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Your mistake is my mistake . . . or is it? Behavioural adjustments following own and observed actions in cooperative and competitive contexts

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Your mistake is my mistake . . . or is it? Behavioural adjustments following own and observed actions in cooperative and competitive contexts

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A social speeded choice-reaction-time task was used to study adaptive behaviours following own and observed actions (errors and correct responses) in cooperative and competitive contexts. After making an erroneous response, the appropriate remedial action to avoid future errors in speeded reaction tasks is to slow down. Consistent with previous results, people indeed slow down following their own errors. Importantly, people who slow down most following own errors also slow down following observed errors in a cooperative situation. In a competitive context, a different pattern was found. People accelerated after errors from their opponent. The current findings demonstrate that the social context determines the way people respond to the errors of others, indicating that the neural systems that control remedial actions are highly flexible. These systems may underlie social adaptive behaviour, enabling people to respond flexibly to other people's actions in a wide variety of social contexts.

Keywords: Error monitoring; Adaptive behaviour; Social cognition; Performance adjustments; Cooperation; Competition.

Our everyday experience suggests that detection of our own errors leads us to engage in corrective or adaptive behaviours. When we miss a turn we should have taken while driving, we frequently realize this mistake as we pass the turning and

quickly initiate corrective actions: braking, turning around, and so on. The first question addressed in this paper is whether the system responsible for these corrective or adaptive behaviours is also engaged when we observe errors in

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others. As a passenger, do we try to depress a phantom brake when our friend misses the turning even though this behaviour has no obvious function? The second question is whether the system that initiates remedial actions is flexible. Does the social context determine whether we initiate the same corrective actions following observed errors? In particular, do we depress a phantom brake when the driver is not a friend, but rather someone whose errors we enjoy?

The ability of humans to flexibly adapt their behaviour after they make errors has been investigated experimentally using speeded choice-reaction-time tasks. In these tasks, errors are usually the result of premature responding. Consequently, an appropriate adaptive response to improve performance is to take extra time to process the next stimulus and prevent a similar mistake. This adaptive behaviour is also known as post-error slowing (Rabbitt, 1966). Correct responses following impulsive erroneous responses are usually slower than correct responses that follow correct responses, although there are substantial individual differences in the degree of post-error slowing (e.g., Klein et al., 2007).

Recent electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) studies have demonstrated that the medial frontal cortex plays a key role in the detection of errors and in subsequent behavioural adjustments (see, e.g., Hester, Barre, Mattingley, Foxe, & Garavan, 2007). For example, the amplitude of the error-related negativity (ERN; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993), a component of the event-related brain potential generated in the medial frontal cortex, which occurs following errors, is related to the amount of post-error slowing (Debener et al., 2005; Gehring et al., 1993). In a series of recent studies (Bates, Patel, & Liddle, 2005; Miltner, Brauer, Hecht, Trippe, & Coles, 2004; van Schie, Mars, Coles, & Bekkering, 2004), an ERN was also found when people observe another person making an error, suggesting that the detection of one's own and other's errors (observed errors) is mediated by similar neural

mechanisms. Indeed, recent fMRI findings from our lab indicated similar involvement of medial frontal cortex in processing of both own and other's errors (De Bruijn, de Lange, von Cramon, & Ullsperger, 2009).

Schuch and Tipper (2007) recently demonstrated post-error slowing in response to observed errors in a neutral context, suggesting that similar remedial actions are engaged by own and observed errors. However, it remains to be determined whether this similarity reflects the action of the same functional mechanism as that responsible for adaptive behaviour. Moreover, while own errors are almost always negative events, observed errors by one's opponent in a competitive context may actually be a good thing. It is presently unknown whether the social context in which errors are observed influences the type of adaptive behaviours that are performed. To answer this question, we studied the relationship between post-error behaviour following own and observed errors in a social speeded choice-reaction task in cooperative and competitive contexts.

Method

Participants

A social go/no-go task was given to participants under cooperative and competitive conditions (De Bruijn, Miedl, & Bekkering, 2008). In one condition, 14 pairs of subjects ($N = 28$, 21 female, mean age = 22.8 years, $SD = 2.3$ years) performed a cooperative go/no-go task together. In the second condition, 14 different pairs of subjects ($N = 28$, 23 female, mean age = 21.4 years, $SD = 2.6$ years) competed against each other on the same task.

Design and task

The aim of the task was to respond as quickly and accurately as possible to the presentation of a single letter on one shared computer screen. There were four possible letters. Each member of the pair was instructed to respond following presentation of two of the letters (70% "go") and to withhold their response to the other two letters (30% "no-go"; see Figure 1, left). There was only partial

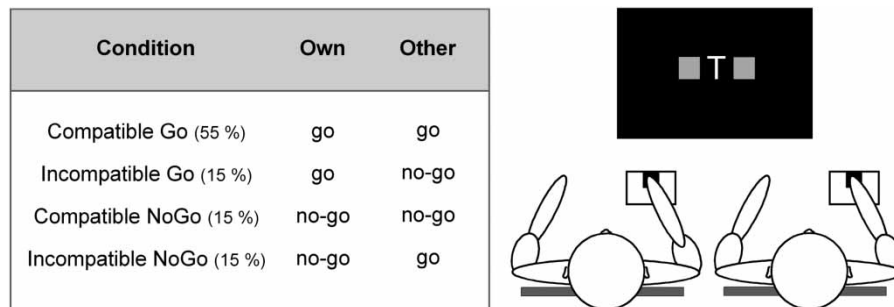


Figure 1. Social go/no-go task. Left panel: Design and frequencies of the four different conditions. Right panel: Experimental set-up.

overlap between letter-response assignments such that on 70% of the trials (compatible trials), the letter stimuli required the same action in both members of the pair (both should respond or both should withhold their response), while on 30% of the trials (incompatible trials) the required action was different (one should respond while the other should withhold their response). Each stimulus (the letters P, F, E, or T) was associated with one of these four conditions.

In the cooperative context, participants were instructed to respond as quickly and accurately as possible as a pair in order to win an additional “team bonus” (a gift certificate of 5 euros for both) after the entire experiment. In the competitive context, participants were instructed to directly compete with each other in order to win an “individual bonus” (a gift certificate of 5 euros for the winner) after completion of the task.

In both conditions, stimuli were presented for 100 ms in white against a black background in the centre of a computer screen between two grey boxes (see Figure 1, right). The boxes corresponded to the response buttons of the left and right participants. The left grey box coloured yellow when the left participant responded, while the right grey box coloured yellow when the right participant responded. The intertrial interval varied randomly between 2,000 and 3,000 ms. An experimental session consisted of eight blocks of 200 trials.

In the cooperative context, participants received feedback on their performance (reaction time averaged over correct responses and the total number

of incorrect responses) as a pair after they had completed the task. In the competitive condition, similar feedback was presented but for each participant separately. An end score was calculated by adding the total number of errors to the average reaction time. The pair or the competitor with the lowest end score was declared the winner and received the additional bonus. There was a short break between the blocks, and each experiment lasted about 1 hour.

Analyses

The overall effects of frequency and correctness on reaction time were investigated by means of two 2×2 repeated measures general linear models (GLMs). One analysis included go stimuli only and had the between-subjects factor context (cooperation vs. competition) and the within-subject factor frequency (frequent vs. infrequent). Frequency refers here to the distribution of the different conditions: 55% for the frequent condition and 15% for the infrequent one. The second analysis had the between-subjects factor context (cooperation vs. competition) and correctness (correct go vs. incorrect no-go).

To investigate post-error behaviour (PEB), own reaction times for correct responses when both subjects had to respond (compatible go trials) were analysed as a function of the outcome of the preceding trial (see left panels, Figures 2 and 3). This criterion ensured that only trials of the same frequency entered the analyses. Own post-correct response times were those for trials that were preceded by a correct response, while

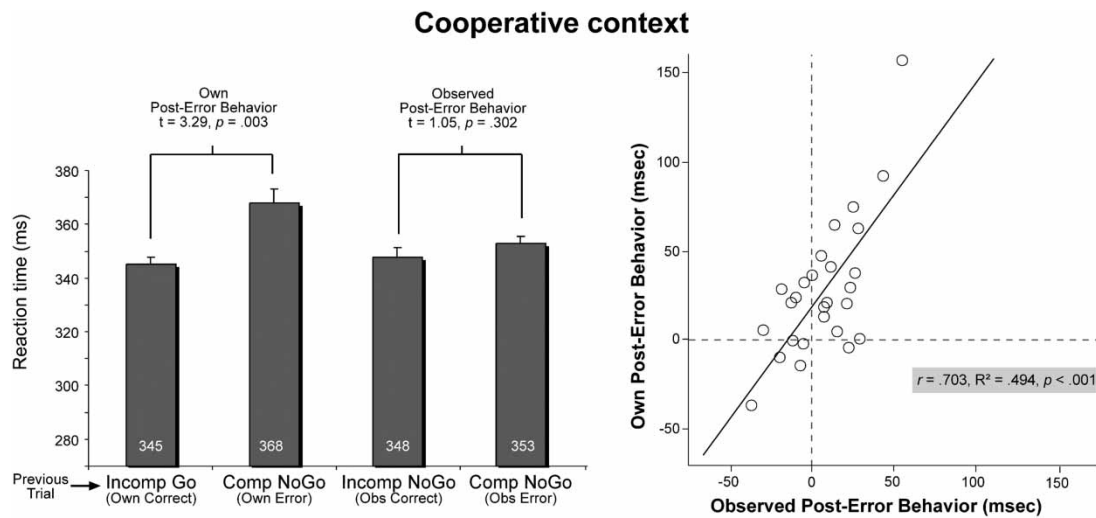


Figure 2. Results from the cooperative context. Left panel: Reaction times on Compatible Go trials as a function of the preceding trial. Error bars reflect within-subject confidence intervals (Loftus & Masson, 1994). Right panel: Scatterplot and correlation analysis of Own and Observed post-error behaviour.

own post-error response times were those for trials that were preceded by an error (i.e., an incorrect response on a no-go stimulus). Own post-error behaviour was then defined as the difference between own post-error and own post-correct response

times. Observed post-correct response times were defined as the response times on correct trials preceded by a correct response by the other person, while observed post-error response times were response times for trials preceded by an error by

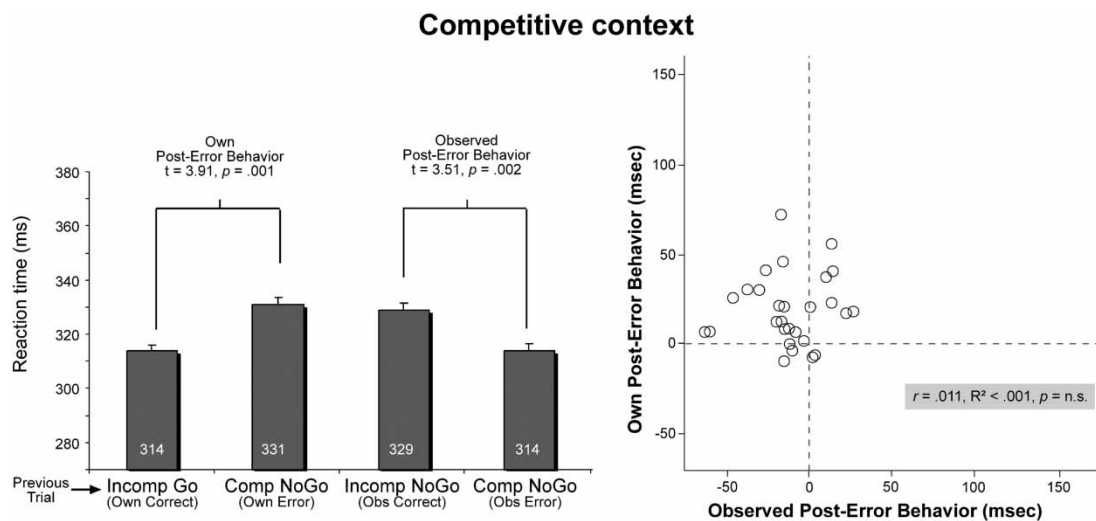


Figure 3. Results from the Cooperative context. Left panel: Reaction times on Compatible Go trials as a function of the preceding trial. Error bars reflect within-subject confidence intervals (Loftus & Masson, 1994). Right panel: Scatterplot and correlation analysis of Own and Observed post-error behavior.

the other person. Observed PEB was then defined as the difference between observed post-error and observed post-correct. Importantly, the nature of own and other responses—that is, responding or withholding—were always matched within the comparisons. For example, to determine own post-error behaviour, the participant of interest responded on both the previous and the current trial. The other participant had to withhold his or her response on the previous trial and did this successfully. Both participants responded correctly on the current trial. So, except for the own response on the previous trial, all other responses within this comparison are correct ones. These selection criteria ensured that possible effects in PEB were not contaminated either by differences in the nature of responding or by possible differences in the correctness of the response made by the other participant.

These post-error behavioural adjustments were then investigated by entering the individual averages for reaction times derived as described above into a $2 \times 2 \times 2$ repeated measures GLM with the between-subjects factor context (cooperation vs. competition) and the within-subject factors post-error behaviour (post-error vs. post-correct) and agent (own vs. observed). To control for possible overall context differences in reaction times, mean reaction times for all responses were entered as a covariate in these overall analyses.

Significant three-way interactions were further investigated by means of 2×2 repeated measures analysis of variance (ANOVA) followed by two-tailed paired t tests. Also, the relation between own PEB and observed PEB was investigated by means of Pearson correlations and linear regression. The correlations for the two contexts were directly compared by means of a Fisher's Z_r transformation.

Results

Overall analysis

Figure 4 depicts the results from the analyses of reaction times without regard to the response accuracy of the previous trial. On average, participants responded correctly to 95.4% of the go trials and

correctly withheld their response to 82.3% of the no-go trials. Mean response times to the frequent compatible go trials were faster (322 ms) than those to the infrequent incompatible go trials (361 ms), $F(1, 54) = 162.40$, $p < .001$. Responses were also significantly faster in the competitive context (331 ms) than in the cooperative one (351 ms), $F(1, 54) = 13.62$, $p = .001$. Also, the interaction between frequency and context was significant, $F(1, 54) = 4.19$, $p = .046$. Follow-up t tests demonstrated that this interaction was caused by faster reaction times to the frequent compatible go trials in the competitive context (309 ms) than in the cooperative context (334 ms; $t = 5.26$, $p < .001$). Response times did not differ significantly between the two contexts for the infrequent incompatible go trials (competitive: 354 ms; cooperative: 367 ms; $t = 1.91$, $p = .061$).

Finally, the analyses of the second GLM revealed that incorrect responses to no-go trials were faster (301 ms) than correct responses to go trials (330 ms), $F(1, 54) = 230.02$, $p < .001$. Again, a main effect of context was found, indicating faster responses in the competitive context (304 ms) than in the cooperative context (327 ms); $F(1, 54) = 20.10$, $p < .001$. The interaction between the two was not significant ($F < 1$).

Post-error behaviour

The main findings and analyses of the cooperative and competitive tasks are depicted in Figures 2 and 3, respectively. The analyses of behavioural adjustments revealed neither main effects (all $ps > .4$) nor significant two-way interactions (all $ps > .2$). Importantly, the three-way interaction between agent (own vs. observed), post-error behaviour (post-error vs. post-correct), and context (cooperation vs. competition) was significant, $F(1, 53) = 4.68$, $p = .035$. The significant interaction was further investigated by analysing the behavioural adjustments separately for the two contexts.

Cooperative context

A 2×2 repeated measures GLM with the within-subject factors post-error behaviour (post-error vs. post-correct) and agent (own vs. observed) was conducted for the cooperative context separately.

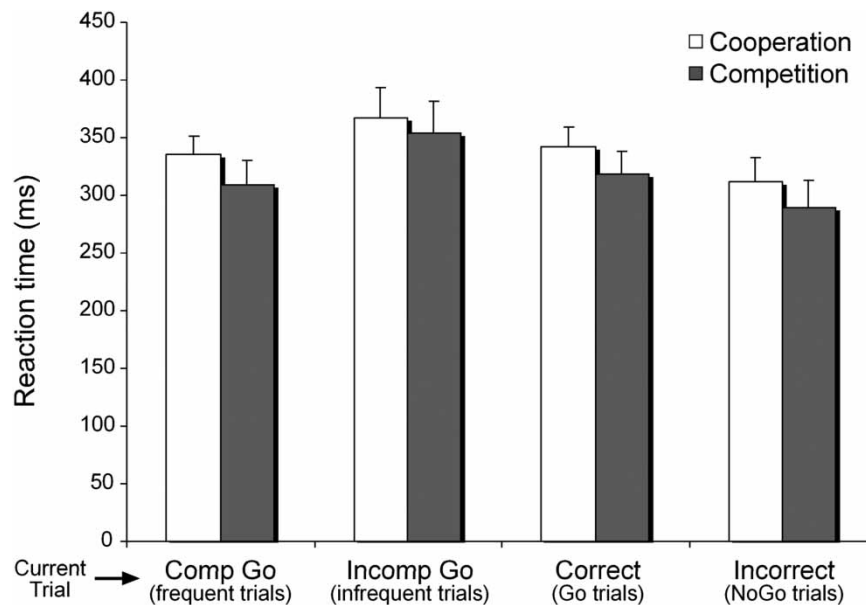


Figure 4. Mean overall reaction times independent of the accuracy of the preceding trial for frequent and infrequent go trials and for correct and incorrect responses for the cooperative and the competitive contexts. Error bars reflect standard deviations.

This analysis revealed a main effect of post-error behaviour, $F(1, 27) = 7.18, p = .012$, and a significant interaction between post-error behaviour and agent, $F(1, 27) = 13.91, p = .001$. Further t tests showed that post-error slowing in the cooperative context was significant following own (23 ms; $t = 3.29, p = .003$) but not following observed errors (5 ms; $t = 1.05, p = .302$). However, there were large individual differences in post-error slowing following both own and observed errors (see right panel of Figure 2). A correlation analysis revealed a strong relationship between own and observed PEB ($r = .703, p < .001$). To explore this correlation further, we conducted a median split analysis in which subjects were divided into large and small own post-error slowing groups. In this analysis, those subjects ($N = 14$) who slowed large own post-error slowing (49 ms) also showed significant post-error slowing after observed errors (13 ms; $t = 2.40, p = .032$).

Competitive context

A 2×2 repeated measures GLM with the within-subject factors post-error behaviour

(post-error vs. post-correct) and agent (own vs. observed) was conducted for the competitive context separately. This analysis revealed no significant main effects ($F_s < 1$), but the interaction between post-error behaviour and agent was significant, $F(1, 27) = 31.08, p < .001$. Further t tests demonstrated that post-error reaction times were slower than post-correct reaction times for own responses (17 ms; $t = 3.91, p = .001$), but the reverse pattern was found for observed responses (–15 ms; $t = -3.51, p = .002$). The correlation analyses did not reveal a relationship between own and observed PEB in the competitive context ($r = .011, p = .955$). A direct comparison of the correlations for the different contexts showed that the two differed significantly ($z = 3.03, p = .003$).

Discussion

The current study investigated behavioural adjustments following own and others' actions under two conditions employing a cooperative and a competitive version of a social go/no-go task. In both

conditions, participants displayed slower responses following own errors than following own corrects. Despite the absence of an overall observed post-error slowing effect in the cooperative context, further analyses demonstrated that participants who slowed down the most following their own errors also slowed down following errors made by their partner. In the competitive context, however, participants accelerated following errors made by their opponents.

In the cooperative context, the relatively large individual differences in behavioural adjustments most likely contributed to the absence of an overall effect of observed post-error slowing. Such individual differences are not uncommon in speeded choice-reaction tasks (see, e.g., Klein et al., 2007) and are most likely the result of the conflict induced by speed-accuracy instructions. Also, although instructions stress cooperative behaviour, it may be the case that some participants always remain competitive to some extent, because they simply do not want to perform worse than their partner. This bias for competition might have added to the increased individual differences. However, the correlation analyses revealed a strong relationship between the degrees of own and observed post-error slowing. This result extends the findings of Schuch and Tipper (2007) by showing that those subjects who showed large post-error slowing after their own errors also showed post-error slowing after observed errors. This relationship between own and observed post-error slowing in a cooperative context suggests that similar mechanisms may underlie these remedial actions. This finding is also in line with recent studies that report that the ERN is elicited when people observe errors in another person in a neutral context (Bates et al., 2005; Miltner et al., 2004; van Schie et al., 2004), suggesting that the monitoring of our own and others' errors is mediated by the same neural mechanism. Observing an error in one's partner may thus trigger the remedial-action system in the same way as detecting an error in oneself, and similar adaptive behaviour is elicited. The currently found correlation between own and observed post-error slowing may suggest that, in a

cooperative context, when people see their partner make a mistake, they react to that error as if it was their own and adjust their behaviour to optimize performance of the cooperative pair.

In the competitive context, a different pattern of results was found. While participants showed post-error slowing after their own errors, they accelerated after observing errors in their competitor. Note that since our measure of post-error behaviour is based on the difference between postcorrect and post-error reaction times, the apparent acceleration after observed errors could be due either to post-error acceleration or to post-correct slowing. However, the overall faster reaction times in the competitive than in the cooperative context seem to suggest that participants focused more on speed in the competitive context. Accelerating after an observed error may thus have resulted from the competitive instruction and the emphasis on speeded responding. On the other hand, one may argue that observing a competitor being successful is actually a *negative* event, which triggers the remedial-action system in a similar way as an error by oneself. In particular, remedial actions that make future own errors less likely are initiated in response to a correct response of the competitor, leading to slower responses on the subsequent trial. There is some support for this post-correct slowing assumption in the present data, as the postobserved error reaction time (313 ms) is very similar to the postown correct reaction time (314 ms), while the postobserved correct reaction time is longer (328 ms) and similar to postown error reaction time (329 ms).

Importantly, however, this alternative explanation is not supported by the outcomes of a recent study from our lab. Using fMRI, we investigated processing of own and other's errors in cooperative and competitive contexts and demonstrated that the posterior medial frontal cortex (pmFC) was similarly involved in processing the different error types (De Bruijn et al., 2009). Activation in pmFC was increased for errors compared to correct actions even when participants were observing an opponent's error that resulted in a gain. This activation pattern is in line with

previous studies demonstrating pMFC to be crucially involved in regulating adaptive behaviour and updating of action values (Debener et al., 2005; Rushworth, 2008). Therefore, the current results from the competitive context are best interpreted as reflecting adaptive behaviour following an opponent's error rather than changes in behaviour in response to an observed correct action. So although the process of error detection is insensitive to the context in which an interaction is taking place, the exact formalization of adaptive behaviour is dependent on the context. Finally, since there was no relationship between behavioural adjustments following own and observed errors in the competitive context, the mechanisms that underlie these behaviours may not be as similar as those in the cooperative context. Future research should aim at investigating the relationship between error-detection mechanisms and adaptive behaviour in competitive contexts.

Interestingly, the overall faster reaction times pattern in the competitive context shows that participants focused more on speed in competition than in cooperation. One explanation may be related to the actual presence of the direct competitor increasing motivation to give speeded responses. Alternatively, the two contexts differed in respect to reward likelihood and timing of reward delivery, which might also affect motivational processes. In the competitive context, participants had a 50% chance of receiving a reward immediately following completion of the task, while in the cooperative context this chance was around 7%, and the actual delivery of the reward was delayed until completion of the entire study. Although the current design does not allow conclusions to be drawn on this matter, the exact role of motivation and differences in reward on the current processes of interest may be an additional interesting future research topic.

CONCLUSIONS

Humans try to optimize their own performance by adjusting their behaviour to avoid future errors.

The current study demonstrates that this holds not only for individual action but also for joint action and that the social context in which performance takes place determines the exact formalization of these adaptive behaviours. While subjects slowed down after their own errors regardless of context, they only slowed down after observing an error in their partner when they had a common goal. Note that this pattern was only present for those subjects who showed largest posterror slowing following their own errors. In contrast, when they were competing with their coactor, they accelerated after an observed error. Thus, the present study suggests that the functional systems responsible for initiating adaptive behaviours may be more similar for own and observed errors in cooperation than in competition. Importantly, however, these results show that the post-error slowing following observed errors is not simply a slowing down following an unexpected event. The correlation between own and observed posterror slowing and the fact that post-error behaviour is different depending on the task context show that the observed post-error slowing is due to a specific cognitive mechanism for performance monitoring.

To conclude, the functional systems that feed into remedial-action systems to regulate adaptive behaviours are highly flexible and play a central role in optimizing performance, not only in individual tasks but also in social tasks. These systems may crucially underlie social adaptive behaviour, behaviour that enables people to respond flexibly to other people's actions in a wide variety of social contexts.

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