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Blinded by an error

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ABSTRACT

Errors are typically followed by a series of behavioural changes. Although most of these changes are well understood, accuracy changes following errors are not. A new paradigm is presented where participants performed a flanker task followed by a rapid serial visual presentation (RSVP) of numbers (1–9). In most trials, a letter was presented on three possible positions of the RSVP (1–3–6). This was done with and without immediate feedback on the flanker task. In both experiments participants had worse target detection after an error in the flanker task. These findings support non-functional accounts for error monitoring that predict decreased post-error performance (Dudschig & Jentzsch, 2009; Jentzsch & Dudschig, 2009; Notebaert et al., 2009). In a third experiment we tried to dissociate between a bottleneck and an orienting account and showed decreased target detection after irrelevant red signals, irrespective of frequency. This result is interpreted in support for the bottleneck account (Dudschig & Jentzsch, 2009; Jentzsch & Dudschig, 2009).

1. Introduction

Several behavioural and neural correlates of error commission have been described in the literature. For instance, heart rate deceleration (Danev & de Winter, 1971), pupil dilation (Critchley, Tang, Glaser, Butterworth, & Dolan, 2005) and a larger skin-conductance response (O'Connell et al., 2007) have been reported to follow an erroneous response. Event-related potential (ERP) studies on the other hand, demonstrate error-related negativity (ERN) peaking frontally within 50–200 ms after an error (for a recent review see Hajcak, 2012), followed by a more posterior error-related positivity that peaks between 200 and 400 ms after an error. In addition to measures taken at the time of error commission, behaviour after making an error has also been investigated thoroughly. Three hallmarks of behaviour following an error are post-error slowing, post-error reduction of interference and post-error improvement in accuracy (PIA). Post-error slowing (PES, e.g. Debener et al., 2005; Laming, 1968; Rabbitt, 1966) refers to the finding that people respond slower following an error than after a correct trial. PES has been shown to be reliable over periods ranging from 20 min, a couple of weeks (Segalowitz et al., 2010) to several months (Danielmeier & Ullsperger, 2011). The second behavioural post-error effect is observed in congruency tasks such as the flanker task (Eriksen & Eriksen, 1974), where participants have to categorise a centrally presented target that is flanked by stimuli associated either with the correct response (congruent) or the incorrect response (incongruent). In these tasks, it is observed that the interference effect, i.e. slower and less accurate responses to an incongruent stimulus compared to a congruent stimulus, is reduced after errors (Ridderinkhof et al., 2002). This effect is known as post-error reduction of interference (PERI). Several studies indicate that PES and PERI are independent (although Carp & Compton, 2009 found a correlation) and are produced by different neuronal networks (de Bruijn, Hulstijn, Verkes, Ruigt, & Sabbe, 2004; King, Korb, von Cramon, & Ullsperger, 2010; Ridderinkhof, 2002). The third behavioural finding is the observation that errors are followed by improved accuracy (e.g. Laming, 1968; Maier, Yeung, & Steinhauser, 2011; Marco-Pallares, Camara,

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Munte, & Rodriguez-Fornells, 2008). This finding, however, is not universal as some studies reported no difference between post-error and post-correct accuracy (e.g. Hajcak, McDonald, & Simons, 2003; King et al., 2010) while others reported a decline in accuracy directly after an error (e.g. Cheyne, Carriere, & Smilek, 2009; Rabbitt & Rodgers, 1977; Steinborn, Flehmig, Bratzke, & Schröter, 2012). PIA does not correlate with PERI (King et al., 2010) and also PES does not always correlate with PIA (Carp & Compton, 2009; Cohen & van Gaal, 2012; Danielmeier, Eichele, Forstmann, Tittgemeyer, & Ullsperger, 2011; King et al., 2010). Hajcak et al. (2003) did find a positive correlation between PES and PIA where greater PES resulted in improved post-error accuracy. Taken together, the behavioural findings concerning PIA are not unequivocal. As Danielmeier and Ullsperger mentioned in their review (2011), PIA research is highly influenced by overall accuracy rates in an experiment as chances of committing double errors are higher when more errors are made.

Understanding post-error accuracy changes, however, is very important because it can be used to distinguish between functional and non-functional theories for PES. Functional theories hold that error processing and subsequent adjustments are intended to improve performance on the following trial(s). In this light, PES is functional in the sense that it increases response caution. Perhaps the best-known example of a functional framework is the conflict monitoring theory, although this theory is even better known for conflict monitoring (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Within this framework, an error results in co-activation of two or more responses, which is recognised as conflict. Conflict detection increases cognitive control by increasing the response threshold resulting in slower and more accurate performance. Dutilh et al. (2012) recently provided support for increased response caution following errors in a lexical decision task, by means of diffusion modelling. The inhibition account (Marco-Pallares et al., 2008; Ridderinkhof, 2002) has much in common with the conflict monitoring theory. It states that after error commission selective suppression or inhibition of response activation occurs. In support for this account, PES correlates with an increase in beta band power that is associated with motor inhibition processes (Kühn et al., 2004; Marco-Pallares et al., 2008; Swann et al., 2009). Another well known functional theory integrates findings on reward processing and reinforcement learning (the reinforcement learning theory: Holroyd & Coles, 2002). Studies on reward processing in primates show a phasic increase or decrease in activity of the dopamine system when events are better or worse (respectively) than expected (Schultz, 2000, 2002). In most cases, errors are events that are worse than expected. These dopaminergic reinforcement signals are used for selecting and reinforcing the motor controllers to perform the ongoing task optimally. All of the functional accounts share the common idea that PES is a compensatory, adaptive mechanism aimed at improving performance.

Non-functional theories, on the other hand, explain PES in terms of reduced cognitive processing after errors. Typically, these accounts predict PES and post-error accuracy *decrease*. The bottleneck error-monitoring theory (Dudschig & Jentzsch, 2009; Jentzsch & Dudschig, 2009) claims that error monitoring requires time and resources from a capacity-limited central information processor. This bottleneck leads to slower and less accurate performance when a task immediately follows an error. However, when there is enough time between the error and the following trial, compensatory mechanisms, like the ones described above, are implemented to prevent subsequent mistakes. Another theory that predicts worse performance directly after making an error is the orienting account for PES (Notebaert et al., 2009). This theory explains PES as the consequence of an orienting response to errors. Because errors are mostly infrequent and/or salient events, attention is directed towards them and, as a consequence, performance on the next trial is disturbed. According to this account there should be an attention dip immediately after making an error. A similar explanation is postulated in the bidirectional model for attention lapses (Cheyne, Carriere, Solman, & Smilek, 2011) where errors caused by lapses in attention can on their turn induce dips in attention. A third non-functional account explains PES in terms of persistent malfunctioning (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Gehring & Knight, 2000), where it is argued that the error is caused by a lapse of attention which lingers onto the following trial.

As Danielmeier and Ullsperger (2011) point out in their review on post-error adjustments, there is evidence for functional and non-functional accounts and these accounts are probably not mutually exclusive. As already indicated by Jentzsch & Dudschig, 2009; Dudschig & Jentzsch, 2009, it is conceivable that immediately following the error, non-functional effects cause post-error accuracy decrease while cognitive mechanisms only kick-in when more time elapsed. In order to understand post-error performance, it is crucial to develop a paradigm that does not rely on double errors, as traditional post-error accuracy measurements do. Here, we propose a new approach by combining two well-known tasks in cognitive psychology, the Eriksen flanker task (Eriksen & Eriksen, 1974) and the Attentional Blink Paradigm (Chun & Potter, 1995). First, a modified speeded Eriksen flanker task that is known to elicit a large amount of errors is presented, followed by a rapid serial visual presentation (RSVP) of numbers (1–9). In 95% of the trials one letter is presented in the RSVP and participants have to indicate whether they did or did not see a letter, and if they did, which one. The original attentional blink paradigm (Chun & Potter, 1995) was used as a means to investigate the temporal dynamics of attention processes. In numerous studies it has been shown that when two targets are presented shortly after each other in a stream of non-target stimuli, it is harder to identify the second target (T2) when it is presented within 200–500 ms after the first target. This failure to detect T2 is called the attentional blink effect (for a review on the attentional blink paradigm see Shapiro, Arnell, & Raymond, 1997 and Martens & Wyble, 2010). Notably, when both targets are presented within about 100 ms, T2 is detected much more often; this is referred to as lag-1 sparing (Potter, Staub, & O'Connor, 2002). By using this paradigm we can measure the effect of accuracy on subsequent target detection.