Received: 17 July 2017 | Revised: 12 December 2017 | Accepted: 12 December 2017

DOI: 10.1111/psyp.13057

ORIGINAL ARTICLE

WILEY PSYCHOPHYSIOLOGY SPR SOCIETY FOR PSYCHOPHYSIOLOGICAL RESEARCH

My mistake? Enhanced error processing for commanded compared to passively observed actions

Lisa Weller | **Katharina A. Schwarz** | **Wilfried Kunde** | **Roland Pfister**

Department of Psychology, University of Würzburg, Würzburg, Germany

Correspondence
Lisa Weller or Roland Pfister,
Department of Psychology, University of Würzburg, Röntgenring 11, 97070 Würzburg, Germany.
Email: lisa.weller@uni-wuerzburg.de
or
roland.pfister@psychologie.uni-wuerzburg.de

Funding information
German Research Council (Deutsche Forschungsgemeinschaft; DFG) (PF 853/2-1) (to R. P.), (KU 1964/14-1) (to W. K.)

Abstract

We often ask other people to carry out actions for us in order to reach our goals. However, these commanded actions may sometimes go awry, and goal attainment is hindered by errors of the following person. Here, we investigated how the commanding person processes these errors of their follower. Because such errors indicate that the original goal of the command is not met, error processing for these actions should be enhanced compared to passively observing another person's actions. Participants thus either commanded another agent to perform one of four key press responses or they passively observed the agent responding. The agent could respond correctly or commit an error in either case. We compared error processing of commanded and passively observed actions using observation-related post-error slowing (oPES) as a behavioral marker and observed-error-related negativity (oN$_E$/oERN) and observed-error positivity (oP$_E$) as electrophysiological markers. Whereas error processing, as measured via the oERN, was similarly pronounced for commanded and observed actions, commanded actions gave rise to stronger oPES and a stronger oP$_E$. These results suggest that enhanced monitoring is an automatic by-product of commanding another person's actions.

KEYWORDS

error observation, error processing, post-error slowing, social action

1 | INTRODUCTION

Our movements are typically initiated in order to reach certain goals. Often, we do not reach our goals singlehandedly, but we rely on other agents in our surroundings to reach our goals, and we do so by asking them to carry out certain actions for us. These commanded actions, however, may not always attain their original goal, and goal attainment may be hindered, both by initial misunderstandings or by action slips of the person we ask for a specific action. When intending to buy fresh rolls from the local bakery, for instance, we might ask the woman behind the counter to fetch two of those whole-grain ones to the left. She nods, turns around, and takes the first roll up. Unfortunately, it is not the type of roll that we had in mind, and we immediately intercept by adding, "No, not these ones, the ones on the upper shelf." Scenes such as the bakery example are commonplace in day-to-day interactions, and anecdotal experience suggests that we readily notice whenever a commanded action goes awry. Despite its high prevalence in day-to-day interactions, the cognitive processing of such errors in commanded actions has not been examined in experimental studies. The present study provides a first step in this direction, and it capitalizes on behavioral and electrophysiological markers of error processing.

On a behavioral level, own errors in experimental tasks are typically followed by a slowing of subsequent behavior (post-error slowing; Laming, 1968; Rabbitt, 1966) that has been traced back to a range of contributing mechanisms, such as orienting responses to unexpected events (Notebaert et al., 2009), sustained performance monitoring after error commission (Jentzsch & Dudschig, 2009), and increased response caution after erroneous responses (Rabbitt & Rodgers, 1977). On an electrophysiological level, own errors typically give rise to a distinct signature in the ERP with an initial negative-going peak (error negativity, N_E, or error-related negativity, ERN) being followed by a marked positivity (error positivity, P_E; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993; Renault, Ragot, & Lesevre, 1980). The N_E/ERN response is taken to reflect error detection and an assessment of error significance, as well as affective processes, whereas the P_E response is associated with more elaborate processing related to error awareness (Gehring, Liu, Orr, & Carp, 2012; Hajcak & Foti, 2008; Hajcak, Moser, Yeung, & Simons, 2005; Maier, Di Pellegrino, & Steinhauser, 2012; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005; Steinhauser & Yeung, 2010).

The processes that promote detection and monitoring of own errors are also recruited when people passively observe others committing errors. For instance, if two persons take turns at a task and one person commits an error, the other person's subsequent responding is slowed down and, just as for own errors, this observation-related post-error slowing (oPES) has been proposed to reflect orienting responses and sustained monitoring of the other's actions (De Bruijn, Mars, Bekkering, & Coles, 2012; Schuch & Tipper, 2007). This interpretation is supported by reports of N_E/ERN and PE responses for the passive observation of errors (oERN and oP_E, respectively; Bates, Patel, & Liddle, 2005; Carp, Halenar, Quandt, Sklar, & Compton, 2009; Koban, Pourtois, Vocat, & Vuilleumier, 2010; Miltner, Brauer, Hecht, Trippe, & Coles, 2004; van Schie, Mars, Coles, & Bekkering, 2004).

Studies on error observation thus have often concluded that observed errors are processed much like own errors (Miltner et al., 2004; Schuch & Tipper, 2007; van Schie et al., 2004). Even though this coarse assessment is backed up by empirical data, several studies have shown that the effects of error observation vary depending on the nature of the social situation. That is, whereas cooperative interactions gave rise to pronounced effects of post-error slowing after observed errors (oPES) and corresponding electrophysiological signatures (oERN, oP_E), these markers were absent or even reversed in competitive settings (Castellar, Notebaert, Van den Bossche, & Fias, 2011; De Bruijn, De Lange, Von Cramon, & Ullsperger, 2009; De Bruijn et al., 2012; Koban et al., 2010). These observations may be taken to suggest that monitoring of observed errors is specifically tuned to situations in which observed errors potentially yield negative consequences for the observer.

Commanded actions, such as the ones described in the introductory example, may be construed as the prime scenario in which observed errors are significant for the observer, since the goal of commanded actions, by definition, is to evoke a specific response from another person. Thus, observing errors of that other person indicates that own goals are not met.

Recent work on effect-based action control further suggests that people anticipate the behavior they evoke in others and that these anticipated consequences of social motor actions play an important role in planning, initiating, and monitoring of own actions (e.g., Flach, Press, Badets, & Heyes, 2010; Herwig & Horstmann, 2011; Kunde, Lozo, & Neumann, 2011; Müller, 2016; Pfister, Dignath, Hommel, & Kunde, 2013; for a review of such "sociomotor" action control, see Kunde, Weller, & Pfister, 2017). This research is inspired by ideomotor theory and assumes that own actions can be represented and retrieved by the observable behavior that these actions consistently evoke in others. Specifically, people acquire associative links between their own actions and the behavior of others that is consistently prompted by own actions. These acquired links can afterward be used for action control: Anticipating other people's behavior automatically activates those actions that have been linked to others' behavior by previous experience. In line with that assumption, recent studies found that actions are generated more quickly and more accurately when these actions are foreseeably being imitated rather than counterimitated by a partner (i.e., when participants know their actions will evoke the same rather than different actions in others; Müller, 2016; Pfister et al., 2013; Pfister, Weller, Dignath, & Kunde, 2017).

Another person's errors committed during commanded actions, thus, should be much more relevant compared to a situation where errors of another person are merely observed. Based on these considerations, we hypothesized that error processing should specifically be enhanced for commanded as compared to merely observed actions.

To approach this hypothesis, we had our participants command another agent to perform one of four key press responses. Participants received immediate feedback if these responses were correct or erroneous. We compared this condition to a condition in which participants passively observed correct or erroneous responses from the other agent. Participants could not see their partner's responses directly, but the responses were symbolized on the computer screen and participants were told that they would observe another person acting. In fact, the responses were controlled by the computer. This was done to parallelize both conditions with respect to the stimulation presented to the participants and overall error rates. Following the above considerations, we expected larger oPES in the command condition than in the observation condition. The hypothesized increase in oPES for the commanded condition may further be driven by increased error significance or increased monitoring of the other's behavior. We probed for these possible mechanisms in terms of the electrophysiological analyses, with the oERN targeting error significance (as suggested by results from studies on the standard ERN; Hajcak et al., 2005; Maier & Steinhauser, 2016) and

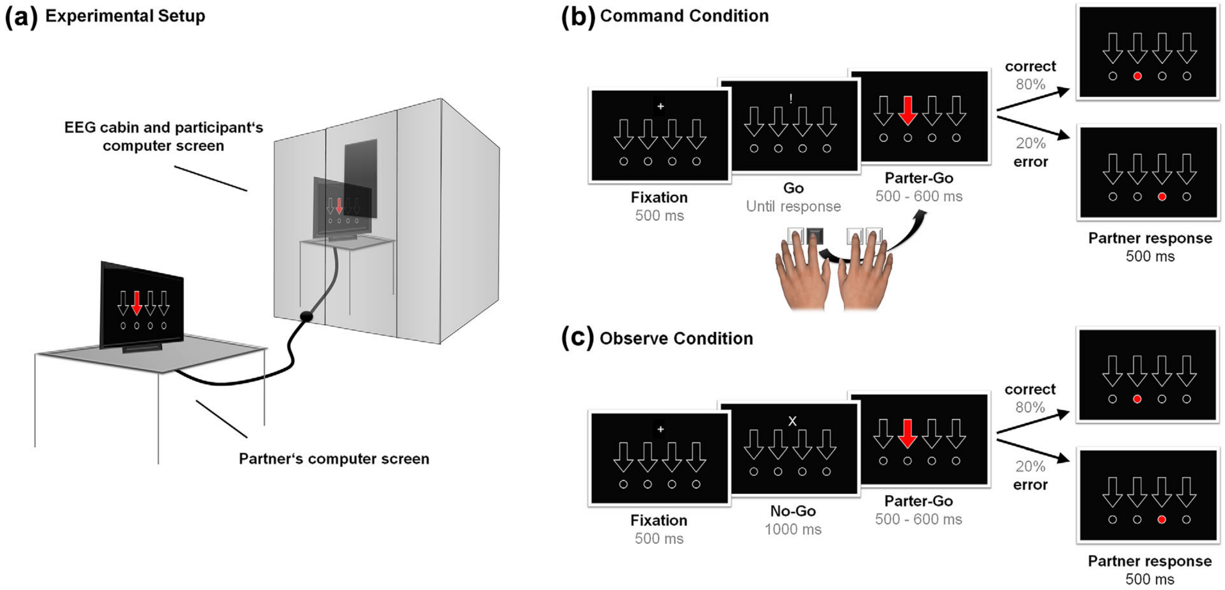

FIGURE 1 Setup and trial structure of the experiment. (a) Participants were led to believe that they interacted with the experimenter who operated a computer outside the EEG cabin. They received feedback about the experimenter's actions (one of four key presses) by small circles that lit up. Contrary to initial instructions, feedback about the partner's response was controlled by the computer program to parallelize both conditions for timing and overall error rate. Each trial started with a white fixation cross that was followed by either an exclamation mark, signaling the command condition (b) or by an X, signaling the observe condition (c). In the command condition, the exclamation mark prompted participants to choose one of four response keys. When a key was pressed, the corresponding arrow turned red. Shortly after, one of the four circles turned red, signaling the partner's response (timing jittered between 500 and 600 ms to mirror the partner's response times). Circle and arrow position corresponded in case of correct trials whereas one of the noncorresponding circles turned red in an error trial. In the observe condition, the participants were not allowed to press a key. After 1,000 ms following the X, one arrow automatically turned red. One of the four circles turned red after an interstimulus interval of 500 to 600 ms, signaling the partner's response. The intertrial interval was 1,000 ms for both conditions

the oP_E targeting monitoring through attention allocation (De Brujin, Schubotz, & Ullsperger, 2007).

2 | METHOD

2.1 | Participants

An a priori power analysis based on previous results of error observation suggested a sample size of 10 for a power of $1 - \beta = .80$ to detect oPES effects (Schuch & Tipper, 2007: $d_z = \frac{\sqrt{F}}{\sqrt{n}} = \frac{\sqrt{33.0}}{\sqrt{30}} = 1.04$), a sample size of 9 to detect an oERN (Bates et al., 2005: $d_z = \frac{t}{\sqrt{n}} = \frac{3.94}{\sqrt{12}} = 1.14$), and a sample size of 4 to detect an oP_E (De Brujin et al., 2007: $d_z = \frac{\sqrt{F}}{\sqrt{n}} = \frac{\sqrt{95.29}}{\sqrt{18}} = 2.30$). To allow for sufficient power to detect at least medium between-condition differences, we decided to increase these sample sizes and recruited 32 participants in total. This sample size further allowed us to compensate for potential drop-outs of participants who were skeptical as to whether they had indeed interacted with another person. Mean age was 26.5 years (range: 20–42), 11 participants were men and 21 were women. One participant was left-handed. All participants gave informed consent prior to the experiment and received either monetary compensation or course credit for participation.

2.2 | Stimuli, apparatus, and experimental setup

Participants sat in an electrically shielded chamber in front of a 17″ monitor and operated a standard German QWERTZ keyboard. The keys *S*, *D*, *K*, and *L* served as response keys, and participants used the index and middle finger of each hand to operate these keys. Throughout the experiment, white outlines of four downward-facing arrows (height: 6 cm, width: 4 cm) were presented in a horizontal row across the center of the display against a black background (see Figure 1). Below each arrowhead, a white framed circle (diameter: 1.5 cm) was presented. Outside the electrically shielded chamber was a second monitor mirroring the participant's monitor and a second keyboard that could be controlled by the experimenter.

EEG was recorded using a BrainVision QuickAmp amplifier with 32 active electrodes (actiCAP; Brain Products, Germany) positioned according to the International 10–20 system (FP1, FP2, F7, F3, Fz, F4, F8, FCz, FC1, FC2, AFz, T7, C3, Cz, C4, T8, TP9, CP1, CP2, TP10, P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, PO10), including left and right mastoids (M1, M2). The EEG signal was recorded using average reference with a sampling rate of 500 Hz, low-pass filtered at 100 Hz. Additional passive electrodes were placed above and below the left eye, as well as at the outer canthi of the eyes to record vertical and horizontal electrooculograms (EOGs) to control for eye movements. We aimed at keeping impedances of all electrodes below 10 kΩ.

2.3 | Experimental procedure

Participants received written instructions at the beginning of the experiment. They were told that they would work together with the experimenter throughout the experiment and that their responses would control the arrows on the screen, whereas the experimenter would control the circles. If a key was pressed by the participant, the corresponding arrow would be filled red (i.e., a key press with the left middle finger would fill the outer left arrow red) and likewise a key press by the experimenter would fill the corresponding circle. Participants were given ample time to acquaint themselves with how pressing a key would change the arrows' filling from black to red.

After the initial familiarization, the experimenter explained the actual trial structure, and participants completed a practice block of eight trials together with the experimenter. During that practice block, the experimenter sat in front of the second monitor outside the chamber, and the door of the chamber was left open so that participant and experimenter could see each other. At the beginning of each trial, the four arrows and the four circles were presented with a black filling, and a white plus sign was displayed above the arrows (see Figure 1). After 500 ms, one of two possible stimuli replaced the white cross. In the command condition, a white exclamation mark was presented for up to 2,000 ms, prompting the participant to press one of the four keys. Participants could freely decide which key to press, but were instructed to use all keys about equally often throughout the experiment. If participants pressed a key, the corresponding arrow turned red. In the observe condition, a white X was displayed instead of the exclamation mark, informing participants that they should not press a key. After 1,000 ms, a randomly chosen arrow was filled red (but within one block, each arrow was chosen equally often). Participants were told that the experimenter's task was to respond to a filled arrow by filling the corresponding circle, independently of whether the arrow had been controlled by the participant's key press or by the computer. Thus, in the practice block, a red arrow prompted the experimenter to press the corresponding key (i.e., if the outer left arrow was filled red, the experimenter responded with the left middle finger), and thus the corresponding circle was filled red. During the actual experiment, the door of the chamber was closed, so that participant and experimenter could not see or hear each other. Participants were informed that closing the door was necessary in order to shield the EEG from electrical noise.

To match both conditions in terms of response time and error frequency, we departed from the initial instructions, and the experimenter did not control the circles in the actual experiment. Instead, the circle was filled red automatically after a randomly chosen delay between 500 and 600 ms (uniformly distributed). In 80% of the trials, the circle corresponding to the arrow was filled red, simulating a correct trial of the experimenter. In 20% of the trials, a randomly chosen, noncorresponding circle was filled red, simulating an error of the experimenter (no error message was shown to equate visual stimulation across conditions). Whenever participants committed an error (i.e., responded in an observe trial, failed to respond in a command trial, or pressed a key any time after an arrow had already been filled red), an error message was displayed for 500 ms and the trial was aborted. The intertrial interval was 1,000 ms.

The experiment consisted of 10 blocks of 56 trials. Half of the trials in each block were command trials, and half were observe trials, randomly distributed across a block. Each trial had a one in five chance to be an error trial (randomly determined at the beginning of each trial), resulting in approximately 20% error trials. To ensure that participants attended to these errors, they were instructed to count all errors of the experimenter in one block (for a similar design, see Miltner et al., 2004). At the end of each block, participants reported the number of errors they had counted and received feedback. After the experiment, participants were debriefed, and it was noted whether participants had been skeptical of the social setting during the experiment.

2.4 | Data exclusions

Five participants mentioned in the debriefing that they did not believe the cover story and were therefore skeptical whether the experimenter had indeed controlled the circles. These participants were excluded from all analyses. Three additional participants were excluded due to technical malfunction of the EEG equipment, and two participants missed more than 10% of the errors in the counting tasks. The final sample thus comprised 22 participants.

2.5 | EEG processing

For the EEG analyses, we used MATLAB (Mathworks Inc.) and the MATLAB toolbox FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011). The EEG data were segmented into 2,000-ms epochs, using a prestimulus baseline of 100 ms. Electrodes T7 and T8 were discarded from the EEG analysis due to a technical malfunction of the EEG equipment. The EEG signal was offline rereferenced to the mastoids and filtered with a 47.5–52.5 Hz band-stop filter. Epochs contaminated with artifacts were excluded using the automatic artifact rejection function of FieldTrip based on z scores (with a threshold of $z = 20$). Data were then corrected for eye movements by performing an independent component analysis and rejecting all components that correlated with at least one EOG channel (threshold at $r \geq 0.4$). Afterward, data were refiltered with a 1–14 Hz band-pass filter for the oERN analysis (following van Schie et al., 2004), whereas we decreased the high-pass criterion and used a 0.1–14 Hz band-pass filter for analysis of the oP_E (following van Elk, Bousardt, Bekkering, & van Schie, 2012). ERPs were computed time-locked to the onset of the circle filling for each participant, action type (observed, commanded), and trial type (correct trials, error trials). To analyze oERN and oP_E, ERP data were averaged across trials for each participant, electrode, and condition. Because a strong oP_E response was also evident in the oERN-filtered data, we determined the peak latency of the oERN as the global minimum of the error-minus-correct difference wave (227 ms), and computed the corresponding mean amplitudes in a window of ± 50 ms around this time point. The oP_E was quantified as the mean amplitude in a similar window around the maximum of the error-minus-correct difference wave (381 ms ± 50 ms).

3 | RESULTS

3.1 | Manipulation check

Mean detection error (absolute difference of participants' error count and the real number of errors) was 0.62 ($SE = 0.13$). To ensure that partner error and partner correct trials did not differ in other relevant aspects except for the error of the partner itself, we compared the reaction times (RTs) of partner error and partner correct trials for the command condition (in which participants performed key presses). These RTs should not differ since the error was only committed after participants had pressed a key and this was confirmed by a two-tailed, paired t test, $t(21) = 0.35$, $p = .733$, $d = 0.07$. Furthermore, the response location (i.e., which key was pressed by the participant) also did not differ between partner error and partner correct trials, $t(21) = 0.53$, $p = .600$, $d = 0.11$. Additionally, because arrows and circles were presented horizontally and the location of erroneous colored circles was chosen randomly in each error trial, we examined whether the laterality of visual stimulation (i.e., the position of the red colored circle) was comparable in the observe condition and the command condition. Two-tailed, paired t tests confirmed that the conditions did not differ with regard to the location of the red colored circle, $t(21) = 0.24$, $p = .816$, $d = 0.05$, and with regard to the distance of the erroneously red colored circle and the correct response, $t(21) = 1.02$, $p = .317$, $d = 0.22$.[1]

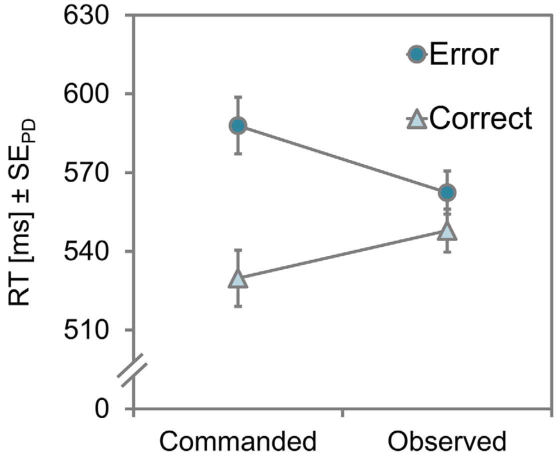

FIGURE 2 Reaction times (RTs) following correct partner trials and erroneous partner trials for each action type of the preceding trial (commanded vs. observed). Error bars indicate standard errors of paired differences (SE_{PD}; Pfister & Janczyk, 2013) for each comparison of trials following partner's errors and trials following partner correct trials

3.2 | Observation-related post-error slowing (oPES)

For RT analysis, only trials of the commanded condition could be analyzed as participants were asked not to respond in observe trials. Figure 2 shows the mean RTs following partner correct and partner error trials. All trials with errors of the participants and trials following these error trials (2.1%) were excluded from RT analysis, as well as all trials deviating more than 2.5 standard deviations from the cell mean (2.6%). Participant's RTs in the command condition were subjected to a 2 × 2 repeated measures analysis of variance (ANOVA) with the factors partner accuracy in the previous trial (error vs. correct) and action type in the previous trial (command vs. observe).

The results showed a strong effect of partner accuracy with slower responding after partner errors as compared to partner correct responses, $F(1, 21) = 19.57$, $p < .001$, $\eta_p^2 = .48$. There was no main effect of action type, $F(1, 21) = 0.17$, $p = .688$, $\eta_p^2 = .01$, but a significant interaction of partner accuracy and action type, $F(1, 21) = 20.30$, $p < .001$, $\eta_p^2 = .49$. Two-tailed, paired t tests revealed that this interaction was mainly driven by significant oPES for trials following command trials ($M_\text{correct} = 530$ ms, $SE = 23.7$, $M_\text{error} = 588$ ms, $SE = 26.3$), $t(21) = 5.42$, $p < .001$, $d = 1.16$, but smaller and only marginally significant oPES for trials following observe trials ($M_\text{correct} = 548$ ms, $SE = 25.1$, $M_\text{error} = 562$ ms, $SE = 26.7$), $t(21) = 1.77$, $p = .091$, $d = 0.38$.

3.3 | Observed-error-related negativity (oERN)

Figure 3 shows the grand-averaged ERP responses of the oERN-filtered data. Mean ERP amplitudes in the oERN time

---

[1] To further address whether unsystematic differences in lateral stimulation might have affected the data, we confirmed that the results of the EEG analysis were replicated when matching correct and error trials for lateral positions by selecting only the temporally closest correct trial with the same red-colored circle for each error trial.

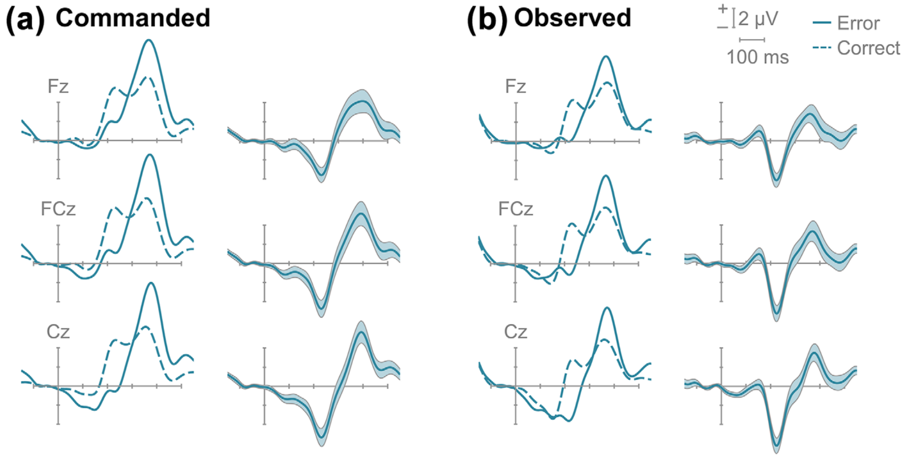

FIGURE 3 Grand-averaged ERP waveforms for commanded (a) and observed (b) partner actions for the oERN analysis and corresponding difference waves ± one standard error (shaded area)

window were subjected to a 2 × 2 × 3 repeated measures ANOVA with the factors partner accuracy (error vs. correct), action type (command vs. observe), and electrode (Fz vs. FCz vs. Cz). We report Greenhouse-Geisser corrected *p* values whenever the sphericity assumption was violated, accompanied by the corresponding ε estimate for correcting the degrees of freedom.

The results yielded robust oERNs as suggested by a main effect of partner accuracy, $F(1, 21) = 51.77$, $p < .001$, $\eta_p^2 = .71$. This effect did not interact with action type, $F(1, 21) = 0.02$, $p = .887$, $\eta_p^2 = .00$, nor was the three-way interaction significant, $F(2, 42) = 0.41$, $p = .587$, $\eta_p^2 = .02$ ($\varepsilon = .68$). A significant main effect of electrode, $F(2, 42) = 40.58$, $p < .001$, $\eta_p^2 = .66$ ($\varepsilon = .73$), and a significant interaction of electrode and partner accuracy, $F(2, 42) = 24.86$, $p < .001$, $\eta_p^2 = .54$ ($\varepsilon = .65$), further indicated oERN responses to increase from Fz over FCz to Cz. Finally, a significant main effect of action type, $F(1, 21) = 17.53$, $p < .001$, $\eta_p^2 = .45$, was driven by overall larger amplitudes for commanded actions than for observed actions, and this difference increased from Fz over FCz to Cz, as indicated by an interaction of electrode and action type, $F(2, 42) = 6.50$, $p = .013$, $\eta_p^2 = .24$ ($\varepsilon = .61$). Detailed descriptive statistics are provided in Table A1 in the Appendix.

To follow up on these results, we further computed the effect of partner accuracy (error − correct) for each action type and electrode. Significant oERN responses were obtained across all conditions as shown in Figure 4, $ts > 4.63$, $ps < .001$, $ds > .98$, whereas pairwise comparisons of oERN amplitudes between commanded versus observed actions were not significant for any electrode, $|t|s < 3.10$, $ps > .759$, $|d|s < 0.07$.

3.4 | Observed-error positivity (oP$_E$)

Figure 5 shows the grand-averaged ERP responses in the oP$_E$-filtered data. Mean ERP amplitudes in the oP$_E$ time window were subjected to a 2 × 2 × 3 repeated measures ANOVA with the factors partner accuracy (error vs. correct), action type (command vs. observe), and electrode (Fz vs. Cz vs. Pz).

The results yielded robust oP$_E$ effects as suggested by larger amplitudes after erroneous as compared to correct partner responses, $F(1, 21) = 40.25$, $p < .001$, $\eta_p^2 = .66$. In contrast to the oERN analysis, oP$_E$ effects were larger for commanded actions than for observed ones as indicated by an interaction of partner accuracy and action type, $F(1, 21) = 8.58$, $p = .008$, $\eta_p^2 = .29$. This applied to all electrodes as suggested by a nonsignificant three-way interaction, $F(2, 42) = 0.12$, $p = .801$, $\eta_p^2 = .01$ ($\varepsilon = .66$). Interestingly, mean amplitudes were higher over Fz and Cz as compared to Pz, $F(2, 42) = 5.67$, $p = .013$, $\eta_p^2 = .21$ ($\varepsilon = .77$), whereas the effects of partner accuracy were especially pronounced over Cz and Pz as compared to Fz as indicated by an interaction of electrode and partner accuracy, $F(2, 42) = 5.80$, $p = .015$, $\eta_p^2 = .22$ ($\varepsilon = .68$). A significant main effect of action type, $F(1, 21) = 17.74$, $p < .001$, $\eta_p^2 = .46$, was again

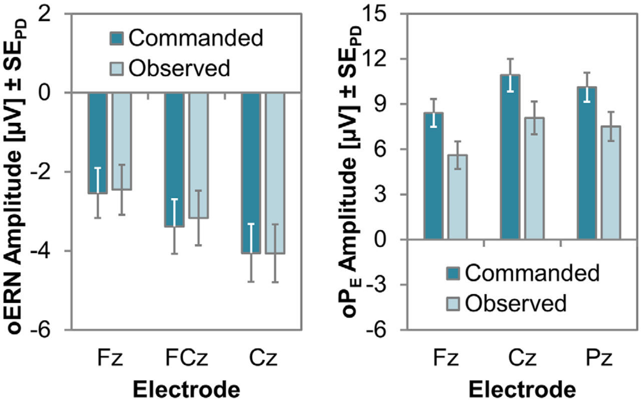

FIGURE 4 Mean amplitudes for the oERN (left) and oP$_E$ (right) for each action type (commanded vs. observed) and each relevant electrode. Error bars indicate standard errors of paired differences (SE$_{PD}$; Pfister & Janczyk, 2013) for each comparison of commanded and observed actions

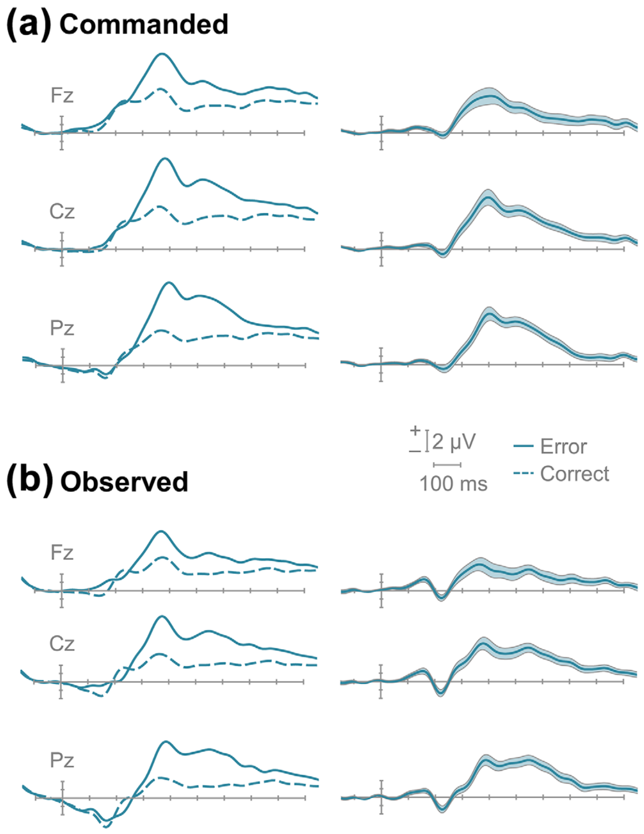

FIGURE 5 Grand-averaged ERP waveforms for commanded (a) and observed (b) partner actions for the oP_E analysis and corresponding difference waves ± one standard error (shaded area)

driven by overall larger amplitudes for commanded actions than for observed actions, and this difference increased descriptively from Fz over Cz to Pz, though the interaction of electrode and action type was not significant, $F(2, 42) = 2.93$, $p = .091$, $\eta_p^2 = .12$ ($\varepsilon = .63$). Detailed descriptive statistics are provided in Table A2 in the Appendix.

As for the oERN analysis, we followed up on these results by computing the effect of partner accuracy (error − correct) for each action type and electrode. Significant oP_E responses were obtained across all conditions as shown in Figure 4, $ts > 3.65$, $ps < .001$, $ds > .77$, and pairwise comparisons of oP_E amplitudes now indicated significant differences between commanded and observed actions for all electrodes, $ts > 2.63$, $ps < .016$, $ds > 0.56$.

4 | DISCUSSION

In this experiment, we investigated error processing for commanded actions. Participants were told that they commanded another agent to perform one of four key press responses, and their partner could either respond correctly to this command or commit an error. We compared behavioral and electrophysiological markers of error processing for such commanded actions with a control condition in which participants merely observed this agent responding correctly or erroneously.

We found evidence for error processing in both commanded and observed actions and, critically, these processes were more pronounced for commanded actions than for merely observed ones. This was suggested by stronger oPES and a larger oP_E for commanded errors. The oERN, however, did not differ between commanded and observed errors. Taking results from studies on the processing of own errors into account (Hajcak et al., 2005; Maier & Steinhauser, 2016), it thus seems that errors during commanded and observed actions were detected and assessed similarly quickly and efficiently, as suggested by similar oERN responses, whereas pronounced differences regarding both action types only emerged on a larger timescale, as suggested by the enhanced oP_E response. Previous studies suggest that the (o)P_E is related to explicit error awareness and subsequent attentional processing (De Brujin et al., 2007; Murphy, Robertson, Allen, Hester, & O'Connell, 2012; Steinhauser & Yeung, 2010). A stronger oP_E for commanded errors thus may signify that commanded actions specifically lead to an increase in error monitoring compared to merely observed actions.

In contrast to other studies (De Bruijn et al., 2012; Schuch & Tipper, 2007), we did not find significant oPES for observed actions in our study, even though the results showed a descriptive trend toward oPES. However, electrophysiological markers clearly indicate that participants processed the agent's errors even when they merely observed the agent. Thus, the present results may reflect a Type II error. In contrast to earlier studies on oPES, in the observe condition of the present experiment, the agent's task was less relevant to the participants because they never completed the same task as the agent, whereas in other studies on oPES in observed errors participants took turns with the agent at the same task or a similar task (Castellar et al., 2011; De Bruijn et al., 2012; Schuch & Tipper, 2007). This may have reduced oPES in the present study.

It should be noted that the partner's errors in the present experiment were not particularly disadvantageous for the participants, neither for commanded nor for observed actions. Participants were further unable to intercept and remedy what their partner had done wrong. Despite these constraints, it seems as though the behavior of other agents is represented more strongly when it is brought about by own commands rather than without own involvement. It is further conceivable that this difference increases in more naturalistic settings in which the outcome of a commanded action typically comprises some kind of reward (in the bakery example from earlier, for instance, getting the bread roll you desire), rendering a commanded error even more significant. As it has been proposed that the ERN reflects an evaluation of error significance (Hajcak et al., 2005; Maier & Steinhauser, 2016;

Maier et al., 2012), differences in the oERN between commanded and observed actions might therefore occur when error significance differs between these situations. Even though we did not measure the standard ERN following own errors in the present experiment, previous research suggests a close relation between the oERN and the standard ERN. Although the oERN peaked later than the standard ERN (De Bruijn & von Rhein, 2012; Miltner et al., 2004; van Schie et al., 2004; but see Bates et al., 2005), the spatial distribution did not differ and both components could be explained by a common source (Bates et al., 2005; Miltner et al., 2004; van Schie et al., 2004). Whether a manipulation of error significance would further align the oERN following commanded actions with the standard ERN, however, remains to be tested.[2]

Irrespective of error significance, it is further conceivable that error observation for commanded actions prompts the observer to engage in error correction behavior. Spontaneous post-error tendencies to correct once failures have been documented in terms of post-error speeding when participants were allowed to correct their responses (Crump & Logan, 2013; Rabbitt & Rodgers, 1977), and investigating such tendencies for commanded or observed errors of equal significance might be a promising avenue for future research. Furthermore, there are different reasons why an action is not carried out as commanded, and error correction behavior of the observer might differ depending on why an error occurred (from the observer's perspective). For instance, as in the bakery example, the agent may misunderstand the request of the commanding person. Then, the agent performs an action which he or she believes to be correct, but for the commanding person it will be an error. This can, for instance, occur when people rely solely on pointing gestures to communicate an action goal. As people often use different mechanisms to produce and to interpret pointing gestures, this introduces a misunderstanding of each other's pointing gestures when no supporting language is used or stimuli are not salient (Herbort & Kunde, 2016a,b). In this case, the commanding person would have to correct the error by communicating his or her action goal more properly. On the other hand, commanding person and agent may target the same action goal, but the agent may simply fail to execute an action properly (i.e., a slip or lapse according to Reason, 1990). In this instance, the commanding person would not necessarily have to engage in error correction behavior or may simply remind the agent to act more carefully.

Another possible reason for why an action may not be carried out as commanded is that the other person deliberately decides to take a different course of action. Such rule violations have recently been shown to affect cognitive processing in that they incur cognitive conflict for the rule-violating agent (Pfister, Wirth, Schwarz, Steinhauser, & Kunde, 2016; Pfister, Wirth, Schwarz, Foerster et al., 2016; Wirth, Pfister, Foerster, Huestegge, & Kunde, 2016), and attributing an unexpected partner response to a rule violation may similarly affect cognitive processing of the observer (Bolling et al., 2011; Fehr & Fischbacher, 2004; Reese, Steffens, & Jonas, 2013).

To conclude, our results indicate that, when we ask someone to carry out actions for us, errors of that person trigger similar processes as our own errors do. Furthermore, error processing is increased compared to the passive observation of errors, suggesting that we closely monitor these commanded errors. Such monitoring was evident even though participants could not remedy their partner's errors and neither could they affect the partner's future responses in any way, suggesting that the enhanced monitoring is an automatic by-product of commanding an action.

REFERENCES

Bates, A. T., Patel, T. P., & Liddle, P. F. (2005). External behavior monitoring mirrors internal behavior monitoring: Error-related negativity for observed errors. *Journal of Psychophysiology*, *19*(4), 281–288. https://doi.org/10.1027/0269-8803.19.4.281

Bolling, D. Z., Pitskel, N. B., Deen, B., Crowley, M. J., McPartland, J. C., Mayes, L. C., & Pelphrey, K. A. (2011). Dissociable brain mechanisms for processing social exclusion and rule violation. *NeuroImage*, *54*, 2426–2471. https://doi.org/10.1016/j.neuroimage.2010.10.049

Carp, J., Halenar, M. J., Quandt, L. C., Sklar, A., & Compton, R. J. (2009). Perceived similarity and neural mirroring: Evidence from vicarious error processing. *Social Neuroscience*, *4*(1), 85–96. https://doi.org/10.1080/17470910802083167

Castellar, N. E., Notebaert, W., Van den Bossche, L. & Fias, W. (2011). How monitoring other's actions influences one's own performance: Post-error adjustments are influenced by the nature of the social interaction. *Experimental Psychology*, *58*(6), 499–508. https://doi.org/10.1027/1618-3169/a000118

Crump, M. J., & Logan, G. D. (2013). Prevention and correction in post-error performance: An ounce of prevention, a pound of cure.

---

[2] Further open questions relate to interindividual differences regarding the oERN. The standard ERN has been shown to differ with regard to a range of trait variables such as anxiety (Hajcak, McDonald, & Simons, 2003) and obsessive-compulsive dispositions (Hajcak & Simons, 2002). Interindividual differences on such traits may reflect differences in general defensive reactivity (Weinberg, Riesel, & Hajcak, 2012), a trait that may also come to bear in the context of commanded actions. Moreover, the oERN for commanded actions may be sensitive to how individuals approach situations in which they have the power to command. Individual tendencies to "objectify" subordinates in this situation seem especially relevant in this regard (Gruenfeld, Inesi, Magee, & Galinsky, 2008). Objectification has been shown to affect memory for commanded actions with high objectification scores predicting that the commanding person will falsely remember an action as having been performed by him or herself (Pfister, Schwarz, Wirth, & Lindner, 2017); whether a similar moderating role also exists for the oERN remains to be studied.

Journal of Experimental Psychology: General, *142*(3), 692–709. https://doi.org/10.1037/a0030014

De Bruijn, E. R. A., De Lange, F. P., Von Cramon, D. Y., & Ullsperger, M. (2009). When errors are rewarding. *Journal of Neuroscience*, *29*(39), 12183–12186. https://doi.org/10.1523/JNEUROSCI.1751-09.2009

De Bruijn, E. R. A., Mars, R. B., Bekkering, H., & Coles, M. G. H. (2012). Your mistake is my mistake … or is it? Behavioural adjustments following own and observed actions in cooperative and competitive contexts. *Quarterly Journal of Experimental Psychology*, *65* (2), 317–325. https://doi.org/10.1080/17470218.2010.545133

De Brujin, E. R. A., Schubotz, R. I., & Ullsperger, M. (2007). An event-related potential study on the observation of erroneous everyday actions. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 278–285. https://doi.org/10.3758/CABN.7.4.278

De Brujin, E. R. A., & von Rhein, D. T. (2012): Is your error my concern? An event-related potential study on own and observed error detection in cooperation and competition. *Frontiers in Neuroscience*, *6*. https://doi.org/10.3389/fnins.2012.00008

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1990). Effects of errors in choice reaction tasks on the ERP under focused and divided attention. In C. H. M. Brunia, A. W. K. Gaillard, & A. Kok (Eds.), *Psychophysiological brain research* (Vol. *1*, pp. 192–195). Tilburg, The Netherlands: Tilburg University Press.

Flach, R., Press, C., Badets, A., & Heyes, C. (2010). Shaking hands: Priming by social action effects. *British Journal of Psychology*, *101*(4), 739–749. https://doi.org/10.1348/000712609X484595

Fehr, E., & Fischbacher, U. (2004). Third-party punishment and social norms. *Evolution and Human Behavior*, *25*(2), 63–87. https://doi.org/10.1016/S1090-5138(04)00005-4

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science*, *4*(6), 385–390. https://doi.org/10.1111/j.1467-9280.1993.tb00586.x

Gehring, W. J., Liu, Y., Orr, J. M., & Carp, J. (2012). The error-related negativity (ERN/Ne). In S. J. Luck & E. Kappenman (Eds.), *Oxford handbook of event-related potential components* (pp. 231–291). New York, NY: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374148.013.0120

Gruenfeld, D. H., Inesi, M. E., Magee, J. C., & Galinsky, A. D. (2008). Power and the objectification of social targets. *Journal of Personality and Social Psychology*, *95*(1), 111–127. https://doi.org/10.1037/0022-3514.95.1.111

Hajcak, G., & Foti, D. (2008). Errors are aversive: Defensive motivation and the error-related negativity. *Psychological Science*, *19*(2), 103–108. https://doi.org/10.1111/j.1467-9280.2008. 02053.x

Hajcak, G., McDonald, N., & Simons, R. (2003). Anxiety and error-related brain activity. *Biological Psychology*, *64*(1–2), 77–90. https://doi.org/10.1016/S0301-0511(03)00103-0

Hajcak, G., Moser, J. S., Yeung, N., & Simons, R. F. (2005). On the ERN and the significance of errors. *Psychophysiology*, *42*(2), 151–160. https://doi.org/10.1111/j.1469-8986.2005.00270.x

Hajcak, G., & Simons, R. (2002). Error-related brain activity in obsessive-compulsive undergraduates. *Psychiatry Research*, *110* (1), 63–72. https://doi.org/10.1016/S0165-1781(02) 00034-3

Herbort, O., & Kunde, W. (2016a). How to point and to interpret pointing gestures? Instructions can reduce pointer–observer misunderstandings. *Psychological Research*, 1–12. https://doi.org/10.1007/s00426-016-0824-8

Herbort, O., & Kunde, W. (2016b). Spatial (mis-)interpretation of pointing gestures to distal referents. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(1), 78. https://doi.org/10.1037/xhp0000126

Herwig, A., & Horstmann, G. (2011). Action–effect associations revealed by eye movements. *Psychonomic Bulletin & Review*, *18* (3), 531–537. https://doi.org/10.3758/s13423-011-0063-3

Jentzsch, I., & Dudschig, C. (2009). Why do we slow down after an error? Mechanisms underlying the effects of posterror slowing. *Quarterly Journal of Experimental Psychology*, *62*(2), 209–218. https://doi.org/10.1080/17470210802240655

Koban, L., Pourtois, G., Vocat, R. & Vuilleumier, P. (2010). When your errors make me lose or win: Event-related potentials to observed errors of cooperators and competitors. *Social Neuroscience*, *5*(4), 360–374. https://doi.org/10.1080/17470911003651547

Kunde, W., Lozo, L., & Neumann, R. (2011). Effect-based control of facial expressions: Evidence from action–effect compatibility. *Psychonomic Bulletin & Review*, *18*(4), 820–826. https://doi.org/10.3758/s13423-011-0093-x

Kunde, W., Weller, L., & Pfister, R. (2017). Sociomotor action control. *Psychonomic Bulletin & Review*. Advance online publication. https://doi.org/10.3758/s13423-017-1316-6

Laming, D. R. J. (1968). *Information theory of choice reaction times*. London, UK: Academic Press.

Maier, M. E., Di Pellegrino, G., & Steinhauser, M. (2012). Enhanced error-related negativity on flanker errors: Error expectancy or error significance? *Psychophysiology*, *49*(7), 899–908. https://doi.org/10.1111/j.1469-8986.2012.01373.x

Maier, M. E., & Steinhauser, M. (2016). Error significance but not error expectancy predicts error-related negativities for different error types. *Behavioural Brain Research*, *297*, 259–267. https://doi.org/10.1016/j.bbr.2015.10.031

Miltner, W. H. R., Brauer, J., Hecht, H., Trippe, R., & Coles, M. G. H. (2004). Parallel brain activity for self-generated and observed errors. In M. Ullsperger & M. Falkenstein (Eds.), *Errors, conflicts, and the brain: Current opinions on performance monitoring* (pp. 124–129). Leipzig, Germany: MPI of Human Cognitive and Brain Sciences.

Müller, R. (2016). Does the anticipation of compatible partner reactions facilitate action planning in joint tasks? *Psychological Research*, *80*(4), 464–486. https://doi.org/10.1007/s00426-015-0670-0

Murphy, P. R., Robertson, I. H., Allen, D., Hester, R., & O'Connell, R. G. (2012). An electrophysiological signal that precisely tracks the emergence of error awareness. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00065

Notebaert, W., Houtman, F., Van Opstal, F., Gevers, W., Fias, W., & Verguts, T. (2009). Post-error slowing: An orienting account. *Cognition*, *111*(2), 275–279. https://doi.org/10.1016/j.cognition.2009.02.002

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, *2011*, 1. https://doi.org/10.1155/2011/156869

Overbeek, T. J., Nieuwenhuis, S., & Ridderinkhof, K. R. (2005). Dissociable components of error processing: On the functional significance of the Pe vis-à-vis the ERN/Ne. *Journal of Psychophysiology*, *19*(4), 319–329. https://doi.org/10.1027/0269-8803.19.4.319

Pfister, R., Dignath, D., Hommel, B., & Kunde, W. (2013). It takes two to imitate anticipation and imitation in social interaction. *Psychological Science*, *24*(10), 2117–2121. https://doi.org/10.1177/0956797613489139

Pfister, R., & Janczyk, M. (2013). Confidence intervals for two sample means: Calculation, interpretation, and a few simple rules. *Advances in Cognitive Psychology*, *9*(2), 74–80. https://doi.org/10.2478/v10053-008-0133-x

Pfister, R., Schwarz, K. A., Wirth, R., & Lindner, I. (2017). My command, my act: Observation inflation in face-to-face interactions. *Advances in Cognitive Psychology*, *13*(2), 166–176. https://doi.org/10.5709/acp-0217-8

Pfister, R., Weller, L., Dignath, D., & Kunde, W. (2017). What or when? The impact of anticipated social action effects is driven by action-effect compatibility, not delay. *Attention, Perception and Psychophysics*, *79*(7), 2132–2142. https://doi.org/10.3758/s13414-017-1371-0

Pfister, R., Wirth, R., Schwarz, K., Steinhauser, M., & Kunde, W. (2016). Burdens of non-conformity: Motor execution reveals cognitive conflict during deliberate rule violations. *Cognition*, *147*, 93–99. https://doi.org/10.1016/j.cognition.2015.11.009

Pfister, R., Wirth, R., Schwarz, K. A., Foerster, A., Steinhauser, M. & Kunde, W. (2016). The electrophysiological signature of deliberate rule violations. *Psychophysiology*, *53*(12), 1870–1877. https://doi.org/10.1111/psyp.12771

Rabbitt, P. (1966). Errors and error correction in choice-response tasks. *Journal of Experimental Psychology*, *71*(2), 264–272. https://doi.org/10.1037/h0022853

Rabbitt, P., & Rodgers, B. (1977). What does a man do after he makes an error? An analysis of response programming. *Quarterly Journal of Experimental Psychology*, *29*, 727–743. https://doi.org/10.1080/14640747708400645

Reason, J. (1990). *Human error*. New York, NY: Cambridge University Press.

Reese, G., Steffens, M. C., & Jonas, K. J. (2013). When black sheep make us think: Information processing and devaluation of in- and outgroup norm deviants. *Social Cognition*, *31*(4), 482–503. https://doi.org/10.1521/soco_2012_1005

Renault, B., Ragot, R., & Lesevre, N. (1980). Correct and incorrect responses in a choice reaction time task and the endogenous components of the evoked potential. *Progress in Brain Research*, *54*, 547–554. https://doi.org/10.1016/S0079-6123(08)61685-4

Schuch, S., & Tipper, S. P. (2007). On observing another person's actions: Influences of observed inhibition errors. *Perception & Psychophysics*, *69*(5), 828–837. https://doi.org/10.3758/BF03193782

Steinhauser, M., & Yeung, N. (2010). Decision processes in human performance monitoring. *Journal of Neuroscience*, *30* (46), 15643–15653. https://doi.org/10.1523/JNEUROSCI.1899-10.2010

van Elk, M., Bousardt, R., Bekkering, H., & van Schie, H. T. (2012). Using goal- and grip-related information for understanding the correctness of other's actions: An ERP study. *PLOS One*, *7*(5), e36450. https://doi.org/10.1371/journal.pone.0036450

van Schie, H. T., Mars, R. B., Coles, M. G., & Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience*, *7*(5), 549–554. https://doi.org/10.1038/nn1239

Weinberg, A., Riesel, A., & Hajcak, G. (2012). Integrating multiple perspectives on error-related brain activity: The ERN as a neural indicator of trait defensive reactivity. *Motivation and Emotion*, *36* (1), 84–100. https://doi.org/10.1007/s11031-011-9269-y

Wirth, R., Pfister, R., Foerster, A., Huestegge, L., & Kunde, W. (2016). Pushing the rules: Effects and aftereffects of deliberate rule violations. *Psychological Research*, *80*(5), 838–852. https://doi.org/10.1007/s00426-015-0690-9

How to cite this article: Weller L, Schwarz KA, Kunde W, Pfister R. My mistake? Enhanced error processing for commanded compared to passively observed actions. *Psychophysiology*. 2018;55:e13057. https://doi.org/10.1111/psyp.13057

APPENDIX

TABLE A1 Mean ERP amplitudes (standard errors) in the oERN time window

	Commanded			Observed		
Partner accuracy	**Fz**	**FCz**	**Cz**	**Fz**	**FCz**	**Cz**
Error	2.12 (0.70)	1.56 (0.78)	−0.18 (0.85)	0.83 (0.70)	−0.11 (0.71)	−2.44 (0.77)
Correct	4.66 (0.47)	4.94 (0.58)	3.88 (0.68)	3.28 (0.62)	3.06 (0.62)	1.62 (0.61)
oERN	−2.53 (0.54)	−3.38 (0.64)	−4.06 (0.65)	−2.45 (0.53)	−3.17 (0.56)	−4.06 (0.57)

Note. Individual oERN amplitudes were computed as the difference error minus correct.

TABLE A2 Mean ERP amplitudes (standard errors) in the oP_E time window

	Commanded			Observed		
Partner accuracy	**Fz**	**Cz**	**Pz**	**Fz**	**Cz**	**Pz**
Error	17.71 (1.48)	19.97 (1.68)	17.86 (1.61)	12.76 (0.79)	14.03 (1.01)	11.92 (1.05)
Correct	9.29 (1.04)	9.06 (0.99)	7.75 (0.87)	7.14 (1.61)	5.95 (1.20)	4.40 (1.04)
oP_E	8.41 (1.80)	10.91 (1.62)	10.11 (1.41)	5.61 (1.54)	8.08 (1.32)	7.53 (1.15)

Note. Individual oP_E amplitudes were computed as the difference error minus correct.