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It's not just my fault: Neural correlates of feedback processing in solo and joint action

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ABSTRACT

People often coordinate their actions with others' in pursuit of shared goals, yet little research has examined the neural processes by which people monitor whether shared goals have been achieved. The current study compared event-related potentials elicited by feedback indicating joint errors (resulting from two people's coordinated actions) and individual errors (resulting from one's own or another person's observed actions). Joint errors elicited a reduced feedback-related negativity (FRN) and P3a relative to own errors, and an enhanced FRN relative to observed errors. In contrast, P3b amplitudes did not differ between joint and individual errors. These findings indicate that producing errors together with a partner influences neural activity related to outcome evaluation but has less impact on activity related to the motivation to adapt future behaviour.

Efficient and flexible behaviour often requires that people monitor the outcomes of their actions to determine whether their goals have been achieved. Research investigating the cognitive and neural mechanisms underlying action monitoring (see Ullsperger, Danielmeier, & Jocham, 2014a, for a review) has focused predominantly on how people monitor *individual* action outcomes, i.e., outcomes of a single person's actions. However, humans are highly social beings; a significant portion of our behavioural repertoire is obtained through social interactions that require sensitivity to the outcome of both our own and others' actions. Recent studies have begun to unravel the impact of social context on action monitoring, typically by examining how people process *observed* individual outcomes in tasks that require them to monitor their own and another person's performance on successive trials (Koban & Pourtois, 2014). Little research has examined action monitoring in social contexts that require people to actively coordinate their actions with each other in pursuit of a *joint* action outcome (e.g., scoring a goal in hockey as a result of multiple players passing the puck back and forth; see Sebanz, Bekkering, & Knoblich, 2006). Joint outcomes present a challenge for the action monitoring system, as each person involved has only partial control over the outcome despite actively adapting their own actions to other people's. Furthermore, joint outcomes often take the form of external feedback that provides information about the joint performance as a whole and is available only at the end of the entire shared action sequence. Nevertheless, people are typically able to identify errors that have been committed, attribute them to a single person or to the group as a whole, and adapt their future behaviour accordingly.

Researchers have identified several event-related potential (ERP) components associated with evaluating individual action outcomes and adapting ongoing behaviour based on external feedback. The feedback-related negativity (FRN) is an anterior, negative-going ERP that peaks ~250 ms after feedback (Gehring & Willoughby, 2002; Miltner, Braun, & Coles, 1997). FRN amplitudes are larger following negative feedback indicating an unfavourable outcome (e.g., an error) compared to positive feedback (Walsh & Anderson, 2012). The FRN is thought to reflect an initial evaluation of the outcome as better or worse than expected (Nieuwenhuis, Holroyd, Mol, & Coles, 2004) or as simply unexpected (Ullsperger, Fischer, Nigbur, & Endrass, 2014b). The FRN is often followed by a P3, a positive-going potential with two sub-components: an earlier, anterior P3a and a later, posterior P3b. The P3a is thought to reflect an orienting response related to the initial evaluation of stimuli as task-relevant (Polich, 2007). The P3b is thought to reflect internal

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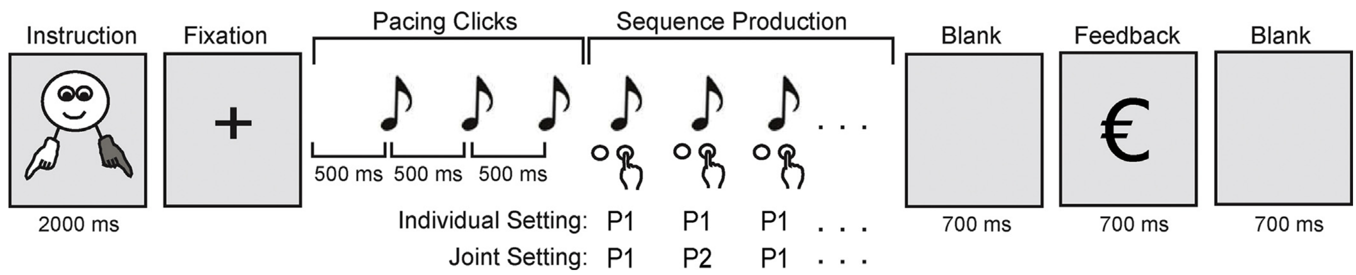

Fig. 1. Schematic illustration of the sequence production task in the individual and joint settings. Following instructions and fixation, participants heard a series of isochronous pacing clicks (illustrated by eighth note symbols) and then produced a sequence of tones (illustrated by combined button press and eighth note symbols, labelled P1 and P2 for Participants 1 and 2, respectively). After producing the last tone, participants received feedback indicating whether the sequence they produced matched the pace set by the isochronous clicks.

decision-making processes that facilitate appropriate behavioural responses to task-relevant stimuli (Nieuwenhuis, Aston-Jones, & Cohen, 2005).

Given the ubiquity of joint actions in everyday life and the need to establish healthy brain functioning during social interactions to better understand social disorders such as psychopathy (Brazil et al., 2011; de Bruijn, 2012), it is critical to examine how the neural mechanisms underlying action monitoring are modulated by the social context in which actions are performed. The current study compared ERPs elicited by jointly committed errors to ERPs elicited by individual errors committed by oneself or another person. We predicted that joint errors would elicit reduced ERP amplitudes relative to one's own errors but enhanced ERP amplitudes relative to another person's errors, based on previous work showing that reduced control over action outcomes reduces both FRN and P3 amplitudes (e.g., Li, Han, Lei, Holroyd, & Li, 2011; Li et al., 2010; Yeung, Holroyd, & Cohen, 2005) and that observing errors elicits reduced FRN amplitudes compared to producing them (e.g., Bellebaum, Kobza, Thiele, & Daum, 2010; Yu & Zhou, 2006).

1. Method

1.1. Participants

Twenty two adults (8 male, 4 left-handed, mean age = 24.23, SD = 3.12) participated in the study. Participants were recruited in pairs without regard for specific gender combinations. Of the 11 pairs, 4 pairs consisted of two females, 1 pair consisted of two males, and 6 pairs were mixed-gender. All participants provided written informed consent according to procedures reviewed by the medical ethics committee at Radboud University Nijmegen. Participants were compensated with €30 for their participation.

1.2. Design and procedure

In order to compare ERPs elicited by individual vs. jointly committed errors, we employed a sequence production task that could be performed either alone or in coordination with a partner. Specifically, participants were asked to produce sequences of 4 or 6 tones that matched the pace set by an initial series of isochronous clicks (see Fig. 1). Participants produced the tone sequences in two settings: individual and joint. In the individual setting, each member of the pair produced the tone sequences alone while the other member of the pair sat quietly beside them. Each sequence in the individual setting therefore elicited ERP responses to *own* action outcomes for the participant who produced the tone sequences, and to *observed* action outcomes for the participant who observed the other person produce the tone sequences. In the joint setting, the two participants alternated button presses so as to produce the tone sequences together. Sequences produced in the joint setting elicited ERP responses to *joint* action outcomes for both participants.

During the experiment, participants sat next to each other on the same side of a table. A computer screen was centered between them, approximately 80 cm from the edge of the table. Each participant had a Logitech Gamepad F310 game controller aligned with their right hand, approximately 20 cm from the edge of the table. The game controllers were modified to include pressure sensitive buttons (2 cm diameter) that registered presses without providing auditory feedback. Each button press triggered a 1000 Hz sinusoidal tone (100 ms duration; 20 ms rise/fall time; sound pressure level 70 dB). The initial series of isochronous clicks was produced in a snare drum timbre. Tones and clicks were presented via speakers placed on either side of the computer screen. Stimuli were presented using Presentation software (Neurobehavioral Systems, Inc.; Albany, CA), which also recorded participants' button presses.

Participants were fitted with EEG caps and then performed two practice trials (one for the individual setting and one for the joint setting) during which the experimenter controlled the presentation of the events that comprised a trial and explained the task. Participants then completed a training phase (two blocks of 18 trials) and a test phase (12 blocks of 30 trials) with the timing described below. At the beginning of each block, instructions presented on the computer screen indicated the sequence length and whether participants were to produce the tones alone or together. Blocks alternated between individual and joint settings, the order of which was held constant through both the training and test phases and was counterbalanced across pairs. Sequence length was either 4 or 6 tones, held constant for a given block and randomly determined with the constraint that half of the blocks in each setting were of length 4 and the other half of length 6. The person producing the sequence (individual setting) or the first tone in the sequence (joint setting) was randomly determined on each trial with the constraint that one participant produced or started the sequence on half of the trials and the other participant produced or started the sequence on the other half of the trials.

Each trial consisted of the following sequence of events, shown in Fig. 1. A cue indicating which person was to produce the tone sequence (individual setting) or the first tone in the sequence (joint setting) appeared on a black computer screen for 2000 ms. The cue consisted of a cartoon face with two arms, one of which was colored red to indicate that the person on that side of the table should produce or begin the sequence. A white fixation cross then appeared and remained on the screen until the last tone of the sequence was produced. Three pacing clicks were presented at 500 ms intervals (beginning 500 ms after the onset of the fixation cross). Participants were instructed to produce the tone sequence while maintaining the pace set by the clicks. After the last tone was produced, a black screen was presented for 700 ms, followed by feedback indicating whether the participants had successfully maintained the required pace. The feedback was presented for 700 ms, after which a black