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Position-dependent and position-independent attention shifts: Evidence against the spotlight and premotor assumption of visual focussing

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Summary. One implication of the spotlight metaphor of visual-attention shifts is that attention moves from position to position, from one object in the visual field to another. According to this view, attention shifts start at the last-focussed position, their spatiotemporal course therefore being *position dependent*. A different, yet also position-dependent, formulation is implied in the so-called "premotor hypothesis of attention" (Rizzolatti et al., 1987; Umiltà et al., 1991). In this paper these two accounts are tested against an alternative, *position-independent* conception. It is maintained that in the case of onset-triggered processes, the course of the attentional shifts is independent of the last-focussed position.

On the basis of these considerations, three experiments measure choice-reaction times of stimuli at different spatial positions after peripheral cuing of the same or another position within the visual field. Results show no evidence for the position-dependent conception of the spotlight metaphor or the premotor hypothesis with a long SOA (stimulus–onset asynchrony) between cue and stimulus. Only with a short SOA is the premotor hypothesis supported by the data. As an alternative interpretation, a position-independent thesis is favored, in which it is assumed that attention shifts can be adjusted during an early stage of processing.

Introduction

The ability to look out of the corner of one's eyes without eye movements, shifting attention to a stimulus in the periphery, has already been described by James (1901, chap. 11), Wundt (1911, chap. 1), and Ulrici (1866, part 4, chap. 1). The origins of the analogy that visual attention acts like a spotlight on a stage whose contents receive priorized processing also date back to the end of the nineteenth, and the beginning of this, century. It refers to the ability to shift the focus of attention spatially within the visual field.[1] Some of the modern authors who have contributed to the spotlight metaphor are, for example, Shulman, Remington, and McClean (1979), Posner (1980; see also Posner & Cohen, 1984), Treisman and Schmidt (1982), and Tsal (1983).

If we use the spotlight in its literal sense, the metaphor suggests a specific spatiotemporal course of focussing: first of all, the assumption of a continuous movement through the visual field (Posner, 1980; Shulman et al., 1979; Tsal, 1983; but, for a critical view, see Chastain, 1991; Remington & Pierce, 1984; Shephard & Müller, 1989). Like any movement, distance and time can be plotted to a not necessarily linear, but at least increasing, function. Therefore, as is stated by the metaphor, attention shifts are time variable (Tsal, 1983; but see Eriksen & Murphy, 1987; Kwak, Dagenbach, & Egeth, 1991; Remington & Pierce, 1984). In addition, the locations through which attention passes should also receive attention (Shulman et al., 1979; but see Tsal, 1983). Last, but not least, the focus should be of constant size during shifts (Klein & McCormick, 1989; McCormick & Klein, 1990; but see Castellio & Umiltà, 1990; Downing & Pinker, 1985; Stoffer, 1991). All of these assumptions are in principle independent of each other, and each requires separate, empirical confirmation – if this has not been carried out already. Thus, in some of the studies listed above, the spotlight metaphor was rejected or modified into a less explicit version, in which – for example – the movement assumption is dropped (Driver & Baylis, 1989; Eriksen & Murphy, 1987; Shepherd & Müller, 1989).

This contribution presents a further critical analysis of the spatiotemporal course of attention shifts. It is based on one aspect suggested by the spotlight metaphor and by a

[1] Recently, a (not necessarily alternative) metaphor has been joined to this idea, stipulating that an attention shift is not primarily a shift in the spatial dimension, but that the focus of attention changes its size in order to switch from attending to a whole object to attending to one of its parts, or vice versa. This gave rise to the so-called "zoom-lens" metaphor (see, e. g., Eriksen & St James, 1986; Neumann, 1980; Stoffer, 1991).

different approach, the so-called "premotor hypothesis of attention" (Rizzolatti et al., 1987; Umiltà, et al., 1991).

Position-dependent and position-independent attention shifts

A further assumption suggested by the spotlight metaphor is that the spotlight moves from object to object, from position to position, within the visual field. Because of this, the position previously focussed is the starting point for the following attention shift, and in this sense, the shift is *position dependent*: its course depends on the position previously focussed.

In recent years, a very different approach that is nonetheless position dependent has been presented, termed the "premotor hypothesis of attention" (Rizzolatti et al., 1987; Umiltà et al., 1991). It postulates that attention is directed when the specific oculomotor program has been prepared – in other words, when the parameters for direction and amplitude of saccades have been specified (Rizzolatti et al., 1987, p. 39). The saccade itself need not be carried out, because peripheral inhibition mechanisms can prevent it. Although, in the present context this approach does not imply an attention shift from one position to another – as the spotlight metaphor does – there is a dependence on the position previously focussed, as it should be easier to make a mere amplitude adjustment or a change of direction (in relation to the last focussed position) than to respecify both parameters. Moreover, an amplitude adjustment should be simpler than a change in direction, since the former only requires an adjustment in activation instead of a new ocular program for a different set of muscles (for an overview, see Becker, 1989). Consequently, a stimulus located in the same direction as the position previously focussed is processed faster, thus receiving an advantage in reaction time compared to a stimulus that takes another direction. Hence, this approach is position dependent too, because amplitude and direction of the position previously focussed influence the attention shift.

Earlier research has already cast doubt on the position-dependent idea (Müsseler, 1987; see also Müsseler & Neumann, 1992). The theoretical considerations and empirical findings in those studies were based on a close link between attention shifts and eye movements – as in the premotor hypothesis (for recent overviews see, e. g., Rayner, 1984; van der Heijden, 1992, chap. 4.7–4.8). However, as several authors have suggested (e. g., Posner, 1980; Posner & Cohen, 1984; Wolff, 1987), one possible function of attention shifts is to determine the target position of the subsequent saccade. Thus, an attention shift precedes each goal-directed saccade and its programming (e. g., Klein, 1980; Remington, 1980; Shepherd, Findlay, & Hockey, 1986; van der Heijden, 1992, chap. 4.8) and not vice versa, as the premotor hypothesis suggests.

It can be assumed that under everyday conditions foveation and attentional focussing normally coincide, i. e., attention is directed to the foveated region, then shifted to a peripheral region, and is finally retracted to the fovea (after the execution of the saccade). On this assumption, there is a continuous interplay between foveation and attention. It is concluded that the visual system determines the momentarily focussed position in relation to the fovea, because this could be used to program the subsequent saccade. This leads to the assumption that attention shifts are viewed as being completely independent of the position previously focussed (Müsseler, 1987; Müsseler & Neumann, 1992).

This *position independence* can in principle be realized by at least three different processes. First, it can be assumed that the sudden onset of a stimulus resets the system and always triggers an attention shift from the fovea to the new stimulus. Second, it can be assumed that attention is immediately directed to the new location without any starting point or detours. The third possibility seems to be less position independent than time independent (cf. Kwak et al., 1991; Remington & Pierce, 1984): Although the attentional course starts at the last focussed position, the processing time does not depend on the distance of the attention shift. But since the processing (time) of the new stimulus is independent of the last focussed position, all three possibilities are in the following subsumed under the label *position independent.*

Rizzolatti et al. (1987) and Umiltà et al. (1991) have provided support for the premotor hypothesis with data from studies in which a central cue precedes the imperative stimulus. Findings are less clear when a peripheral cue is used. Umiltà et al. (1991; see also Reuter-Lorenz & Fendrich, 1992) found no advantage for an amplitude adjustment compared with a change in direction in simple reaction times. Using peripheral cues, Crawford and Müller (1992, Exp. 1) also found no support for the premotor hypothesis in saccade latencies (but see Crawford & Müller, 1992, Exp. 2). In this context, the registration of simple reactions could be critical, as no further discriminative processing is required at the stimulus itself, and its onset can specify the motor reaction directly (direct parameter specification: Neumann, 1990). For example, Bédard et al. (1993) found considerably greater effects of the cued position in choice reaction times than in simple reaction times with auditory stimuli.

To clarify these issues, the following three experiments use peripheral cuing and a choice reaction task. The aim is to compare the position-dependent assumptions of the spotlight metaphor and the premotor hypothesis with the assumption of a position-independent attention shift. Attention is first attracted to different peripheral positions by means of a cue (a Go or a No-go signal). Subsequently, reactions to a test stimulus at the same or another position are gathered.

Experiment 1

The following sequence of stimuli was used (see Figure 1). Stimuli were displayed at two eccentric positions to the left and right of a fixation point. After a cue (two horizontally arranged bars as Go, two broken bars as No-go), which indicated the position of the subsequent imperative test stimulus (TS), an M or its inversion W was presented either at the same or at one of the other positions. After a Go signal, the M or the W required the response of pressing

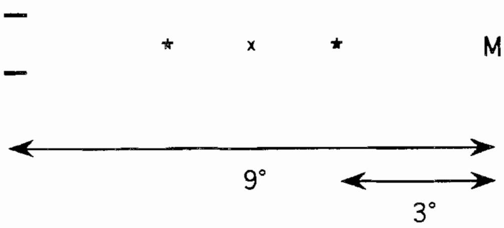

Fig. 1. The stimulus display in Experiments 1 and 2. After a cue (here a Go signal, i. e., two horizontally arranged bars), that is displayed randomly at one of four positions (here outer left), an imperative stimulus is displayed at either the same or another position (here an M, outer right). x marks the fixation point; asterisks mark further display positions and are not part of the stimulus display

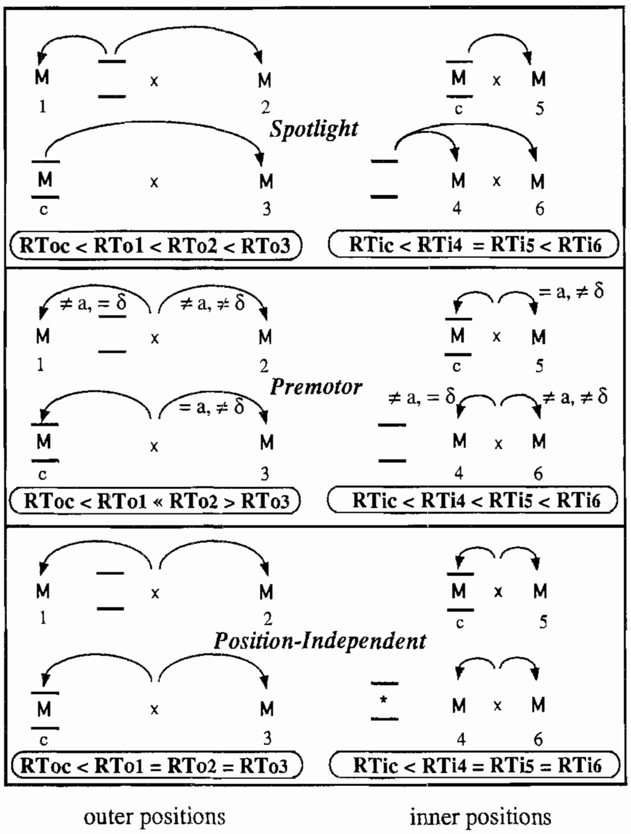

Fig. 2. The different predictions for the attention shift to the TS according to the spotlight metaphor, the premotor hypothesis, and the position-independent hypothesis. The bars arranged horizontally represent the display positions of the cue (the Go signal, position c); the M's that of the TS (positions 1–6). For comparison of TS reactions with equal eccentricity, predictions for eccentric, outer reactions (RTo) are entered on the left; inner positions (RTi), on the right

one of two keys (for details, see below). If the spatial position of the Go signal attracted the focus of attention, the approaches discussed in the previous section lead to different predictions regarding the course of focussing to the TS, and hence to different reaction times (RT).

To avoid comparing RTs of different stimulus eccentricities, predictions take account of whether the TS was displayed at the eccentric outer or inner positions. In what follows, the predicted RTs for the outer TS positions are specified (RTo; cf. left-hand column in Figure 2); the corresponding predictions for the inner TS positions (RTi, right-hand column) were analogous and are neglected. Additionally, predictions are given only if the Go signal is presented at the outer or inner left side; predictions for the two other, right positions are simply inverted.

When TS appears at the cued position of the Go signal, all three approaches predict the shortest reaction times (RToc). When TS is presented at one of the other positions, the spotlight metaphor in its most obvious version[2] predicts that RT will increase as a function of the distance between the previously focussed Go signal and the TS positions 1 to 3. As Figure 2 shows, this predicts the following sequence of reaction times: RToc < RTo1 < RTo2 < RTo3.

In the premotor hypothesis, a respecification of the ocular parameters – i. e., of saccadic amplitude (a) and direction (δ) – has to be considered. The arrows in Figure 2 indicate that a shift of the fovea to positions of equal eccentricity is intended. Following a prior Go-signal parametrization that is linked to the attention shift, only the amplitude has to be adjusted at position 1 ($\neq$ a, = δ; RTo1); for the reasons mentioned above, this should be executed faster than a pure change in direction to position 3 (= a, $\neq$ δ; RTo3). In turn, this should happen faster than when both amplitude and direction differ in relation to the Go position, as at position 2 ($\neq$ a, $\neq$ δ; RTo2).[3] This results in the following anticipated reaction-time differences: RToc < RTo1 < RTo3 < RTo2 or in the identical chain, taking into account the prior sequential position: RToc < RTo1 << RTo2 > RTo3. In the last sequence, the double arrow stands for *much smaller*, so that here RTo1 < RTo3 as well.

Finally, according to the position-independent hypothesis, the anticipated RTs are completely independent of the last focussed position. This leads to the predicted sequence: RToc < RTo1 = RTo2 = RTo3.

Method

Apparatus and stimuli. The experiment was carried out on a laboratory computer (Rhothron rho-prof 200) with a monochrome monitor. Stimuli were displayed black on white at the centre of the screen. The Go signal consisted of two horizontally arranged bars, the No-go signal of identical, but broken, bars (0.5° × 1.5°). The TS was an M or its inversion W (0.2° × 0.3°). Both Go and No-go signals and TS were displayed at all four positions (see Figure 1). The stimulus positions were each 3° apart, providing a maximum eccentricity of 4.5°. The

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[2] This spotlight version assumes a continuous movement and thus a time-variable shift (as illustrated in the Introduction). The aim of this restriction is to contrast the predictions. A time-invariant version may be included implicitly in the position-independent assumption, but this is not attached to the spotlight idea here (see above).

[3] Umiltà et al. (1991, p. 250) do not necessarily predict an amplitude effect because this feature could be computed in parallel during the execution of the saccade. If this is true, the premotor hypothesis would have to be specified to the formulation that attention is directed only if the direction parameter is present, independently of amplitude parametrization. Then one prediction would be that there are no differences between the cued positions and the ipsilateral, uncued positions (RToc = RTo1 respectively RTic = RTi4). Another, more probable prediction would hold that the contralateral positions yield identical RTs (RTo2 = RTo3 respectively RTi5 = RTi6). The results will have to clarify this point.

subject's head was placed on a chin and forehead rest set up 550 mm from the monitor.

Design. TS positions differed according to whether TS was displayed at the two outer or the two inner positions. In addition, it was taken into account whether TS appeared in the left or in the right visual field. Finally, which of the four positions the Go signal cued was also controlled. As all subjects were confronted with all conditions, the experiment had a complete 2 × 2 × 4 repeated-measures design.

Procedure. Each trial began with a centred fixation cross that remained visible until the response was given. After 1 s, the Go or No-go signal was presented randomly at one of the four positions for 28 ms (i. e. for two vertical synchronizations of the cathode ray, VSYNC), accompanied by a short acoustic signal. After 70 ms (five VSYNC's), the TS appeared for 28 ms, providing a 98-ms SOA (stimulus–onset asynchrony). This short SOA ensured that findings would not be influenced by eye movements.

Each subject performed a total of 1,125 trials, including 14.6% No-go trials, in which subjects were instructed not to respond. In 62.5% of the remaining 960 trials, the Go signal provided a valid cue to the subsequent position of the TS; the TS was randomly displayed at another position in 37.5% of the trials. Subjects were informed about these probabilities at the beginning of the experiment.

The instruction stressed that subjects should concentrate on the fixation point. After presentation of the Go signal, their task was to press a key with the index finger of the right hand for an M and another key with the middle finger for a W as quickly and accurately as possible. To familiarize subjects with the task, they were given a training block of 150 trials. The entire experiment lasted about 2 hours, including two 10-min breaks.

Subjects. Subjects were 13 female and 4 male college students with an average age of 27.7 years. They had normal or corrected vision and were paid for their participation.

Table 1. Summarized predictions and results on mean reaction times (RT), standard errors (SE), error probabilities, and false-alarm probabilities of the No-go trials (Experiment 1, $N = 17$)

RT to outer TS							
Predictions							
Spotlight	RToc	<	RTo1	<	RTo2	<	RTo3
Premotor	RToc	<	RTo1	<<	RTo2	>	RTo3
Position-independent	RToc	<	RTo1	=	RTo2	=	RTo3
Results							
Mean RT (ms)	611.1	<	636.1	<<	676.1	>	656.5
Mean SE[1]	9.5		20.7		22.7		21.4
Errors (p)	.124		.129		.112		.106
False Alarms (p)	.121		.219		.166		.118
RT to inner TS							
Predictions							
Spotlight	RTic	<	RTi4	=	RTi5	<	RTi6
Premotor	RTic	<	RTi4	<	RTi5	<	RTi6
Position-independent	RTic	<	RTi4	=	RTi5	=	RTi6
Results							
Mean RT (ms)	535.9	<	554.3	≤	566.0	=	569.8
Mean SE[1]	6.8		15.9		16.4		16.4
Errors (p)	.023		.021		.022		.032
False Alarms (p)	.075		.038		.023		.040

Note. For RT notation, see Figure 2

[1] Mean standard error within subjects. SE was lower in cued positions because more observations per subject were entered in the cells of this design.

Results

RTs and errors were entered as dependent variables into a three-factor ANOVA[4]. The factor Visual Field and its interactions were not significant in the reaction-time and error analyses. Therefore, this factor was averaged across conditions in the following descriptions.

In the remaining design, the Position of the TS (outer vs inner) was significant, $F(1, 16) = 79.06, p < .001$. When TS was displayed at the more eccentric positions, RTs were longer, as was anticipated. This was also accompanied by an increasing number of errors, $F(1, 16) = 38.20, p < .001$. In addition, RTs were influenced by the Position of the Go signal, $F(3, 48) = 29.21, p < .001$, and the interaction between the two factors, $F(3, 48) = 4.69, p = .006$. The Scheffé test exhibited the critical differences of 18.1 ms ($p < .05$) and 22.2 ms ($p < .01$), which were used for further detailed analysis.

Table 1 shows that RTs were shortest when the Go signal provided a valid cue to the position of the TS (RToc or RTic: for notation cf. Figure 2). The second-fastest, though significantly differing, RTs were found for stimulus positions ipsilateral to the Go signal: when an inner position was cued, the outer position of the same half of the visual field was favored (RTo1, $p < .01$) and vice versa (RTi4, $p < .05$). According to the premotor hypothesis, only an amplitude adjustment in relation to the Go-signal position was necessary in this situation. When only a change of direction had to be performed, RTs for the outer TS positions increased significantly once more, (RTo3, $p < .01$); for the inner TS positions (RTi5), this was only a trend ($p < .10$). The slowest RTs were obtained when both a change of direction and an amplitude adjustment were necessary (RTo2 or RTi6) – an effect that nonetheless differed significantly from a pure amplitude adjustment only at the outer TS positions (RTo3 < RTo2, i. e., 656.5 < 676.1 ms, $p < .05$). At inner positions, a difference between the change of both ocular parameters and a pure amplitude adjustment was still a trend (RTi4 < RTi6, i. e., 554.3 < 569.8 ms, $p = .10$). However, it could no longer be confirmed that this differed from a mere change in direction (RTi6 = RTi5, i. e., 569.8 = 566.0 ms).

The previous findings explicitly considered the eccentricity of the TS. However, it was still necessary to test whether the different effects found were not just caused by differences in the eccentricity of the Go signals. Although a particularly large and easily discriminable Go or No-go signal had been selected for this reason, it could be argued that its processing varied with eccentricity, thus also influencing the subsequent RT to the TS. The critical comparison was given by RTs of equal eccentricity with different Go-signal positions. The findings excluded this interpretation reliably, because the critical RT differences were either contradictory (RTo3 < RTo2, i. e.,

[4] In order to avoid the risk of violating statistical assumptions that is present in repeated-measures designs through the inhomogeneity of the variance-covariance matrix, the F probabilities in the present and following designs were corrected according to Huynh and Feldt (1980).

656.5 <676.1 ms, p <.05) or did not occur at all (RTi6 = RTi5, i. e., 569.8 = 566.0 ms, n. s.).

A further analysis computed the number of responses to No-go trials. As Table 1 shows, subjects tend to withhold reaction to a No-go signal correctly on an average of nearly 90%. Although the false-alarm rate is slightly higher than the overall error rate, the pattern of results is similar to the error analysis. If TS were presented at the more eccentric positions, the false-alarm rate to the No-go signals increased from .045 to .156. As in the error analysis this is the only significant effect, $F(1, 16) = 27.25$, $p < .001$, and hence the false-alarm rate is also independent of the cued position.

Discussion

The findings on reactions to outer TS are incompatible with the spotlight metaphor as well as with the position-independent hypothesis. In contrast, the pattern of RTs fits the predictions of the premotor hypothesis precisely. Thus, choice RTs after peripheral cuing are influenced not only by changes of direction, but also by amplitude adjustments.

The pattern of findings for inner TS is not as clear cut. Although means also take the direction predicted by the premotor hypothesis, statistically they are only trends or are not confirmable. This may be due to the fact that stimulus eccentricities of 1.5° are still too foveal to generate stronger effects. On the other hand, the amplitude effect, which should produce the difference between RTi5 and RTi6, is controversial within the premotor hypothesis (cf. footnote 3). Thus, the findings of Experiment 1 should be interpreted in the framework of the premotor hypothesis rather than in terms of the other approaches, as these in no way provide a better fit to the data.

However, there is one objection that calls for a careful interpretation of the data. It results from the short SOA between Go signal and TS, and follows the argument that although an attention shift is induced by the Go signal, this is not necessarily completed within the 98-ms interval. Hence the TS could appear during the process of shifting attention to the Go signal, which would only lead to an adjustment of this shift. In other words, RTs do not necessarily measure the shift from Go signal to TS, as intended, but more a spatially modified shift to the Go signal, from which the processing of the TS benefits. A possible (spatial) adjustment of a process towards the TS, which was originally directed to the Go signal, may have caused at least some of the RT differences found in this experiment. It should be earsier, for example, to adjust the spatially near positions RTi4 than to adjust the contralateral positions RTi5 or RTi6. The general idea of this assumption resembles an attentional approach (Neumann, 1982, 1987; Neumann & Müsseler, 1990) that was introduced in a completely different context and will be discussed in more detail below. The position-independent assumption is already integrated in this context (Müsseler, 1987; Müsseler & Neumann, 1992).

To be able to interpret differences in RTs as the result of an attention shift from Go signal to TS, it is necessary to ensure that the shift to the Go signal has been completed. This was the goal of the following experiment.

Experiment 2

To ensure that the attention shift to the Go signal was completed before the TS appeared, it was decided that subjects should initiate the TS presentation themselves. In the procedure, subjects pressed two keys with the left hand and the Go signal appeared with no time restrictions. During this period, subjects controlled their position of the fixation and of the attentional focus. The TS, to which they should respond just as in Experiment 1, appeared when they released the keys. Under these conditions a new attentional shift to the TS can be initiated that is temporarily independent of the previous shift to the Go signal. In contrast to the position-dependent hypotheses and to the results of Experiment 1, it was now predicted that the RTs are independent of the last focussed position.

Method

Stimuli. Stimuli were essentially the same as in Experiment 1. With an observation distance of 300 mm, the stimulus positions were again 3° apart, resulting in a maximum eccentricity of 4.5°. The Go signal measured 0.6° × 1.7°, the TS 0.3° × 0.4°. With the modified experimental conditions, it was no longer necessary to display a No-go signal.

Control of eye movements. A monocular presentation was used to the right eye. To provide subjects with an additional aid in controlling their eye movements, the blind-spot projection technique was used (see Mateeff et al., 1991). A black disc was projected about 15° to the right of the fixation point. Its position and size were adjusted individually for each subject in a prephase of the experiment. The disc was enlarged or diminished and moved around until the subjects were able to report 1° horizontal fixation shifts by detecting either a right margin (when fixation shifted to the left) or a left margin (by a shift to the right) of the black disc. If, during the experimental trials, the subject still perceived the disc projected onto the blind spot, or even only felt irritated by it, that trial could be rated as invalid and was then dropped from analysis.

Design. The design was the same as in Experiment 1.

Procedure. Fixation cross and blind spot were displayed on the monitor throughout the experiment. By pressing two keys simultaneously with the left hand, the subject initiated the Go signal, which remained visible until both keys were released. Subjects were instructed explicitly to release the keys only when they were fixating the fixation cross and were unable to perceive the disc on the blind spot.

After the release of the keys and another period of 98 ms, the TS was again presented randomly at one of the four positions for 28 ms. As before, subjects had to respond as quickly and accurately as possible by pressing one of two keys with the right hand. Compared to Experiment 1, the total number of trials was reduced by the number of No-go trials. Otherwise, presentation probabilities of cued and uncued positions were the same.

Since the blind-spot projection technique tires subjects, the experiment was distributed over three sessions on three successive days. There were additional breaks, so that the entire experiment lasted approximately 2½ hours.

Subjects. Subjects were 8 female and 4 male employees of the Institute for Psychology, University of Munich, and the Max Planck Institute for

Table 2. Summarized predictions and results on mean reaction times (RT), standard errors (SE), and error probabilities (Experiment 2, $N = 12$)

RT to outer TS							
Predictions							
Spotlight	RToc	<	RTo1	<	RTo2	<	RTo3
Premotor	RToc	<	RTo1	<<	RTo2	>	RTo3
Position-independent	RToc	<	RTo1	=	RTo2	=	RTo3
Results							
Mean RT (ms)	643.9	<	685.7	=	677.0	=	679.3
Mean SE[1]	11.1		24.9		21.0		23.9
Errors (p)	.121		.097		.119		.096
RT to inner TS							
Predictions							
Spotlight	RTic	<	RTi4	=	RTi5	<	RTi6
Premotor	RTic	<	RTi4	<	RTi5	<	RTi6
Position-independent	RTic	<	RTi4	=	RTi5	=	RTi6
Results							
Mean RT (ms)	569.1	<	595.5	=	613.2	=	606.0
Mean SE[1]	9.9		19.7		23.2		20.3
Errors (p)	.011		.017		.015		.025

Note. For RT notation, see Figure 2

[1] Mean standard error within subjects. SE was lower in cued positions because more observations per subject were entered in the cells of this design.

Psychological Research in Munich. They had an average age of 25.1 years and were paid for their participation. All subjects were unaware of the research issues and hypotheses.

Results

Once more, the factor Visual Field and its interactions were not significant, in either the reaction-time or the error analyses, so that this factor was again averaged across conditions. An analysis of covariance was also computed in which the time spent with the Go-signal keys was entered as a covariate alongside both dependent variables, i. e. RTs and errors. Subjects kept the keys pressed for a mean period of 499.2 ms. This time had no detectable influence on the dependent variables.

The Position of the TS (outer vs inner) was again significant: reactions to outer TS positions were slower than reactions to inner TS positions, $F(1, 11) = 43.45, p < .001$. This effect was accompanied by a corresponding increase in errors – again the only significant error effect, $F(1, 11) = 26.64, p < .001$. As in Experiment 1, there was a reaction-time effect of the Position of the Go signal, $F(3, 33) = 11.89, p < .001$, although no interaction between the two factors was detectable, $F(3, 33) = 1.34$, n. s.. The critical differences for pairwise comparisons were 27.7 ms ($p < .05$) and 34.4 ms ($p < .01$).

Table 2 shows that RTs were about 36.3 ms faster when the Go signal provided a valid cue on the position of the TS (RToc and RTic). In contrast, RTs did not differ when the stimulus was displayed at one of the other positions. This applied to reactions to both outer and inner TS positions. Although in the latter, the maximum mean difference was 17.7 ms (between RTi5 and RTi4), this value was far from significance.

Discussion

Owing to the short SOA, Experiment 1 excludes the possibility that the findings are influenced by eye movements. In Experiment 2, eye movements would be critical if they were to explain the pattern of results. If subjects had not followed the instructions and had shifted their eyes towards the Go signal (and thus towards the anticipated position of the TS), it could be predicted that this would have been accompanied by an advantage for ipsilateral, and a disadvantage for contralateral, positions. However, RTs and errors do not display this. Thus, the results do not point to eye movements and confirm that subjects did follow the instructions.

When the results are compared with those of Experiment 1, findings seem to be influenced strongly by the longer, self-regulated SOA between Go signal and TS. While the results of Experiment 1 provide relatively clear support for the premotor hypothesis, the results of Experiment 2 suggest that when the process of shifting attention to the Go signal is completed, the processing of the TS is nearly independent of the position previously focussed. This pattern of findings is similar to that found by Umiltà et al. (1991) for peripheral cues and SOAs between 150 and 1,100 ms.

The discussion of Experiment 1 suggested that given a short SOA, the TS appears during the attention shift to the Go signal. At this point in time, the ongoing process can be adjusted accordingly, so that the TS can benefit from it. The modified design in Experiment 2 guarantees that the shift to the Go signal is completed, and an independence from the position previously focussed is revealed. Before discussing this further, Experiment 3 will be reported next, which replicates the results of both previous experiments.

Experiment 3

Experiment 3 was designed to make an additional evaluation of the three approaches and to make a further spatiotemporal specification of the attention shift. The premotor hypothesis does not predict any qualitative differences between small and large changes in direction, because every change in direction requires entirely different groups of ocular muscles to be activated and coordinated – at least, when the directions differ in the horizontal and vertical meridians (cf. Hughes & Zimba, 1987). The purpose of Experiment 3 was to test small and large changes in direction in relation to the cued position.

Stimuli were presented at the four corners, forming a virtual rectangle centred on the fixation point (see Figure 3). When the TS is not presented at the Go-signal position (upper left in Figure 3), each alternative TS position requires a change of direction. Nonetheless, the spatial distance between vertical positions is smaller than a change between horizontal positions. The premotor hypothesis

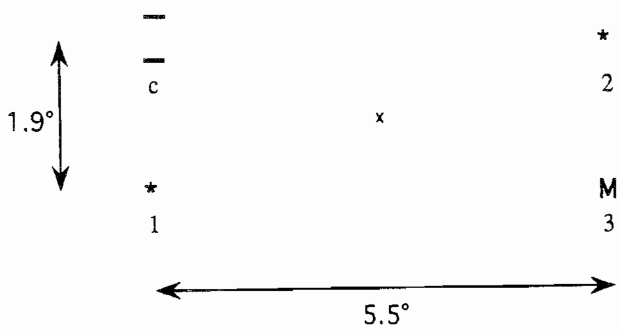

Fig. 3. The stimulus display in Experiment 3. After the cue (here upper left), the imperative stimulus was displayed either at the same (position c) or at another position (1–3) forming a rectangle (here an M, lower right). x marks the fixation point; asterisks mark further display positions and are not part of the stimulus display

makes no discrimination here and predicts the sequence: RTc <RT1 = RT2 = RT3.

According to the spotlight metaphor, RTs should vary with distance. When the Go signal is presented in the upper-left corner, this results in the prediction: RTc <RT1 <RT2 ≤RT3. However, it is questionable whether the small difference in distance between positions 2 and 3 would still be reflected in a corresponding effect, so that RT2 = RT3 would also be a plausible result.

The position-independent hypothesis makes the same predictions as the premotor hypothesis when the attention shift to the Go signal is completed before the TS appears. If, on the other hand, the TS is presented during the attention shift to the Go signal, it is predicted, in line with the interpretation of the previous experiments, that the TS could still take advantage of the process that actually applies to the Go signal. This should become increasingly easier, the smaller the spatial distance between Go signal and TS. In the present display, this is the case for the shift from the cued position c to position 1 which is smaller than those to positions 2 and 3. Thus, with a short SOA, the position-independent hypothesis predicts the reaction-time sequence: RTc <RT1 <RT2 = RT3.

In order to test the different effects, it is therefore necessary to vary the SOA. The 98-ms SOA from Experiment 1 and approximately the mean self-regulated 500-ms SOA from Experiment 2 were used in Experiment 3.

Method

Stimuli. Both Go and No-go signals and TS were displayed at the four positions forming a rectangle (see Figure 3). The separation between the stimuli was 5.5° in the horizontal and 1.9° in the vertical plane. With an observation distance of 300 mm, each stimulus position was 2.9° distant from the fixation point. Otherwise, the stimuli corresponded to those in Experiment 2, but with the additional use of No-go signals (two broken bars, see Experiment 1).

Control of eye movements. The blind-spot projection technique from Experiment 2 was used. Here as well, subjects could rate a trial as invalid when they perceived the disc on the blind spot or felt irritated by it.

Table 3. Summarized predictions and results on mean reaction times (RT), standard errors (SE), error probabilities, and false-alarm probabilities of the No-go trials (Experiment 3, N = 17)

RT with SOA 98 ms							
Predictions							
Spotlight	RTc	<	RT1	<	RT2	≤	RT3
Premotor	RTc	<	RT1	=	RT2	=	RT3
Position-independent	RTc	<	RT1	<	RT2	=	RT3
Results							
Mean RT (ms)	595.5	<	621.8	<	(639.1	=	644.5)
Mean SE[1]	8.5		20.1		21.9		22.6
errors (p)	.031		.036		.035		.045
False Alarms (p)	.144		.090		.063		.054
RT with SOA 504 ms							
Predictions							
Spotlight	RTc	<	RT1	<	RT2	≤	RT3
Premotor	RTc	<	RT1	=	RT2	=	RT3
Position-independent	RTc	<	RT1	=	RT2	=	RT3
Results							
Mean RT (ms)	541.2	<	564.5	=	563.4	=	573.7
Mean SE[1]	7.5		18.1		18.2		16.8
Errors (p)	.021		.015		.025		.022
False Alarms (p)	.039		.021		.012		.015

Note. For RT notation, see Figure 3

[1] Mean standard error within subjects. SE was lower in cued positons because more observations per subject were entered in the cells of this design.

Design. The Go signal and the TS were presented at the four positions. To control whether RTs varied with the quadrant of the visual field, TS positions were coded in relation to Go-Signal positions. In addition, the SOA varied across two levels (98 and 504 ms), resulting in a 4 × 4 × 2 repeated-measures design.

Procedure. Subjects started a trial by pressing two keys simultaneously with the left hand. After a break of 1,000 ms, the Go or the No-go signal appeared for 28 ms at one of the four positions selected at random. After a SOA of either 98 or 504 ms, the TS was displayed for 28 ms at the same or at another position. The subject had to react with either the index or the middle finger of the right hand.

The number of trials and the accompanying probabilities were identical to those in Experiment 1. The experiment was carried out in three sessions and lasted a total of 2½ hours.

Subjects. There were 10 female and 7 male subjects, who were paid to participate in the experiment. Their average age was 23.2 years. Some of the subjects had already participated in Experiment 2.

Results

In the error analysis, only the SOA proved to be significant, i. e., a longer SOA led to fewer errors, $F(1, 16) = 9.30$, $p = .008$ (see Table 3). Although the false-alarm rate in the No-go trials was significantly increased when stimuli were presented with the short SOA, $F(1, 16) = 13.88$, $p = .002$, subjects tended to withhold reactions correctly on an average of nearly 95%. Additionally, there was a tendency for the position of the No-go signal to influence the false-alarm rate, $F(3, 48) = 2.97$, $p = .078$.

In the reaction-time analysis, the position, and thus the quadrant, of the visual field in which the Go signal was presented proved to be irrelevant. In contrast, the position of the TS in relation to the Go signal was statistically significant, $F(3, 48) = 21.97$, $p < .001$, as the SOA, $F(1, 16) = 86.82$, $p < .001$. In longer SOAs, RTs seemed to be generally shorter, an effect that has also been reported by Crawford and Müller (1992). There was no interaction between these two factors, $F(3, 48) = 1.84$, n. s.. The critical differences for pairwise comparisons were 21.9 ms ($p < .05$) and 26.9 ms ($p < .01$).

In detail, RTs for positions that had been validly cued by the Go signal were again shorter (RTc, 595.5 or 541.2 ms). With the longer 504-ms SOA, there was, as in Experiment 2, no difference in the remaining RTs. With the shorter 98-ms SOA, there was also none between RT2 (639.1 ms) and RT3 (644.5 ms), but there was a difference between RT3 and RT1 (621.8 ms, $p < .05$). The difference between RT1 and RT2 was only a trend.

Discussion

While with the short SOA, reaction times show a high level of agreement with the predictions of the spotlight metaphor, these predictions do not fit the longer SOA condition. But, as was mentioned above, the attentional focus is assumed to be more likely at the Go signal position with a longer, than with a shorter, SOA; this is precisely where the predicted differences should appear. Therefore, this experiment also shows that the spotlight metaphor fails to explain the data.

In contrast, the premotor and position-independent hypotheses do not anticipate any differences for the longer SOA. This is actually the case. For the short SOA, differences are predicted by the position-independent hypothesis and not by the premotor hypothesis. These differences seem to be confirmed. In line with the interpretation of the previous experiments, a nearby TS benefits from the focus shift that was originally directed to the Go signal.

General discussion and conclusions

The spotlight metaphor cannot provide a satisfactory explanation for the findings in any of the experiments reported. Accordingly, a position-dependent attention shift in a manner suggested by the spotlight metaphor is not indicated; another result that has to shed doubt on the usefulness of the metaphor (cf. Driver & Baylis, 1989; Eriksen & Murphy, 1987; Sagi & Julesz, 1985; Shepherd & Müller, 1989; Yantis, 1988).

The premotor hypothesis (Rizzolatti et al., 1987; Umiltà et al., 1991) is mainly supported by the findings of Experiment 1 that use a short SOA. According to this view, RTs seem to be influenced by whether an amplitude adjustment, a change of direction, or a change of both ocular parameters is necessary for shifting attention to the TS. On the other hand, the predictions of the premotor hypothesis are not met in the case of larger SOAs (Experiment 2) nor do they account for any quantitatively different changes in direction (Experiment 3). While it may be possible to integrate the latter finding into an extension of the approach, premotor effects should be particularly facilitated with large SOAs, because here the specification of the ocular parameters to the Go signal should surely be completed and hence should have an effect on the subsequent attention shift to TS. Here, as has been mentioned, Umiltà et al. (1991, Experiments 3, 4, 5) and Crawford and Müller (1992, Experiment 1, but see Experiment 2) have also failed to confirm the premotor hypothesis with peripheral cuing, although Crawford and Müller's experiment used saccade latencies as their dependent variable (see also Reuter-Lorenz & Fendrich, 1992, Experiment 1).

Umiltà et al. (1991) interpret this failure of the premotor hypothesis with an inhibition mechanism (cf. "inhibition of return," Posner & Cohen, 1984). They maintain that the peripheral cue evokes a motor program that must be aborted because the instruction requires fixation. And "This would cause a transient bias against motor programs that share the direction feature with the aborted one and, possibly, a transient bias in favour of motor programs towards the opposite direction" (Umiltà et al., 1991, p. 263). This interpretation cannot explain the present data, because valid cuing produces strong effects, even with long SOAs. The cued position should suffer from this inhibition mechanism, and this is not the case here.

Attention shifts are not restricted to the physical limitations that apply to ocular movements. In addition, a dependence of attention on the specification of ocular parameters is questionable. Instead, as was mentioned above, there are hints that attention shifts precede saccades (Klein, 1980; Rayner, 1984; Shepherd, Findlay, & Hockey, 1986) in order to specify the target position and therefore fullfill a functional role for the saccade that resets the eye to a position with an appropriate grain size, i. e., the fovea (Wolff, 1987; van der Heijden, 1992, chap. 4.8). Under ecological conditions the fovea is the effector that has to be controlled in order to make goal-directed saccades. It could be efficient to specify the ocular parameters in relation to the fovea, which is hence a candidate for a spatial reference point.[5]

In the present experiments, the choice reactions require a discriminative performance on the stimulus. This can be assisted by a completed attention shift, which is one that has reached the target position. Earlier findings have already been applied to assume that the stimulus onset triggers two kinds of processes – coding and attentional which take place simultaneously, but are terminated at different times (cf. Müsseler & Neumann, 1992; Neumann, 1982, 1987; Neumann & Müsseler, 1990). Coding processes include all operations that serve to create an internal code of the stimulus, such as computing its contour, its colour, size, location, and so forth. The result of the coding processes is the updating of an internal spatial map of the visual environment, and this updating has a short latency as compared to the time required for attentional processes. These are initiated by the transient response to the onset of the stimulus and consist in a shift of the attentional focus to the stimulus. The result of the coding processes will not be available for further processing unless this shift has been completed. Thus, it could happen that while the attentional

[5] The focussed position is another candidate (Nicoletti & Umiltà, 1989; Stoffer, 1991; but see Hommel, 1993).

shift is still in process, a further change occurs, which is then processed together with the first change. A similar idea has been successfully applied to several visual phenomena, e. g., to metacontrast masking (Fehrer–Raab Effect, cf. Neumann, 1982) and two motion effects (Tandem and Fröhlich Effect, cf. Müsseler, 1987; Müsseler & Neumann, 1992).

In recent years a related, more physiological model has been developed by Bachmann (1984, 1988). He assumes that the stimulus onset leads to an activation of feature-specific channels and to an activation of a nonspecific arousal (i. e. attentional) system located in the brain-stem reticular formation and the generalized thalamic nuclei. This nonspecific system is activated by the collaterals from the specific impulses and has a longer latency to reach the cortex than the specific activity. Here too the convergence of both channels is necessary for further processing.

If – as in the suggestion above – the TS appears when the nonspecific impulses (the attentional shift) to the cue are still not yet completed, the TS can benefit from this situation as long as its specific impulses (the coding processes) are completed and the attention shift is (still) open to adjustment. TS and Go signal are then processed together – by a process initiated by the Go signal and terminated while the TS is presented. A possible adjustment may depend critically on which stimulus information can be taken into account. Experiment 3 found this for stimuli with close spatial distance. Under certain experimental conditions, there may also be an advantage for the visual half-field or quarter-field (Hughes & Zimba, 1985, 1987) in which the cue is displayed. This remains to be clarified in future research.

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