

**Flexible coupling of covert spatial attention and motor planning based on learned spatial contingencies**

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Data, analysis scripts and e-prime files can be retrieved from the Open Science Framework: [https://osf.io/73bak/?view\\_only=01a3fb2e4e6c45ad872afe58fc053bb4](https://osf.io/73bak/?view_only=01a3fb2e4e6c45ad872afe58fc053bb4)

### **Abstract**

The present study tested whether the coupling of covert attentional shifts and motor planning of pointing movements can be modulated by learning. Participants performed two tasks. As a primary movement task, they executed a pointing movement to a movement target (MT) location. As a secondary visual attention task, they identified a discrimination target (DT) that was presented shortly before initiation of the pointing movement. These DTs either occurred at the same or at different locations with the MT. A common finding in such and similar settings is the enhanced visual target identification when locations of MT and DT coincide. However, it is not known which factors govern the flexibility of spatial attention-action coupling. Here, we tested the influence of previously learned spatial contingencies between MT and DT on the coupling of covert attention and motor planning. These contingencies were manipulated in three groups (always same locations, always opposite locations, non-contingent locations) in a training session. Results indicated that in a subsequent test phase, previously learned contingencies enhanced visual identification accordingly, even when targets for the movement task and the visual task were presented at opposite sides. These results corroborate previous findings of a rather flexible interaction of attention and motor planning, and demonstrate how can learn to control attention by means motor planning.

(213 words)

*Keywords:* Attention in action, spatial attention, pre-motor theory of attention, pointing movements

## Introduction

Goal directed hand movements like grasping and pointing require that we pay attention to the object or location of interest. Indeed, humans are particularly good at identifying objects at the location towards which we plan our movements (e.g., Craighero, Fadiga, Rizzolatti & Umiltà, 1999). Because of this close link between spatial attention and motor planning, it has been suggested that motor planning requires an obligatory shift of attention to the movement goal (Rizzolatti, 1989; Rizzolatti & Craighero, 1999; Rizzolatti & Craighero, 2010). More specifically, the Premotor Theory of Attention states that motor planning and attention share the same neural representations and hence each motor plan requires a preceding shift of attention to the movement goal (see Smith, & Schenk, 2012, for recent review).

However, there has been some debate of how rigid or flexible the spatio-temporal coupling of the two attention systems is: In line with a more rigid view, the predictions for the interaction of motor planning and attentional allocation are quite precise: “According to the premotor theory of attention, shifts of attention are an immediate and inevitable consequence of spatially directed response preparation [...]. [...] The fact that attention and action cannot be spatially dissociated even when this is required by task instructions clearly indicates that the links underlying these domains are not merely optional [...]” (Gherri & Eimer, 2009, p. 962/968). However, there are also contrasting views claiming a more flexible coupling of perception- vs. movement-related attention. In the following, we will summarize evidence for both views.

There is considerable evidence to support the claim of an obligatory coupling. When planning a movement, for instance a saccade, perception at the saccade goal is enhanced because a covert attention shift to the goal location precedes the actual movement (Hoffman & Subramaniam, 1995; Kowler, Anderson, Doshier & Blaser, 1995; Deubel & Schneider, 1996; Huestegge & Koch, 2010; Li, Barbot & Carrasco, 2016). Imaging studies showed a substantial overlap of neural networks that are active in tasks that require covert attention and tasks that require saccade planning (Corbetta, 1998). Neurophysiological data provided evidence for specific early ERP components that reflect pre-motoric attentional allocation if visual probes are presented at the movement target location (Gherri & Eimer, 2009). Finally, several studies with non-human primates have shown that micro-stimulation in monkeys' frontal eye field, which governs saccade planning and is crucial for the action-attention interplay, directly affects the perceptual sensitivity for stimuli at saccade goals (e.g., Moore & Fallah, 2001).

A well-known behavioral paradigm to study the interplay of motor planning and spatial attention has been established by Deubel and Schneider (1996). In this *visuo-motor dual-task* paradigm, participants performed a primary motor task and a secondary visual discrimination task. As the primary task, participants were required to prepare a saccade to one of several target locations, which were indicated by a movement cue. After a go-signal, participants executed the saccade to the movement target (MT). The secondary task was to identify a visual target. During movement preparation, a set of masked stimuli changed to distractors (2 or 5) and a discrimination target (DT; E or 3, see figure 1 of an illustration). Participants had to report which DT stimulus they had

seen. In accordance with the premotor theory and VAM, perceptual discrimination performance was enhanced when the location of DT and MT coincided.

The same paradigm has also been used to investigate the impact of manual pointing movements on spatial attention (Tipper, Lortie & Baylis, 1992; Baldauf, Wolfe, & Deubel, 2006; Stewart & Ma-Wyatt, 2015; see Baldauf & Deubel, 2010 for a review). The tasks were the same as in the Deubel and Schneider (1996) study described above, with the only difference that participants now executed a pointing movement with the finger instead of a saccade. The eyes remained fixated at a central position to ensure that any performance gain was due to a covert shift of attention before the initiation of the finger movement started. Participants identified the DT more accurately when it occurred at the goal of the pointing movement compared to movement-irrelevant locations. The authors interpreted this finding as evidence for an obligatory coupling between motor planning in general (irrespective of the particular effector system) and covert attention (Baldauf et al., 2006).

Despite this empirical evidence in favor of a strong spatial coupling between attention and motor planning, there have also been several studies that suggested some flexibility. For instance, using the visuo-motor dual-task paradigm, Kowler and colleagues (1995) found that when they instructed participants to prioritize the visual discrimination task over the motor task, these participants could reallocate attention away from the saccade goal to another target (although only to some degree) without loss in saccade performance (Exp. 4 in Kowler et al., 1995; for similar results, see Dore-Mazars, Pouget, & Beauvillain, 2004; Moehler & Fiehler, 2014; Klapetek, Jonikaitis, & Deubel, 2016). A similar division of attention has been shown in a study by Montagnini

and Caset (2007). They manipulated the frequency of trials in which visual DT and MT matched. At the beginning of each block of trials, participants were explicitly informed about these probabilities. Interestingly, participants could use their expectations to guide attention and showed not only better discrimination performance at MT locations in blocks with mostly matching trials, but also better performance at non-MT locations in blocks with mostly non-matching trials (although this effect was not significant in a larger, less trained population, see Exp. 2 in Montagnini & Caset, 2007).

To summarize, although numerous studies have provided evidence for a close coupling between attention and action, this coupling is not necessarily obligatory and seems to allow for some flexibility, especially under specific boundary conditions. Therefore, it is important to specify the conditions and possible mechanisms that affect the flexibility of the attention-action link.

### **The present study**

In this article, we suggest that contingency learning can be a determinant to affect the coupling between attention and action. Specifically, we asked whether the interplay between motor processes and spatial attention evolves as a consequence of acquired spatial contingencies between DT and MT. Consider that with natural grasping or pointing movements the object or location of interest is usually near the end-point of the movement. Consequently, it is usually advantageous to link motor programming and visual attention to the same locations in space. Yet, this does not mean that this link is obligatory and hard-wired; but it may emerge as a consequence of the experience that movement end-points and locations (or objects of interest) often coincide. If this inference is correct, it should principally be possible to “rewire” this link by learning

different contingencies of motor planning and spatial attention requirements. If, for example, observers face a situation where objects of interest always appear at locations opposite to the side they are going to move to, this may, after sufficient learning, result in superior perceptual processing of objects at locations opposite to a movement's target location.

In the present experiment, we trained participants using different training regimes in which MT and DT i.) always appeared at identical locations, ii.) always appeared at opposite locations, or iii.) were uncorrelated. We then tested how training affected attentional shifts in a test phase in which the locations of MT and DT were uncorrelated. Participants performed a primary movement task and a secondary visual discrimination task (see Figure 1). The primary task was to execute a manual pointing movement with the right hand. The movement cue, a centrally presented arrow, indicated to prepare a pointing movement to the target area on a touch screen either on the right or left hand side. Participants had to withhold the execution of the movement until the onset of an acoustic go-signal after which they had to execute the movement as fast as possible. The secondary task was a visual discrimination task (for a similar task, see Deubel & Schneider, 2003). At the beginning of a trial, a mask (a seven-segment digit 8) was presented at both locations. During the movement preparation period, one of the 8s was replaced by the DT (seven-segment E or 3) while at the other position a distractor (2 or 5) was shown. After a brief presentation time, targets and distractors were replaced by post-masks (8s) to prevent perfect discrimination. Participants were asked to indicate target identity after execution of the movement. As usual in such dual-task settings, participants were instructed to prioritize the primary (pointing) task.

To vary the contingency of motor planning and discrimination task requirements, participants performed a training session on the day before the test phase. In the training session, we manipulated the contingency of the locations of the MT and DT, such that the training was either compatible (the DT always appeared at MT location), incompatible (the DT always appeared at the opposite side of the MT location), or neutral (the assignment of DT and MT locations was random). In the following, we use the terms training-compatible, training-incompatible, and training-neutral to refer to these between-subject manipulations of the training condition.

In the test session, we tested the impact of training condition on the coupling of motor planning and visual attention. Thus, the assignment of MT and DT was always random, resulting in trials in which the DT occurred either at the same side or at the opposite side compared to the MT position. We use the terms congruent and incongruent to refer to this within-subject manipulation.

We tested two main hypotheses how learning could affect visuo-motor coupling: We dubbed the first hypothesis the *specific learning account*. We reasoned that learning in the training-compatible group strengthens already existing visuo-motor couplings, leading to better discrimination performance at congruent compared to incongruent trials during test (compared to the training-neutral group). This is based on the assumption that participants can acquire contingencies that correspond with typical attention-action contingencies as usually experienced in natural pointing movements. Because in natural pointing, the location of interest usually coincides with the end-point of the movement, participants in the training-compatible group should thus benefit from a training of these ecologically valid contingencies. Yet, participants in the training-



incompatible group should not benefit from training, because the learned attention-actions covariations in this training regime are conflicting with naturally acquired covariations. Therefore, the specific learning account predicts substantial *constraints* regarding the flexibility of possible attention-action couplings.

In contrast, the *general learning account* assumes that any attention-action covariation can be acquired, irrespective of previously over-learned covariations encountered in daily-life pointing situations. Thus, this account predicts better discrimination performance for congruent than incongruent test trials in the training-compatible group and, more importantly, a *reversed* compatibility effect in the training-incompatible group, resulting in better discrimination performance in incongruent than in congruent test trials. The general learning account thus proposes a fully flexible learning of attention-action couplings.

## Method

### Participants

Forty participants were paid for their participation in the experiment. All of them were naïve regarding the purpose of the experiment, had no previous experience with similar experiments, were right-handed, under 30 years of age, had normal or corrected-to-normal vision and gave informed consent. Sample size was determined based on a pilot study.

### Apparatus and Stimuli

Participants were seated in a dimly lit room at a desk of about 80 cm height. On the desk, a 22-inch color monitor (1024 x 768 pixel, 60 Hz; Faytech FT0220TM) with

touch functionality was positioned on which stimuli were presented and which also recorded the end position of pointing movements. The start key (space bar on a QWERTZ keyboard) was placed in front of the touchscreen at a distance of approximately 30 cm. Movements always started at the start key. The movement cue was an arrow presented at the center of the screen. Visual stimuli (seven segment characters *E*, 3, 2, 5, and 8) appeared on the left/right side at an eccentricity of 6.4 deg from the central fixation cross. The horizontal width of the cue and the stimuli was 0.9 deg of visual angle and their height was 1.4 deg.

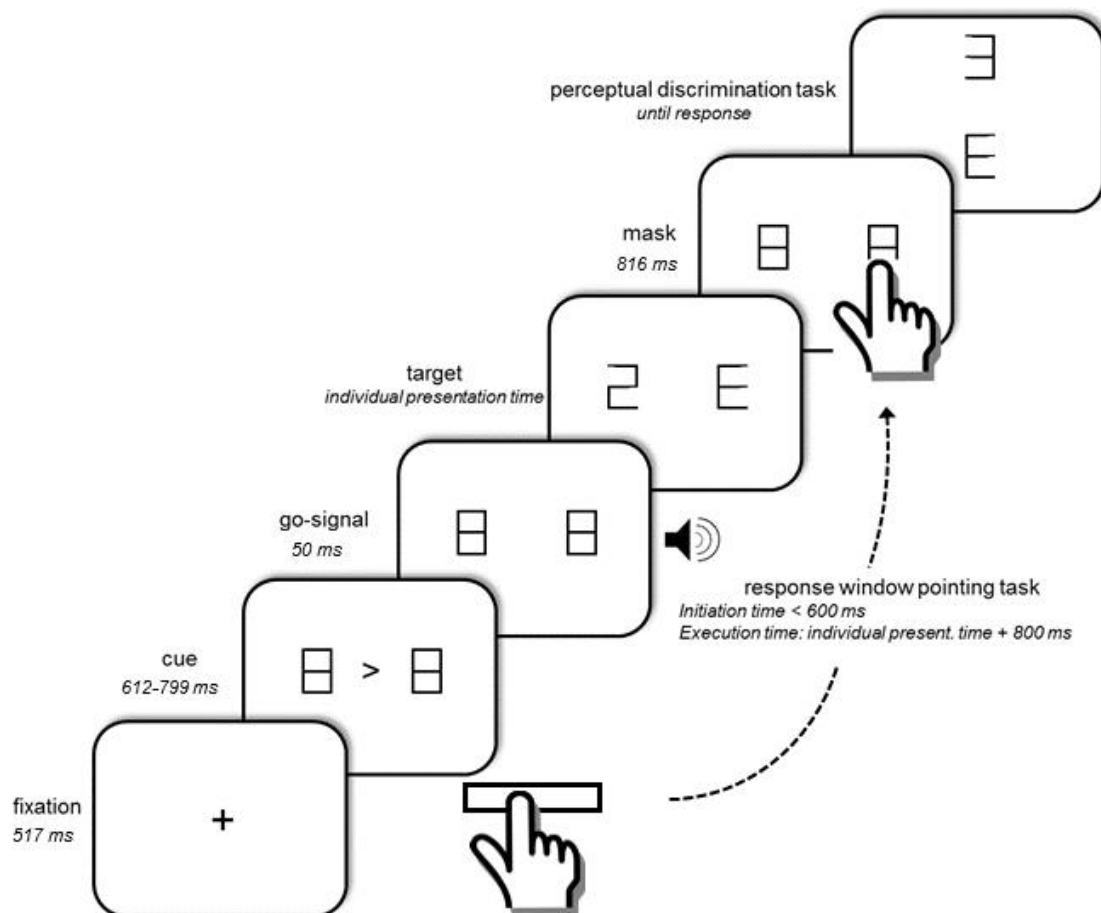
In order to restrict head movements, participants were required to place their chin and forehead on a chin rest, with a viewing distance of 60 cm to the monitor. The acoustic go-signal was presented using supra-aural headphones. Additionally, participants were reminded after each block to remain fixated on the center, and the instruction at the beginning of the experiment emphasized the importance of fixation. Initiation times and movement times as well as discrimination performance were recorded on-line by a PC with E-Prime Software 2.0.10.353 (Psychology Software Tools, Inc., Pittsburgh, PA, USA; Schneider, Eschman, & Zuccolotto, 2002). Eye movements were registered using an desktop mount EyeLink 1000 system (SR Research, Ottawa, Canada) by measuring the position of the right pupil with a temporal resolution of 1000 Hz and a spatial resolution of less than 0.01° (recording mode: pupil with corneal reflection). Saccades were registered via the SR Research built-in saccade parser.

## Procedure and Design

Participants performed the training and test sessions on two consecutive days (with 20-30 hours in between). The sequence of stimuli in a trial is shown in Figure 1. Participants started a trial by pressing the start key with their right index finger. At the beginning of each trial, the display showed a fixation cross. After a delay of 517 ms the fixation cross was replaced by two pre-mask elements (digital 8) and a small arrow indicating whether the left or the right 8 represented the target location for the pointing task. After a variable duration between 612 and 799 ms (randomly sampled), the cue disappeared and an acoustic go-signal (a 440 Hz tone for 50 ms) was presented. Participants had to hold the start key pressed until the onset of the go-signal. Upon the onset of this go-signal, participants were required to execute a pointing movement with the index finger of the right hand. The time from the onset of the go-signal to the release of the start key was measured as the initiation time. The time from release of the start key until contact with the touch screen was measured as the movement time. After 50 ms following the offset of the go-signal, one of the digital 8s were replaced by a distractor (resembling a digital 2 or 5) and the other one by the DT, which resembled the digital character *E* or 3. After an individually adjusted presentation time (see below), the DT and the distractor were replaced by digital 8s presented for 816 ms. At the end of each trial participants had to indicate with a non-speeded response of the left hand which of the two possible DTs had been presented.

When executing an incorrect movement, the German words for “wrong movement” (“falsche Bewegung”) were presented. When initiating the movement too slowly (> 600 ms) or when the movement time was too long (> 1000 ms), the German

words for “too slow” (“zu langsam”) appeared on the screen. When executing the movement before the go-signal, the German words for “too early” (“zu früh”) were presented. Error feedback was presented for 3000 ms in red font. Error trials were rerun at a random position at the end of the block. For the discrimination response, participants received visual feedback whether they performed the discrimination task correctly only during the training session but not in the test session.



*Figure 1.* Trial sequence. Participant’s primary task was to point to a left or right target location on the screen, using their dominant, right hand. As a secondary, non-speeded task they had to identify a target stimulus (presented after the go signal, immediately prior to movement initiation) by pressing one of two keys (not depicted here) with their left hand. For the analysis, only trials were included in which the target stimulus was no longer present when the actual movement started.

### **Adjusting presentation times and training phase**

Participants were randomly assigned either to the training-compatible, training-incompatible, or training-neutral condition. Participants were not informed about the contingencies of the target locations for the movement task and the discrimination task. At the beginning of the training phase, participants practiced the movement task alone for 32 trials. Then participants practiced both the movement task and the perceptual discrimination task for 2 blocks of 32 trials each. Presentation time of the DT was 408 ms in the practice blocks. Subsequently, presentation times were adjusted during the progress of the training session. We determined the presentation time for the DT for each participant individually, because in a pilot study we observed that naïve participants differ considerably in their ability to discriminate briefly presented target letters (see also Fan, McCandliss, Sommer, Raz, & Posner, 2002; Baldauf et al., 2006; Collins, Schicke, & Röder, 2008). We adjusted the presentation time with a staircase procedure with 11 blocks consisting of 32 trials each. In the first block, the DT was presented for 255 ms. Then the duration of the DT was shortened or prolonged, depending on the percentage of correct responses. If the percentage of correct responses was below 75% in a block, the presentation time of the DT increased in the next block. If the proportion correct was more or equal to 75%, the presentation time in the following block decreased. The presentation time changed with decreasing intervals over the course of the training session (68 ms for the first block, 51 ms for the second block, 32 ms for the third block, 17 ms for the remainder of the training).

## Test phase

Participants performed the test session one day after the training session. In the test phase, each participant performed one practice block of 32 trials, which was not included in the data analysis. Then, participants performed 15 experimental blocks, consisting of 32 trials each. The DT was presented either at the same side as the movement goal (congruent) or at the opposite side as the movement goal (incongruent). In one half of the trials, the DT was the letter “E”, in the other half the digit “3”, and the distractor was either the digit “2” or “5”. This resulted in 16 different trial types in total (2 movement directions x 2 locations of DTs x 2 types of DTs x 2 types of distractors). Each of these combinations was presented twice in each experimental block. The order of trials was selected randomly in each block.

## Data analysis and exclusion of trials

Since participants were required to remain fixated on the central cue, we excluded any trials in which participant executed saccades larger than  $0.5^\circ$  of visual angle within the time frame of cue presentation until the end of the trial. Four participants executed saccades  $> 0.5^\circ$  in more than half of the trials during the test session and were therefore not included in the final analysis. Of the remaining sample, one participant still showed a high rate of saccades ( $M = 44\%$  of trials,  $> 3$  SD) and was also excluded. Furthermore, one participant initiated movements while the DT was still present in  $70\%$  of the trials. Of the remaining sample, two additional participants showed a high rate of movement initiation before the DT had been masked ( $M > 38\%$ ,  $> 3$  SD). Data of these participants were also not further analyzed. Please note that all effects reported below remain significant when including all 40 participants.

The final sample comprised of 8 participants in the compatible training group, 11 participants in the neutral training group and 13 participants in the incompatible training group. Trials in which the pointing goal was missed (end-point deviated by more than 11 mm from center of target) or the movement was erroneously executed toward the non-cued pointing position were not further analyzed (10.3 %). Similarly, trials in which the movement was initiated too slowly (> 600 ms) or started too early (before the go-signal) were also not analyzed (5.6% and 0.6%). Trials in which participants executed a saccade were excluded from the analysis (9.3 %). A one-way ANOVA showed that there were no significant differences between the training conditions,  $F(2,31) = 1.65$ ,  $p = .21$ ,  $\eta_p^2 = .097$ . Saccades occurred in 13.3 %, 10.3 % and 6.0 % of the trials in the training-compatible, training-neutral and the training-incompatible group respectively. Finally, to ensure that the DT was no longer present when the actual movement started, trials with onset latencies longer than 50 ms (duration of the Go-signal) plus the individual presentation time were excluded from further analysis (2.9 %).

## Results

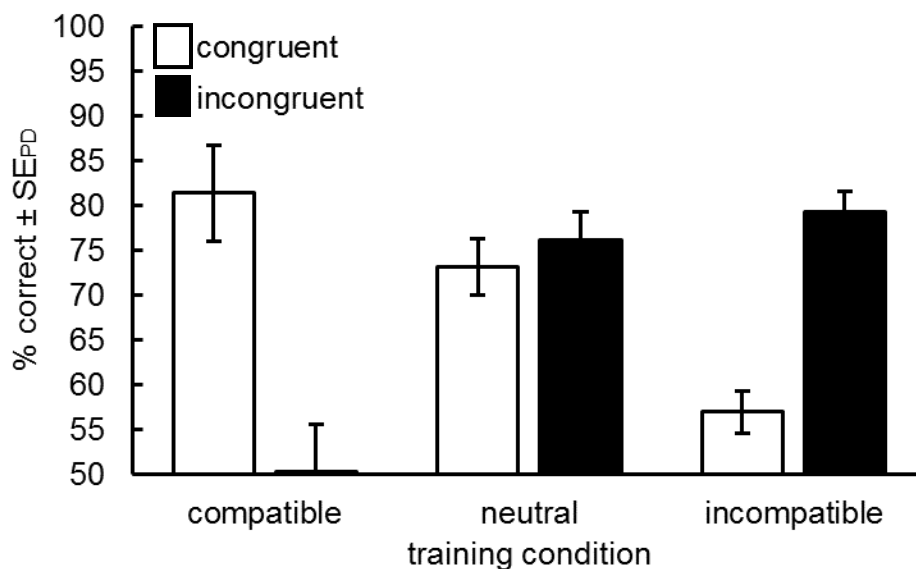
### Presentation times

Presentation times for the visual targets showed an interindividual variation ranging from 17 ms to 260 ms ( $M = 95$  ms). The mean presentation times for each condition were 102 ms ( $SD = 23$  ms) for training-compatible, 92 ms ( $SD = 25$  ms) for training-neutral and 91 ms ( $SD = 20$  ms) for training-incompatible. A one-way ANOVA with the between-subject factor training condition revealed no significant differences between these means,  $F < 1$ .

**Perceptual discrimination task**

The accuracy of perceptual performance was defined as the percentage of correct decisions on the identity of the DT. For any ANOVA reports, all p-values are Greenhouse-Geisser corrected where necessary. For within comparison between congruent and incongruent trials, the standardized mean difference effect size for within-subjects designs (Cohen's  $d_z$ ) was calculated.

Figure 2 summarizes the results. A mixed ANOVA with the between factor *training condition* (training-compatible, training-neutral, training-incompatible) and the within factor *congruency* in the test trials (congruent, incongruent) revealed no significant main effects ( $p_s > .13$ ) but a significant interaction,  $F(2, 29) = 36.67, p < .001, \eta_p^2 = .717$ . Pairwise comparisons revealed that participants with compatible training identified targets better in congruent (81.4%) than incongruent (50.3%) trials,  $t(7) = -9.89, p < .001, d_z = 1.16$ . In the training-neutral condition, discrimination accuracy for congruent (73.1 %) and incongruent trials (76.2 %) did not differ significantly,  $t(10) = 1.33, p = .213, d_z = 0.41$ . In the incompatible training group participants identified targets more often correctly in incongruent (79.3%) than congruent trials (57.0%),  $t(12) = 4.17, p = .001, d_z = 3.49$ .





*Figure 2.* Mean discrimination performance for congruent (movement target and discrimination target locations coincide) and incongruent (movement target and discrimination target locations did not coincide) conditions as a function of training condition. Error bars indicate the standard error of paired differences for the within-subject comparison between congruent and incongruent trials.

### **Initiation time and movement time**

A corresponding ANOVA was performed on the movement data. For initiation times, none of the effects reached significance,  $F_s < 1$ . For movement times, the analysis revealed a significant interaction,  $F(2, 29) = 3.42$ ,  $p = .046$ ,  $\eta_p^2 = .191$ . Participants with compatible training tended to exhibit shorter movement times when MT and DT were congruent vs. incongruent ( $\Delta = 3$  ms), although this effect did not reach significance,  $t(7) = 2.23$   $p = .061$ . For the incompatible training group, this data pattern was reversed: Here participants with incompatible training showed shorter movement times when MT and DT were incongruent vs. congruent ( $\Delta = 3$  ms),  $t(12) = -2.82$   $p = .016$ ,  $d_z = 0.78$ . In the training-neutral condition, movement times did not differ,  $t < 1$ .

#### **Table 1**

*Mean initiation (IT) and movement times (MT) for congruent (movement target and discrimination target locations coincide) and incongruent (movement target and discrimination target locations did not coincide) conditions depending on training condition in ms, standard errors are presented in parenthesis.*

Training condition

|             | compatible |           | neutral   |           | incompatible |           |
|-------------|------------|-----------|-----------|-----------|--------------|-----------|
|             | <i>IT</i>  | <i>MT</i> | <i>IT</i> | <i>MT</i> | <i>IT</i>    | <i>MT</i> |
| congruent   | 289 (20)   | 686 (24)  | 284 (17)  | 722 (21)  | 287 (15)     | 697 (19)  |
| incongruent | 289 (20)   | 689 (24)  | 283 (17)  | 722 (21)  | 287 (15)     | 694 (19)  |

### Discussion

In the present experiment, we tested how learning of visuo-motor contingencies affects the coupling of covert attention and motor planning. Participants performed pointing movements to target locations (primary task) and identified visual targets (secondary task) that were presented during the planning of the movement or maintaining of the movement plan. In a training session, participants learned specific spatial contingencies; locations for the visual and the movement tasks either consistently coincided (same side, training-compatible), consistently occurred at opposite sides (training-incompatible), or randomly occurred on the same or the opposite side (training-neutral).

Results showed a strong influence of these training conditions on the accuracy of visual identification during a neutral test phase one day after training. More specifically, discrimination performance was better for congruent than incongruent test trials in the training-compatible group whereas in the training-incompatible group, discrimination performance was better in incongruent than in congruent test trials. This is in line with a general learning hypothesis suggesting that participants acquired contingencies between MT and DT locations during training and that retrieval of these contingencies

modulated the attention-action link in the subsequent test phase. Importantly, the reversed compatibility effect in the training-incompatible group shows that this process is not specific to overlearned, compatible attention-action contingencies, but generalizes to arbitrary contingencies between movement plan and covert attention shifts. Finally, in the training-neutral group, we did not observe a compatibility effect. This null effect replicates a previous study showing no facilitatory influence of movement planning on attention with considerably long delays between movement planning and execution (cf. Deubel & Schneider, 2003). We will discuss these findings in turn.

### **Learning of attention-action contingencies**

The present results and in particular the incompatible training condition are inconsistent with a strong interpretation of the premotor theory of attention that predicts a mandatory coupling between motor planning and shifts of attention. However, a weak interpretation of this theory, which holds that shifts of attention are dependent upon motor planning, but which does not presuppose that movement planning and attention are functionally identical, could accommodate the present results. Accordingly, learning of regularities between motor plans and potential target locations would guide attentional shifts.

To explain in more detail how such a learning process could guide attention, we will use the concept of a salience map which describes a common representational medium for attention (Koch & Ullman, 1985). Objects in this map compete against each other solely through their physical distinctiveness over time in a bottom-up manner, and the most salient object is selected. Despite the importance of object distinctiveness, the relevance of the stimulus for the organism is coded via top-down mechanisms (Fecteau, Bell & Munoz, 2004). We propose that the acquired knowledge about relational

distributions is integrated in this map. Research has shown that acquired knowledge about the distributional relation between objects and space leads to facilitated recognition of critical stimuli (e.g., Chun & Jiang, 1999; 2003; Hoffmann & Kunde, 1999; Hoffmann & Sebold, 2005; Miller, 1988; Musen, 1996). While these studies addressed a somewhat different type of spatial contingency learning (e.g., where an object is located relative to other objects), the general underlying mechanisms could indeed be similar to the spatial contingency learning regarding the spatial relation of DT and MT. According to this reasoning, learned contingencies between task-relevant visual events (e.g. the DT) and movement plans (e.g. the MT) allow for a flexible coupling between motor commands and attention.

Furthermore, recent neurophysiological data suggests that the lateral intra-parietal area (LIP) provides a neuroanatomical analog for a spatial map coding pragmatic affordance. The LIP integrates information from multiple sources including behavioral goals and context, expectation of reward, and memory for past events (Gottlieb, Balan, Oristaglio, & Schneider, 2009; Thompson & Bichot, 2005 for the highly connected region FEF; see Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Bressler, Tang, Sylvester, Shulman, & Corbetta, 2008 for evidence regarding a localization of expectations in the lateral intraparietal sulcus in humans; see Astafiev, Shulman, Stanley, Snyder, Van Essen & Corbetta, 2003 for a comparison of monkey and human brain areas). Indeed, the integrative role of the parietal cortex has been emphasized by recent studies with patient CF who suffered from a parietal damage with unilateral optic ataxia (Khan et al., 2009). This patient showed a dissociation of correct saccade execution and pre-saccadic perceptual facilitation. CF was tested in the paradigm of Deubel and Schneider

(1996), where visual targets were presented at either the goal of a saccade or at a non-goal location. The patient was able to execute saccades to the impaired and the intact visual field. However, he showed a sharp decline of perceptual performance at the saccade goal in the impaired, but not in the intact visual field. Based on that finding, Khan et al. (2009) reasoned that saccade planning and attentional enhancement at the saccade goal are separable, and assumed a mediating role of the parietal cortex (see Striemer, Locklin, Blangero, Rossetti, Pisella, & Danckert, 2009, for a similar finding with the same patient CF for pointing movements). Our present results are in line with this assumption of separable processes and additionally demonstrate how different spatial contingencies can be learned via training.

### **Open issues**

The results of the present study corroborated the observation of Deubel and Schneider (2003) that covert attention and motor planning can be decoupled for longer delays between movement cue and movement initiation. In that study, planning of hand movements went hand in hand with enhanced identification at the MT location only for short delays between the movement cue and the movement go-signal, but not for delays longer than 300 ms. Possibly, this failure to observe a facilitatory effect of movement planning on target discrimination might indicate that a coupling is not possible for long cue-go-signal intervals. Accordingly, the authors speculated that under these circumstances, movements are executed “off-line” (Deubel & Schneider, 2003), that is, without any spatial processing shift towards the location of the MT. However, other studies that used considerably longer cue-go signal delays (1500 ms) observed facilitation of target detection for visual targets that were congruent with the planned

reaching movement (Fagiolo, Hommel, & Schubotz, 2007; Wykowska, Schubö, & Hommel, 2009). Against this background, the present study provides first evidence that attention-motor coupling can be modulated by previous learning experiences. Possibly, learning or retrieval of visuo-motor contingencies is facilitated with more time available to plan a movement. While short delays between movement planning and initiation might cause automatic shifts of attention, long delays might allow for more controlled and endogenous allocation of attention. However, this speculation awaits further testing.

Another open question is whether the present findings would generalize to the oculomotor system. While some studies argued for shared attentional resources of the oculomotor and the manual motor system (Song & McPeck, 2009; Khan, Song, & McPeck, 2011; Huestegge & Adam, 2011; Huestegge, Pieczykolan, & Koch, 2014), others have suggested independent attentional resources (Jonikaitis, Schubert, & Deubel, 2010; Jonikaitis, & Deubel, 2011), probably with different underlying characteristics. Empirically, it has been shown that attention-action coupling for saccades produces a compatibility advantage even for cue-go-signal delays up to 1300 ms (Deubel & Schneider, 2003). Albeit speculatively, this discrepancy could be rooted in differences regarding learning experiences or instrumental usage regarding the two effector systems. While saccades usually produce a change in the visual field as the only consequence of the movement (except for specific contexts or lab situations, see Huestegge & Kreutzfeldt, 2012), hand movements produce much diverse consequences, because hand movements directly interact with the environment, for instance by avoiding obstacles or manipulating tools (e.g. Deubel & Schneider, 2004;

Collins, Schicke & Röder, 2008). These predictions should be explicitly tested in future studies by focusing on oculomotor (instead of manual) movements.

Finally, the present study is not decisive whether the observed training advantage is specific for the learning of visuo-motor contingencies or whether it reflects a more general effect of statistical learning between two events. Clearly, isolating the contribution of motor planning for attentional shifts is pivotal for the premotor theory of attention. At the same time, it might be interesting for studies on perceptual learning to consider the role of motor components in more details, since most visual learning tasks afford at least covert eye movements.

In conclusion, the present study provided evidence for the influence of learned contingencies for the allocation of spatial attention during motor planning of hand movements. The results show that the spatial coupling of spatial attention and motor planning can be highly flexible and dependent on learning history.

### **Compliance with Ethical Standards**

The authors declare that they have no conflict of interest. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.



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