

Attention Allocation During Movement Preparation

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Abstract

Identification performance was measured for letters which were briefly presented at different spatial locations and time delays relative to the beginning of manual movement preparation. Identification performance depended on the complexity of the upcoming movement and decreased prior to movement onset. Further findings of similar identification performance with different spatial relations between probe location and manual movement direction cast doubt on the generality of a premotor theory of attention.

Introduction

In studies of visuo-spatial attention, the experimenter typically biases a subject's attention toward particular locations in the visual field and probes for identification accuracy or detection time; differences between (unbiased) baseline and experimental performance are interpreted as attentional effects. Until recently, however, attention research has neglected a crucial aspect of performance, because subjects were typically instructed to suppress overt movements toward attention probes. The present paper argues that attending to the motor part of cognition might provide a new understanding of the nature of attentional processes.

Recent findings suggest that attentional effects on perception might be a consequence of covert movement planning. For example, Stoffer (1991) demonstrated that the current attentional focus determines spatial compatibility effects, providing an attentional account for this manual response selection problem. Meegan and Tipper (1993) showed that an irrelevant distractor interfered more with overt reaching when it was blocked by an obstacle; thus, the complexity of potential reaches incurred attentional costs. Further, interference was stronger when the distractor was located between the hand and the target than when it was beyond the target location (Tipper et al., 1992); attentional gradients in 3-space can thus be conceived as reflecting action-centered attention (see also Downing & Pinker, 1985). Moreover, attentional benefits appear to be "attached" to objects, moving with them to new spatial locations (Tipper et al., 1991) and thus suggesting the continuous revision of action plans toward objects in the visual field. An attentional effect may therefore be understood as the updating of an object representation, including "...the responses it should appropriately evoke" (Kahneman et al., 1992, p. 178).

These and other findings support the assumption that attentional cuing leads to covert preparation of orienting responses, which are then, however, successfully inhibited by the subject. The instruction to suppress overt movements of the eyes or the hands toward the stimulus might therefore dissociate a natural relationship between perception and action. This is also evident from the well-known Simon effect (Simon, 1969): A tendency to select responses based on the irrelevant location of an imperative stimulus leads to faster (and even erroneous) responses of the hand that is closer to the source of stimulation. To better understand the attentional component in this relationship between perception and action, a systematic investigation of the time course of attentional effects relative to movement planning and its overt execution seems warranted.

The *Premotor Theory of Attention* (Rizzolatti et al., 1987; Umiltà et al., 1991) offers a framework for such an investigation. This theory postulates an identity of covert orienting (attention shifts) and movement preparation (motor programming). Specifically, it assumes that a subject cannot refrain from preparing a movement (typically of the eyes) toward an attended location. This preparatory process is assumed to be hierarchically organized, with the specification of movement direction (relative to the midsagittal plane) preceding the specification of movement amplitude. While there is evidence for such hierarchical preparation prior to manual movement execution (Rosenbaum, 1980), the premotor theory itself is largely based on indirect evidence in the absence of overt movements (other than simple key presses). Support for the notion of attention as a motor program is reflected in an increase in response latencies to events at recently but no longer attended locations. If the withdrawal of attention is a decision to not overtly orient toward a location, then this *inhibition of return* effect reflects the temporal cost of reprogramming this movement. A few studies have shown this effect with overt movements of the eyes (e.g., Vaughan, 1984; Rafal et al., 1989), but it is unknown whether this relationship between perception and action holds for movements in general.

Consider the dual task of performing a hand movement and simultaneously trying to identify a lateralized probe. Both tasks tap specific areas of the brain; identification performance therefore systematically depends on the spatial relationship between side of movement and side of probing. If the motoric task engages the attentional resources of a hemisphere, ipsilateral probe identification will be poor, relative to a condition in which the motor task is controlled by the other hemisphere (*intrahemispheric interference* hypothesis; e.g. Kinsbourne & Hicks, 1978). If, however, lateralized activity from motor planning supports other cognitive processes in the same hemisphere, then ipsilateral probe identification will be better, relative to a condition in which the motor task is controlled by the other hemisphere (*intrahemispheric facilitation* hypothesis; e.g. Verfaellie et al., 1988). Finally, if attentional effects on perception reflect motor programming activity, then the visual hemifield toward which the movement is directed will exhibit improved identification performance (*premotor theory of attention*). Two experiments tested these predictions. The findings of the first experiment are in conflict with the facilitation hypothesis, because letter identification was better in the visual field contralateral to the side of movement. The findings of the second experiment cast doubt on the generality of a premotor theory of attention, because lateralized letter identification was not affected by movement direction of the hand.

Experiment 1

The first experiment examined how the spatial relation between movement preparation and probe presentation affects probe identification. Crossing *Hand of Movement* (left/right) with *Hemifield of Probe Presentation* (ipsilateral/contralateral) yielded four conditions. The hemispheric interference hypothesis predicts a perceptual advantage in the two contralateral conditions (left/right and right/left) over the two ipsilateral conditions; the hemispheric facilitation hypothesis makes the opposite prediction. The prediction of the premotor theory depends on the movement direction of the

hand. To make eye movements unlikely, subjects in this first experiment moved their hands from peripheral to central keys on a keyboard centered in their midsagittal plane, so that both the movement cue and the movement target were centered in foveal vision. The premotor theory predicts a perceptual advantage for the two contralateral hemifields, because movement *direction* planning should induce contralateral attention allocation.

A corollary of all theories regards the size of attentional effects. The two hemispheric activation theories predict that the amount of interference or facilitation depends on the amount of required movement preparation. The premotor theory, however, predicts no synergy at all between action and perception if a movement does not require specification of direction and/or amplitude. Thus, two different *Movement Instructions* were compared: Subjects either just lifted the index finger from a start key or had to move it onto a target key.

The perceptual consequences of movement preparation were investigated by briefly presenting a probe letter and measuring the subject's identification performance directly after movement completion. To capture the time course of attentional effects, the *Probe Delay* relative to the movement cue onset was varied; the probe appeared either 50, 150, 250, or 350 ms after the movement side had been instructed by a centrally presented go signal.

Apparatus

Subjects sat in front of a Macintosh Plus computer with a black on white screen of 22 cm diagonal size (see Fig. 1). Two vertical wooden panels, positioned on both sides of the keyboard, held two tiltable mirrors horizontally above the keyboard. The upper mirror obstructed the subject's view on the screen and reflected stimuli on the lower mirror, from which they could be read by the subject while at the same time visually monitoring the movement. This device was used to encourage the sharing of spatial attention between tasks. The "1", "=", "6", and "7" keys in the top row of the keyboard were used to register reaction times and movement times in the movement task, and the remaining alphabet keys ("a" through "z") registered the subject's perceptual identification responses. The movement distance between a peripheral start and central target key (center to center) was 95 mm, and each key's width was 13 mm.

Method and Stimuli

Sixteen right-handed subjects (mean age 21 years) with normal or corrected vision were randomly assigned to one of the two *Movement Instruction* groups. All but three reported some basic skill in touchtyping. All subjects were instructed to give priority to the fast completion of the movement task and then to type in the letter they had seen (or to guess if necessary) at their leisure. They adjusted the keyboard as well as both mirrors such that a fixation cross ("+") appeared on the lower mirror close to and above the two central target keys.

After the subject pressed down both peripheral start keys, a warning tone (3500 Hz) sounded, and after 400 ms the fixation cross was replaced by the movement cue. The cue was a small arrowhead pointing to the left or right ("<" or ">"). After the probe delay a lowercase letter appeared for 117 ms at one side of the arrow, with an eccentricity of 4° (the start keys had a visual eccentricity of 17°). At the end of the presentation interval the screen was blanked to white. A tone following the correct response (liftoff from the peripheral key "1" or "=" in the Lift group, touchdown on the central key "6" or "7" in the Move group) prompted the subject to type (or guess) the letter he/she had seen.

Design and Procedure

Movement Instruction was a between-subject factor, whereas Hand of Movement, Hemifield of Probe Presentation, and Probe Delay were randomized within subjects. Each subject first practiced the movement task without concurrent letter identification and then participated in two blocks of 160 experimental trials (10 per

condition). Only data from the second block were analyzed. Trials with reaction times below 200 or above 1000 ms were discarded (1.1% of all observations).

Movement errors as well as reaction and movement times and the proportion of correctly identified letters from trials with correct movement completion were analyzed with 2 (Movement Instruction) x 2 (Hemifield of Probe Presentation) x 2 (Hand of Movement) x 4 (Probe Delay) ANOVAs.

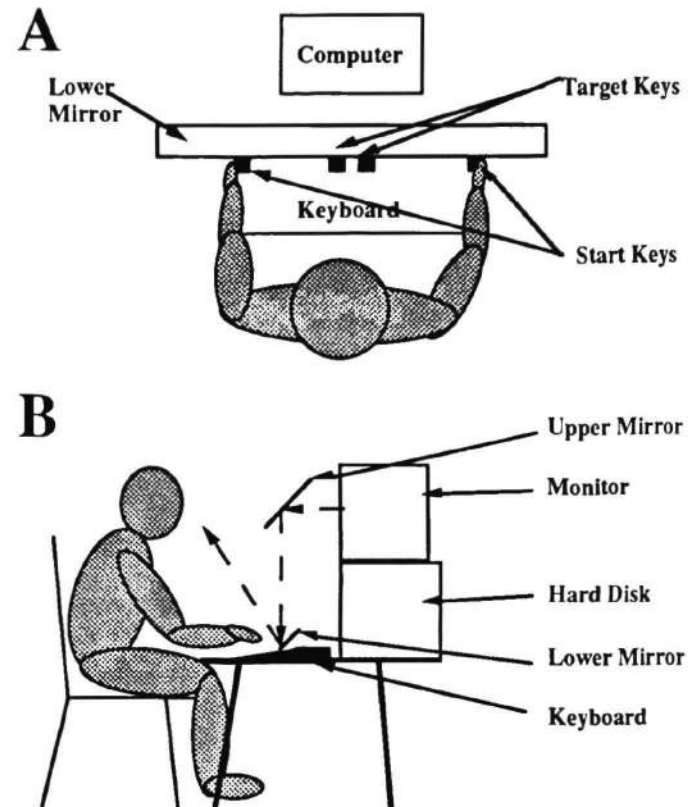


Figure 1: Experimental Setup. A: Top view; B: Side view. (Parts of the mirror device have been omitted for clarity.)

Results

Movement Errors. For the Move and the Lift group 26 and 100 erroneous lift-offs were counted (2% and 7.9%), respectively, $F(1,14) = 15.89, p < .01$. A significant interaction of Movement Instruction, Probe Delay, and Hemifield, $F(3,42) = 2.98, p < .05$, indicated different error patterns in the two groups: Errors in the Move group were evenly distributed across conditions; for the Lift group, many errors occurred with the 150 ms Probe Delay, irrespective of hemifield, and contralateral probing induced more errors at the 50 ms compared to the other probe delays. No other main effect or interaction was significant.

Reaction Times. The times from directional cuing to movement onset were on average 452 ms for lifting and 513 ms for aiming with the finger, $F(1,14) = 6.82, p < .05$. Responses were on average 11 ms faster when probing at the side of movement preparation, compared to contralateral probing, $F(1,14) = 10.20, p < .01$. This effect was restricted to the 50 ms probe delay. The effect of Probe Delay was highly significant, $F(3, 42) = 36.76, p < .001$; at the 350 ms delay responses were on average 48 ms slower than for the shorter delays, which did not differ. The right hand was not reliably

faster than the left hand, and all remaining interactions were not significant. Figure 2 shows that, aside from the main effect of Movement Instruction, the reaction time patterns for the two groups were quite similar.

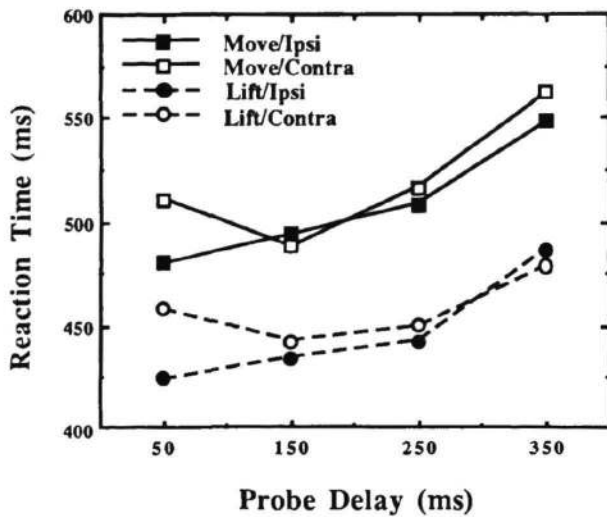


Figure 2: Movement Onset Times for each Probe Delay. Ipsi: Probe and moving hand in the same visual hemifield; Contra: Probe and moving hand in opposite visual hemifields.

Identification Performance. The Lift group identified on average 72% of the letters, the Move group only 56%, $F(1,14) = 5.84, p < .05$. Identification was 11% better when the right hand moved than when the left hand moved, $F(1,14) = 17.33, p < .001$. A significant effect of Probe Delay, $F(3,42) = 12.97, p < .001$, was due to poorer performance at 350 ms compared to the other delays. While the Hemifield effect was not significant, $F(1,14) = 3.14, p > .09$, there was a large advantage of *contralateral* over *ipsilateral* probe trials at the 250 ms probe delay, $F(3,42) = 5.45, p < .01$. Thus, 250 ms after the movement preparation had begun, probes were identified more accurately when they appeared in the visual hemifield toward which the subject planned to move. Fig. 3 shows that, aside from the main effect of Movement Instruction, the performance patterns of the two groups were again similar.

Movement Times. For the Move group, average time from liftoff to touchdown on the target key was 320 ms, and no significant differences across conditions were obtained.

Discussion

The first experiment found strong interactions between attentional processes and movement preparation in a dual task. Letter identification depended on the degree of concurrent movement preparation: When subjects had to prepare a goal-directed movement, less attention was available to aid perception than when subjects merely had to lift a finger. This was reflected in a reaction time difference of 61 ms and an identification difference of 16% between the groups. The low performance before movement onset further supports this notion of a resource conflict (intrahemispheric interference) and shows that subjects in both groups could strategically and rapidly allocate attention between the visual and motoric task; it also suggests that goal-directed movements demand controlled processing, even for their initial, ballistic part.

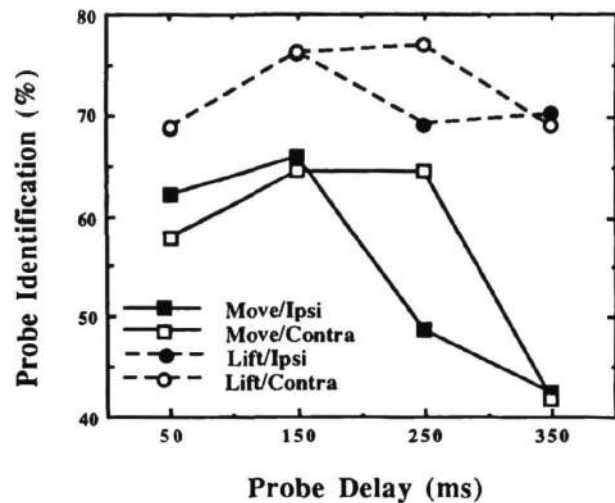


Figure 3: Identification Performance for each Probe Delay.

The spatial relation between planned movement activity and location of probing affected probe identification performance. This was evident at both the 50 ms and the 250 ms probe delays. For the 50 ms probe delay, reaction times in both groups were about 32 ms *shorter* when the probe had appeared at the side of instructed movement rather than in the opposite hemifield. This effect of spatial compatibility between location of probing and location of motor activity is not in agreement with the notion of intrahemispheric interference. It rather suggests facilitated planning when the probe onset commands attention into the same hemifield. The error pattern in the Lift group supports this interpretation; it shows that early peripheral onsets can induce faulty effector specification, leading to the observed tendency to respond with the effector that is closer to the source of stimulation (Simon, 1969).

Identification performance at the 250 ms probe delay, however, remained accurate in the *contralateral* hemifield only: Planning to respond with the left hand improved perception of letters in the right visual field, and vice versa. Such a finding was predicted by the premotor theory of attention and by the intrahemispheric interference hypothesis; thus, the benefit can be interpreted either as an indication that attention shifted in the direction of the forthcoming movement, or as a relative improvement of letter processing in the hemisphere that was less taxed by motor planning.

The strikingly similar identification pattern for both groups across the time course of movement preparation suggests that the underlying preparatory processes were similar. This finding might be taken as evidence against the premotor theory, because subjects in the Lift group presumably planned a less complex movement with different direction and amplitude. However, subjects in both groups typically used the same finger they had just moved (according to the movement instruction) to subsequently type in the perceived letter, and kept their other index finger on the start key throughout a trial. Since all relevant letter keys were located between the two start key locations, it is conceivable that subjects in *both* groups always prepared movements directed to the midsagittal plane.

This argument calls for a control experiment in which movement direction could also be from the center of the keyboard outwards. This situation provides a direct test of the premotor theory against the hemispheric interference hypothesis: The premotor theory predicts improved ipsilateral identification for outward movements and improved contralateral identification for inward movements. The hemispheric interference hypothesis predicts that, irrespective of

movement direction, probes in the hemifield contralateral to the side of movement preparation should always be identified better than ipsilateral probes.

Experiment 2

The second experiment addressed the issues raised in the discussion of the initial study. First, Movement Direction varied between four experimental blocks: Moving from the peripheral to the central keys, moving from the central to the peripheral keys, lifting the finger from the peripheral keys, and lifting the fingers from the central keys. This was achieved by simply assigning the target keys from Experiment 1 as start keys (and vice versa) in the two new conditions of the present experiment. The other conditions were direct replications of the first experiment. To accommodate concerns regarding the between-groups comparison in the previous study, all subjects participated in all conditions in a counterbalanced order. To control for the possibility of anticipatory preparation of typing responses in the Lift conditions, subjects touched down on their start key prior to typing the perceived letter. Thus, even if a directional component for this simple motor program were specified, its value would be irrelevant for a possible attention shift.

Another modification of the method concerned the fact that manual reaction times increased with longer probe delays in the first experiment. This could simply reflect a procrastination strategy with which subjects tried to improve their letter perception. Note, however, that in the previous experiment the movement cue was always erased at the end of probe presentation; longer probe delays may therefore have delayed attentional disengagement from the cue. This could account for the observed increase in reaction times across probe delays, because the offset of an attended stimulus facilitates manual as well as eye movement latencies (Fischer & Rogal, 1986). Alternatively, the advance of movement preparation with longer probe delays might have made it harder to divert attention back to the visual domain, thus making the required attention switch from the primary (motor) task to the secondary (perceptual) task costlier for the later probes. The second experiment attempted to clarify this issue by leaving the movement cue visible after probe presentation. If the increase of reaction times with longer probe delays in the first experiment was due to the easier disengagement of attention for early probe delays, then this effect should disappear.

Because all subjects participated in all movement conditions, the extensive training regime of the first experiment was replaced by only ten practice trials in each movement condition prior to data collection. To maintain a reasonable level of identification accuracy, the eccentricity of the peripheral probe letters was slightly reduced from 4° to 3° (increase the probe duration would have invited eye movements). To further prevent eye movements (e.g., toward the peripheral target keys), in 20% of the trials of each condition the probe was presented for only 17 ms just above the central arrow; identification performance for these trials served as an objective fixation control measure. Furthermore, subjects were repeatedly instructed to fixate the arrow at the center of the display and could also not predict the location of a forthcoming probe. Finally, the fact that the movement cue was no longer deleted with the probe also reduced the likelihood of eye movements.

The apparatus, method, stimuli, design, and procedure were the same as in Experiment 1, with the above modifications. Eight right-handed subjects with normal or corrected vision (mean age 23 years) participated. All reported to have some touchtyping skills. The data were analyzed with 2 (Movement Instruction) x 2 (Hemifield of Probe Presentation) x 2 (Start Location) x 2 (Hand of Movement) x 4 (Probe Delay) ANOVAs.

Results

Movement Errors. In the Move and Lift conditions, 8.7% and 7.5% erroneous lift-offs were observed, respectively, $F < 1$. A significant interaction of Hemifield with Probe Delay, $F(3,21) = 7.40, p < .01$, indicated that at the earliest delay the contralateral

probes induced more errors than all other conditions. This effect was more pronounced for the right than for the left hand, $F(3,21) = 3.42, p < .05$. An interaction of Movement Instruction with Start Location, $F(1,7) = 6.33, p < .05$, showed that lifting the correct index finger was easier at the peripheral than at the central start location, whereas moving the index finger to a different key was easier when starting at the central than when starting at the peripheral start location. Finally, there were more errors associated with contralateral than with ipsilateral probing, $F(1,7) = 8.83, p < .05$.

Fixation Control. An overall identification level of 93% for letters presented for only 17 ms above the central arrow shows that the subjects conformed with the instruction to fixate the movement cue during movement preparation. However, with longer delays of the central probe the probability to correctly identify this letter was reduced from 96.5% to 89.8%, $F(3, 21) = 2.95, p < .06$.

Reaction Times. Reaction times were on average 465 ms for lifting and 474 ms for moving the finger, $F(1,7) = 1.06, p > .34$. Responses were initiated 33 ms later from the peripheral than from the central start keys, $F(1,7) = 10.34, p < .02$. There was no main effect of Probe Delay, $F(3,21) = 2.23, p > .1$, but contralateral probing led to 12 ms slower reactions on average than ipsilateral probing, $F(1,7) = 23.87, p < .01$. This main effect of Hemifield was qualified by a significant interaction with Probe Delay, $F(3,21) = 6.90, p < .01$: While reaction times for ipsilateral probing increased with Probe Delay, contralateral probing led to slower responses at the 50 ms delay than at any other probe delay. Finally, there was an interaction of Probe Delay with Hand, $F(3,21) = 5.11, p < .01$, such that all left-hand trials were more affected by the early probes than right-hand trials. No other main effect or interaction was significant. Figure 4 focuses on the two Move conditions; it shows that, aside from the main effect of Start Location, the reaction time patterns for both movement directions were similar.

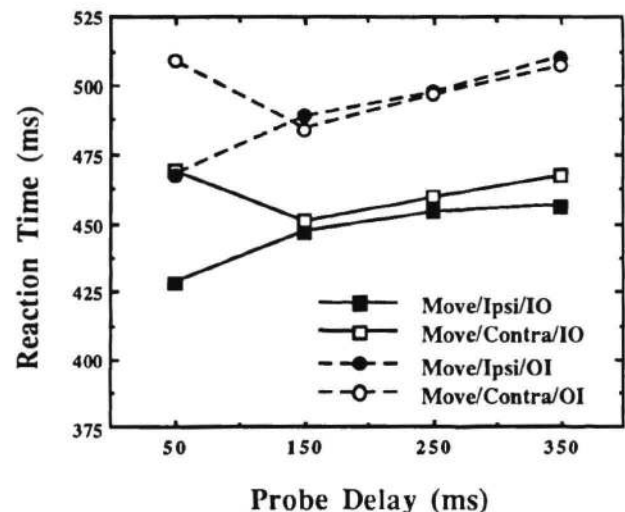


Figure 4: Movement Onset Times for the Move conditions. IO: Inside out movements; OI: Outside in movements.

Identification Performance. In the Lift and Move conditions subjects identified on average 81.6% and 77.0% of the probes correctly, $F(1,7) = 6.45, p < .05$. Performance was about 8% worse for left-hand compared to right-hand trials, $F(1,7) = 15.85, p < .01$. However, this effect of Hand only held for ipsilateral probing, $F(1,7) = 7.43, p < .05$. There was a main effect of Probe Delay, $F(3,21) =$

9.58, $p < .001$: Identification improved from an initial 78.3% at 50 ms to 83.4% at the 150 ms probe delay; then it dropped from 79.6% to 75.9% at the longest delay. This main effect was qualified by interactions of Probe Delay with Movement Instruction, $F(3,21) = 7.38$, $p < .01$, with Start Location, $F(3,21) = 2.97$, $p < .06$, and with Hand of Movement, $F(3,21) = 8.05$, $p < .001$. The peaked performance pattern was only present in the Move conditions, whereas in the Lift conditions subjects were about equally accurate across all probe delays. The peak for 150 ms was also more pronounced when starting at the center than when moving toward the center, and it was largely due to the performance in left-hand trials. However, no other main effect or interaction was significant. Figure 5 focuses on the two Movement conditions; it shows that, aside from the main effect of Movement Instruction, performance for the two movement directions (in-out and out-in) was similar.

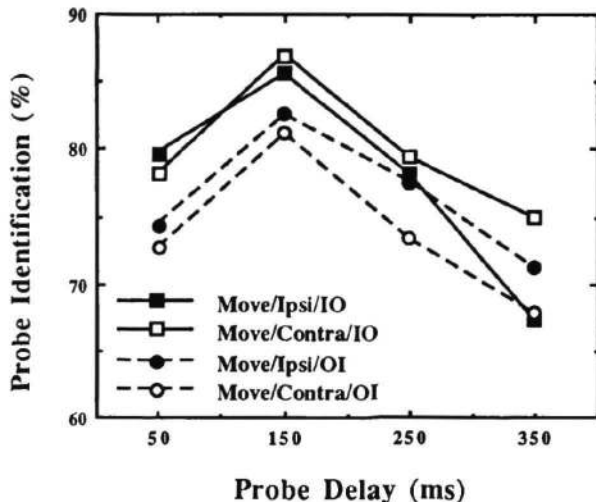


Figure 3: Identification Performance for the Move conditions. IO: Inside out movements; OI: Outside in movements.

Movement Times. In the Move conditions, average time from liftoff to touchdown on the target key was 347 ms, with no significant differences between conditions.

Discussion

The findings of the second experiment allow us to qualify the different hypotheses regarding the possible relationships between perception and action. Most importantly, there were no effects of Movement Direction, but also not of Hemifield of Probing on letter identification performance. This result fails to replicate the earlier finding of higher identification performance in the contralateral visual field, especially at the 250 ms probe delay. To accommodate this finding, both the inrahemispheric facilitation hypothesis and the inrahemispheric interference hypothesis require the ad hoc assumption that the degree of interaction between the two tasks used in the second experiment was noncritical. The present finding is especially damaging for the premotor theory; note that, due to the directing of attention during movement preparation, the premotor theory predicted performance to improve with longer probe delays for outward movements with ipsilateral probing (black squares) and for inward movements with contralateral probing (white circles in Figure 5). It is not clear which of the modifications in the experimental procedure caused this failure to replicate a previous finding. It is probably not due to the shortened practice with the new subjects, because the advantage of contralateral probes at the 250 ms probe delay is present even in the practice data from Experiment 1. The continuous presentation of the movement cue after probe exposure

could not have affected perceptual processing of the probe, but it might have prevented immediate access to the probe's representation in visual short-term memory (Sperling, 1960).

On the other hand, the second experiment replicated several findings from the first study. Probes appearing only 50 ms after the onset of the arrow cue induced erroneous responses if they were in the hemifield contralateral to the side of movement preparation. Subjects overcame this interference only at the cost of delayed response times. The fact that this Simon effect is limited to the 50 ms probe delay suggests that 150 ms after presentation of the movement cue the direction component of the motor program was reliably installed. However, the disadvantage for the left hand in these right-dominant subjects implies that the movement tasks required controlled processing at all times when they were performed with the non-dominant hand.

The finding of increased reaction times for longer probe delays, even with continuous exposure of the movement cue, rules out an explanation of this increase in terms of delayed attentional disengagement from the cue. It rather supports the notion that attentional resources are strategically allocated to the preparation of the forthcoming movement, thus incurring higher costs of switching back to the visual field for more delayed probes. This hypothesis also accounts for the systematic decrease of performance in the fixation control trials.

The absence of effects of manual response selection on visual perception was previously reported by Rafal et al. (1989, Exp. 5) and by Pashler (1991). Their use of less complex motor tasks, however, did not allow us to specifically evaluate the premotor theory of attention. The present study showed that, irrespective of movement complexity, manual preparation does not induce differential effects of movement direction planning on lateralized probe identification. Together with the fact that performance patterns were similar for the Move and Lift conditions, this indicates that the general identity between movement preparation and attention allocation, as proposed in the premotor theory of attention, does apparently not apply to manual movement preparation. Studies of hierarchical manual preparation (e.g., Rosenbaum, 1980) do therefore not provide support for the premotor theory.

Subsequent experiments using this probing technique can investigate letter perception during movement execution as well as during movement preparation, to address the issue of whether visuo-spatial attention remains organized in extrinsic or in action-centered coordinates. To test the relevance of movement amplitude planning for attention allocation, probes could also be presented at the target location of a movement. This will, however, require a touch-screen interface. Furthermore, a comparison of performance with and without overlap of visual and motor space can reveal whether attentional effects operate on an intrinsic representation. The use of nonlateralized (e.g., vocal) responses to identify the probe letters may clarify the extent to which the letter probes may have activated concurrent motoric representations in the present subjects, who were mostly semi-skilled typists.

In summary, the concept of attention as motor preparation cannot account for the present results obtained with hand movements, suggesting that the inference from eye movements to motor preparation in general may have underestimated the complexity of the mechanisms linking perception with action.

Acknowledgements

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