Shifting Attention: ERP Correlates of Action Orientation in Processing Behaviorally Irrelevant Information

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The present study examines the role of interindividual personality differences in the modulation of the inhibition of return effect (IOR) by means of event-related potentials (ERPs). The IOR mechanism protects humans from reattending to already scanned visual locations and is suggested to be modulated by interindividual differences in action control. Action-oriented individuals are more skilled at the efficient use of action control strategies compared with state-oriented subjects. They confine their attention to behaviorally relevant information, and inhibit the processing of irrelevant information more efficiently than state-oriented individuals. The results of this study revealed that, as expected, IOR developed faster in action-oriented subjects. In the cue-evoked ERPs, this behavioral effect was reflected in a shorter latency of the N2. Thus, behavioral and electrophysiological data indicated more efficient inhibitory mechanisms in action- compared with state-oriented individuals. Group differences were especially pronounced in target processing and early sensory cue processing (N1, P1). These results support the theory of action control: Action-oriented individuals are more efficient in activating prefrontal top-down control and better at inhibiting behaviorally irrelevant information compared to state-oriented individuals, which can also be shown at the physiological level.

Keywords: action- and state orientation, inhibition of return, posterior parietal cortex, prefrontal cortex, spatial attention control

Response latencies to stimuli presented in the visual field are reduced when these stimuli are preceded by a visual cue at the same location. However, this priming effect only occurs within short time intervals between cue and target presentation (stimulus onset asynchrony: SOA).

For longer cue-target intervals, the priming effect turns into the "inhibition of return (IOR)" effect (Posner & Cohen, 1984), meaning RTs to targets at the cued location are prolonged relative to uncued targets. This IOR effect is restricted to tasks with uninformative cues, that is, cues which are not predictive of the subsequent target position (Wright & Richard, 2000). The SOA sufficient to generate the IOR effect is referred to as crossover point (McDonald, Ward, & Kiehl, 1999). This crossover point depends on several factors such as task difficulty (Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999) or response modality (Briand, Larrison, & Sereno, 2000). Additionally, Wascher, Falkenstein, and Wild-Wall (2011) associated earlier development of the IOR effect with more efficient control of irrelevant information. Though the underlying mechanisms of the IOR phenomenon

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are still not completely understood, there is evidence that both motor and attentional processes are influenced (Kingstone & Pratt, 1999; Taylor & Klein, 2000). Along this line, the basic idea behind the IOR concept deals with the facilitation of the visual search process in the case that an attentional shift back to a recently attended but uninformative location is inhibited (Klein, 1988; Klein, 2000; Posner & Cohen, 1984). This assumption is confirmed by results of electrophysiological studies using target-evoked event-related potentials (ERPs). These studies show that targets at a previously cued location lead to a reduction of early sensory ERP components in comparison with targets at uncued positions (McDonald et al., 1999; Wascher & Tipper, 2004).

Changes in the time course of the IOR effect have been shown in neurological (see, e.g., Couette, Bachoud-Levi, Brugieres, Sieroff, & Bartolomeo, 2008; Possin, Filoteo, Song, & Salmon, 2009) and psychiatric disorders (Dai & Feng, 2009; Liu et al., 2010; Nelson, Early & Haller, 1993). In this line, Wascher et al. (2011) only recently found variations in the development of the IOR effect attributable to age. By analyzing the cue-evoked ERPs, the authors demonstrated that this effect was reflected, among others, by the absence of the frontocentral N2, an ERP component that reflects inhibition and cognitive control (Falkenstein, 2006; Falkenstein, Hoormann, & Hohnsbein, 1999; Karch et al., 2010). However, in addition to health status and age, the IOR effect may be modulated by motivation and interindividual personality differences which influence inhibitory control processes. Against this background, we examined the impact of interindividual differences in action control on the IOR effect. According to Kuhl's "Theory of Action Control" (Kuhl & Goschke, 1994), the term "action control" refers to all psychological processes which mediate the formation, maintenance, implementation and disengagement of intentions. Action control describes the selective processing of information relevant to intention combined with the filtering and inhibition of irrelevant information. In this context, the term "intention" encompasses mental representations of action plans that cannot be carried out immediately. Action control is then required to postpone the execution of a certain action to a defined future situation and to retain the intention for this action. Moreover, action control is essential if a conflict emerges between two competing action tendencies. Thus, the implementation of action control strategies is necessary, for instance, when an intended action competes against an automatic action impulse for execution (Jostmann & Koole, 2010; Kuhl, 1994). In this context, the action control theory specifies several volitional strategies that facilitate the cognitive maintenance and enactment of intentions. One example of these action control mechanisms is "attentional control," which we measured with the IOR and which is the focus of the current study (for a more detailed description of the other control mechanisms please see Kuhl & Goschke, 1994). Individuals differ markedly in the extent to which they employ these action control mechanisms. To account for these differences, action control theory describes two modes of action control: action and state orientation. Action orientation is a change-promoting mode of control and can be characterized as the ability to facilitate the implementation of context-appropriate actions by the efficient use of volitional action control strategies. State orientation instead is defined as a change-preventing mode of action control, in which flexible and contextually appropriate behavior is impaired as a result of the deficient use of volitional action control strategies. In previous studies, it has been shown that action-oriented subjects outperform state-oriented individuals when subjects have to terminate decision processes and initiate intended actions. Personality differences in action control are especially influential in situations involving time pressure (Stiensmeier-Pelster, 1994) and persisting task duration (Kuhl & Beckmann, 1994). More recently, it was shown that action-oriented individuals performed better than state-oriented individuals in conditions of depleted self-control resources (Gröpel, Baumeister, & Beckmann, 2014) or in highly demanding Stroop task conditions (e.g., when Stroop trials included an additional task; Jostmann & Koole, 2007). Moreover, state-oriented individuals under high cognitive load had longer latencies when they themselves had to choose which of two goals to pursue, compared with a condition in

which the goal to be pursued was externally cued (Kazen, Kaschel, & Kuhl, 2008). Additionally, Fischer, Plessow, Dreisbach and Goschke (2015) showed that even low-level, bottom-up-driven processes of self-control such as conflict adaptation are systematically moderated by individual differences in control modes in a number version of the Simon task. Based on these previous studies and according to assumptions made by the action control theory, we expected differences in the time course of the IOR effect between action- and state-oriented subjects. In our IOR task, subjects had to form and follow the intention to respond as fast as possible to a target stimulus and to defend this intention against the competing impulse to attend the cued location. We assumed that IOR develops earlier in action-oriented subjects, because action orientation goes along with faster and easier action initiation as well as better conflict resolving capacities regarding competing behavioral impulses. We further hypothesized that differences in the time course of the IOR effect can be attributed to differences in action control related to the sensory processing of the cue stimulus. Though uninformative, the cue is a salient visual stimulus that cannot be completely excluded from being processed. Thus, efficient attentional control is expected to lead to faster cue processing and, subsequently, to an earlier inhibition of the uninformative cue. To test these assumptions, we investigated IOR task performance in action- and state-oriented individuals while recording electrophysiological ERP data using an electroencephalogram (EEG). By analyzing cue-evoked ERPs, we expected to find differences between action- and state-oriented subjects in ERP components reflecting early sensory processing (P1, N1; Hillyard & Anllo-Vento, 1998; Gómez, Vázquez, Vaquero, López-Mendosa, & Cardozo, 1998), and in the inhibitory frontocentral N2 (Falkenstein, 2006; Falkenstein et al., 1999; Wascher et al., 2011).

Method

Participants

Forty-two young adults (27 female/15 male) from 19 to 28 years of age (23.2 ± 2.5) partic-

ipated in the study. Participants took part in return for course credits or a payment of 20€. All participants were right-handed, had normal or corrected-to-normal vision, and no history of psychiatric or neurological diseases (see Table 1, for demographics and test scores). As can be gathered from Table 1, there are some marginal differences between groups with regard to age, depression and handedness. Because of the relative small sample in this ERP-study, we decided to leave them unconsidered in our analyses.

To assess the interindividual differences regarding action and state orientation, we used the "Action Control Scale (ACS-90)" developed by Kuhl (1981, 1994), which distinguishes between different types of action and state orientation. For the purpose of this study, we used the decision-related subscale (AOD) of the ACS because of its association with decision making and initiative regarding the implementation of prospective intentions (Kuhl, 1994). The subscale consists of 12 items, each of which describes a challenging situation and an action-versus state-oriented way of coping with it. For example, "When I know I must finish something soon: (a) I have to push myself to get started (i.e., state orientation) or (b) I find it easy to get it over and done with (i.e., action orientation)." Action-oriented choices were coded as 1 and state-oriented choices as 0. Higher sum scores in the form of a continuous variable indicate more action orientation. For descriptive reasons, we classified participants according to

Table 1
Participants' Characteristics

Measure	Action oriented group		State oriented group		$F(1, 40)$	p
	M	SE	M	SE		
Age	24.0	.575	22.7	.566	2.927	.095
AOD	8.4	1.690	2.8	1.721	113.944	<.001
CES-D	9.6	1.513	14.5	2.209	3.357	.074
Beck Depression Inventory	5.3	1.035	8.5	1.410	3.235	.080
EDI	92.0	3.039	80.4	4.982	4.003	.052

Note. The Center for Epidemiological Studies–Depression Scale (CES-D) is from Lewinsohn, Seeley, Roberts, and Allen (1997); the Beck Depression Inventory is from Hautzinger, Bailer, Worall, and Keller (1995); Edinburgh Handedness Inventory (EDI) is from Oldfield (1971).

the proposed cut-offs, either as action-oriented (AOD >5: 13 women, 8 men), or as state-oriented (AOD ≤5: 14 women, 7 men). The ACS-90's validity and reliability have been well established (Dieffendorff, Hall, Lord, & Strean, 2000; Kuhl, 1994).

Before taking part in the study, each participant gave written informed consent. The study was approved by the local ethics committee.

Stimuli and Experimental Procedure

We used a modified version of the inhibition of return task by Wascher and Tipper (2004) (see Figure 1).

Two symmetrically positioned white square frames were presented on a black background. Their inner edges were located either 2.21° (small frames) or 1.72° (large frames) above or under a white fixation cross. At the beginning of each trial, one of the two squares was replaced by a bold yellow square. This cue disappeared after 50 ms. Subsequently,

the target stimulus was presented at 50, 130, 270, 380, 550, 750, 980, or 1240 ms after cue onset in one of the two squares. The target stimulus was a diagonal cross with the same thickness and color as the cue. It was presented for 200 ms. As the cue position was not indicative of target position (50% validity), targets were presented at the cued and uncued position in a pseudorandom order. Subjects had to indicate as fast as possible at which position the target stimulus appeared. They had to press an upper button with the right hand when the target was presented in the upper square, and a lower button with the left hand when it was presented in the lower square. The left or right response hand use was counterbalanced across subjects. Overall, 1600 trials were presented: 40 trials for each SOA, target position and cued/uncued condition. To minimize response anticipation errors, 20% of the trials were catch trials, that is, no target was presented after cue presen-
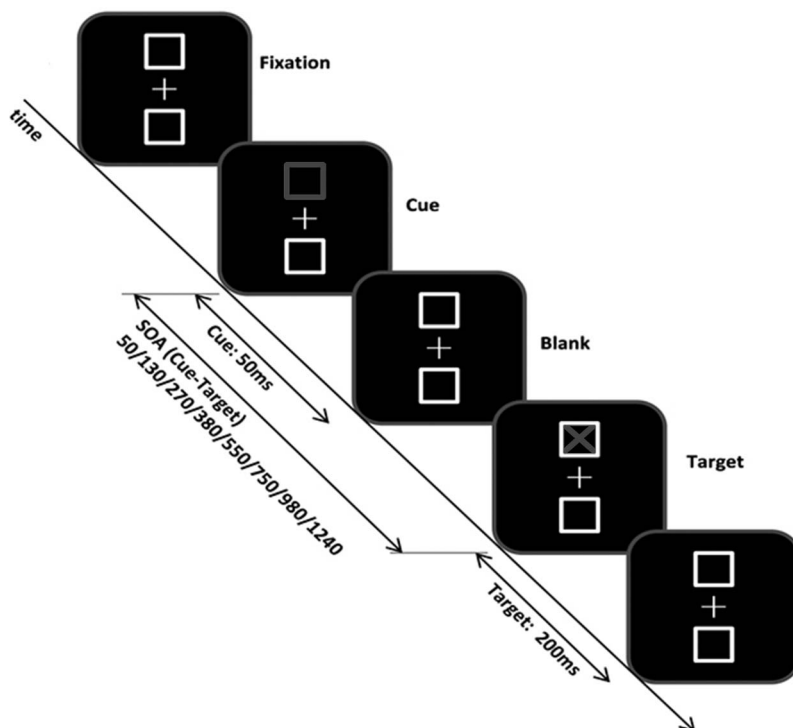

Figure 1. Experimental procedure in the inhibition of return task. The uninformative cue stimulus (grey frame) was followed by the target stimulus (grey cross) with varying SOAs. Subjects had to indicate the position at which the target occurred with a speeded response.

tation. The intertrial interval varied between 800 and 1200 ms. If no response was given, or in catch trials, the interval between the presentations of two subsequent cues was 2000 ms. Breaks were set automatically after every 400 trials. The task took about 60 minutes.

EEG Data Processing

While subjects performed the IOR task, EEG signals were recorded from 65 Ag-AgCl electrodes using standard positions (FCz, FP1, FP2, F7, F3, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, PO10, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT9, FT7, FC3, FC4, FT8, FT10, C5, C1, C2, C6, TP7, CP3, CPz, CP4, TP8, P5, P1, P2, P6, PO7, PO3, POz, PO4, PO8) according to the extended 10/20 system (Pivik et al., 1993). Electrode FCz was used as the primary reference. The sampling rate of all recordings was 1kHz (filter bandwidth: 0.05-80Hz). Electrode impedances were kept below 5kΩ (filter bandwidth: 0.5 – 20Hz). Before data filtering, the sampling rate was reduced to 256Hz. The filtered data were visually inspected and trials contaminated by technical artifacts were rejected. Subsequently, eye movements were corrected in the EEG using independent component analysis (ICA) (infomax algorithm) applied to the unsegmented data. Segments with a length of 2000 ms (-500 ms to 1500 ms with respect to cue onset) were defined to analyze cue-evoked activity. Baseline was set to 250 to 50 ms preceding the cue stimulus. To rule out any differences between action- and state-oriented subjects in the IOR task related to differences in early sensory attention components of target processing, we additionally examined the target-evoked P1/N1 complex that has been shown to be associated with cueing effects (McDonald et al., 1999; Wascher & Tipper, 2004). Segments with a length of 1250 ms (-250 ms to 1000 ms with respect to the onset the target stimulus) were defined for each SOA and cued/ uncued condition. Baseline was set to 250 ms to 50 ms preceding the target stimulus. Artifact rejection for cue- and target-evoked ERPs was performed semiautomatically with an amplitude threshold of $\pm$ 80 μV. Before ERPs were quantified, we calculated the current source density (CSD) of the signals to achieve a reference-free evalua-

tion (Nunez et al., 1997; Perrin, Pernier, Bertrand, & Echallier, 1989) using the following parameters: order of splines m = 4, and maximum degree of the Legendre polynomials n = 10, with a precision of 2.72^{-7}. The exact mathematical procedure is explained in detail in Perrin et al. (1989).

Behavioral Data

For the behavioral data, RTs below 100 ms and above 1000 ms were defined as errors and excluded from further analyses. Mean RTs were analyzed with a repeated measures ANOVA with the within-subjects factors "cueing" (cued vs. uncued) and "SOA" (50, 130, 270, 380, 550, 750, 980, 1240 ms) and the between-subjects factor "group" (action vs. state orientation). To determine whether the onset of the IOR effect varied among action- and state-oriented individuals, we calculated the IOR effect score by subtracting RTs in the cued from RTs in the uncued condition for each SOA (uncued-cued). The IOR effect score was analyzed in a repeated measures ANOVA with "SOA" (50, 130, 270, 380, 550, 750, 980, 1240) as within-subjects factor and "group" (action vs. state orientation) as between-subjects factor. For error analysis, a repeated measures ANOVA was conducted with the within-subjects factors "cueing" and "SOA" and the between-subjects factor "group." Besides post hoc test ANOVAs, t tests were applied to further analyze significant interactions. Significances were Bonferroni- and Greenhouse-Geisser-corrected, if necessary. The significance level was $p < .05$ for all statistical tests for behavioral and neurophysiological data. Mean (M) and standard error (SEM) are indicated ($M \pm SEM$). All analyses were computed with Predictive Analytics Software (PASW) 18.0.

Cue Processing

Subsequent to averaging, P1, N1, and N2 were calculated time-locked to the cue stimulus. Cue analysis was restricted to SOAs from 550 ms to 1240 ms to exclude a potential overlap of target-evoked ERPs. P1 was defined as the most positive peak between 20 ms and 100 ms after cue onset. N1 was defined as the most negative peak between 50 ms and 150 ms, and frontocentral N2 was defined as the most negative peak between 350 ms and 450 ms after cue

onset at FCz. All cue-related peaks were analyzed relative to baseline. According to the scalp topographies, amplitudes and latencies for the ERPs were calculated: P1 was calculated at electrodes P7 and P8, N1 was quantified at electrode Oz, and N2 was measured at electrode FCz.

Amplitudes and latencies for each ERP were measured separately for each group. Neurophysiological data of cue-evoked P1, N1, and N2 were analyzed separately. The cue-related P1 data was analyzed in a repeated measures ANOVA with the within-subjects factor "electrode" (P7, P8), and "group" (action vs. state orientation) as the between-subjects factor. Data of the cue-evoked N1 and N2 was analyzed in separate one-way ANOVAs using the factor "electrode" as within-subjects factor (N1: electrode Oz; N2: electrode FCz) and "group" (action vs. state orientation) as the between-subjects factor.

Target Processing

The target-evoked P1 was defined as the most positive peak until 100 ms after target onset, and the target-evoked N1 as the most negative within 50 to 150 ms after target onset. Target-related peaks were analyzed peak to peak. According to the scalp topographies, the ampli-tudes were quantified at PO7 and PO8. The analyses focused on these electrodes, because early visual processing is most pronounced in this region. Data of the target-related P1/N1 complex was analyzed in a repeated measures ANOVA with the within-subjects factors "SOA" (380 ms/550 ms/750 ms/980 ms), "cueing" (valid/invalid) and "electrode" (PO7/PO8) and the between-subjects factor "group" (action vs. state orientation).

Results

State and Action Orientation

According to the norm values of the ACS-90 (Kuhl, 1994), subjects were assigned either to the action-oriented ($N = 21$) or to the state-oriented group ($N = 21$).

Behavioral Data

Figure 2a presents the mean correct RTs for each SOA separately for action and state orientation analyzed by the two cueing conditions. A repeated measures ANOVA for RTs revealed a main effect of "cueing," $F(1, 40) = 20.16$; $p < .001$, with RTs overall faster in cued (418.49 ± 7.03) than in uncued trials (425.68 ± 7.08). Further, a main effect of "SOA" was found,

F2

Figure 2. (a) Reaction times (in ms) in the inhibition of return task. Separate for action- and state-oriented subjects for the uncued and cued condition. (b) IOR effect score (RTs uncued – RTs cued) for action- and state-oriented subjects. Positive values mean priming, negative values mean inhibition. * $p < .05$. *** $p < .001$. See the online article for the color version of this figure.

$F(7, 280) = 30.19$; $p < .001$, with RTs decreasing from SOA 50 ms to 270 ms and then increasing again from SOA 380 ms to 1240 ms. No main effect of "group" was evident ($p > .60$). "Cueing" varied with "SOA", $F(7, 280) = 35.086$; $p < .001$. This interaction reflected the typical IOR effect characterized by increasing RTs accompanying increasing SOAs in the cued compared to the uncued condition. Moreover, a significant three-way interaction "Cueing" × "SOA" × "Group," $F(7, 280) = 2.26$; $p < .05$; $\eta^2 = .053$ was obtained. As revealed by effect sizes in two separate post hoc repeated measures ANOVAs for state- and action-oriented subjects, RTs decreased slower with increasing SOAs in state-oriented subjects (state-orientation: $\eta^2 = .43$; action-orientation: $\eta^2 = .45$).

Two separate post hoc ANOVAs for cued and uncued trials provided a "SOA" × "Group" interaction, $F(7, 280) = 3.038$; $p < .01$; $\eta^2 = .071$ for uncued trials only. Whereas action-oriented subjects' RTs decreased across SOAs from 428.52 to 418.24 ms, state-oriented participants showed a more pronounced decrease from 445.56 to 424.68 ms.

Additionally, a significant interaction of "Cueing" × "Group," $F(1, 40) = 4.71$; $p < .04$, was discovered, with state-oriented subjects slower in uncued than in cued trials (uncued: 432.93 ± 9.56; cued: 422.21 ± 9.44), $t(20) = -4.55$; $p < .001$. This effect did not occur in the action-oriented subject group (uncued: 414.69 ± 10.41; cued: 418.43 ± 10.46), $t(20) = -1.70$; $p > .10$.

The IOR effect score (RT uncued − RT cued) for both subject groups is presented in Figure 2b, where positive values describe a priming effect and negative values indicate the turnover from priming to IOR. A repeated measures ANOVA revealed a significant main effect of "group," $F(1, 40) = 6.94$; $p < .02$, wherein IOR developed earlier in action-oriented subjects (SOA 380ms) compared to state-oriented subjects (SOA 750). Further, a main effect of "SOA," $F(1, 40) = 18.04$; $p < .001$, was found, with difference scores decreasing as SOAs increased. Separate one-way ANOVAs for each SOA revealed that action- versus state-oriented subjects differed significantly in SOA 130 ms, $F(1, 40) = 5.26$; $p < .03$, and SOA 380 ms, $F(1, 40) = 16.06$; $p <$

.001. No significant interactions were obtained for the other SOAs (all $p > .05$).

The overall error rate in our IOR paradigm was below 3%. A repeated measures ANOVA with the within-subjects factors "cueing" and "SOA" and the between-subjects factor "group" revealed a main effect of "cueing," $F(1, 40) = 24,62$; $p < .001$, with subjects making less errors in the cued (1.61 ± 0.19) as opposed to the uncued condition (2.53 ± 0.31). Additionally, an interaction "Cueing" × "SOA" was found, $F(7, 280) = 4.28$; $p < .003$. Post hoc t tests revealed that this interaction was attributable to between-groups error differences in SOAs 50 ms $t(41) = -4.08$; $p < .001$, 130 ms $t(41) = -3.55$; $p < .009$) and 270 ms $t(41) = -3.30$; $p < .02$, wherein subjects made more mistakes in the uncued condition. No main effect of "group" and no other interactions were found regarding errors in our IOR task (all $p > .27$).

Neurophysiological Data

Cue-evoked ERPs. For the cue-evoked P1, neither amplitude nor latency varied with action versus state orientation (all $p > .86$). Likewise, neither N1 amplitude nor N1 latency varied between action versus state orientation (all $p > .80$). N2 as measured at electrode FCz peaked significantly earlier in action-oriented subjects (373.8 ± 7.8) than in state-oriented subjects (403.1 ± 8), $F(1, 41) = 6.85$; $p < .02$. No group effect was found for N2 amplitude, $F < 1$. Action-oriented subjects showed a mean amplitude of −4.815 mV ± 2.433, whereas state-oriented subjects showed a slightly pronounced amplitude of −5.064 mV ± 2.412. Figure 3 shows grand averages of the cue-evoked N2 for action- and state-oriented subjects.

Target-evoked P1/N1 complex. Because behavioral data revealed that turnover from priming to IOR was present at SOA 380 ms for action-oriented subjects and at SOA 750 ms for state-oriented subjects, we restricted the analysis of target-evoked P1/N1 effects to SOAs 380 ms to 980 ms.

A repeated measures ANOVA with the within-subjects factors "cueing," "SOA," and "electrode" and the between-subjects factor "group" revealed no effects for P1 latency (all $p > .29$). For P1 amplitude, a main effect of "SOA," $F(3, 123) = 5.12$; $p < .003$, was found, with higher
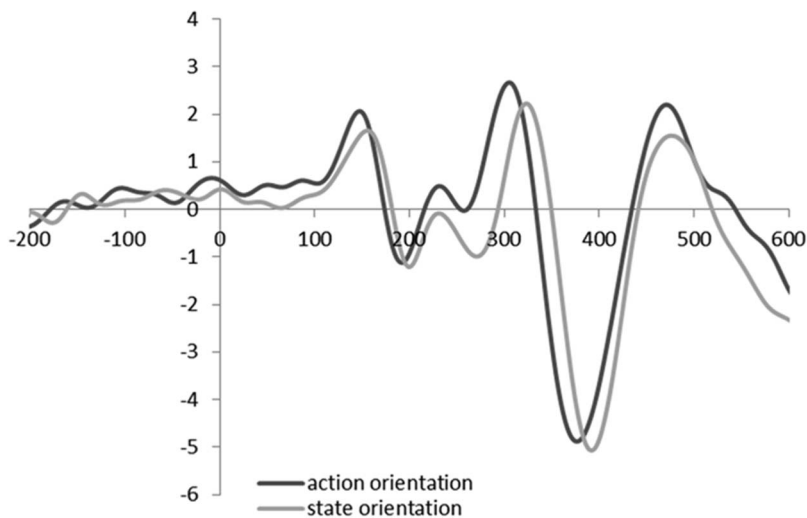
F3

Figure 3. Cue-evoked event-related potentials for the IOR paradigm. The N2 is shown at electrode FCz for action- and state-oriented subjects separately. Time point "0" denotes the point of cue presentation. Amplitudes are given in μV. Positivity is plotted upward.

amplitudes accompanying longer SOAs (380 ms: 10.28 ± 1.4; 550 ms: 8.14 ± 1.0; 750 ms: 11.16 ± 1.1; 980 ms: 10.9 ± 1.1). No main effect of group (action vs. state orientation), $F < 1$; and no interactions with action orientation were discovered (all $p > .08$). For N1 latency, an interaction between channel and action orientation became apparent, $F(1, 41) = 4.454$; $p < .05$. Post hoc t tests evidenced that this interaction was attributable to marginal between-groups latency differences at PO8, $t(41) = 1,86$; $p = .071$. Accordingly, action-oriented subjects showed longer N1 latencies (214.31 ± 17.6) compared with state-oriented individuals (202.33 ± 24.3; see Figure 4).

For N1 amplitude, the analysis revealed main effects of "SOA," $F(3, 123) = 6.181$; $p < .01$, and "cueing," $F(1, 41) = 5.539$, $p < .05$. These effects indicated that amplitudes were less pronounced with longer SOAs (380 ms: −18.46 ± 2.1 mV; 550 ms: −18.98 ± 2.1 mV; 750 ms: −15.71 ± 2.0 mV; 980 ms: −17.681 ± 2.1 mV) and also less pronounced in uncued

(−16.89 ± 2.1 mV) compared to cued trials (−18.53 ± 1.9 mV). Additionally, a marginally significant interaction between "Action orientation" × "Electrode" × "SOA" × "Cueing" was discovered, $F(1, 41) = 3,671$, $p = .062$. Post hoc t tests revealed that this interaction was due to cue-evoked N1 amplitude differences at electrode PO8 for state-oriented subjects in SOA 380 ms only, $t(20) = −1,901$; $p = .072$, wherein state-oriented subjects showed less negativity in uncued compared to cued trials. A reversed pattern was apparent in SOA 980ms, $t(20) = 2.825$; $p < .05$, (see x-intercept, Figure 5). For action-oriented subjects, no differences between cued and uncued trials in any SOA were evident (see Figures 4 and 5).

F5

Discussion

In the current study, the impact of interindividual differences in action control on the IOR effect was examined. IOR was shown to occur earlier, at SOA 380, in action-oriented compared

F4

Figure 4 (opposite). Event-related potentials (ERPs) at posterior electrodes (PO7, PO8) for the cued und uncued condition. The data are presented as a function of the four stimulus onset asynchronies (SOA), superposed for state-oriented (dark colored; blue) and action-oriented (light colored; red) in the cued (dashed line) and uncued (continuous line) condition. All profiles are time-locked to target onset. See the online article for the color version of this figure.
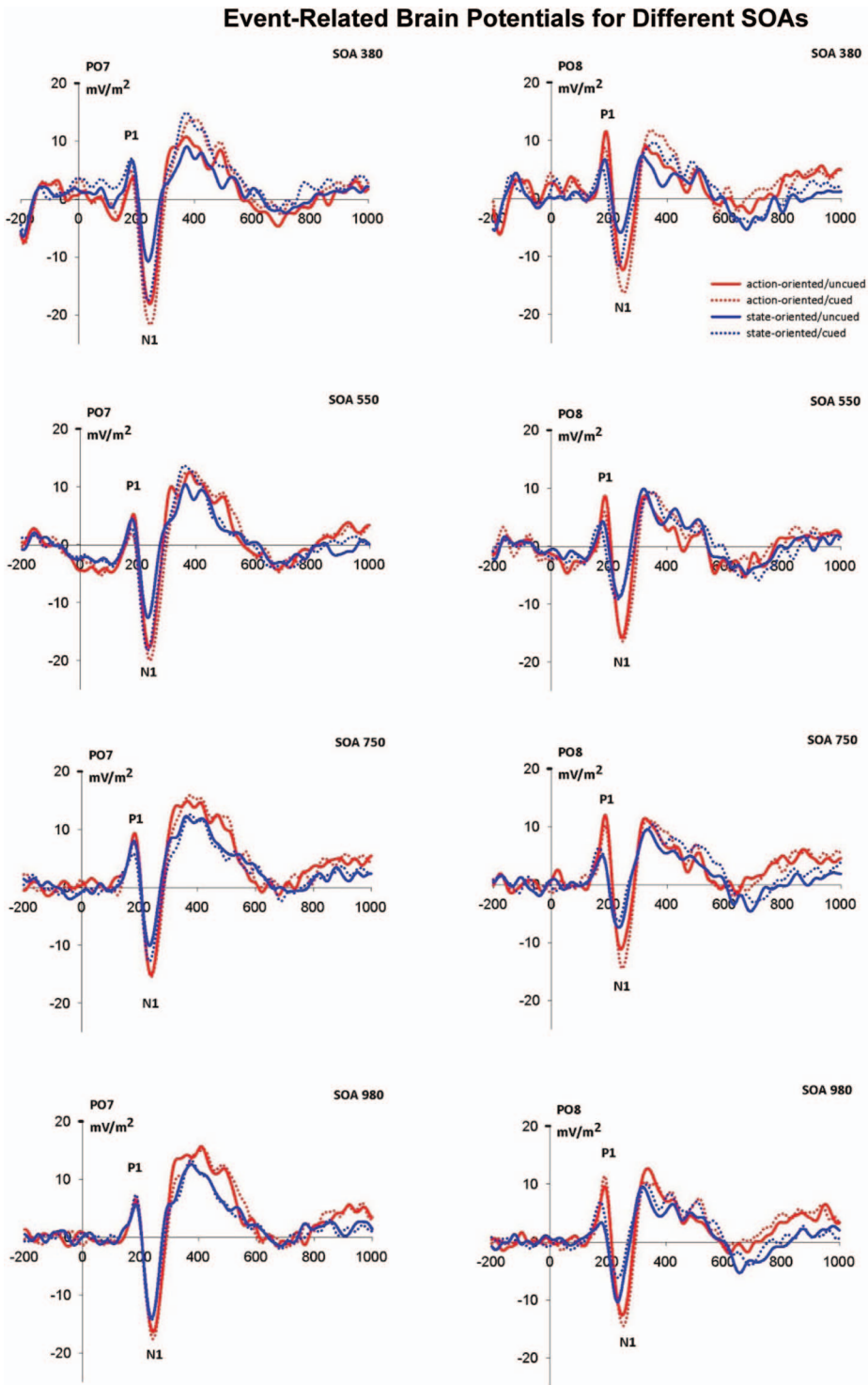
Event-Related Brain Potentials for Different SOAs
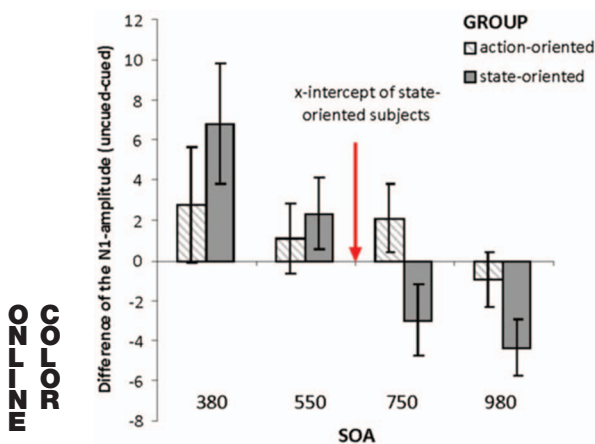
Figure 4 (opposite).

Figure 5. Mean differences (uncued-cued) of the N1 amplitudes for different stimulus onset asynchronies (SOA) and the two groups at electrode PO8. All profiles are time-locked to target onset. See the online article for the color version of this figure.

with state-oriented subjects, in which it occurred later, at SOA 750. This suggests that the IOR mechanism is less efficient in state-oriented subjects. As reflected by the ERP data, this effect is attributable to differences in cue processing, as a shorter latency of the cue-evoked N2 was observed in action-oriented subjects.

Our results can be interpreted against the background of previous research. Interindividual differences in IOR onset have also been discovered with respect to other interindividual variables such as age, wherein IOR developed later in elderly people (Wascher & Beste, 2010). This behavioral effect was also reflected in ERP differences: Elderly people displayed a markedly reduced cue-evoked frontocentral N2 amplitude combined with an enhanced P300 amplitude. Because the frontocentral N2 is commonly known to reflect inhibition processes (e.g., Falkenstein et al., 1999; Falkenstein, 2006), Wascher and Beste (2010) explained the ERP differences in their study in terms of ineffective inhibition of cue processing (reduced N2) in conjunction with an intensified processing of the uninformative cue information (enhanced P300). In line with the study by Wascher and Beste (2010), later IOR development in the state-oriented subjects in our study can also be explained by differences in cue processing. Yet, we did not find a difference in the amplitude of the cue-evoked frontocentral

N2, but instead a significant reduction of the N2 latency in action-oriented subjects. Because the cue in our IOR paradigm is uninformative, that is, it only predicts the target position in 50% of the trials, the best strategy for the subjects is to ignore the cue and to inhibit its processing. Accordingly, the earlier cue-evoked frontocentral N2 amplitude peak in the action-oriented subjects group may reflect a more efficient selective attentional mechanism in visual search. In general, by suppressing the orientation toward previously inspected locations and objects early on, IOR encourages the orientation toward novelty (Posner & Cohen, 1984) and can consequently serve as a search or foraging facilitator (Itti & Koch, 2001; Klein, 1988; Klein & MacInnes, 1999). As stated by Wascher and Beste (2010), the time course of the IOR effect is modulated by the efficient control of cue information and by the amount of attention paid to the cue. Accordingly, earlier IOR development combined with the forward shift of the cue-evoked frontocentral N2 in the action-oriented subject group can be accounted for by superior cognitive control mechanisms, which bias performance against responding to stimuli from the cued location (see Ivanoff & Taylor, 2006). Importantly, the later N2 in the state-oriented subjects did not lead to a complete lack of the IOR effect, but only to a delayed inhibition of the uninformative cue information.

As shown in several studies, the source of the N2 is located in brain areas related to inhibition processes and attentional control such as the anterior cingulate cortex and the right orbitofrontal cortex (see, e.g., Botvinick, Braver, Barch, Sarter, & Cohen, 2001; Aron et al., 2004; Bekker, Kenemans, & Verbaten, 2005; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Wascher et al., 2011). Accordingly, the earlier N2 peak in the action-oriented subjects group may reflect faster inhibition of cue processing, leaving more attentional resources for further target processing and reaction.

Additionally, in contrast to action-oriented subjects, state-oriented individuals seem to inhibit the processing of (irrelevant) stimuli in their visual field more slowly. This may lead to a more ineffective selection algorithm and a perseveration tendency, which generates some costs in the case of uncued, goal-oriented performance.

However, our results also revealed ERP group differences regarding sensory processing components (N1; Gomez Gonzalez, Clark, Fan, Luck, & Hillyard, 1994; Herrmann & Knight, 2001; Wascher & Beste, 2010). Based on our pattern of results, it could be postulated that the interindividual difference of being state- or action-oriented influences higher order top-down strategies, while at the same time also impacting sensory bottom-up processes, especially in the right hemisphere (PO8). The modulation of top-down mechanisms as observed in action-oriented subjects has also been shown in various studies in the past using induction by extrinsic motivational manipulations. In this line, Sänger and Wascher (2011), for instance, recently showed that monetary incentives lead to an enhancement of the N2pc, a component reflecting higher level cognitions in a change detection paradigm.

Furthermore, it has been postulated in the past that modulations of the early sensory N1 component can be selectively found in the right hemisphere of state-oriented individuals. Moreover, the right hemisphere is especially relevant for the discrimination of attended stimuli when only restricted mental processing capacities are available (Ritter, Simson, & Vaughan, 1988; Mangun & Hillyard, 1991; Vogel & Luck, 2000; Hopf et al., 2004). In addition, the N1 component seems to indicate a more precise perception and processing of a cue at a specific location. (Luck, Heinze, Mangun & Hillyard, 1990). Accordingly, state-oriented subjects seem to bind their spatial attention to the cued target location before IOR development (greater N1 component for cued trials). In contrast, this location biases attentional changes in favor of the uncued position after IOR occurrence. This effect seems to be based on processing mechanisms located in the posterior parietal cortex (PPC), measurable at electrode PO8. According to Knudsen (2007), the PPC along with the prefrontal cortex (PFC) constitute essential brain areas needed for spatial working memory abilities. Additionally, it is postulated by several authors that activity in the PPC represents the relative saliency of all stimuli and, besides that, motor intentions for actions (Bisley & Goldberg, 2003). This system thus controls processes that play a key role in priming. In contrast to this, negativity in the PFC seems to reflect the detection of deviations in the physical characteristics of serially presented cues (Näätänen, 1992) and should therefore facilitate the process of inhibition. However, because its activity persists to a lesser extent than that of the PFC, the PPC is more prone to distractions (Powell & Goldberg, 2000; Fuster, 1995). The results of our study suggest that action-oriented, as opposed to state-oriented individuals, are more efficient in activating goal-induced, strategic top-down control. Further research in this framework should aim to determine the endogenous motivational processes at play, as well as to replicate the findings elaborated post hoc in this paper.

Additionally, as mentioned in the Method section above, the groups differed marginally with respect to age, depression, and handedness. Further studies with greater samples should elucidate the potential explanatory contribution of these variables, which was not taken into account in the current study.

In conclusion, our data suggest that action and state orientation modulate basic sensory as well as higher order top-down inhibitory processes. In the IOR paradigm used, action-oriented subjects seem to robustly represent a target that is stored in working memory via prefrontal cortex activity leading to a very efficient inhibition of the uninformative, behaviorally irrelevant cue (N2). In contrast, state-oriented subjects show a less efficient inhibition and a specific modulation of the activity of the PPC from cued to uncued trials when the IOR effect occurs.

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