Introduction

- Role of conscious error perception for action outcome optimization
- Event related potentials (ERP; Nieuwenhuis et al., 2001, Endrass et al., 2005): modulation of the error positivity (Pe) by error awareness – a normal Pe was found in case of an aware error, a diminished Pe was observed in case of an unaware error; the error related negativity (ERN) was present on aware and unaware errors
- Behavioural: post-error slowing (PES) only after an aware error
- Rostral cingulate zone (RCZ; most probable generator of the ERN) active on error processing (Debener et al., 2005)
- Research questions:
  1. Are there sizeable differences in RCZ activity or in the activity of other error processing related brain areas due to error awareness?
  2. What are the behavioural correlates of error awareness?

Methods

a) Participants and Task
- Thirteen healthy right handed subjects (8 female, mean age = 26.15 years)
- Antisaccade task (Nieuwenhuis et al., 2001; 476 Trials; see Figure 1)
- Brief precue (to increase error rate) was presented at the position where the gaze should be directed to (to reduce predictability in 33% of the trials the precue was presented at the position of the following peripheral stimulus)
- Post-error slowing more likely when errors are consciously perceived
- Interoceptive awareness (Critchley et al., 2004) and regulation of autonomic responses
- Errors may be detected by RCZ without being consciously perceived

b) FMRI
- Error > Correct: Pre-SMA, RCZ and Insula (see Table 1 & Figure 7)
- Aware > Unaware: Left insula (see Table 1 & Figure 7)
- Timecourses: Greater activity in the insular cortex for aware errors, no such difference can be found in RCZ (see Figure 7)
- Parametric second-level analysis with post-error reaction time as a regressor: the more a person slowed down after an aware error, the more activity can be found in the pre-SMA (x = 1, y = 6, z = 48; see Figure 8)

Results

a) Behavioural
- Errors faster than correct responses (see Figure 3 to 6 for details)
- Considerable variance in Pe across subjects; PES in 9 out of 13 subjects
- Lower error rate after an aware error
- False alarm rate: 3%; rate of not classifiable trials due to technical problems: 6.1%

b) FMRI
- Error > Correct: Pre-SMA, RCZ and Insula (see Table 1 & Figure 7)
- Aware > Unaware: Left insula (see Table 1 & Figure 7)
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Table 1

<table>
<thead>
<tr>
<th>Region</th>
<th>z-value</th>
<th>t-value</th>
<th>MNI Coordinates</th>
<th>Volume (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L Insula</td>
<td>3.01</td>
<td>5.12</td>
<td>x = -38, y = 11, z = 0</td>
<td>336,52</td>
</tr>
<tr>
<td>R Insula</td>
<td>3.64</td>
<td>5.12</td>
<td>x = 31, y = -41, z = 12</td>
<td>343,76</td>
</tr>
<tr>
<td>Pre-SMA</td>
<td>2.92</td>
<td>3.01</td>
<td>x = 2, y = 18, z = 51</td>
<td>250,56</td>
</tr>
<tr>
<td>Insula</td>
<td>3.00</td>
<td>3.01</td>
<td>x = 1, y = 6, z = 27</td>
<td>256,30</td>
</tr>
<tr>
<td>pFMC</td>
<td>2.93</td>
<td>3.01</td>
<td>x = 2, y = 30, z = 42</td>
<td>243,52</td>
</tr>
</tbody>
</table>

Discussion

RCZ
- Active on both error types (aware & unaware) – in line with previous findings, showing no modulation of the ERN by error awareness
- Differences in Pe not generated in RCZ
- Error related RCZ activity is not sufficient for conscious error awareness
- Errors may be detected by RCZ without being consciously perceived

Insular Cortex
- Interoceptive awareness (Critchley et al., 2004) and regulation of autonomic responses
- Enhanced awareness of the autonomic reaction to an error or higher autonomic response itself (direction of relationship cannot be revealed by this study)
- Feeling of having committed an error via visceral reactions to the erroneous event
- Insula by itself unlikely to generate directly the Pe; but maybe via interactions with other cortical areas involved in generating the Pe

Positive correlation between pre-SMA and post-error slowing after an aware error
- Posterior medial frontal cortex (pFMFC) involved in signalling the need for performance adjustments
- Post-error slowing more likely when errors are consciously perceived
- Increased RCZ activity alone is insufficient to initiate post-error speed-accuracy adjustments (only on aware errors while RCZ activity is the same for aware and unaware errors)
- Additional processes must co-occur with RCZ activity to enable performance adjustments in N+1

Conclusion

- RCZ and the anterior, inferior insular cortex around the polus insulae seem both important constituents of the performance monitoring system
- RCZ/pFMFC activity seems to signal the need for post-error adjustments, it can fulfil this function only when additional conditions – most likely a sufficiently strong general error signal in the cognitive system – are met
- Activity in the anterior inferior insular cortex covaries with error awareness and seems to reflect the awareness of the autonomic response to the error and/or the implementation of this autonomic response itself

Figure 1. Schematic of the antisaccade task. Average trial duration 6 s.

Figure 2. Results of the metaanalysis projected onto a sagittal (x = -32) and a coronal slice (y = 15).

Figure 3. Accuracy in trial N

Figure 4. Post error accuracy

Figure 5. Reaction times in trial N

Figure 6. Post error reaction times

Figure 7. Results of the parametric second-level analysis of brain activity related to awareness using post-error slowing as a regressor, revealing a significant correlation in the pre-SMA (x = 1, y = 6, z = 48).

Figure 8. Results of the parametric second-level analysis of brain activity related to awareness using post-error slowing as a regressor, revealing a significant correlation in the pre-SMA (x = 1, y = 6, z = 48).

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References