RESEARCH ARTICLES

**Jochen Müsseler · Peter Wühr · Claudia Danielmeier ·
Stefan Zysset**

Action-induced blindness with lateralized stimuli and responses

Abstract Previous dual-task studies showed that the
selection and/or execution of a response interfere with
concurrent visual encoding (action-induced blind-
ness). Four experiments examined how the lateralization of
stimuli and responses might affect action-induced blind-
ness. Participants responded to tones (S1) by pressing keys
with the left or right hand (R1), and simultaneously
identified stimuli (S2) presented to the left or right visual
field. Results revealed a complex pattern of cross-talk
effects between response preparation and visual encoding.
Firstly, preparing a response generally impaired concurrent
visual encoding. Secondly, action-induced blindness was
equally present for ipsilaterally and contralaterally pre-
sented stimuli. Thirdly, response preparation facilitated
processing of visual stimuli at ipsilateral locations,
probably a case of action-centered attention. Finally, the
facilitatory effect of R1–S2 correspondence on visual
encoding was complemented by a S2–R1 correspondence
effect on response execution. Thus, acting while seeing
can have both beneficial and detrimental effects on
identification performance at the same time.

Keywords Visual encoding · Hemifields · Dual task ·
Stimulus–response · Action-induced blindness

J. Müsseler (✉)
Institut für Arbeitsphysiologie, Universität Dortmund,
Ardeystr. 67,
44139 Dortmund, Germany
e-mail: muesseler@ifado.de
Tel.: +49-231-1084311
Fax: +49-231-1084340

P. Wühr
Institute of Psychology, University Erlangen,
Erlangen, Germany

C. Danielmeier · S. Zysset
Max Planck Institute of Human Cognitive and Brain Sciences,
Leipzig, Germany

Introduction

Humans often experience difficulties when confronted
with two tasks at the same time. One of the most
established paradigms for investigating dual-task perfor-
mance is the psychological refractory period (PRP)
paradigm. In the PRP paradigm, participants perform
two speeded responses to different stimuli presented in
close succession. With short stimulus onset asynchronies
(SOAs), processing of the two tasks overlaps in time, and
the second response is prone to interference (Telford
1931). Behavioral evidence suggests that the costs
originate at a central processing stage (possibly response
selection) that can only handle one task at a time (cf.,
Pashler 1998). As long as the first task (the S1–R1 task)
occupies the central bottleneck, the processing of the
second task (the S2–R2 task) is assumed to be postponed
(e.g., Pashler 1998). Neuroimaging studies showed that
dual-task performance is subserved by a network of frontal
and parietal brain areas, in particular by the lateral
prefrontal areas along the inferior frontal sulcus, the
middle frontal gyrus and the parietal areas along the
intraparietal sulcus (e.g., Szameitat et al. 2002; see also
Schubert and Szameitat 2003).

Most research on dual-task performance has been
conducted with combinations of two speeded choice-
response tasks. Yet, recent behavioral studies also revealed
that the first task is able to affect visual encoding in the
second task. In these studies a speeded S1–R1 task was
combined with an unspeeded S2-identification task (e.g.,
De Jong and Sweet 1994; Jolicoeur 1999; for an overview
see Müsseler and Wühr 2002). When the temporal overlap
between these tasks was increased, by decreasing the SOA
between S1 and S2, identification performance for S2
deteriorated. It was observed that increasing the temporal
overlap between these tasks (by decreasing the SOA
between S1 and S2) increasingly impaired identification
performance of S2. Moreover, Müsseler and Wühr (2002)
were able to demonstrate that response planning in the first
task affects visual encoding in the second task. In their
first task (S1–R1), participants made a Go-NoGo decision

to different letters (e.g., an 'm' or 'b' required different keypresses with the right hand, whereas an 'x' or 'o' required no response). In the second task (S2 identification), participants discriminated between masked left- or right-pointing arrowheads presented at central fixation. The results showed that visual identification was impaired the more both tasks overlapped in time. Furthermore, identification was worse in Go-trials than in NoGo-trials especially at short SOAs. This can be taken as evidence that the selection and/or execution processes of R1, which were only required in Go-trials, (additionally) impaired visual encoding of S2 (so-called action-induced blindness —AIB).

Recently, the AIB effect was successfully replicated in an event-related functional magnetic resonance imaging (fMRI) study (Danielmeier et al. 2004). The larger perceptual costs in Go-trials were correlated with a decreased activation in the medial visual area V3 and lateral V3A—with the latter decrease mainly in the left hemisphere. Thus, the planning and execution of an action modulates activity in extrastriate visual areas. Both areas, V3 and V3A, are known to be contrast and orientation sensitive visual areas (Tootell et al. 1997).

The observation of Danielmeier and co-workers that action-induced modulations of activity in V3A were larger in the left than in the right hemisphere inspired the present set of experiments (Danielmeier et al. 2004). The authors discussed whether this laterality originated from the fact that participants performed their responses R1 with the right hand. In other words, the larger modulation of V3A activity in the left hemisphere might stem from the fact that motor areas in the same hemisphere controlled the responses. The present study aimed at testing this speculation. In particular, it was asked whether performing a lateral response, R1, with the left or right hand affects visual discrimination of visual stimuli in the left of right visual hemifield differently.

The laterality of the cerebral hemispheres in visual processing and motor control is well established. In particular, each hemisphere predominantly receives its visual input from the contralateral visual field and controls the muscles on the contralateral side of the body. This laterality might also suggest a laterality of interference between response planning and visual processing. Yet, it is possible that such laterality effects are counteracted by the high speed of interhemispheric exchange and/or the high degree of hemispheric specialization (for overviews see Hellige 2000; Springer and Deutsch 1998).

In recent years, PRP studies with lateralized stimuli and/or responses were also used to investigate spatial stimulus–response (S–R) compatibility (for an overview see Lien and Proctor 2002). These studies observed cross-task correspondence effects that operated in both directions. For example, responding in the second task was faster when R1 and R2 locations did correspond than when they did not (e.g. Lien and Proctor 2000). Furthermore, lateral presentation of S2 was also found to affect response speed in the first task when this task required a left or right response. This effect was especially pronounced at short SOAs (S2–R1 correspondence effect; see also Müsseler et al. 2004; J. Müsseler, P. Wühr and C. Umiltà, submitted for publication 2004). Note that the tasks used for investigating compatibility effects usually combined two speeded response tasks, whereas the present study used a speeded response task in combination with an unspeeded identification task. Hence, the dual-task situations are

Fig. 1 The sequence of events in the experiments. In the keypress task, participants pressed a left or right key (R1) in response to tones (S1) as fast as possible. While doing this, a masked square S2, in which a horizontally or vertically oriented gap was to be identified, appeared to the left or to the right of fixation with different stimulus onset asynchronies (SOAs, here 400 ms). An unspeeded report (R2) of S2 identity completed the trial
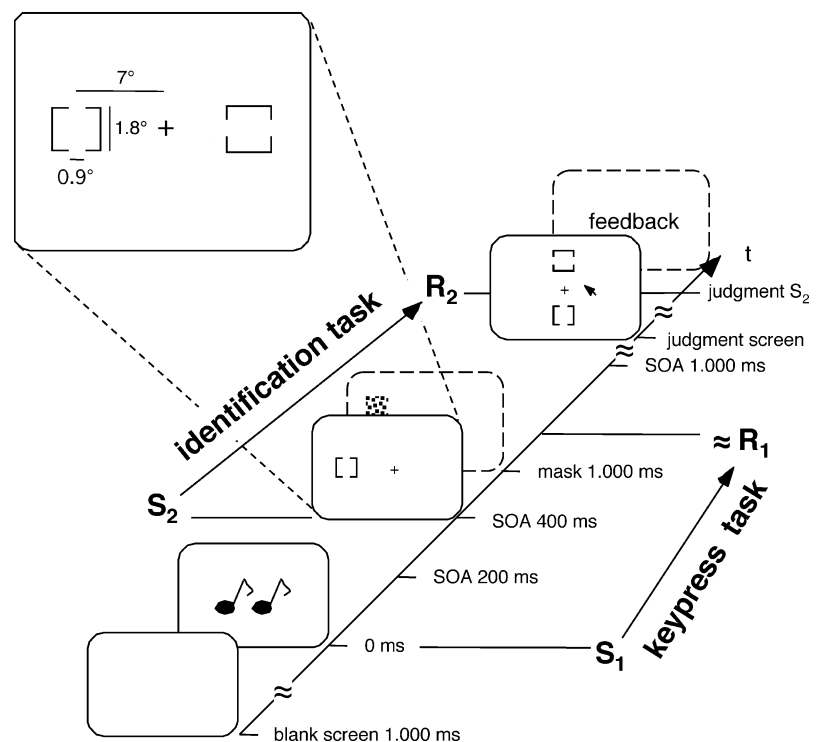
quite different. Yet, despite these differences, similar cross talk effects as those observed in the compatibility studies might also show up in the present experiments. Therefore, possible effects of spatial compatibility might need to be distinguished from possible effects of varying processing demands within and between the cerebral hemispheres.

Experiments 1a and 1b

Participants performed in two temporally overlapping tasks. The first task was a speeded four-alternative-choice response task: A binaurally-presented low tone required a left-hand keypress, whereas a high tone indicated required a right-hand keypress. Additionally, tones were either one long tone or a sequence of two short tones requiring a long or short keypress, respectively. This rather difficult S1–R1 task was used to increase the likelihood of cross-talk effects from the S1–R1 task onto the S2–R2 task at short SOAs (cf. van Selst et al. 1999). The second task was an unspeeded visual identification task. Participants were presented with a backward-masked square (S2) that had small gaps, either horizontally or vertically oriented (cf. Fig. 1). S2 was presented either to the left or right of fixation, but location was task irrelevant. The participants' tasks were to respond as quickly as possible to the tones and to simultaneously identify the orientation of the two gaps (horizontal or vertical).

The major experimental manipulations concerned (1) the temporal overlap between the two tasks, and (2) the relationship between the responding effector and the stimulated visual field. The temporal overlap between the tasks was manipulated by varying the SOA between S1 and S2. The relationship between the effector and the stimulated visual field was manipulated by having participants respond with their left or right hand and by presenting S2 in the left or right hemifield.

Our main question was whether presenting S2 in the same or to the opposite hemifield, with regard to the location of the responding effector, would affect identification performance for S2. Recall that behavioral studies showed perceptual impairments during response preparation and execution (e.g., Jolicoeur 1999; Müsseler and Wühr 2002). If the involvement of the same or different cerebral hemispheres is important, then two outcomes are possible. The first possibility is that response preparation only interferes with perceptual processing in the same hemisphere. In that case, an effect of SOA on identification performance should only arise with ipsilateral responses but not with contralateral responses. The second possibility is that response preparation affects perceptual processing in both hemispheres differently. In that case, SOA effects should arise in each case, but identification performance is either more (or less) strongly impaired in the ipsilateral case than in the contralateral case. The dependent variable of interest is the accuracy in the perceptual identification task. Yet, reaction time performance in the first keypress task was also analyzed.

To investigate a broader range of SOAs, and to control for hand effects on reporting S2, we conducted two parallel experiments. In Experiment 1a, S1 and S2 were separated by SOAs of either 200, 400, or 1,000 ms. In experiment 1b, S1 and S2 were separated by SOAs of either 100, 600, or 1,600 ms. In both experiments, participants reported S2 by clicking with the mouse on a corresponding symbol on the computer screen. Participants operated the mouse with the left hand in experiment 1a and with the right hand in experiment 1b. In all other respects, the two experiments were identical.

Method

Participants

Fifteen healthy adults participated in experiment 1a (aged between 20 and 34 years, mean 23.1 years; ten female) as well as in experiment 1b (aged between 17 and 34 years, mean 23.7 years; 12 female). Most were students at the University of Munich. In the present and subsequent experiments, all participants were right-handed by his/her own account, with normal or corrected-to-normal vision, and with no history of neurological impairment. The experiments have been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All persons gave their informed consent prior to inclusion in the study.

Apparatus, stimuli and tasks

The experiments were run on a Macintosh computer with the Matlab program, using the Psychophysics Toolbox extension (Brainard 1997; Pelli 1997). The stimuli were presented on a 17-inch color CRT monitor (75 Hz refresh rate, 1024×768 pixels). The participant's head was placed on a chin rest 500 mm in front of the monitor. The experiment was carried out in a dimly lit and soundproof chamber.

Auditory stimuli (S1) were generated by square waves of 500 or 1,500 Hz and were presented binaurally. A single tone lasted 50 ms, a two-tone sequence consisted of two 5-ms tones with an inter-stimulus interval of 40 ms. The mapping rules for the keypress task were as follows: a single low tone required a long keypress ($\geq$250 ms) with the left-hand middle finger, whereas two low tones required a short keypress (<250 ms) with the same finger. Similarly, a single high tone was mapped to a long keypress with the right-hand middle finger, whereas two high tones required a short right-hand keypress. Responses (R1) were recorded with micro-switches mounted on a board that was placed in front of the participants. Perceptual judgments (R2) were recorded with the computer mouse placed to the right (experiment 1a) or to the left (experiment 1b) of the response board.

Visual stimuli (S2) were displayed as black-on-white projection and were presented 7° to the left or to the right

of the screen center. S2 were squares of 1.8°×1.8° visual angle that had small gaps of 0.9° either in the left and right edge, or in the upper and lower edge (Fig. 1). The participants' task was to identify the orientation of the two gaps in the square (horizontal or. vertical). S2 was displayed for an individually adjusted presentation time (see Procedure) and replaced by a mask. The mask consisted of a square of 3.6°×3.6°, in which each pixel was set white or black with equal probability.

Design

The experiments rested on a 2×2×3 within-participants design. The first factor concerned the presentation of S2 in the left or right hemifield. The second factor concerned the relationship between the hand used to perform R1 and the stimulated hemifield: R1 was either ipsilateral or contralateral to the stimulated hemifield. The third factor concerned the temporal overlap between the two tasks (SOA). It had three levels in experiment 1a (200, 400, and 1,000 ms) and in experiment 1b (100, 600, and 1.600 ms). Each participant completed a total of 12 blocks of 48 trials. In a block, each combination of responding hand, visual hemifield, and SOA was repeated four times, in random order.

Procedure

All trials started with the presentation of a fixation cross. After 1 s, the tone(s) occurred for 50 ms, which signaled the required response R1. The instructions stressed the importance of responding quickly to the tone(s) and urged participants not to wait for S2 to appear before executing R1.

S2 followed S1 with a variable SOA (see above), and appeared either to the left or to the right of the fixation cross. A mask immediately replaced S2. Two seconds after S1, a judgment screen appeared in which the two possible S2 were shown one above the other. In the judgment screen, the two stimuli changed their relative positions randomly from trial to trial. Participants reported S2 identity by selecting a stimulus with the computer mouse. After lifting the hand from the microswitch, participants operated the mouse with the right hand in experiment 1a, and with the left hand in experiment 1b. An inter-trial interval of 1 s followed an error-free trial. An error feedback was given if R1 was incorrect, if reaction time for R1 exceeded 1,000 ms, and/or if participants reported S2 incorrectly.

To avoid ceiling or floor effects in the identification task, the presentation duration of S2 was adjusted every ten trials to achieve 75% performance accuracy across all SOA conditions. The presentation time was decreased by one screen-refresh when the error rate was equal or lower than 15%. It was increased by one refresh when the error rate was equal to or above 35%.

The experimental phase was preceded by a practice phase of half-an-hour, in which the S1–R1 mapping and the identification of S2 were practiced. The practice phase was also used to determine the initial presentation duration of S2 for the experimental phase. The experimental phase consisted of two sessions of 45 min each, which were performed on subsequent days.

Results

Keypress task

Reaction times (RTs) for R1 were calculated for those trials in which none of the errors described above had occurred. The overall RTs were 438 ms (experiment 1a) and 456 ms (experiment 1b). In this task participants made an error in 5.97% of the trials in experiment 1a and in 10.82% of the trials in experiment 1b. For each experiment, separate 2×2×3 [[visual hemifield of S2, left/right)× (keypress R1, ipsilateral/contralateral with regard to the visual hemifield of S2)× (SOA)] analyses of variance (ANOVA) for repeated measures were performed on RTs and on error rates.

Experiments 1a and 1b yielded similar patterns of RT results. Participants responded faster with an ipsilateral keypress R1 than with a contralateral keypress (434 vs 441 ms in experiment 1a, $F_{(1,14)}$=6.74, p=0.021; 451 vs 462 ms in experiment 1b, $F_{(1,14)}$=18.06, p=0.001). More interestingly, RTs indicated an interaction of keypress laterality and SOA (experiment 1a: $F_{(2,28)}$=5.08, p=0.013; experiment 1b: $F_{(2,28)}$=11.18, p<0.001). At the short SOAs of 200 ms (experiment 1a) and 100 ms (experiment 1b) RTs were shorter in the ipsilateral conditions (428 and 446 ms) than in the contralateral conditions (442 and 471 ms). This cross-task laterality effect disappeared at the longer SOAs. This means that the ipsilateral presentation of S2 either improved the production of R1, or that the contralateral presentation of S2 impaired the production of R1. Yet, the factor hemifield had no effect on RTs.

Results of the error analyses were similar to those of RT analyses. Fewer errors occurred in the ipsilateral condition (5.4 and 9.8%) than in the contralateral condition (6.5 and 11.8%; experiment 1a: $F_{(1,14)}$=3.51, p=0.082; experiment 1b: $F_{(1,14)}$=8.95, p=0.010). However, the laterality×SOA interaction was only significant in experiment 1a ($F_{(2,28)}$=6.96, p=0.004). Instead, experiment 1b showed a decrease of errors with an increase of the SOA ($F_{(2,28)}$=21.03, p<0.001). Obviously, the keypress task was more difficult when the 100-ms SOA was included.

Identification task

The mean adjusted presentation duration for S2 across all participants was 40 ms (experiment 1a), and 36 ms (experiment 1b). For each experiment, the probabilities of correctly reported S2s were computed for each condition, and subjected to 2×2×3 repeated-measures ANOVA.

These analyses revealed three consistent findings (cf. Fig. 2). First, identification performance decreased with decreasing SOA (experiment. 1a: $F_{(2,28)}=13.73$, $p<0.001$; experiment. 1b: $F_{(2,28)}=15.27$, $p<0.001$). Second, identification performance was better in the right than in the left visual hemifield (experiment 1a: $F_{(1,14)}=5.16$, $p=0.039$; experiment 1b: $F_{(1,14)}=22.13$, $p<0.001$). Third, as can be seen from Fig. 2, in both experiments ipsilateral presentation of S2 revealed somewhat better identification performance than did contralateral presentation. However, this effect showed only a non-significant tendency when both experiments were analyzed together ($F_{(1,28)}=3.13$, $p=0.088$).

Discussion

In experiments 1a and 1b, participants responded to tones (S1) by pressing a key with the left or right hand and discriminated visual stimuli (S2) that were presented in the left or right visual hemifield. Thus, the response was either ipsilateral or contralateral to the visual hemifield in which S2 occurred. By manipulating the SOA between S1 and S2, we varied the temporal overlap between the keypress task and the identification task. The two experiments differed with respect to the levels of SOA, and with respect to the hand that operated the mouse for reporting S2 identity. Because both experiments yielded similar findings, the hand used to report S2 does not seem to affect the results.

The keypress task revealed the expected results. At short SOAs (100 or 200 ms), RTs were affected by the relationship between the responding hand and the hemifield in which S2 appeared. In particular, RTs were shorter when S2 appeared in the same hemifield in which R1 was about to be performed, than when S2 appeared in the opposite hemifield. In other words, the spatial
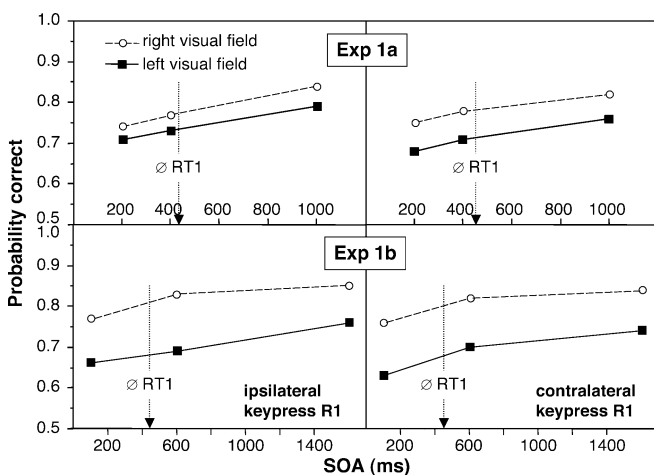
correspondence between S2 and R1 location yielded a cross-task effect of spatial compatibility (see also Müsseler et al. 2004). Importantly, RTs were not affected by SOA, suggesting that participants did not withhold R1 until S2 had appeared.

Our main question of interest was whether performing a lateral response R1 with the left or right hand would affect identification of stimuli presented in the left of right visual hemisphere differently. The results were quite clear with respect to that question. There was a strong interference effect, that is, the ability to identify S2 decreased with decreasing SOA (see also De Jong and Sweet 1994; Jolicoeur 1999; Müsseler and Wühr 2002; Wühr and Müsseler 2002). This interference effect appeared to be similarly strong with ipsilateral and contralateral responses. In terms of hemispheric processing, preparing and executing a motor response with the left or right hand seems to impair visual processing in both hemispheres to the same extent.

Independently from this interference effect, there was a slight improvement in identification performance for ipsilaterally presented stimuli. For example, performing an action with the left hand slightly improved perceptual discrimination in the left visual field. However, since this observation showed only a non-significant tendency, this improvement needs further empirical evidence from the subsequent experiment. In experiment 2, the keypress task was not a four-alternative, but two-alternative choice response task. This much simpler keypress task was introduced to reduce the mapping demands and to emphasize instead the effects of laterality in the S1–R1 task. In experiment 3 we examined whether the improvement in identification performance for ipsilaterally presented stimuli occurred with reference to the effector (i.e., hand) or with reference to response location. Another consistent finding of the present experiment was that stimuli presented in the right visual field were better identified than stimuli presented in the left visual field. Experiment 4 examined whether this finding could occur without the keypress task.

Fig. 2 Mean probabilities of correctly identified S2 with an ipsilateral or contralateral keypress (R1) in experiments 1a and 1b. *Solid lines* and *dashed lines* depict S2 presentation in the left and right visual field, respectively; the *x*-axis depicts the stimulus onset asynchrony (SOA) between the presentation of S1 and S2; *RT1* mean reaction time for R1

Experiment 2

In experiment 1 the S1–R1 task was a four-alternative-choice response task. This rather difficult task was used to facilitate carryover effects from the S1–R1 task to the S2 identification task. However, the difficulty of the S1–R1 task in experiment 1 might have mainly affected the processes involved in mapping stimuli onto responses, rather than affecting the processes involved in generating a lateralized response. Therefore, it is possible that the difficulty of the S1–R1 task in experiment 1 rather decreased than increased the laterality effects on the identification of S2. To examine this possibility, a two-alternative-choice task was used as the S1–R1 task in the present experiment.

Method

Participants

Thirteen healthy adults (aged between 19 and 36 years, mean 23.7 years; seven female) participated in the experiment.

Stimuli, design, and procedure

These were the same as in experiment 1a, with the following exceptions. Auditory stimuli (S1) were now single tones of 400 and 2,000 Hz mapped to left-hand and right-hand keypresses. Additionally, visual stimuli (S2) were now circles with a diameter of 2° and small vertically or horizontally oriented gaps of 1°. These minor changes in S2 were introduced to examine the generalization of the findings with different stimuli.

Results and discussion

Keypress task

The overall RT of R1 was 366 ms and thus about 81 ms faster than in the previous experiment. This difference between experiments probably originated from a less difficult S1–R1 task in the present experiment. Further, RTs were faster with the right hand (355 ms) than with the left hand (377 ms; $F_{(1,12)}=17.46$, $p=0.001$).

With regard to laterality, RTs were again shorter with ipsilaterally presented S2 than with contralaterally presented S2 (364 vs 369 ms; $F_{(1,12)}=6.12$, $p=0.029$]. A corresponding finding was observed in the errors (2.86% in the ipsilateral condition vs 4.09% in the contralateral; $F_{(1,12)}=9.34$, $p=0.01$). More interestingly, this laterality effect again interacted with the SOA. Only at the short 200-ms SOA, were ipsilateral responses faster (360 ms) and less error-prone (2.89%) than contralateral responses (374 ms, 5.85%). This interaction showed only a non-significant tendency in the ANOVA of RTs ($F_{(2,24)}=2.65$, $p=0.091$), but significant in the ANOVA of the errors ($F_{(2,24)}=4.88$, $p=0.017$). Additionally, errors decreased with an increase of the SOA ($F_{(2,24)}=7.00$, $p=0.004$).

Identification task

The mean adjusted presentation duration for S2 was 38 ms across all participants. As in the previous experiment, identification performance decreased with decreasing SOA ($F_{(2,24)}=4.06$, $p=0.030$) and identification performance was better for stimuli in the right visual field than for those in the left visual field ($F_{(1,12)}=20.22$; $p=0.001$). More importantly, discrimination performance for S2 was significantly better with an ipsilateral R1 than with a contralateral one ($F_{(1,12)}=9.04$, $p=0.011$; cf. Fig. 3). Thus, this experiment clearly confirmed the tendency observed

in experiment 1 that performing an action with the left (right) hand improved perceptual discrimination in the left (right) visual field. This observation might reflect a case of action-based attention, i.e., an attentional bias favoring the processing of stimuli at locations at which a response is about to be performed. So far, this bias has been mainly observed in reaction-time studies (cf. Tipper et al. 1993; Tomonaga 2002). The present experiments established this effect with a visual discrimination task.

Experiment 3

The results of Experiment 1 and 2 suggested a laterality effect of response planning on visual identification. There was an improvement in identification performance for ipsilaterally presented stimuli. This observation might reflect an attentional tendency favoring the processing of stimuli at locations at which a response is about to be performed. The present experiment 3 further explored this effect.

The major aim of experiment 3 was to investigate the source of the perceptual improvement at the response side. Does this effect occur with respect to the responding hand or with respect to the response location? In the first case, *left hand* responses produce a gain in processing left-side stimulation, regardless of whether the left hand responds to the left or to the right side of the body. In the second case, *left side* responses produce a gain in processing left-side stimulation, regardless of whether the response is performed with the left or with the right hand. Experiment 3 tested this issue by having participants respond with crossed arms. In that case, the left hand operates the right key, and the right hand operates the left key.

Responding with uncrossed and crossed arms has been used to study the source of spatial compatibility effects (e.g., Simon et al. 1970; Wallace 1971). The result was that stimuli facilitate responses at the same relative location, regardless of whether the left or the right hand is used for responding. In other words, relative response location in the external world, and not the anatomical effector, determines the main direction of the spatial compatibility effects (however, for other differences in
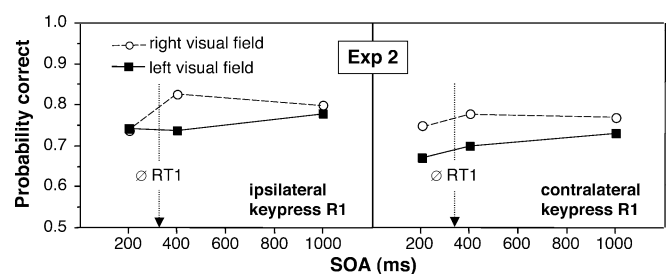
Fig. 3 Mean probabilities of correctly identified S2 with an ipsilateral or contralateral keypress (R1) in experiment 2. In contrast to experiment 1a, the keypress task was not a four-alternative but two-alternative choice response task. *Solid lines* and *dashed lines* depict S2 presentation in the left and right visual field, respectively; the *x*-axis depicts the stimulus onset asynchrony (SOA) between the presentation of S1 and S2; *RT1* mean reaction time for R1

hemispheric processing with crossed and uncrossed hands see, e.g., Wascher et al. 2001).

The predictions for experiment 3 were the following. If the hand produces the effect, responses with the left hand should improve discrimination of stimuli appearing in the left hemifield, despite the fact that the left hand responds at the right side of the body. If response position produces the effect, responses with the left hand should improve discrimination of stimuli appearing in the right hemifield, because the left hand responds in the right hemifield, and vice versa.

Method

Participants

Fifteen healthy adults (aged between 18 and 31 years, mean 24.8 years; 13 female) participated in the experiment.

Stimuli, design, and procedure

These were the same as in experiment 1a, with the following exceptions. Participants performed the keypress task with crossed arms (left arm above right arm). In order to report S2, the mouse was operated with the left hand.

Results and discussion

Keypress task

Again, RTs were faster with the right hand (454 ms) than with the left hand (480 ms; $F_{(1,14)}=7.18$, $p=0.018$). Correspondingly, fewer errors were observed with the right hand (6.7%) than with the left hand (10.6%, $F_{(1,14)}=6.80$, $p=0.021$).

When relative response location is used as the reference, the RT results of experiment 3 were similar to those of experiments 1 and 2. First, RTs were shorter with ipsilaterally presented S2 than with contralaterally presented S2 (462 vs 472 ms; $F_{(1,14)}=8.31$, $p=0.012$). Second, this laterality effect interacted with SOA ($F_{(2,28)}=4.17$, $p=0.026$). At the short 200-ms SOA, ipsilateral responses (456 ms) were faster than contralateral responses (478 ms). This effect decreased with increasing SOA. The error analysis revealed no effects.

The pattern of RT results is similar to that observed in single task studies. When the hands were crossed, the effects of spatial stimulus-response compatibility occurred with reference to relative response location, and not with reference to anatomical effector (Simon et al. 1970; Wallace 1971).

Identification task

The mean adjusted presentation duration for S2 was 36 ms across all participants. The critical question was whether responding with crossed hands produced similar or different effects of response planning on visual-identification performance as responding with uncrossed hands (experiments 1 and 2). If relative response location is used as the reference for laterality effects, experiment 3 produced similar results as experiment 1 (Fig. 4). First, identification performance decreased with decreasing SOA ($F_{(2,28)}=5.79$, $p=0.008$). Second, identification performance was better for stimuli in the right visual field than for stimuli in the left visual field ($F_{(1,14)}=26.82$; $p<0.001$). Third, discrimination performance for S2 was again better with ipsilaterally presented stimuli than with contralaterally presented stimuli, although this difference was not significant ($F_{(1,14)}=1.14$, $p=0.305$).

Nevertheless, the present experiment revealed no evidence for stronger interactions between response planning and visual encoding within hemispheres than between hemispheres. Again, the AIB effect for stimuli presented in the ipsilateral and in the contralateral hemisphere, respectively, was quite similar.
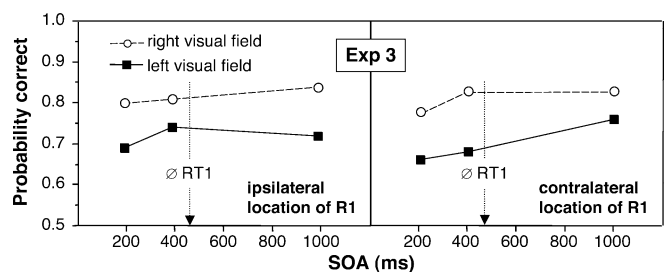
Experiment 4

The previous experiments showed superior identification performance in the right visual field than in the left. It is unclear whether this superiority of the right visual field depends upon having participants perform in a dual-task situation. Experiment 4 examined whether this perceptual effect does also occur in a single-task situation.

Method

Participants

Again, fifteen healthy individuals (aged between 17 and 31 years, mean 21.6 years; 12 female) participated in the experiment.

Fig. 4 Mean probabilities of correctly identified S2 with an ipsilateral or contralateral keypress (R1) in experiment 3. In contrast to experiment 1a, participants performed the keypress task with crossed hands. *Solid lines* and *dashed lines* depict S2 presentation in the left and right visual field, respectively; the *x*-axis depicts the stimulus onset asynchrony (SOA) between the presentation of S1 and S2; *RT1* mean reaction time for R1

Stimuli, design, and procedure

These were the same as in experiment 1a, except for the following changes. Auditory stimuli S1 were presented, but participants did not have to respond to them. The only task was to identify S2. Participants indicated S2 identity by selecting the corresponding symbol with a right-hand mouse click. Each observer was confronted with 288 trials in one session.

Results and discussion

The mean adjusted presentation duration for S2 across all participants was 27 ms. The probabilities of correctly reported S2 entered in a 2×3 [(left/right visual field)× (SOA)] ANOVA. Results again showed that identification performance was better for stimuli presented in the right visual field than for stimuli presented in the left visual field (cf. Fig. 5; $F_{(1,14)}$=6.69, p=0.022). There was no SOA effect and no interaction (both *F*-values <1). Thus, we can conclude that the main effect of visual field can occur both in single-task and in dual-task situations.

General discussion

Previous dual-task studies have shown that the preparation and execution of manual responses impairs concurrent encoding of visual information (e.g., Jolicoeur 1999; Müsseler and Wühr 2002; Wühr and Müsseler 2002). An observation of Danielmeier and co-workers let us think about the possibility that the impact of response preparation on concurrent visual encoding might be stronger within a hemisphere than between the hemispheres (Danielmeier et al. 2004). In other words, visual encoding could be more impaired with an ipsilateral response than with a contralateral one. However, possible effects of varying processing demands within and between the hemispheres might need to be distinguished from possible effects of spatial S–R compatibility. Therefore, another possibility was that action–perception interference is a matter of S–R compatibility, regardless of which hand is

Fig. 5 Mean probabilities of correctly identified S2 in experiment 4. In this experiments, observers did not respond to S1. *Solid lines* and *dashed lines* depict S2 presentation in the left and right visual field, respectively; the *x*-axis depicts the stimulus onset asynchrony (SOA) between the presentation of S1 and S2
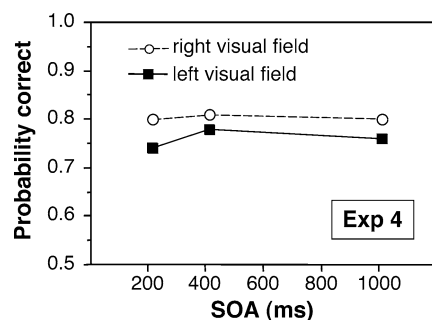
used for responding. Here the question is whether interference effects occur with respect to the responding hand or with respect to the response location.

In the present experiments (except for experiment 4), participants simultaneously performed a keypress task and a visual identification task. In the keypress task, participants responded to tones (S1) by keypresses with the left or right hand. In the visual identification task, participants reported the orientation of gaps in a square (S2). By varying the SOA between S1 and S2, we manipulated the temporal overlap between the two tasks. Moreover, by presenting S2 in the left or right visual field, we manipulated the structural overlap between the two tasks. When participants respond with the left/right hand and S2 appears in the left/right visual field, the same hemisphere controls R1 and processes S2 (ipsilateral condition). In contrast, when participants respond with the left/right hand and S2 appears in the right/left hemifield, different hemispheres control R1 and process S2 (contra-lateral condition). The main question of the present study was whether visual discrimination performance in the ipsilateral and the contralateral conditions would be similar or different. The present experiments revealed four main findings.

The first finding was the expected interference between response preparation/execution and visual encoding (experiments 1–3). The probability of correctly reporting S2 decreased with decreasing SOA. This finding replicates the results of earlier studies, in which different visual tasks were used (e.g., Jolicoeur 1999; Müsseler and Wühr 2002; Wühr and Müsseler 2002). Importantly, this action–perception interference effect was similarly large in ipsilateral and contralateral conditions. Hence, there was no evidence for a laterality of action–perception interference. Moreover, there was also no evidence for stronger action–perception interference within a hemisphere than for interference between hemispheres.

As a second result, besides replicating interference effects, was that experiments 1 and 2 revealed evidence for a beneficial effect of response preparation/execution on visual processing. In experiments 1 and 2 the identification performance was better for ipsilaterally presented stimuli than for contralaterally presented ones. Experiment 3 revealed a qualitatively similar—yet not significant—result, although participants responded with crossed arms. Together, these results suggests that visual identification is enhanced at the relative position of the response (independent of the effector). This finding might reflect a case of action-centered attention (cf. Tipper et al. 1993; Tomonaga 2002).

As a third result, all four experiments in the present study consistently showed an advantage for visual identification of stimuli in the right visual field (i.e., processing in the left cortical hemisphere), when compared with performance for the left visual field. This right-field advantage appeared both with the dual-task conditions of experiments 1–3, and with the single-task conditions of experiment 4. Such asymmetries are often attributed to hemispheric specialization. For example, the left hemi-

sphere is proposed to be especially effective in processing local features of visual stimuli that are coded in high spatial frequencies (e.g., Sergent and Hellige 1986; for a review, see Hellige 1996). The stimuli used in the present study meet these requirements.

The fourth result of the present study consisted of a spatial compatibility effect between the two tasks that—not surprisingly—was restricted to short SOAs (i.e., SOA<RT). Responses to tones were faster and more accurate when S2 appeared in the ipsilateral hemifield than when S2 appeared in the contralateral field. This cross-task compatibility effect (cf. Müsseler et al. 2004, J. Müsseler, P. Wühr and C. Umiltà, submitted for publication 2004) bears similarities to the effects of irrelevant stimulus position on choice responses in single-task studies (e.g., Craft and Simon 1970). The cross-task compatibility effect and the single-task compatibility effect arise with uncrossed and crossed arms. In both cases the effects arise from the correspondence or non-correspondence between relative stimulus location and relative response location (regardless of the effector used for the response).

In sum, the present experiments revealed a rather complex pattern of cross-talk effects between a keypress task, in which participants responded to tones with lateralized keypresses, and a visual encoding task, in which participants encoded local features of laterally presented stimuli. Firstly, preparing a response generally impaired concurrent visual encoding. Thus, response preparation seems to occupy central resources that are also needed for stimulus encoding. Secondly, the action-induced blindness was equally strong for ipsilaterally and contralaterally presented stimuli. Thirdly, response preparation facilitated processing of visual stimuli at ipsilateral locations, probably a case of action-centered attention. Finally, the facilitatory effect of R1–S2 correspondence on visual encoding was complemented by a S2–R1 correspondence effect on response execution. Thus, acting while seeing can have both beneficial and detrimental effects on identification performance at the same time.

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