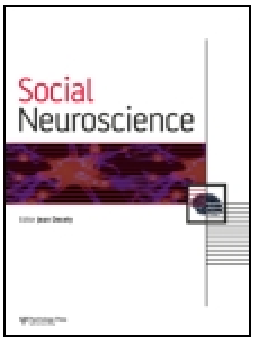

Social Neuroscience

ISSN: 1747-0919 (Print) 1747-0927 (Online) Journal homepage: http://www.tandfonline.com/loi/psns20

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To cite this article: Anne Böckler & Natalie Sebanz (2012) A co-actor's focus of attention affects stimulus processing and task performance: An ERP study, Social Neuroscience, 7:6, 565-577, DOI: 10.1080/17470919.2012.682119

To link to this article: http://dx.doi.org/10.1080/17470919.2012.682119

SOCIAL NEUROSCIENCE, 2012, 7 (6), 565–577

Psychology Press
Taylor & Francis Group

A co-actor's focus of attention affects stimulus processing and task performance: An ERP study

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When acting and attending together, we take each other's perceptual and intentional relations to the environment into account. The present study investigated whether people are also sensitive to a co-actor's attentional relation to jointly attended events. Two participants sat next to each other and performed a two-choice Navon task, responding to the identity of letters formed by identical (congruent) or different (incongruent) smaller letters while EEG was recorded. Crucially, participants either held the same focus of attention (e.g., both attending to local stimulus features) or different foci of attention (e.g., one attending to local and the other to global features). Results revealed a significant slow-down of responses when participants focused on different features. Amplitudes of the occipital P1 and parietal occipital P3 decreased when attentional foci differed. The amplitude of the fronto-central N2 increased when the other attended to local as compared to global features. These results suggest that representations of a co-actor's task can include a specification of his or her focus of attention. Taking into account the other's different attentional relation to stimuli likely induces a conflict at the level of task selection, impairing early allocation of attention (P1) and enhancing the need to monitor response initiation (P3).

Keywords: Task co-representation; Focus of attention; Joint attention; Perspective taking.

Previous research suggests that when acting next to each other, people take their co-actor's tasks into account and represent which stimuli require the other's response (Atmaca, Sebanz, & Knoblich, 2011; Sebanz, Knoblich, & Prinz, 2005; Tsai, Kuo, Jing, Hung, Tzeng, 2006). For instance, in an Eriksen flanker task (Eriksen & Eriksen, 1974), participants showed the same pattern of results when they performed the task alone and when they performed half of it together with another person who was responsible for the complementary part (Atmaca et al., 2011). The joint flanker effect occurred only if the co-actor acted intentionally and not when a machine controlled her actions. Thus, when acting together, participants considered their co-actor's intentional relation to stimuli and represented not only their own, but also the other's task.

In addition to being sensitive to what their co-actors need to do, people also consider others' perceptual relations to a jointly attended environment (Böckler, Knoblich, & Sebanz, 2011; Samson, Apperly, Braithwaite, Andrews, & Scott, 2010; Tversky & Hard, 2009). When different spatial orientations provided people with visual access to unequal amounts of objects (Samson et al., 2011) or with dissimilar views on the same objects (Böckler et al., 2011; Tversky & Hard, 2009), they processed these objects not only in relation to their own, egocentric perspective but also in relation to the other's perspective. This suggests that the way people look at the world is affected by how their co-actors perceive it.

The question we aimed to address in the present study is whether people also take into account another

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www.psypress.com/socialneuroscience http://dx.doi.org/10.1080/17470919.2012.682119

person's attentional relation to the environment, specifying the attentional focus to be applied by their co-actor as part of the task representation. To illustrate this with an example, imagine yourself working alongside others on the assembly line of a chocolate factory. You are supposed to inspect whether the right amount of almonds complements the white praline in each box. The person next to you needs to ensure that the overall pattern of white, brown, and black chocolates in the box is correct. Will your attentional focus be affected by what your co-worker is attending to? The tasks of you and your co-workers are the same (picking out faulty objects) and so are your perceptual relations to the objects (you are sitting next to each other and perceive the same boxes of chocolate). What differs is the attentional relation the two of you hold to the objects on the assembly line. While you focus on local aspects of the box (the almonds on the white praline), your co-worker holds a global focus (monitoring the pattern of all pralines in the box). Do you take into account the other's attentional focus and how does this affects your own attentional relation to the scene?

Earlier studies from our laboratory suggest that people's performance is indeed affected by a co-actor's focus of attention (Böckler, Knoblich, & Sebanz, 2012). In a series of experiments, two participants sat next to each other and performed a two-choice task on the identity of Navon letters (large letters consisting of small letters; see Figure 1). Each participant had to respond to two different letters (e.g., participant A responds to *S* and *F*, while participant B responds to *H* and *O*). The letters assigned to the two participants were never intermixed (e.g., large letters of participant A would never consist of small letters of participant B); thus, participants performed a go-nogo task, never responding to the same stimuli. The Navon letters presented on the screen could be either congruent (linked to the same response, such as a large *S* consisting of small *S*s) or incongruent (linked to different responses, such as a large *S* consisting of small *H*s). In each block, participants were instructed to focus either on the local features (small letters) or on the global features (large letters). Crucially, participants were required to hold either the same or a different focus of attention.

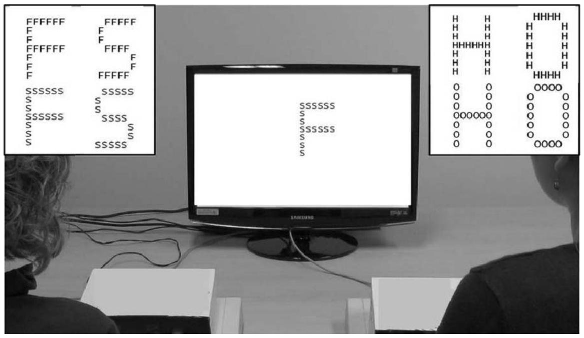

Figure 1. Experimental setting. Participants were sitting next to each other, in pairs, in front of a monitor. Both participants in each pair responded by pressing the respective button with the index fingers of their right and left hands. Hands were covered by boxes.

We hypothesized that participants would specify the other's attentional focus in representing the other's task. Two different hypotheses were tested as to how this could affect performance. According to the biased-focus hypothesis, co-actors would be biased toward the focus of the other, shifting their own local focus toward the other's global focus, or, vice versa, narrowing their global focus when the co-actor focused on the local features. The biased-focus hypothesis predicts decreased control over one's own focus and a tendency to adopt the focus of the other when attentional foci differ. This should impact performance especially on incongruent trials, since different responses are associated with the local and the global stimulus features. Moreover, since global features are processed more readily (a phenomenon known as global precedence; Kimchi, 1992; Navon, 1977; 1981; 2003), the co-actor's focus should have a larger effect when it is global and the participant's focus is local. By contrast, the selection-conflict hypothesis predicts that the representation of the other's different task generally increases the difficulty of selecting and maintaining one's own focus of attention. This hypothesis assumes that the representation of how the other needs to focus attention induces a conflict as to which focus to select when the other's focus is different. Accordingly, when the other holds a different focus, responses should slow down equally in congruent and incongruent trials, independently of whether local or global features are attended to.

Results revealed slower responses when people attended to different stimulus aspects, indicating that people held a representation not only of their own but also of the other's attentional focus. Crucially, the increase of reaction times (RTs) for different foci of attention was found for both congruent and incongruent stimuli. This suggests that participants did not shift their own focus toward the other's focus (biased-focus hypothesis). Rather, when foci differed, co-representing the task of the other induced a conflict as to which focus of attention to select, slowing down responses in all trials. The slow-down when holding different foci was independent of whether participants held a local or a global focus, suggesting that the other's focus did not exert a stronger pull when it was dominant (i.e., global; see Kimchi, 1992). These findings corroborate the selection-conflict hypothesis that postulates a conflict at the level of selecting the appropriate focus.

Subsequent experiments revealed that this effect did not depend on both participants attending to the same stimulus and location on the screen. However, mutual visual access to each other's stimuli was required for the effect to occur. Finally, when participants performed the task alone, but received instructions about another's focus of attention (being told that instructions stemmed from a previous version of the experiment), RTs were not affected by instructions concerning the focus of the absent other. Thus, instructions about another's attentional focus were not sufficient for inducing effects of task co-representation (Böckler, Knoblich, & Sebanz, 2012).

THE PRESENT STUDY

The present study aimed to investigate in more detail how a co-actor's attentional focus exerts its influence. Previous behavioral experiments did not examine how the other's attentional focus affects the way people attend to, perceive, and/or process their own stimuli. This is informative in regard to dissociating between the selection-conflict hypothesis and the biased-focus hypothesis. Previous findings favored the selection-conflict hypotheses, as RTs increased equally in congruent and incongruent trials and regardless of whether participants attended to local or to global features. However, shifts toward the focus of the other may have occurred without being reflected in RTs. Adopting a biased attentional focus might have increased conflict and processing demands in incongruent trials, but this could have been resolved before responses were carried out. Investigating the time course of the processes underlying the behavioral findings allows for a more fine-grained examination of the two hypotheses. Therefore, electroencephalographic activity (EEG) was recorded in the present study.

Moreover, earlier experiments could not address how stimuli requiring the co-actor's response (nogo trials for participants) were processed. It could be, for instance, that participants adopted the focus of the other when perceiving their stimuli. If this was the case, the observed slow-down when attentional foci differed may have been due to costs of switching between one's own and the other's attentional focus.

In order to address these questions, EEG was recorded in pairs of participants performing a Navon task while either attending to the same aspect (e.g., both attending to the global features) or attending to different aspects (e.g., one attending to the global, and the other to the local feature). Event-related brain potentials (ERPs) can be recorded with high temporal resolution to reveal the temporal organization of attentional and cognitive processes. As such, they allow investigation of whether participants adopt the other's focus in go or in nogo trials.

The effect of a co-actor's (different) focus of attention was assessed by means of the following components.

P1

This positive deflection around 100 ms following stimulus onset reflects activation of extrastriate visual areas when processing physical stimulus attributes (Hillyard & Picton, 1987). The amplitude (but not the latency) of the P1 increases when selective attention is directed to the stimulus location (Mangun & Hillyard, 1990, 1991; Schuller & Rossion, 2001). Han and colleagues found the P1 amplitude to be enhanced when participants focused on local features in a Navon task (Han, Fan, Chen, & Zhou, 1997; but see Heinze & Münte, 1993), showing that selective attention to specific levels of hierarchical stimuli can modulate early visual processing. The authors argued that allocation of attention to a relevant stimulus feature increases the amplitude of the P1. If co-representation of the other's focus of attention influences early allocation of selective attention, the amplitude of the P1 should be modulated by whether the other's focus is similar or different. Specifically, if the other holds a different focus of attention, allocation of attention to the relevant stimulus feature should be reduced and the amplitude of the P1 should decrease. While the selection-conflict hypothesis suggests a general effect of the other's different focus (general decrease of P1 amplitude), the biased focus hypothesis predicts a larger decrease when the other's focus is global (dominant). However, allocation of attention as reflected in the P1 may be too early in the course of stimulus processing to reliably distinguish between the two hypotheses.

N2

The N2 reflects perceptual processing linked to identification and classification of stimuli (Han et al., 1997; Mulder, 1986). In turn-taking tasks, the frontocentral N2 has been related to cognitive control processes involved in response inhibition when it is the other's turn, and in deciding to respond when it is one's own turn (see Folstein & Van Petten, 2008, for an overview). Delayed and increased peaks of the anterior N2 have been reported for processing local as compared to global features and for processing incongruent as compared to congruent stimuli (Han et al., 1997). A crucial question of our study was whether participants' own focus would shift toward the focus of the other when attentional foci differ (biased-focus hypothesis). Such shifts should be cognitively demanding, especially in incongruent trials, as in those trials global and local features are linked to different responses and shifting one's focus toward the different focus of the other would increase conflict. If differences between incongruent and congruent trials are enhanced in the fronto-central N2 when the other holds a different attentional focus, this would corroborate the biased-focus hypothesis. If, by contrast, the fronto-central congruency effect is independent of the other's focus, this would strengthen the selection-conflict hypothesis.

Larger amplitudes when processing local as compared to global features also have been reported for the posterior N2, especially in the left hemisphere (Han et al., 1997, 1999; Heinze & Münte, 1993). This posterior N2 was argued to reflect the asymmetrical global RT advantages (Martin, 1979; Sergent, 1982). If the focus of the co-actor affects participants' hierarchical processing, this should be reflected in the posterior N2. According to the biased-focus hypothesis, the effect of the co-actor's focus of attention should be more pronounced when the other holds a global focus, since global features are dominant in the processing hierarchy (Kimchi, 1992; Navon, 1981).

P3

The P3 component is sensitive to the allocation of attention (Kok, 2001, Polich, 1987) in that the amplitude of the P3 decreases for tasks requiring increasing attentional resources (Polich, 2007). It has been argued that the posterior P3 reflects a mediation process between perceptual analysis and response initiation, such as monitoring whether the stimulus classification is appropriately transformed into action (Verleger, Jaskowski, & Wascher, 2005). In Navon tasks, the amplitude of the P3 was found to be larger when attention was paid to global features as compared to local features, and when congruent as compared to incongruent stimuli were processed (Han et al., 1997; Proverbio, Minniti, & Zani, 1998). If representing the co-actor's task that requires a different attentional focus generally enhances the attentional and/or monitoring demands for participants' own stimuli (selection-conflict hypothesis), this should be reflected in an overall decrease of the P3 amplitude. In contrast, the biased-focus hypothesis predicts stronger effects of the other's different focus when trials are incongruent and when the other holds a global focus.

Nogo N2 and P3

Finally, in order to investigate how stimuli of the co-actor were processed, electrophysiological components were examined time-locked to stimuli of the co-actor. If participants adopted the other's focus when perceiving her stimuli (on nogo trials), this could potentially account for our previous findings (slower responses when foci differ), as it would make it more difficult to apply their own attentional focus on go trials where foci differ. Amplitudes of the N2 and P3 were analyzed time-locked to the stimuli of the co-actor. If the other's focus is adopted, amplitudes elicited by the co-actor's stimuli should change according to the focus of the other. In contrast, if the other's focus is not adopted, these components should be unaffected by attentional focus altogether or reflect participants' own focus of attention.

METHODS

Participants

Ten pairs of undergraduate students (mean age 24 years; 10 women; 17 right-handed) participated in the experiment and received course credits or payment for participation. All of them reported normal or corrected-to-normal vision and signed informed consent statements prior to the experiment.

Stimuli and procedure

Participants were tested in pairs sitting next to each other (see Figure 1) with a viewing distance of 70 cm to the 22-inch TFT monitor. Ambient light was kept at a constant level.

Navon stimuli were large letters (2.3° × 3.8° visual angle) consisting of small letters (0.24° × 0.5° visual angle) according to a 6 × 7 matrix. Each participant was assigned two letters (participant A: *F* and *S*; participant B: *H* and *O*). Letters could be congruent (e.g., an *F* made of *F*s or an *S* made of *S*s) or incongruent (an *F* made of *S*s or an *S* made of *F*s), while letters of the two participants were not intermixed (e.g., there were no *S*s made of *H*s). Thus, eight different stimulus letters were presented equally often in a randomized order: an *F* made of *F*s, an *S* made of *S*s, an *F* made of *S*s, an *S* made of *F*s, an *H* made of *H*s, an *O* made of *O*s, an *H* made of *O*s, and an *O* made of *H*s.

Each trial started with the presentation of a fixation cross (0.8° visual angle) at the center of the screen. Then, 900 ms later, a letter appeared at one of four possible locations (0.8° visual angle around the fixation cross) for 200 ms. Following participants' responses (or a maximum of 1100 ms), the screen stayed blank for another 700–1000 ms (randomized interstimulus interval).

Stimuli appeared in randomized order, and participants were asked to respond only to their own letters as fast and as accurately as possible by pressing one of two keys with the index fingers of the their left and right hands (two-choice). Responses were collected by two button boxes with two horizontally arranged keys. Carton boxes were placed above participants' hands in order to prevent them from perceiving each other's responses.

The experimental session consisted of a practice block and 12 experimental blocks. Each block contained 48 trials and was followed by a short rest. Ahead of each block participants were informed about their own and the other's focus of attention through written instructions on the screen (e.g., "participants A responds to the large letters, participant B responds to the small letters"). Participants focused on the global aspect of the stimulus (large letters) in six blocks and on the local aspect (small letters) in the other six blocks. In half of these blocks, the co-actor attended to the same aspect (e.g., global when they attended to global), and in the other half, the co-actor attended to the other aspect of the stimulus (e.g., local when they attended to global). Hence, each of these four combinations of own (global vs. local) and other's tasks (same vs. different) appeared in three blocks. The specific assignment of own and other's tasks changed blockwise in such a way that the four different combinations of tasks were shuffled three times in a row. Overall, the experimental session took about 50 min.

Psychophysiological recordings and data analysis

The EEG of both participants was recorded continuously from 32 Ag/AgCl electrodes according to the international 10–20 system (FP1, FP2, F3, F4, F7, F8, FC1, FC2, FC3, FC4, C3, C4, T7, T8, P3, P4, P7, P8, PO3, PO4, PO7, PO8, O1, O2, Fz, FCz, Cz, Pz, and POz). AFz served as ground electrode. All electrodes were referenced online to a right mastoid electrode. Vertical electroocular (vEOG) and horizontal EOG (hEOG) activity was registered above and below the left eye and from the left and right outer canthi, respectively.

Electrode impedance was kept below 5 kΩ. EEG and EOG were filtered online, using a 70-Hz low-pass filter and a time constant of 15 s. All EEG signals were digitized with a sample frequency of 250 Hz. Trials containing blinks were corrected off-line, using Brain Vision Analyzer (Brainproducts, Munich) Remaining artefacts were eliminated semi-automatically according to visual inspection. Trials with hEOG or vEOG activity exceeding a range of 25 μV during the epoch were discarded from all analyses. Off-line data were referenced to the mastoids. The EEG epochs were then averaged separately for each participant and experimental condition, and aligned to a 200-ms baseline preceding stimulus onset. Epochs of 700 ms were analyzed.

In line with earlier P1 literature, we focused on the electrodes with largest P1 amplitudes, namely O1, O2, PO3, and PO4. By means of automatic peak detection, positive peaks were identified between 100 and 120 ms following stimulus onset. Amplitudes (mean activity) were analyzed in the time range from 100 to 120 ms.

N2 latencies were analyzed at fronto-central electrode sites (FCz, Cz, FC1, FC2, FC3, and FC4), and amplitudes (mean activity) were analyzed at the same fronto-central and at posterior electrode sites (Pz, POz, Oz, P3, P4, P7, P8, PO3, PO4, PO7, PO8, O1, and O2). By means of automatic peak detection, latencies of negative peaks were identified between 200 and 290 ms. Amplitudes (mean activity) were analyzed in the time range between 240 and 290 ms following stimulus onset.

P3 latencies and amplitudes (mean activity) were analyzed at parietal and occipital electrodes (Pz, POz, Oz, P3, P4, P7, P8, PO3, PO4, PO7, PO8, and O1, O2). Amplitudes (mean activity) were analyzed in the time range from 270 to 370 and in the time range from 370 to 450 ms.

In order to investigate how participants processed their co-actors' stimuli, the N2 and P3 were analyzed time-locked to the stimuli of the co-actor.

Data analysis

Repeated-measures ANOVAs (model 1) were performed on RTs, error rates, and ERP measures, including the variables Own focus of attention (global versus local), Other's focus of attention (same focus versus different focus), and Congruency (congruent versus incongruent). Huynh–Feldt corrections (Huynh & Feldt, 1976) were applied if necessary. Planned single comparisons were performed by means of two-tailed *t*-tests.

RESULTS

Behavioral results

RTs

Two participants were excluded due to error rates that were more than two standard deviations above average. Results are depicted in Figure 2. Only trials with correct responses were included in the analysis. A main effect of Congruency was found, $F(1, 17) = 60.9$, $p < .001$, due to faster responses to congruent than incongruent letters. Participants responded faster to the global than the local stimulus feature, $F(1, 17) = 30.5$, $p < .001$. Congruency effects, even though present in both conditions, $ts(17) > 5.1$, $ps < .001$, were larger in the local than the global condition: two-way interaction of Own focus of attention × Congruency, $F(1, 17) = 39.6$, $p < .001$.

A main effect of Other's focus of attention was revealed, $F(1, 17) = 5.0$, $p < .05$, due to slower responses when the co-actor attended to the different aspect of the stimulus rather than to the same aspect. This effect was not modulated by Congruency or Own focus of attention, $Fs(1, 17) < 1$. Hence, the slow-down elicited by the other's different focus of attention did not differ between congruent and incongruent trials and appeared independently of whether participants themselves held a local or a global focus.

Error rates

Mean error rate was 3.1%. A main effect of Congruency was found, $F(1, 17) = 48.3$, $p < .001$, as participants responded more accurately to congruent letters.

Electrophysiological results

The same two participants who were excluded from behavioral analysis were excluded from ERP analysis.

Go trials

P1. The P1 amplitude was significantly decreased when the co-actor held a different focus of attention at electrode sites O1 and O2, $F(1, 17) \geq 4.7$, $p < .05$ (see Figure 3). There was a trend toward the same effect at electrode sites PO3 and PO4, $F(1, 17) \geq 3.1$, $p < .08$. No other significant main effects or interactions, $F(1, 17) \geq 1$, were revealed.

N2

Latency. The peak latency was significantly delayed when participants focused on local as compared to global letters at electrode sites FC1, FC2, FC3, and FC4, $Fs(1, 17) \geq 7.0$, $ps < .01$. The factor Congruency reached significance at FC1 and FC3, $Fs(1, 17) > 4.0$, $ps < .05$, as the N2 peaked later for incongruent as compared to congruent stimuli. Additionally, a significant two-way interaction of Congruency and Own focus of attention was found at FC1 and FC3, $Fs(1, 17) \geq 4.0$, $ps < .05$, due to a delay in incongruent trials when participants focused on the local aspect, $t(17) \geq 2.3$, $p < .05$, but not when they focused on the global aspect, $t(17) < 1$. The effect of Congruency was not modulated by Other's focus of attention, $Fs(1, 17) < 1$.

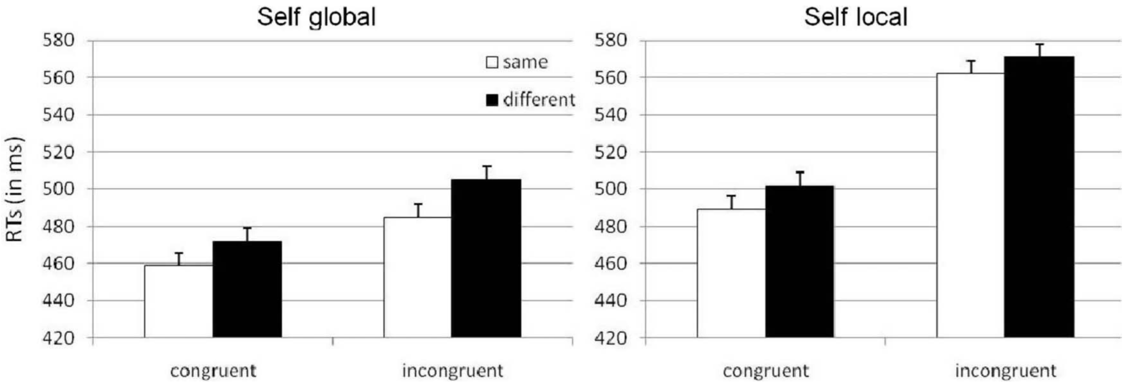

Figure 2. Reaction times. Error bars display within-subject confidence intervals according to Loftus & Masson (1994).

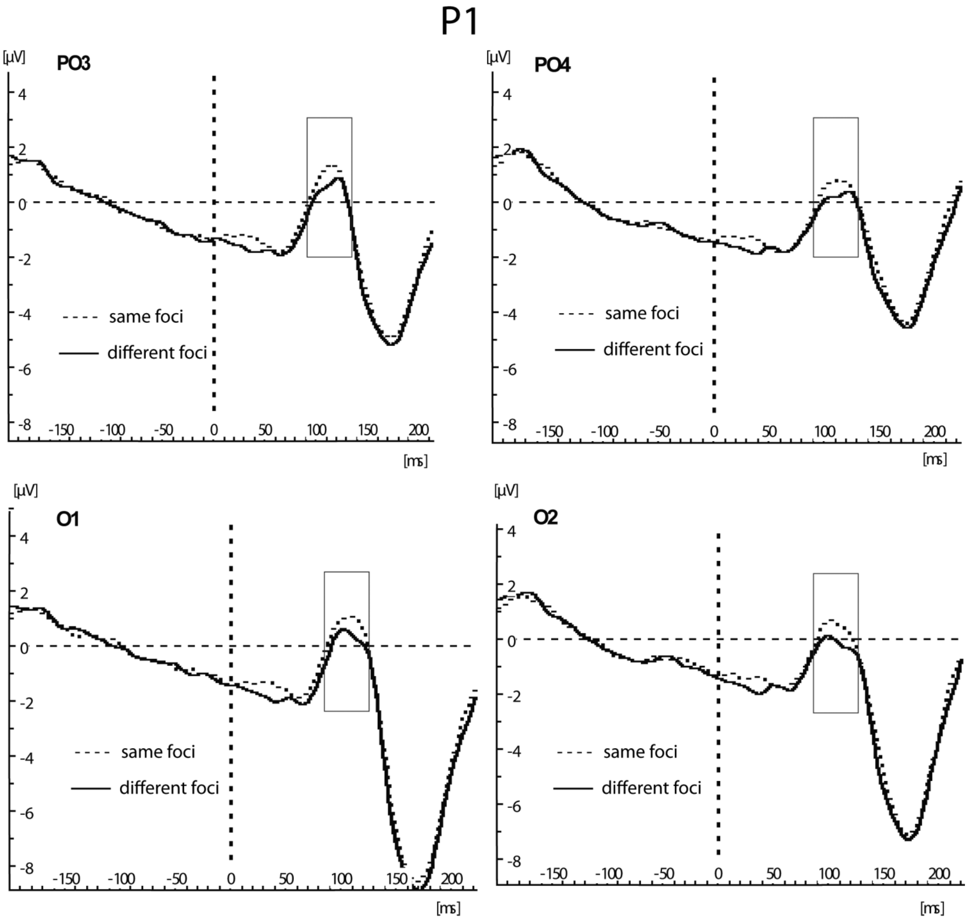

Figure 3. Grand-averaged P1 waveforms for holding the same (dotted line) and different (solid line) attentional foci at parietal occipital sites (PO3, PO4, O1, and O2).

N2

Amplitude. A significant main effect for Own focus of attention was found at left parietal and at occipital electrode sites (P3, P7, PO3, PO7, PO8, O1, and O2), $Fs(1, 17) \geq 4.9$, $ps < .05$, due to more negative amplitudes when local as compared to global letters were attended to.

A significant two-way interaction of Own focus of attention (global vs. local) and Other's focus of attention (same vs. different) was found at FCz, Cz, FC2, and FC4, $Fs(1, 17) \geq 4.2$, $ps < .05$, as N2 amplitudes increased when the other held a local focus of attention (independent of participants' own focus) (see Figure 4). No other effects or interactions reached significance, $Fs(1, 17) < 1$.

P3

Latency. No significant main effects or interactions were found for latencies of the P3 component, $Fs(1, 17) \leq 1$.

P3

Amplitude. The P3 amplitude was more positive when participants attended to global as compared to local letters at all electrode sites (Pz, POz, Oz, P3, P4, P7, P8, PO3, PO4, PO7, PO8, O1, and O2), $Fs(1, 17) \geq 15.9$, $ps < .001$, and it occurred between 270 and 370 ms and between 370 and 450 ms. Furthermore, the P3 amplitude was larger for congruent than incongruent stimuli at electrodes P3, P7, P8, PO3, PO4, PO7, PO8, O1, and O2, $Fs(1, 17) \geq 6.1$, $ps < .05$, and it was present in both time ranges. Finally, when participants attended to different aspects, amplitudes decreased at electrodes (PO7, PO3, O1, and O2), $Fs(1, 17) \geq 4.9$, $ps < .05$ (see Figure 5). This difference occurred between 270 and 370 ms. No interaction of Congruency and Other's focus of attention was found, $Fs\ (1, 17) \leq 1$.

When the additional factor Hemisphere (left hemisphere vs. right hemisphere) was included in the analysis, it interacted significantly with Other's focus of attention, $F(1, 17) = 7.0$, $p < .05$. This was due

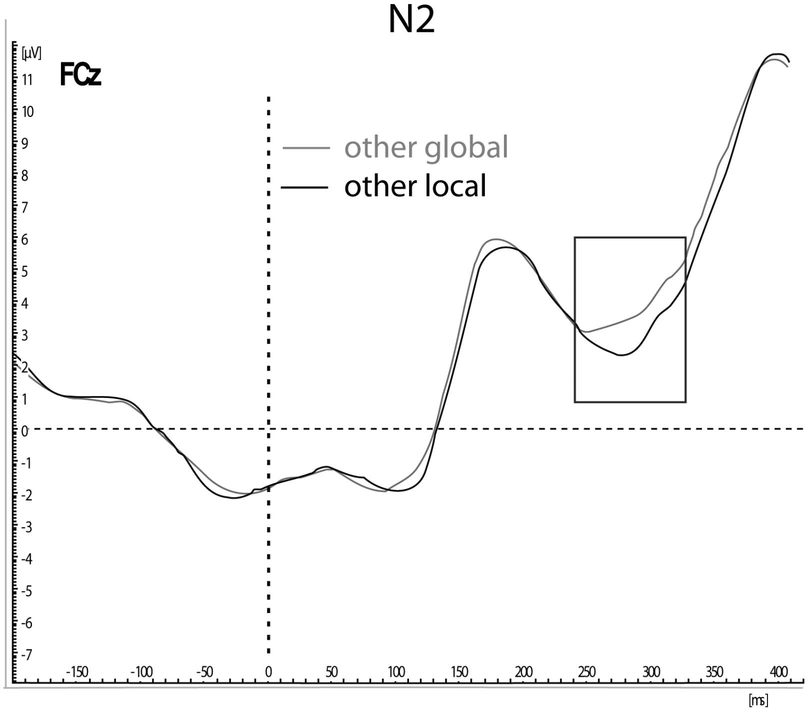

Figure 4. Grand-averaged N2 waveforms for the co-actor holding a global (gray line) and a local (black line) focus of attention at a fronto-central electrode site (FCz).

to a significant decrease of the P3 amplitude when the co-actor held a different focus of attention in the left hemisphere, $F(1, 17) = 4.9$, $p < .05$, but not in the right hemisphere, $F(1, 17) < 1.3$. Hemisphere did not interact with any other factor.

Nogo trials

N2

Latency and amplitude. No significant effects or interactions were found, $Fs(1, 17) < 2.0$.

P3

Latency. No significant main effects or interactions were found for latencies of the P3 component, $Fs(1, 17) \leq 1$.

P3

Amplitude. A significant main effect of Own focus of attention was revealed at electrode sites Pz, POz, Oz, P3, P4, P8, PO3, PO4, PO7, PO8, O1, and O2, $Fs(1, 17) \geq 4.8$, $ps < .05$. This was due to larger P3 amplitudes when participants had to focus on global as compared to local letters. The Other's focus of attention did not affect P3 amplitudes, $Fs(1, 17) \leq 1$.

DISCUSSION

First, the present study replicated established findings on the processing of Navon stimuli. In line with previous research, both behavioral and electrophysiological results revealed a congruency effect and global precedence, suggesting that responding to local letters and to incongruent stimuli was especially demanding. Participants responded slower and less accurately to incongruent than to congruent stimuli, and incongruent trials elicited increased N2 latencies and decreased P3 amplitudes (Han et al., 1997). Participants were slower in responding to local than to global letters, and N2 latencies were longer, left posterior N2 amplitudes were larger, and P3 amplitudes were decreased for local focus of attention (Heinze & Münte, 1993). Congruency effects in response times and the N2 latencies were larger for the local focus.

Second, the present results corroborate earlier behavioral findings on joint task performance (Böckler, et al., 2012). In line with previous experiments, the present results revealed a general slow-down when co-actors attended to different stimulus aspects, indicating that participants took the other's focus of attention into account. The slow-down when the co-actor's attentional focus differed was independent of stimulus congruency and occurred

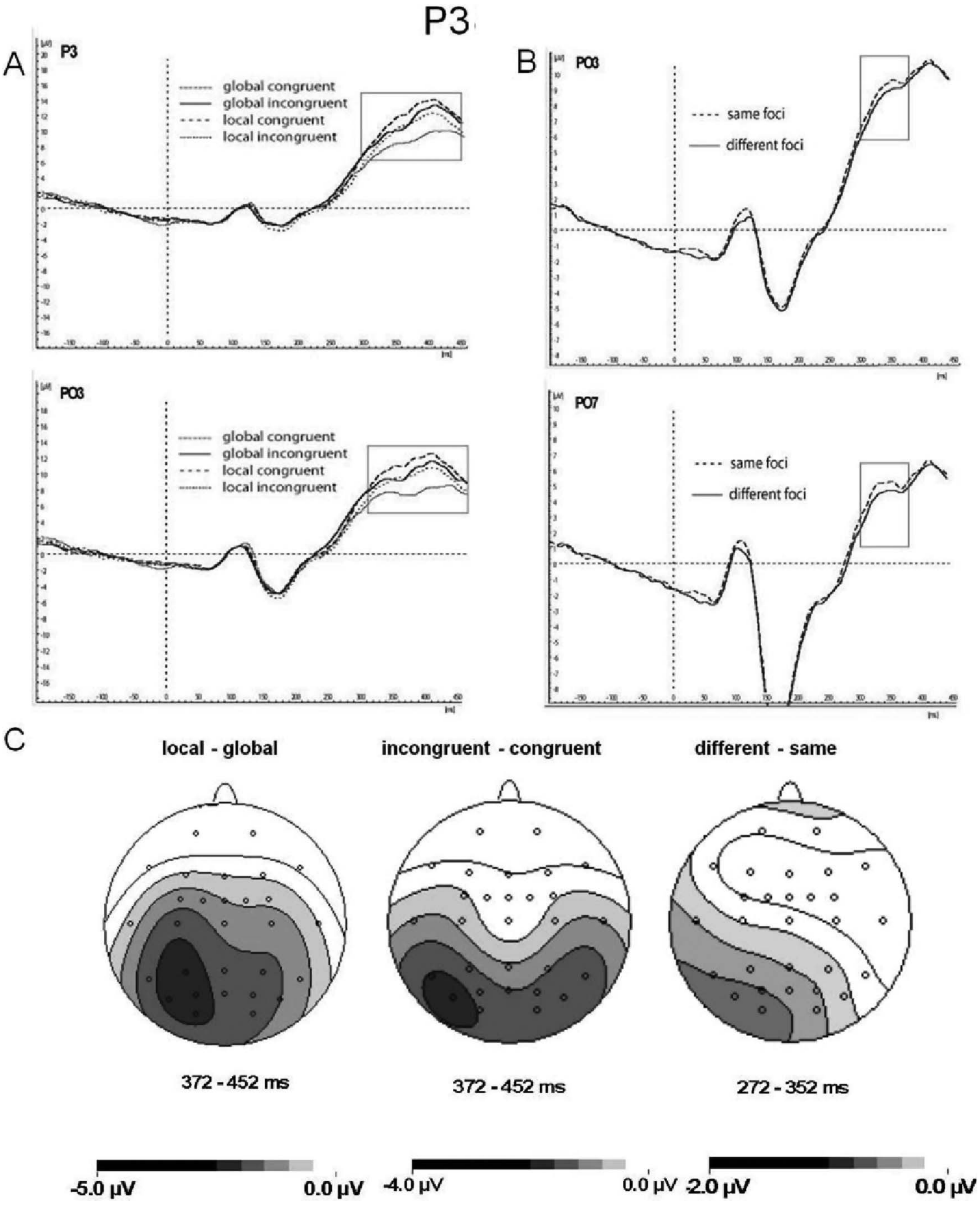

Figure 5. P3. (A) Grand-averaged P3 waveforms for the participants' own focus of attention and both congruency conditions at parietal electrode sites (P3 and PO3). (B) Grand-averaged P3 waveforms for the co-actor holding the same (dotted line) or a different (solid line) focus of attention at parietal electrode sites (PO3 and PO7). (C) Subtraction maps for the P3. Left: subtraction map for global minus local focus of attention in the time range between 372 and 452 ms after stimulus onset. Middle: subtraction map for incongruent minus congruent stimuli in the time range between 372 and 452 ms after stimulus onset. Right: subtraction map for same minus different attentional foci in the time range between 272 and 352 ms after stimulus onset.

irrespective of the focus participants held themselves. This suggests that representing the focus required by the other's task made it generally more difficult for participants to select and apply their own focus. Even though global precedence occurred, participants were not more prone to taking the other's global focus into account than they were to taking the other's local focus into account. This favors the selection-conflict hypothesis, which predicts that conflict between selecting one's own and the other's focus is of stimulus congruency and the dominance of the focus in the processing hierarchy.

To better understand how attentional and cognitive processes are affected by a co-actor's focus of attention, the present study relied on the analysis of ERPs. First, amplitudes of the P1 were significantly reduced when the co-actor held a different focus of attention, showing that early stimulus processing was modulated by the other's attentional focus. The P1 is sensitive to how well attention is focused on a stimulus location (Mangun & Hillyard, 1990, 1991; Schuller & Rossion, 2001) or a stimulus feature (Han et al., 1997). Thus, the co-actor holding a different attentional focus likely decreased participants' attention to the stimulus aspect they needed to focus on. This is in line with the selection-conflict hypothesis, which states that representing what another person focuses on generally increases the difficulty of selecting one's own attentional focus when attentional foci differ. The finding that representing the task of the other affects early processes of attention allocation is a first indication of top-down effects of task co-representation on attentional processing as early as 100 ms following stimulus onset. Representing how a co-actor's attentional focus is to be set seems to affect the allocation of one's own focus of attention.

Note that we did not find larger amplitudes of the P1 when participants' own task was to focus on local compared to global aspects (in line with Heinze & Münte, 1993, but opposed to Han et al., 1997). This may be due to the fact that we presented stimuli at variable locations around fixation, whereas, in Han et al.'s study, stimuli were presented centrally. Presenting stimuli in varying locations may have increased the difficulty of allocating attention to local features.

In addition to the observed P1 modulation, the P3 amplitude decreased at left parietal occipital electrode sites when the co-actor's task required the opposite attentional focus. This decrease when foci differed may indicate that responding to different stimulus features than the co-actor was more demanding in terms of monitoring the transition from stimulus processing to response initiation (P3b) (Verleger, 2008; Verleger et al., 2005) or in terms of the internal decision-making process (Nieuwenhuis, Aston-Jones, & Cohen, 2005). This supports the selection-conflict hypothesis, according to which representing the other's different focus makes it generally harder to select and apply one's own focus of attention. Importantly, we found no indications of increased congruency effects in latencies or amplitudes of the P3 when participants held different attentional foci, indicating that participants were not biased to adopt a focus that was shifted toward the other's (biased-focus hypothesis). Similarly, the other's different focus did not exert a stronger effect when it was directed to global features, a finding that further dissents from the biased-focus hypothesis and corroborates the selection-conflict hypothesis. The effect of the other's focus of attention on P3 amplitudes was found at posterior electrode sites. Some of the suggested neural generators of the P3 component (see Verleger, 2008) are located in posterior parietal areas, such as the posterior parietal cortex (PPC), which serves goal-directed attention and visuomotor integration (Bledowski et al., 2004). This topography substantiates our interpretation of the present P3 result as an indicator of increased demands on planning appropriate responses to one's own stimuli when representing the different attentional focus required by the co-actor's task.

Finally, N2 results did not provide any evidence for the biased-focus hypothesis. This hypothesis predicts enhanced differences between incongruent and congruent trials in the fronto-central N2 when the other holds a different attentional focus. Latencies of the fronto-central N2 were longer for incongruent stimuli and when local stimuli had to be attended to. However, the other's focus of attention did not interact with stimulus congruency. The biased-focus hypothesis also predicted effects of the co-actor's focus of attention on the posterior N2, which reflects hierarchical processing. According to this hypothesis, the effect of the co-actor's focus of attention should be more pronounced when the other holds a global focus, since global features are dominant in the processing hierarchy. No effects of the co-actor's attentional focus on the posterior N2 were revealed, indicating that hierarchical stimulus processing was not affected by the other's attentional focus.

To summarize, the P1 and P3 results suggest that participants represented not only their own task but also the other's task in terms of the attentional focus to be applied. This impaired early allocation of attention and made the monitoring of response initiation more difficult. These effects were not modulated by stimulus congruency or by participants' own focus, suggesting that participants, even though holding a task representation that specified what their co-actor needed to focus attention on, did not actually adopt the co-actor's attentional focus. These results are in line with the selection-conflict hypothesis. The N2 results indirectly support this interpretation, as there was no indication that participants adopted their co-actor's focus.

However, there is one aspect of the N2 results that merits further discussion. Amplitudes of the frontocentral N2 were more negative when the co-actor held a local focus of attention independently of participants' own attentional focus. Given that the N2 amplitude has been associated with deciding whether it is one's turn to act (Folstein & Van Petten, 2008), this finding suggests that considering the stimulus aspect that was relevant to the co-actor's task may have affected how easily participants could classify a given stimulus as a go stimulus. The present experiment required participants to decide for each stimulus whether they needed to respond or not. In such go-nogo tasks, the classification of a given stimulus as a go stimulus demands cognitive control. Accordingly, the present results suggest that the control demand was higher when the co-actor needed to attend to local features. This suggests that participants focused on the stimulus feature that the other needed to respond to when classifying a given stimulus as theirs or the other's. Since processing local stimuli is more demanding than processing global stimuli (Kimchi, 1992; Navon, 1981), cognitive demand increased when co-actors attended to local features. It is important to note that this effect was not reflected in behavioral measures, suggesting that by increasing cognitive control the task could be solved equally well for the other holding a local or a global focus. While this finding shows that people are sensitive to the stimulus aspect that is relevant to their co-actor's task, it does not corroborate the biased-focus hypothesis, since this hypothesis predicted a larger influence of the other's task when the focus required by the other's task was global rather than local.

A final question we aimed to address with the current study concerns how the co-actor's stimuli are processed. The results suggest that participants processed stimuli of the other according to their own attentional focus. P3 amplitudes on nogo trials decreased when participants focused on local as compared to global letters, mirroring the findings of P3 amplitudes locked to participants' own stimuli. This suggests that participants did not adopt their co-actor's attentional focus when it was the co-actor's turn to respond. In summary, while participants did not adopt their co-actor's focus of attention in either go or nogo trials, they formed a representation of the other's task that specified what the other needed to focus on, and this, in turn, increased the difficulty of selecting and applying their own attentional focus.

It could be argued that the observed behavioral and electrophysiological differences between trials in which participants held the same as compared to different attentional foci reflect the processing benefits for holding the same focus rather than the costs of holding different foci. As the observed effects consist of relative differences in RTs and electrophysiological components, we cannot exclude this possibility. Specifying the other's focus of attention in task co-representation could boost selection of the appropriate focus and facilitate initiating the appropriate response. Further research is needed to specify the relative contribution of facilitation and interference effects in the present paradigm. However, in view of earlier studies on task co-representation and perspective-taking which have reported effects of interference rather than facilitation (Samson et al., 2010; Sebanz et al., 2003; Tsai et al., 2006), we consider it likely that representing the other's task led to a conflict in selecting the appropriate focus when the tasks differed. This might appear disadvantageous from an evolutionary perspective at first (e.g., joint visual search for different features would be hindered as opposed to joint visual search for the same feature being enhanced). Taking into account others' focus of attention, however, may be beneficial for predicting and understanding their behavior during more complex social interactions. It has been argued, for instance, that effortless perspective-taking and the co-representation of another person's task may serve to establish the common ground (Clark, 1996; Sebanz, Knoblich, Prinz, & Wascher, 2006) that is needed for successful cooperation.

Our findings extend previous research on joint attention and perspective taking (Böckler et al., 2012; Samson et al., 2010; Tversky & Hard, 2009) in showing that a co-actor's attentional focus is represented even when perceptual relations (visual perspectives) and intentional relations (tasks) do not differ. More specifically, the present results are the first to show that specifying a co-actor's focus of attention as part of representing his or her tasks affects how people attend to and process their own stimuli. Generally increased RTs for different foci of attention indicate that participants represented what feature their co-actors needed to focus their attention on, making it more difficult for participants to select and apply their own attentional focus. The conflict in the level of selecting and applying the appropriate focus was reflected in less focused attention in early stages of stimulus processing (P1) and in higher demands on monitoring response initiation (P3) when the other held a different attentional focus. Neither RTs nor electrophysiological components provided evidence that participants shifted their attentional focus toward the focus of the other when attentional foci differed. Furthermore, participants did not adopt the other's attentional focus on nogo trials, suggesting that none of the observed effects were due to task-switching costs.

The present study adds to the joint action and joint attention literature that has shown how social interaction shapes our attention and perception (Brennan, Chen, Dickinson, Neider, & Zelinsky, 2008; Richardson & Dale, 2005; Richardson, Dale & Kirkham, 2007; Welsh, Higgins, Ray, & Weeks, 2007). People are sensitive to others' attentional relations to the environment even when perceptual relations and task are identical. Returning to the chocolate factory, this suggests that you do take into account what your colleague is focusing on. While this does not make you adopt her attentional focus, it affects how you attend to the scene and how you process task-relevant stimuli. Although the present study used interference as a measure of the extent to which a co-actor's focus was considered, taking into account others' attentional relations in joint settings may be beneficial in everyday life. Representing what a co-actor does, perceives, and attends to may facilitate joint actions by helping actors establish (procedural) common ground from which each other's actions can be understood, predicted, and complemented (Clark, 1996; Knoblich, Butterfill, & Sebanz, 2011; Sebanz, Bekkering, & Knoblich, 2006).

Original manuscript received 26 November 2011
Revised manuscript accepted 19 March 2012

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