Lateralization of spatial information processing in response monitoring

Ann-Kathrin Stock* and Christian Beste
Cognitive Neurophysiology, Department of Child and Adolescent Psychiatry, TU Dresden, Dresden, Germany

The current study aims at identifying how lateralized multisensory spatial information processing affects response monitoring and action control. In a previous study, we investigated multimodal sensory integration in response monitoring processes using a Simon task. Behavioral and neurophysiologic results suggested that different aspects of response monitoring are asymmetrically and independently allocated to the hemispheres: while efference-copy-based information on the motor execution of the task is further processed in the hemisphere that originally generated the motor command, proprioception-based spatial information is processed in the hemisphere contralateral to the effector. Hence, crossing hands (entering a "foreign" spatial hemifield) yielded an augmented bilateral activation during response monitoring since these two kinds of information were processed in opposing hemispheres. Because the traditional Simon task does not provide the possibility to investigate which aspect of the spatial configuration leads to the observed hemispheric allocation, we introduced a new "double crossed" condition that allows for the dissociation of internal/physiological and external/physical influences on response monitoring processes. Comparing behavioral and neurophysiologic measures of this new condition to those of the traditional Simon task setup, we could demonstrate that the egocentric representation of the physiological effector’s spatial location accounts for the observed lateralization of spatial information in action control. The finding that the location of the physical effector had a very small influence on response monitoring measures suggests that this aspect is either less important and/or processed in different brain areas than egocentric physiological information.

Keywords: Simon task, response monitoring, spatial congruency, response evaluation, EEG, multisensory integration, proprioception

INTRODUCTION

In order to adequately interact with our environment, we constantly monitor our actions so that we can adjust them in case of undesired consequences (Logan, 1985; Strauss and Alexander, 2007; Fukui and Gomi, 2012). Properly doing so is a fairly complex endeavor because for a proper adjustment of the outcome, parameters of movements also need to be integrated in the process of response evaluation.

Given that different features (like speed, spatial position, applied force of the response, etc.) influence our movements, these parameters have to be integrated in the evaluation process (Pramanstra et al., 2009; Fukui and Gomi, 2012; Gonzalez and Burke, 2013; Stock et al., 2013). We recently investigated the effects of multimodal sensory integration in response monitoring processes by recording an EEG during a Simon task (see Stock et al., 2013 for details) and demonstrated that both proprioception-based spatial information and efference-copy-based information on the motor execution are integrated in the supplementary motor area (SMA) during response monitoring and evaluation. Among other things, this brain region has been associated with the processing of efference copies of motor commands (Noshige et al., 1988; Ikeda et al., 1995; Babloni et al., 2001; Haggard and Whitford, 2004; Baudot et al., 2012), egocentric proprioceptive information (Tarikka and Hallett, 1991; Hallett, 1994; Loayza et al., 2011), motor control (Angel, 1976; Wolpert and Flanagan, 2001; Allan et al., 2004; Ionardova et al., 2004; Feldman, 2009; Hoffmann and Falkenstein, 2010; Roger et al., 2010), and error monitoring (Petersen et al., 2011). However, we obtained an unexpected pattern of hemispheric activation by asking the subjects to either cross their hands or keep them parallel while responding: in parallel hands, only the SMA contralateral to the responding hand showed a negative deflection of event-related potentials (ERPs) around the time of the response while the SMA ipsilateral to the responding hand showed a positive activation.

As a result, the simple act of crossing one hand one over another reduced most of the differences in hemispheric activations/ERPs as the activity pattern of the hemisphere ipsilateral to the responding hand approximated that of the contralateral hemisphere. This suggests that in case of an unnatural posture (crossed hands) motor efference copies and motor proprioceptive information were allocated to the hemispheres according to different rules: efference-copy-based motor information seemed to be rather immutably locked to the hemisphere in which the motor command was initially processed. In contrast, the hemispheric allocation of proprioception-based spatial information was based on an external representation of space. As a result of these different lateralization mechanisms, crossing hands...
Stock and Beste

Effectors influence response evaluation

Manually entering a “foreign” spatial hemifield most probably resulted in a conflict, yielding an augmented bilateral activation and higher error rates.

Even though these findings seem to answer the question in which hemisphere the monitoring of motor and spatial information is allocated, the paradigm provided no possibility to determine whether the laterized allocation of spatial information during response monitoring was influenced by internal (proprioceptive) information about the position of the physiologic effector (hand) or by external (egocentric) information about the position of the physical effector (button).

In the current study, we aimed at answering this question. For this purpose, we modified the Simon task by introducing a “double crossed” condition. While the regular Simon task only encompasses a parallel-hands and a crossed-hands condition, our new double crossed condition required the subjects to also operate crossed levers in half of the trials. As a consequence, the effect site (button) which was pressed when crossing hands in lever responses was in a different hemifield than the responding hand so that the button was the same as during a regular parallel hands button response (see Figure 1 for further elucidation). Based on this dissociation of physiological effector (hand) and physical effect site (button), our question could be tackled: in case the spatial allocation of the hand is the relevant factor to the lateralization of response monitoring processes, parallel and crossed hands should yield comparable ERPs, irrespective of whether buttons or levers are used to respond. If however, the external effect site of the button was the critical feature, parallel-hands button responses should yield results similar to those of crossed-hands lever responses.

MATERIALS AND METHODS

SAMPLE

Right-handed participants (N = 21; ♀ = 11, ♂ = 10) were included in the study. The mean age was 23.2 years (min 19, max 32, SEM = 0.73) and none of the participants presented with a history of psychiatric or neurological disease. Handedness was confirmed by the Edinburgh Handedness Inventory (Oldfield, 1971), yielding an average score of 0.81 (min 0.25, max 1.0, SEM = 0.05). All subjects gave written informed consent and were treated in accordance with the declaration of Helsinki. Each participant was reimbursed with 15 €. The study was approved by the ethics committee of the medical faculty of the University of Bochum.

SETTINGS AND TASK

Because this study aims to extend previous findings reported by Stock et al. (2013), the settings and task were very similar to that study (see Stock et al., 2013 for details): participants were seated in front of a 17 in CRT computer monitor (at a distance of 57 cm) in a dimly lit and sound-attenuated room. Responses were made with four custom-made buttons mounted on a regular keyboard (see Figure 1 for illustration).

The Simon task originally references the task used by Wascher et al. (2001). Throughout the whole task, a white fixation cross and two horizontally aligned white frame boxes were continuously displayed in the center of a dark blue screen. The two boxes were at the same vertical level as the fixation cross (1.1° distance between fixation cross and the inner border of the frames). Each trial began with the simultaneous presentation of a target stimulus (a yellow capital letter “A” or “B”) and a noise stimulus (three white horizontal bars). Both target and noise stimuli were approximately

![Figure 1](https://example.com/figure1.png)

**FIGURE 1** The four different response conditions resulting from hand position (parallel vs. crossed) and button type (buttons vs. levers). When crossing hands, the participants were instructed to place the left arm (“marked” with two wristbands in the picture) on top of the right arm. In button responses, the physiological effector (hand) is in the same hemifield as the physical effector (button) so that their relevance for the hemispheric allocation of response monitoring processes cannot be determined. In contrast, the levers provide the necessary dissociation because the physical effector (button) is now located in a different hemifield than the physiological effector (hand). For mechanical reasons, buttons had to be pressed while levers had to be lifted.
Ag–AgCl electrodes at standard positions (international 10–20 system) for the settings and task, EEG data recording and data processing (see Stock et al., 2013 for details): an EEG was recorded from 65 channels in blocks 1, 3, 4, 7, and 8 (see Leuthold, 2011; Stock et al., 2013 for details). For statistical analysis, we extracted the mean electrode activity between 180 and 270 ms (the time frame was based on the negative peak and differences between the conditions; see Figure 2). For the analysis of response-locked ERPs, a baseline correction from −200 to 0 ms was run before the segments of the different conditions were averaged. Based on the topographic distribution of the activity and the literature relevant to this task, ERPs were formed for electrodes PO7 and PO8 (Praamstra and Oostenveld, 2003; Wiegand and Wiescher, 2005; Verleger et al., 2003; Cespon et al., 2013; Stock et al., 2013). For this purpose, the values of the hemisphere ipsilateral to the target stimulus site were subtracted from the values of the hemisphere contralateral to the target stimulus site (PO7–PO8 for stimuli presented on the right side and PO8–PO7 for stimuli presented on the left side) and averaged for both hands. For statistical analyses, we extracted the mean electrode activity between −40 and 60 ms (the time frame was based on the differences between the conditions; see Figure 3).

**STATISTICAL ANALYSIS**

Behavioral data (RTs and the number of hits/correct responses) were analyzed using repeated-measures analyses of variance (ANOVA). "Button type" (button responses vs. lever responses), "hand position" (parallel hands vs. crossed hands), and "congruency" (congruent vs. incongruent; codes whether the target stimulus was presented on the side where the responding hand was placed) were used as within-subjects factors. The electrophysiological stimulus-locked data was analyzed using repeated-measures ANOVA with the within-subjects factors "button type," "hand position," and "congruency." Because ERIs are based on the difference between the hemisphere contralateral and ipsilateral to the stimulus presentation site, there was no factor for side/hemisphere.

The electrophysiological response-locked data was analyzed in similar fashion using a repeated-measures ANOVA with the within-subjects factors "button type," "hand position," "congruency," and "executive hemisphere" (electrode above the hemisphere responsible for the motor execution of the response vs. electrode above the hemisphere irresponsible for the motor execution of
FIGURE 2 | The stimulus-locked ERPs for electrodes P7/P8 obtained by subtracting the ERP curve of the hemisphere ipsilateral to the stimulus presentation site from the ERP curve contralateral to the stimulus presentation site. Only factors yielding significant results are depicted. The left side of the figure shows the course of the curves; time point zero denotes the onset of stimulus presentation. The right part of the figure elucidates the significant differences found between the mean activity values which average the time span from 180 to 270 ms. The error bars indicate the respective SEMs; significant differences are marked with an asterisk.

FIGURE 3 | The stimulus-locked ERPs for electrodes FC1/FC2. Only factors yielding significant results are depicted. The upper parts of the figure show the course of the curves; time point zero denotes the response. The lower part of the figure elucidates the significant differences found between the mean activity values which average the time span from −60 to 60 ms. The error bars indicate the respective SEMs; significant differences are marked with an asterisk.
the response). Greenhouse-Geisser-correction was used whenever necessary. All p-levels for post hoc t-tests were adjusted using Bonferroni correction. Effect sizes were given as the proportion of variance accounted for ($\eta^2$). As a measure of variability, the standard error of the mean (SEM) together with the mean values was given.

**RESULTS**

**BEHAVIORAL DATA**

**Accuracy**

A repeated-measures ANOVA of the percentage of hits (within-subjects factors "button type," "hand position," and "congruency") revealed a significant main effect for "hand position" ($F(1,20) = 4.571; p = 0.045; \eta^2_p = 0.186") with more correct answers in parallel-hands trials (89.9% ± 1.653) than in crossed-hands trials (86.6% ± 1.506). There was also a significant main effect for "congruency" ($F(1,20) = 1.197; p < 0.001; \eta^2_p = 0.792") with more correct answers in congruent trials (91.8% ± 1.336) than in incongruent trials (83.7% ± 1.735). There was also a significant interaction of "button type" × "congruency" ($F(1,20) = 19.845; p < 0.001; \eta^2_p = 0.498"). Post hoc t-tests revealed that buttons yielded more correct responses than levers in congruent trials (t(20) = 2.255; p = 0.036; buttons: 94.5% ± 0.695 and levers: 89.2% ± 2.434) but not in incongruent trials (t(20) = -0.217; p = 0.831). Furthermore, there was a significant interaction of "hand position" × "congruency" ($F(1,20) = 6.961; p = 0.005; \eta^2_p = 0.326"). Post hoc t-tests revealed that there were more correct answers in parallel-hands trials than in crossed-hands trials only in incongruent trials (t(20) = 3.163; p = 0.005; parallel: 86.0% ± 1.904 and crossed: 81.5% ± 1.848) but not in congruent trials (t(20) = 0.262; p = 0.796).

**Response times**

A repeated-measures ANOVA of the RTs of correct responses (within-subjects factors "button type," "hand position," and "congruency") revealed significant main effects for all three factors: "hand position" significantly differed ($F(1,20) = 7.365; p = 0.015; \eta^2_p = 0.269") with correct parallel-hands responses being faster (442.3 ms ± 9.579) than correct crossed-hands responses (452.1 ms ± 10.247). There was also a significant main effect for "button type" ($F(1,20) = 27.793; p < 0.001; \eta^2_p = 0.581") with correct button responses being faster (436.1 ms ± 8.958) than correct lever responses (458.4 ms ± 10.914). The significant main effect for "congruency" ($F(1,20) = 73.787; p < 0.001; \eta^2_p = 0.787") was based on faster responses in congruent trials (435.8 ms ± 1.008) than in incongruent trials (457.8 ms ± 9.643). There were also a significant interaction of "button type" × "congruency" ($F(1,20) = 29.994; p < 0.001; \eta^2_p = 0.600") and a significant threshold interaction of "hand position" × "button type" × "congruency" ($F(1,20) = 7.547; p = 0.012; \eta^2_p = 0.274"). A post hoc repeated-measures ANOVA confined to lever responses only showed a significant main effect for "congruency" ($F(1,20) = 21.492; p < 0.000; \eta^2_p = 0.518") with RTs in congruent trials being faster (430.9 ms ± 11.724) than RTs in incongruent trials (456.8 ms ± 10.294). In contrast, the post hoc repeated-measures ANOVA confined to the button responses found a significant main effect for "congruency" ($F(1,20) = 117.445; p < 0.001; \eta^2_p = 0.854; congruent: 420.6 ms ± 8.632 and incongruent: 451.5 ± 9.490") as well as for "hand position" ($F(1,20) = 9.285; p = 0.006; \eta^2_p = 0.316; parallel: 428.7 ms ± 8.614 and crossed: 443.4 ± 9.902"). However, none of the ANOVAs showed a significant interaction ($p ≥ 0.129$).

**Summary of behavioral results**

Briefly summing up the behavioral results, significant interactions show that the subjects' hit rate was differently modulated across congruency: in congruent trials only, button responses had higher hit rates than lever responses while in incongruent trials only, parallel-hand responses had higher hit rates than crossed-hand responses.

Furthermore, a threshold interaction indicated that hit RTs were modulated by button type, congruency, and hand position: while congruency modulated the RT in both button and lever responses (congruent faster than incongruent), only button response RTs were additionally modulated by hand position (parallel faster than crossed).

**NEUROPHYSIOLOGICAL DATA**

**Stimulus-locked data**

Stimulus-locked data at electrodes PO7 and PO8 are depicted in Figure 2. A repeated measures ANOVA (within-subjects factors "button type," "hand position," and "congruency") of the mean ERP activity at electrodes PO7 and PO8 (stimulus-locked data; averaged from 180 to 270 ms) was run. It yielded a significant interaction of "hand position" × "congruency" ($F(1,20) = 7.968; p = 0.011; \eta^2_p = 0.285$). Post hoc t-tests showed that congruent trials produced a bigger/more negative ERP (~9.629 μV/m² ± 1.915) than incongruent trials (~7.612 μV/m² ± 1.980) in parallel-hand trials (t(20) = −3.669, p = 0.002) but not in crossed-hand trials (t(20) = 1.301, p = 0.208; see Figure 2 for visualization).

**Response-locked data**

Response-locked ERPs at electrodes FC1 and FC2 are depicted in Figure 3. A repeated measures ANOVA (within-subjects factors "button type," "hand position" "executive hemisphere," and "congruency") of the mean activity at electrodes FC1 and FC2 (response-locked data; averaged from −60 to 60 ms) was run. It yielded a significant main effect for "hand position" ($F(1,20) = 43.474; p < 0.001; \eta^2_p = 0.685") with a positive mean activity for correct parallel-hands responses (0.189 μV/m² ± 1.296) and a negative mean activity for correct crossed-hands responses (~4.094 μV/m² ± 1.197). The main effect for "executive hemisphere" was also significant ($F(1,20) = 189.227; p < 0.001; \eta^2_p = 0.904") with a negative mean activity over the executive hemisphere (~7.867 μV/m² ± 1.236) and a positive mean activity over the non-executive hemisphere (~3.962 μV/m² ± 1.321) during correct responses. There was a significant interaction for "hand position" × "congruency" ($F(1,20) = 5.220; p = 0.033; \eta^2_p = 0.207$). However, this interaction did not survive post hoc testing. Post hoc t-tests revealed that congruent and incongruent trials neither differed in the parallel-hands condition (t(20) = −1.869, p = 0.076) nor in

www.frontiersin.org January 2014 | Volume 5 | Article 22 | 5

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the crossed-hands condition \( t(20) = 1.523; p = 0.143 \). Likewise, there were significant differences between hand positions in both congruent \( t(20) = 4.775; p < 0.001 \) and incongruent trials \( t(20) = 5.937; p < 0.001 \). Furthermore, there was a significant interaction for "hand position" × "executive hemisphere" \( F(1,20) = 61.960; p < 0.001; \eta^2 = 0.756 \). Finally, there was a significant main effect for "executive hemisphere" × "button type" \( F(1,20) = 35.912; p < 0.001; \eta^2 = 0.642 \). A post hoc repeated-measures ANOVA confined the non-executive hemisphere found a significant main effect for "button type" \( F(1,20) = 62.058; p < 0.001; \eta^2 = 0.756; \) buttons: 3.912 \( \mu \)V/m2 ± 1.504 and levers: 4.012 \( \mu \)V/m2 ± 1.232) and significant interaction of "button type" × "hand position" \( F(1,20) = 10.191 \) \( p = 0.005; \eta^2 = 0.338 \). Tests revealed that in the non-executive hemisphere, there was a difference between button types for correct crossed-hand responses \( t(20) = -2.331; p = 0.050 \) with buttons −0.522 \( \mu \)V/m2 ± 1.368 and levers 1.149 \( \mu \)V/m2 ± 1.119 but not for parallel-hand responses \( t(20) = 1.384; p = 0.182 \), see Figure 3 for visualization.

**Summary of neurophysiological results**

Briefly summarizing the electrophysiological results, the stimulus-locked ERPs of correct responses were modulated by an interaction of congruency and hand position: only in parallel-hand responses, congruent trials evoked significantly more negative ERPs than incongruent trials. Furthermore, the response-locked ERPs of correct responses were modulated by an interaction of button type, hand position, and hemisphere (but not by congruency): in the non-executive hemisphere, button and lever responses differed from each other when hands were crossed (but not when they were parallel). By comparison, the mean amplitudes of the executive hemisphere only differed between parallel and crossed-hand responses.

**DISCUSSION**

The current study aimed at determining whether the location of an internal/physiologic effector (hand) or the location of an external, physical effector (response button) accounts for the previously observed asymmetric lateralization of spatial aspects of response monitoring processes (Stock et al., 2013).

The results (especially the interaction pattern observed in the response-locked ERP data) suggest that the spatial location of the physiologic effectors accounts for the largest part of the observed changes in the hemispheric allocation of spatial information during response monitoring. In order to elucidate the rationale behind this interpretation, we would like to explain the theoretical background of our experimental manipulation: the basic assumption behind the additional factor "button type" is that "each hemispherically preferential process integrates the contralateral egocentric and allocentric spatial information" (Zhou et al., 2012). Following from this, trials with button responses provided a "baseline" measurement because the hand and button involved in a response are always located in the same spatial hemifield. Differences between the two hand positions (parallel vs. crossed) can be attributed to spatial properties of the effectors, but the effectors (hand vs. button) cannot be told apart. In contrast to this, trials with lever responses provide the measurement of our “experimental manipulation” because in this condition, the responding hand and the button pressed are always located in opposing spatial hemifields. Hence, the influence of the different effectors can be distinguished by comparing baseline and experimental manipulation/button and lever trials: influences exerted by the physiologic effector/the location of the hand should yield identical or at least similar result for both button types (i.e., parallel-hand button responses vs parallel-hand lever responses and crossed-hand button responses vs crossed-hand lever responses). In contrast to this, influences exerted by the physical effector/the location of the button should yield opposing or at least different results for the two button types (i.e., parallel-hand button responses vs crossed-hand lever responses and crossed-hand button responses vs parallel-hand lever responses).

The first option is basically what was observed in the response-locked ERPs. Such fronto-central ERPs are known to reflect response monitoring and evaluation processes and are most likely generated within the SMA, anterior cingulate cortex, and adjacent areas (Macer et al., 1999; Luu and Tucker, 2001; Beste et al., 2010a,b, 2012; Roger et al., 2010; Wascher and Beste, 2010). In our previous study, we could demonstrate the response-locked ERPs quantified in this study originate within the SMA and are sensitive to the spatial allocation of the effector (Stock et al., 2013). As described above, we aimed at identifying the effector (physical or physiological) by comparing button and lever response conditions. As can be seen in the top row ("button responses") of Figure 3, placing the effectors in their usual hemifield yields a negativity of the response-locked ERP over the non-executive hemisphere. By contrast, placing the effectors in the "foreign" hemifield yields a negativation of the response-locked ERP over the non-executive hemisphere so that it resembles the course of the ERP curve over the executive hemisphere. Furthermore, it can be noted that the ERP over the non-executive hemisphere is more negative when the effectors are placed in the contralateral hemifield. A repeated-measures ANOVA was run to compare lever responses to button responses. Due to the interactions of factors, the main effects of hand position and hemisphere cannot be subject to interpretation. We would however like to point out that there was no main effect of button type. Hence, there was no basic fundamental difference between buttons and levers which is in favor of assuming the hands to be the relevant effectors. Two interactions are important: first, there was an interaction of hand position and congruency. Because both post hoc tests yielded significant differences between the hand positions (each parallel vs crossed), the finding only differed quantitatively between congruent and incongruent trials. Second, there was a threefold interaction of button type, hand position, and hemisphere. This interaction is crucial when trying to answer the question of which effector (hand or button) accounts for lateralization of spatial aspects of response monitoring processes. The button...
type had no effect on the executive hemisphere that always pro-
cesses efference-copy-based information of the motor aspects of
the response and information on spatial properties of the response
in half of the trials. In the non-executive hemisphere, the button
type only had an effect in crossed hands (lever responses yielding
more positive ERPs than button responses), but not in parallel
hands.

Our interpretation is as follows: the fact that the activation of the non-executive hemisphere does not differ in parallel-hand responses suggests that this hemisphere does not contribute to response monitoring/processing spatial information in neither button nor lever response trials. This suggests that the location of physiological effectors (the hands which stayed within their “natural” hemifield) accounts for the lateralization of response monitoring processes and that the physical effector (the location of the button) does not. The non-executive hemisphere differ-
ence between buttons and levers in crossed hands is not strictly in line with the assumption that only the hands are responsi-
ble for the hemispheric allocation of spatial information during
response monitoring. Yet, it is unlikely that the physical effec-
tor (button) plays a major role in the allocation of response
monitoring processes. The reason for this is that based on the
explanations above, one would expect a “reversal” of parallel and
crossed non-executive hemisphere ERPs across the button types.
In case of an allocation based on the location of the physical effec-
tor, lever responses should produce a positive peak in crossed
hands and a negative peak in parallel hands (crossed > par-
allel) over the non-executive hemisphere. This criterion is not
fulfilled since both in button and in lever responses; parallel hands
yield a more positive ERP than crossed hands (see Figure 1).
Because of the different polarity of ERP peaks around the time of
the response, we based the statistical analysis on mean activity
measures. While these measures can depict differences between
the epochs over which the ERP data was averaged, they unfor-
tunately cannot account for the course of the curves within
these epochs. Yet, we obtained no convincing statistical results
in favor of a physical effector approach and the grand averages
(Figure 3) further support the assumption that the physiologic
effectors (hand) determines the allocation of spatial response moni-
toring processes: despite the detected differences, the course of
the ERP curves of crossed-hand lever responses is very similar
to that of crossed-hand button responses while both crossed-
hand conditions markedly differ from the course of parallel-hand
responses.

Furthermore, the behavioral results of this study are line with
previous findings on this paradigm (e.g., Wiehand and Wascher,
2005; Leuthold, 2011) suggesting that the task was correctly
implemented/worked as intended. Both hit rates and RTs were
modulated by the hand position as well as the spatial congruency
of the stimulus presentation site and the location of the responding
hand. In all significant main effects and interactions, parallel-hand
responses yielded a better (more accurate/faster) performance
than crossed-hand responses and congruent trials yielded better
results than incongruent trials. Matching results were obtained for
the stimulus-locked ERPs/N2pc. As expected, the ERPs showed an
interaction of hand position and congruency (see Praamstra and
Oostenveld, 2003; Wiehand and Wascher, 2005; Böckler et al.,
2011; Leuthold, 2011; Verleger et al., 2012). For the ERPs, there was no
effect of button type whatsoever. Since stimulus–response congru-
ency had been defined with respect to the location of the hand (not
the button), this finding clearly indicates that external/physical
effectors do not seem to have an influence on congruency and
on early attentional processing and/or filtering (Luck and Hill-
yard, 1994; Böckler et al., 2011; Leuthold, 2011; Verleger et al.,
2012).

From this study, it can be concluded that the spatial location of
physiologic effectors (in our case, this would be the hands) plays
a major role in the asymmetrical allocation of response monitor-
ing processes: whenever the physiologic effectors enter a “foreign”
hemifield, the hemisphere contralateral to this hemifield seems to
handle information on spatial aspects of the response. By com-
parison, the location of the physical effector (in our case, this
would be the buttons) plays a minor role. Yet, the possibility that
it still contributes to response monitoring processes cannot be
ruled out completely. Furthermore, these findings allow for the
conclusion that potentially different action goals of button and
lever responses do not substantially influence the lateralized allo-
cation of response monitoring processes (compare to Büchel
et al., 2007). Our study extends the established fact that each hand
operates “in its own egocentric space” (Haggard et al., 2000) by
demonstrating that egocentric space continues to play a role in the
subsequent processes of response monitoring and evaluation. Also,
our results are in line with the findings that proprioceptive (Allain
et al., 2004) and internal sensorimotor information is used for
response evaluation (Fukui and Gomi, 2012) and that each hemi-
sphere preferentially processes information from the contralateral
hemifield (Zhou et al., 2012).

AUTHOR CONTRIBUTIONS

Both authors contributed to the design of the experiment, data
collection, the interpretation of results, and to the written
manuscript.

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