flanker task requiring left or right force sensitive key strikes, erroneous key strikes will be followed by rapid force release indicating an error withdrawal reflex (EWR), somewhat resembling one's reaction to accidentally touching hot surface. If error rapid force release reflects EWR it should grow faster with threat imminence and even faster with the opportunity to avoid threat (Low et al., 2015). We reasoned that participants desire to complete the experimental session as soon as possible. We induced error-related threat by informing participants that each error yields extra five trials to the experimental session. We manipulated threat imminence by adding the extra five "punishment" trials either at the end of the session (delayed threat group) or immediately after error commission (imminent threat group). A third, imminent-avoided threat group was given the opportunity to evade immediate punishment trials through rapid error correction (see Low et al., 2015).

Experiment 2 was two-fold. First, we aimed to establish a link between error key release time (KRT) and the subjective sense of inner-threat. Checking behavior is a marker of one's engagement in inspection of own behavior in order to reduce fear of potential calamity. Several studies have demonstrated that increased checking behavior is linked with extreme concern over errors (see (Weinberg et al., 2016) for a review). If error KRT reflects EWR it should grow faster with participants checking tendencies. Second, we aimed to dissociate the error KRT effect from post-error compensatory mechanisms such as error inhibition and correction. Error inhibition (magnitude of flanker congruency effect (Wiecki & Frank, 2013)) and error correction (immediate shift from erroneous to correct movement (Rodriguez-Fornells et al., 2002)) are not affected by anxiety-related disorders (see, Endrass, Klawohn, Schuster, & Kathmann, 2008; Gehring, Himle, & Nisenson, 2000). Therefore, in contrast to the predicted relationship between error KRT and checking behavior, we predicted no relationship between error inhibition or correction and checking behavior.

2. Experiment 1

2.1. Method

2.1.1. Participants

Three groups of 30 participants volunteered for this study (delayed threat, fifteen females, mean age 23.15 years, SD = 7.51 years; imminent threat, fifteen females, mean age 25.74 years, SD = 8.39 years; imminent-avoided, fifteen females, mean age 26.21 years, SD = 7.75 years). The study protocol was approved by the Open University Research Ethics Board.

2.1.2. Materials

The experiment was programmed using C# language (Microsoft Visual Studio 2015, Student Edition). Stimuli were presented on 15.6-in. laptop screen and responses were recorded using a force sensitive device with two keys (sampling rate, 200 Hz). Participants were instructed to keep their left and right index fingers on the keys and to press the keys in order to respond.

2.1.3. Procedure

Participants responded to a target letter ("H" or "R") surrounded by flankers ("H" or "R") with their right index finger by pressing the "H" key, and with their left index finger by pressing the "R" key. The experiment consisted of one long block of 600 trials with 25% target-flanker congruent trials and 75% target-flanker incongruent trials. Before the experiment, subjects completed a practice session under experimenter supervision with 50 practice trials and the same proportion of trials in the congruent and incongruent conditions. We reasoned that participants desire to complete the experimental session as soon as possible. Thus, adding extra trials in response to error commission would serve as an efficient punishment, inducing error-related threat.

Participants were led to believe that each error adds extra five "punishment" trials to the experimental session although session length was preset. In the imminent threat group, each error was immediately "punished" by five flanker arrays. "Punishment" flanker arrays were painted red to emphasize its negative valence. An error made during the five "punishment" trials added extra five "punishment" trials to the already going "Punishment" arrays. In the delayed threat group, participants were told that punishment trials would be introduced at the end of the session. In the imminent-avoided group, "punishment" was immediate as in the imminent threat group, except error correction occurring < 200 ms from error commission prevented the immediate occurrence of "punishment" trials. All groups were encouraged to respond as quickly and accurately as possible, and to correct their errors as fast as possible.

Subjects were presented with a fixation cross in the center of the screen for 300 ms at the start of each trial. The flanker array then appeared for 300 ms. The target has appeared 100 ms after flankers and remained on screen for 50 ms after which it disappeared. The target and flanker stimuli were both generated using a 45 pt. Arial font. After responding, the screen was left blank for 1000 ms to give participants ample time to correct themselves. If participants failed to respond within 350 ms post target presentation, the word "faster" appeared on screen before the beginning of next trial.

3. Results

3.1. Analytic approach

The threat source driving the withdrawal reflex in Low et al. (2015) was always accessible to subject's conscious awareness. In the error monitoring literature, the term "partial errors" refers to unconscious muscle activation, too weak to cross the force threshold for registration of an overt response. Keeping up with Low et al. (2015), here we were only interested in conscious erroneous key presses. Thus, a response was registered if a key press exceeded 0.686 N, within the actuation force range commonly used in personal computer's key boards. RT was calculated from target presentation to actuation force. Error correction RT was also calculated from target presentation to (corrective) response actuation force because models of error correction hold that corrective processes begin at target presentation (Charles, King, & Dehaene, 2014; Charles, Van Opstal, Marti, & Dehaene, 2013; Yeung, Botvinick, & Cohen, 2004).

First, we demonstrate the error rapid KRT, calculated as the time from force threshold crossing to the point of return to force threshold, and show that unlike error correction RT this effect is modulated by threat imminence and avoidance. We then turn to a more detailed analysis of the force data. The term error inhibition refers to a mechanism aimed at preventing error execution all together (Burle, Roger, Allain, Vidal, & Hasbroucq, 2008; Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Roger et al., 2014; Wiecki & Frank, 2013). Unsuccessful inhibition yet reduces error peak force (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Hochman et al., 2015b; Scheffers, Coles, Bernstein, Gehring, & Donchin, 1996). EWR is by definition a response to inhibition failure. Thus, its effect should become more pronounced immediately after error peak force. To dissociate error inhibition from EWR we contrast the effect of threat imminence and avoidance on error rate-of-ascending force development (AFD) with its effect on error rate-of-descending force development (DFD).

To capture registered responses from onset, ascending force data points were recorded from target presentation and the point of initial force production was post triggered to the point from which force production consistently increased to peak force. Descending force data was calculated from peak force to the point from which force data points ceased to consistently decrease. Rate of ascending force development was calculated as peak force of individual trials over time to peak force (Pf/Tp) (Slobounov, Ray, & Simon, 1998). Rate of descending force development was calculated as peak force of individual