When Outcomes are Worse than Expected: Self-generated Errors and External Malfunctions Recruit the Rostral Cingulate Zone.

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Introduction

A large body of evidence consistently implicates the rostral cingulate zone (RCZ), located in the posterior mesial frontal cortex (pMFC), in performance monitoring. Functional magnetic resonance imaging (fMRI), electroencephalography, and invasive recordings suggest this region to signal the need for adjustments whenever the outcome of an action is worse than intended, or when the intended outcome is at risk. Up to now, monitoring of own performance, particularly of self-generated errors and situations with high likelihood of errors have been in the focus of research. In everyday life, however, actions often do not result in the intended outcome for other reasons, for example machine malfunction. Similarly to self-generated errors malfunctions call for compensatory actions. Current hypotheses predict that not only in self-generated errors but also in other instances when the action goal was not achieved the RCZ should be activated and signal the need for adjustments.

Methods

18 young, healthy participants performed a modified flanker task (Figure 1) while fMRI signals were recorded at 3T. Correct button presses were immediately visually confirmed (correct condition). No confirmation appeared when participants pressed the wrong button (error condition). Participants were instructed to immediately correct encountered errors by a second key press. In addition to self-generated errors, on some correct trials the button press confirmation was omitted (malfunction condition). Prior to the study participants were informed that the response box may sometimes fail to respond for technical reasons. They were instructed to press the correct response button again, when such malfunctions occurred. In order to increase task engagement each correct response was rewarded with 10 points. Errors and malfunctions were not rewarded, unless they were immediately remedied by the appropriate button press. The remedial responses were visually confirmed analogously to correct responses. In 14 participants (10 female, mean age 25.4 years) an adaptive algorithm successfully matched the frequencies of errors and malfunctions for all levels of stimulus-response compatibility, such that only they were included in the further analyses.

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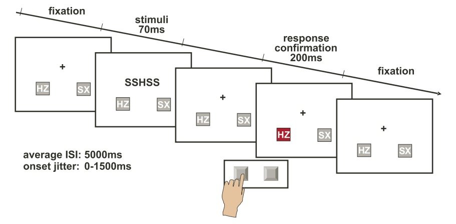

Figure 1. Modified flanker task. Letter strings consisting of four identical distractor letters and one odd target letter were presented in the center of the screen. Target letters appeared at any position of the letter string except for its beginning or end (e.g., "HSHHH", "XXZXX", "SSSZS"). Participants had to identify the target letter and to make a response according to a mapping instructed to the subjects prior to the experiment and shown in symbolic response buttons which were presented on the screen for the entire experiment. Correct responses were immediately followed by a visual confirmation of the button press – according to the pressed button the gray response button symbol on the screen turned red.

Results

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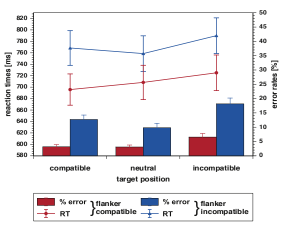

Figure 2. Reaction times of correct responses and proportion of error trials broken down by compatibility of flankers and target position.

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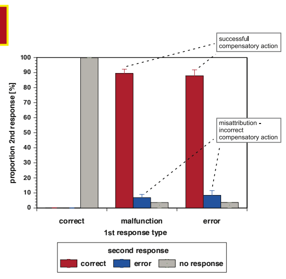

Figure 3. Proportion of second response types broken down by first response type.

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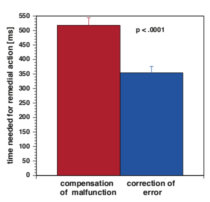

Figure 4. Times needed for compensatory action after malfunctions and errors.

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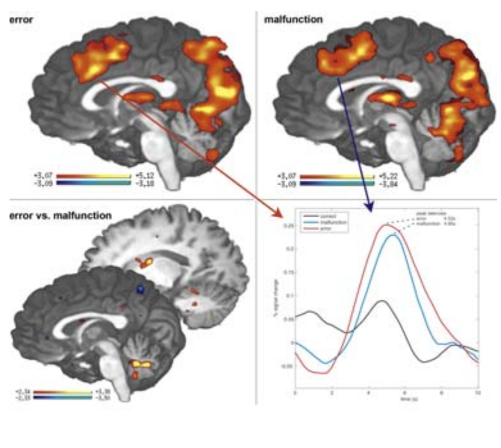

Figure 5. Upper row: Sagittal view of median fMRI signal increases related to errors (left panel) and malfunctions (right panel). Lower row, left panel: direct contrast showing stronger activity for malfunctions in red and for errors in blue. Sagittal median and right paramedian planes. Lower row, right panel: time series in rostral cingulate zone averaged relative to stimulus onset (time=0) separately for correct, malfunction, and error trials.

Stronger activity for malfunctions than for errors was found in the left motor and dorsal premotor cortex, the superior insula and subcentral gyrus, the left caudate nucleus and right putamen, and the cerebellum. Errors elicited stronger activity than malfunctions in the precuneus.

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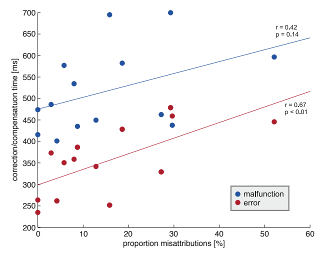

Figure 6. Correlation of error correction rate with error correction time (red) and of compensation rate and compensation time for malfunctions (blue).

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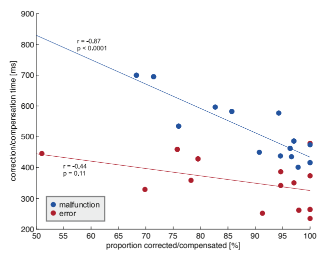

Figure 7. Correlation of misattributions (i.e., incorrect compensatory action after errors and malfunctions) with error correction time (red) and compensation time for malfunctions (blue).

Correlation analyses suggest that participants who less often correctly compensated malfunctions and errors and who more often misattributed the failure need more time for compensatory actions. This suggests that they experienced more uncertainty about the appropriate compensatory action.

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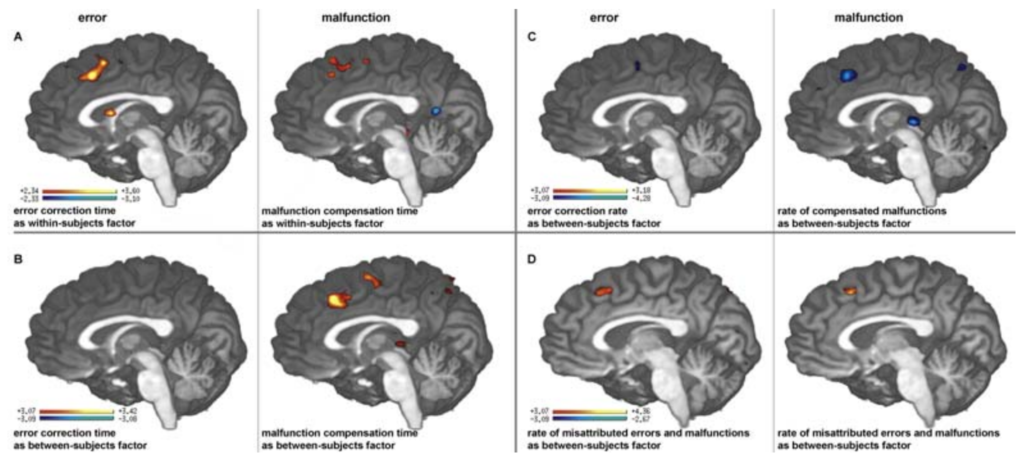

Figure 8. Median sagittal views of parametric analyses for errors and malfunctions (left and right part, respectively, on each panel). A. Parametric analysis with single-trial error correction time (left) and malfunction compensation time (right), respectively, as within-subjects factor. B. Second level analysis with mean error correction time (left) and malfunction compensation time (right), respectively, as between-subjects factor. C. Second level analysis with proportions of corrected errors and compensated malfunctions as between-subjects factor. D. Second level analysis with proportion of misattributions (errors interpreted as malfunctions and vice versa) as between-subjects factor.

Parametric analyses show that the posterior mesial frontal cortex was more active on errors and malfunctions when the compensatory action was slow. Moreover, it is stronger activated with decreasing compensation rates and increasing misattributions.

Discussion

The data show that the pMFC, in particular the RCZ, is similarly activated during self-generated errors and technical malfunctions, both resulting in non-achievement of the goal. This is consistent with the notion that the pMFC signals the need for adjustments whenever the action outcome is worse than expected, independent of the cause.

Error corrections are faster than compensatory actions after malfunctions. This is assumed to result from the following reasons:

- In flanker tasks errors can be detected without external feedback. In contrast, the detection of malfunction requires sensory processing of the nonoccurrence of the expected outcome. This delay in the monitoring process is paralleled by the time course of the BOLD response in the RCZ.
- As errors mostly occur on incompatible trials, the correct response tendency is often built up in parallel, thus allowing fast error corrections.
- Malfunctions require a response repetition, which in contrast to error corrections is not prepared. This additional demand on the motor system may be reflected in the stronger activity of the primary and pre-motor cortices, the basal ganglia, and the cerebellum.

Activity in the pMFC is increased with prolonged compensation times and decreased compensation performance. pMFC activity seems to be modulated by the uncertainty about the appropriate compensatory action. Compared to simple error correction tasks, the present task encompasses higher degrees of freedom in the compensatory actions. It seems conceivable that this uncertainty-related increase in the pMFC activity reflects the increased effort needed to gather the information clarifying the reason of failure and the appropriate compensation.