Journal Club

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The Role of the Error Positivity in the Conscious Perception of Errors

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Review of Steinhauser and Yeung

Goal-directed behavior relies on the ability to detect errors and to correct the action(s) that led to the error. Research on error detection really took off with the discovery almost 20 years ago of two event-related potential (ERP) components found within the human EEG: the error-related negativity [ERN; or error negativity (Ne)] and the error positivity (Pe) (Falkenstein et al., 1991; Gehring et al., 1993). The ERN is a negative deflection that peaks ~50–80 ms after an erroneous button press. The Pe is a positive deflection that peaks ~100–200 ms after an erroneous button press. While most research has focused on the role of the ERN in error detection, recent research is beginning to uncover the function of the Pe.

Several influential theories have been put forth to explain the computation underlying the ERN (Coles et al., 2001; Holroyd and Coles, 2002; Yeung et al., 2004). Specifically, the ERN has been proposed to reflect either competition between the erroneous and correct response representations (Yeung et al., 2004), a mismatch between the actual and expected correct response (Coles et al., 2001), or the result of less-than-expected reward outcomes (Holroyd and Coles, 2002). Thus, the ERN appears to represent an internal signal that an error is likely or has occurred.

However, these theories fail to account for the role of the Pe in error detection. Nevertheless, research has begun to identify conditions that modulate this ERP component (Overbeek et al., 2005). The most consistent finding is that the Pe is generally larger on trials where participants are consciously aware that an error was made, whereas the ERN is similar for perceived and unperceived errors. This is consistent with the possibility that the Pe reflects the motivational significance of an error. Consciously perceived errors would be more significant, and more likely to lead to correcting one's erroneous actions, than unperceived errors.

In a study recently published in *The Journal of Neuroscience*, Steinhauser and Yeung (2010) examined the role of the ERN and the Pe in the conscious detection of an error. They hypothesized that the ERN and the Pe may reflect the accumulation of evidence that an error has occurred and/or the decision that an error was made. The literature reviewed above suggests that the ERN reflects evidence that an error has occurred, whereas the Pe reflects the process that decides that an error has just occurred. However, the results of Steinhauser and Yeung (2010) call these ideas into question.

On each trial, Steinhauser and Yeung (2010) asked participants to complete a difficult perceptual discrimination task that involved picking which of two highly similar boxes on the screen was brighter. The discrimination task was followed by a secondary task that involved signaling whether they thought they had made an error on the discrimination task. The authors introduced a reward schedule to manipulate the criterion participants used to decide whether to report that they made an error. On high criterion trials, participants were instructed to avoid incorrectly signaling an error, leading to fewer errors being signaled, and consequently requiring more evidence to do so correctly. In contrast, on low criterion trials, participants were instructed to avoid not signaling errors, consequently requiring less evidence to do so correctly. Thus, if the ERN (or the Pe) reflects evidence of an error, it should be larger on high criterion trials on which an error was correctly signaled than on low criterion trials on which an error was correctly signaled. If the Pe (or the ERN) reflects the output of the decision to report an error, it should be larger across all low criterion trials than across high criterion trials, as more errors were signaled in the former.

The behavioral results indicated that the criterion manipulation had the desired effects on error signaling accuracy. Participants signaled more errors in the low criterion condition than in the high criterion condition. Accuracy in the primary stimulus discrimination task was equivalent in the two criterion conditions. In addition, reaction times on error trials that were correctly signaled were faster than on error trials that were not signaled, and this was equivalent between the two

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criterion conditions. Thus, the only difference in the behavior for the two criterion conditions was in error signaling rates.

The ERP results indicated that the Pe, but not the ERN, was associated with accumulating evidence of an error. While both ERN and Pe amplitude were larger for detected errors than for undetected errors, only the Pe was larger for correctly signaled errors in the high criterion condition than in the low criterion condition. Thus, only the Pe appeared to reflect the amount of evidence involved in detecting an error. Interestingly, neither component reflected the output of deciding to report that an error was made. Further, Pe amplitude was positively correlated with the extent that participants increased their decision criterion from the low to the high criterion condition. Thus, participants who required more evidence to signal an error in the high (vs low) criterion condition showed a larger Pe on trials where they correctly signaled an error. In addition, the authors modeled Pe data to see how well Pe activity explained error signaling behavior. The model showed that the Pe accurately reflected error signaling accuracy. In addition, the model revealed that, on a single-trial basis, Pe accurately reflected evidence strength.

At first, these results seem to go against a large literature on the ERN. Despite different explanations for what calculation the ERN reflects, most studies place a primary role for the ERN in internal error detection (i.e., not in the conscious realization that an error has occurred). Thus, the ERN seemed like a prime candidate for reflecting evidence strength for signaling an error. One possibility is that the ERN reflects the first evidence that an error has occurred, and is thus associated with low evidence strength, making it less sensitive to error signaling criteria. In line with this suggestion, Ullsperger et al. (2010) proposed that conscious awareness of errors occurs later, after additional forms of evidence have accumulated, such as proprioceptive feedback from the execution of the erroneous response, sensory input such as the sound of the button press, and the perception of autonomic reactions to early information that an error has occurred (e.g., the ERN).

Steinhauser and Yeung (2010) suggest that rather than directly indexing error detection, the ERN indexes features of task performance. Thus, the finding that ERN amplitude was greater for detected errors than undetected errors may simply reflect the finding that detected errors were responded to more quickly than undetected errors. Detected errors tend to occur when the error is subsequently corrected, which leads to conflict between the erroneous and correct response. Accordingly, the lack of an effect of criterion level on ERN amplitude can be attributed to the lack of a difference in primary task performance between high and low criterion trials.

The real novelty of Steinhauser and Yeung (2010) lies in the Pe data. Previous research has generally treated the Pe as a byproduct of error detection, but these authors suggest that the Pe, rather than the ERN, may be a direct index of error detection processes. Rather than reflecting the result of error awareness, the Pe indexes evidence strength and likely serves as input to processes that decide that an error has occurred. This represents a large step in understanding the processes that underlie the Pe, rather than simply indentifying conditions that influence Pe amplitude.

This study raises several new questions about the Pe for future research to examine. As discussed by Steinhauser and Yeung (2010), there is still a question of what brain regions contribute to the Pe. Given the similarity of the Pe to the stimulus-locked P3 component, these components may have similar generators in the prefrontal and parietal cortices. Future imaging studies might use the same error signaling criterion method used by Steinhauser and Yeung (2010) to localize brain regions that reflect error evidence strength. The importance of error monitoring is that it enables the updating of behavior that is no longer adequate for current goals. However, it remains unclear how efficient error signaling influences subsequent behavior.

Future studies should examine whether the strength of evidence that an error has occurred (as indexed by the Pe) is associated with the degree of behavioral adjustments on trials following errors (such as post-error slowing). Previous studies have associated post-error slowing with Pe amplitude (Overbeek et al., 2005), but these studies have not manipulated evidence strength as was done by Steinhauser and Yeung (2010). Also, it may be useful to see whether the indicated function for Pe makes sense in the context of psychopathology. If Pe reflects the strength of pooled evidence a participant used to appraise their primary task accuracy, then will patients with reduced capacity for cognitive control have a smaller Pe? Will children (who would be expected to have a lower capacity for control) also have a smaller Pe? Given their heightened sensitivity to error signaling and their preference toward error avoidance, it seems plausible that adults with obsessive-compulsive disorder would present with an increased Pe. In theory, an increased Pe could reflect a learning strategy that would allow patients to avoid future mistakes by being especially sensitive to previous errors.

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