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Continuing Commentary

Commentary on **B. Fischer and H. Weber (1993). Express saccades and visual attention. BBS 16:553–610.**

Abstract of the original article: One of the most intriguing and controversial observations in oculomotor research in recent years is the phenomenon of express saccades in monkeys and man. These are saccades with such short reaction times (100 msec in man, 70 msec in monkeys) that some experts on eye movements still regard them as artifacts or as anticipatory reactions that do not need any further explanation. On the other hand, some research groups consider them not only authentic but also a valuable means of investigating the mechanisms of saccade generation, the coordination of vision and eye movements, and the mechanisms of visual attention.

This target article puts together pieces of experimental evidence in oculomotor and related research – with special emphasis on the express saccade – to enhance our present understanding of the coordination of vision, visual attention, and the eye movements subserving visual perception and cognition.

We hypothesize that an optomotor reflex is responsible for the occurrence of express saccades, one that is controlled by higher brain functions involved in disengaged visual attention and decision making. We propose a neural network as the basis for more elaborate mathematical models or computer simulations of the optomotor system in primates.

Attention shuts out irrelevant stimuli

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Abstract: Express saccade experiments imply that attention shifts take time. We extend this result with new experiments on manual reaction times. Reaction to a cued target is always slower than reaction to an uncued control, even when the cue is correct, if control trials are blocked to prevent interference from cued trials. Attention functions not to speed response, but to prevent responses at irrelevant locations.

The need to disengage spatially selective attention before executing express saccades supports what I call a "gearshift" model: attention must be disengaged, like an automobile's gearshift, before the next target can be engaged. Each operation takes time – disengagement, shift, and reengagement. From the express saccade data, the model seems almost inescapable. But carried to its logical conclusion, it has some disturbing implications. If each aspect of an attentional shift takes time, attention-engaging tasks should be slower than those requiring no attention, violating our introspection that attention makes things faster. Recent experiments lead to an even more disturbing conclusion: compared with proper controls, attentional processing of a target is always delayed compared to a reaction to the same target without attention. Attention makes one slower, not faster.

The experiments that pushed us to this conclusion began with work on responding to targets that can appear in any of several positions. Does an increase in uncertainty about where a stimulus could appear affect the response time to that stimulus? Previous work has had conflicting interpretations. The attentional spotlight analogy (Posner & Peterson 1990; Posner et al. 1978; 1980) is based upon the hypothesis that stimulus encoding requires the use of a limited-capacity resource pool. Allocation of resources is said to be limited to a single region of the visual field in a "spotlight" of perceptual enhancement. The spotlight can be expanded, contracted, or directed to a specific place in the field. As the spotlight is expanded, its limited resources are spread thin and processing time at any given location increases.

Both the spotlight and the zoom lens metaphors have long histories in psychology. "One can turn the inner point of sight successively to the various parts of the inner field of view. At the same time one can narrow it or broaden it, unlike the point of sight of the external eye, whereby its brightness alternately increases and decreases. Strictly speaking it is thus not a point, but a field of somewhat variable extent (Wundt 1903, p. 334)."

In the Posner et al. experiments that support this hypothesis, subjects allocated their attention based upon a set of probabilities of a target appearing at each location. A primary target position (64–100% probability) was supplemented with one to four secondary positions of varying probabilities. An increase in the probability of a target's appearing at a given location should shift processing capacity to that position if subjects were cued about the probable target position on each trial. As a result, reaction time was reduced at that position and increased at the others. Control trials with no cue also showed longer reaction times.

Using reasoning similar to that employed by Fischer & Weber (1993), we noted that even in control trials, subjects might be in an engaged mode of attention. Since the control trials were interspersed with cued trials at random, subjects might have been unable to change strategies and disengage attention in a single trial. This was tested by comparing reaction times in blocks of cued trials with reaction times in blocks of control trials. By blocking the control trials, we were able to disengage the subjects' attention; they could depend on encountering only uncued trials in the control trial block (Fisher et al. 1990).

The results showed a consistent ordering of reaction times: they were longest when the cue appeared at one location and the target at another; response times to a target at the cued location were shorter, as expected, but response times in the control trials were shorter yet. Thus the fastest responses occurred not in the correct-cue trials, but in the control trials with no location cue at all. The pattern of results implies that spatially directed attention has a cost, even when the cue is directed to the correct location.

If attention can only make things slower, what then is its function? In a natural world where there are many potential triggers for behavior, it would evolve not to speed reactions to one target but to prevent responses to irrelevant targets. The price that the brain pays for selective reaction is a slight slowing of reaction time to the selected target. Attention is inhibitory.

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Authors' Response

Two attentional components for two purposes

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Abstract: Inappropriate saccades are prevented by fixation and by voluntary attention. The fixation system inhibits the saccade system. Like monkeys without a fixation system, humans with a weak fixation system produce many express saccades and cannot suppress prosaccades in an antisaccade task. With permanent attention to a peripheral location only a few express saccades to a stimulus at this location can be elicited: the sustained component of attention acts like fixation. When attention is captured by a precue, more express saccades are obtained: the stimulus-driven component of attention facilitates saccade generation. If the cue correctly indicates the direction for an antisaccade error rate and latencies are increased.

Bridgeman uses manual response time (MRT) and saccadic reaction times (SRT) to suggest a new concept for the functional significance of attention: attentional engagement is needed to prevent inappropriate responses to stimuli in the environment.

There is certainly a need to inhibit reflexlike responses to every suddenly occurring stimulus. Regarding the inhibitory effect of foveally engaged attention, there are strong indications that it has its neuronal basis in the tectal fixation system of primates, which, when activated by a foveal stimulus or by the animal's/subject's intention to stabilize the direction of gaze, it inhibits the saccade generating neurons (Munoz & Wurtz 1993a; 1993b). Experimental inactivation of these fixation cells leaves the animal in a state where it can no longer suppress saccades to suddenly appearing stimuli even in the presence of a fixation point that it has been trained to fixate on. This finding is reminiscent of the oculomotor behavior of some human subjects who are unable to perform an antisaccade task: when required to look to the side opposite a suddenly appearing stimulus (= antisaccade), they cannot avoid making erratic saccades toward the stimulus (= prosaccades). When asked to generate prosaccades to a target in the presence of a central fixation point (overlap condition), they produce unusually high numbers of express saccades. It has been suggested that these subjects may have a functional disturbance of their fixation system, which is not strong enough to prevent the execution of reflexlike prosaccades, even if these are unwanted, as in the case of the antisaccade task (Biscaldi et al. 1996). All these findings suggest that in the case of eye movements, the function of preventing "inappropriate" responses at the cost of an increase in reaction time (express saccades versus regular saccades) is provided by the foveal fixation system.

Regarding the effects of peripherally engaged attention, the experimental results must be considered in more detail: in the early studies on the relation between express saccade generation and peripheral attention engagement (Mayfrank et al. 1986), the subjects were instructed to direct their attention for some time (about two seconds) to a specified peripheral location, before a saccade target was presented. In this situation attention allocation was voluntary and sustained, and as a result the occurrence of express saccades was reduced compared to a control situation without peripheral attention allocation. In later studies (Weber & Fischer 1995) the spatial selectivity of the inhibitory effects of voluntary and sustained attention allocation was investigated by varying the distance between the attention target and the saccade target systematically. The result was a decrease of the number of express saccades toward the attended location, while close-by unattended locations could be reached as often by express saccades as in the control condition (no attention target at all). These findings lead to the same conclusion drawn by **Bridgeman,** namely, that peripherally engaged attention has the result of slowing response latencies.

There are some new results, however, which – at first glance – seem to contradict this notion: when attention was captured by the use of transient peripheral cues, which were presented for 40 msec and preceded the occurrence of the saccade target by a cue lead time of 100 msec, a spatially unselective and transient facilitation of express saccades was observed (Cavegn 1996). In subsequent experiments the cue and the stimulus were presented on opposite sides: the cue occurred with a lead time of 100 msec on one side, correctly indicating that the saccade target would occur at the mirror image *opposite* side (= valid anti-cue). As a result, express saccades to the target were diminished in number or completely absent. The same experiment was then repeated, but with the instruction to generate antisaccades in response to the stimulus; in this case the cue correctly indicated the side to which the antisaccade had to be made (Fischer & Weber 1996). In contrast to our expectations, this experiment yielded increased antisaccade latencies (as compared to the no cue control case) and – even more strikingly – the subjects produced large numbers of erratic prosaccades to the stimulus. Most of these erratic prosaccades were corrected immediately, but – again to our surprise – a large proportion of these "detours" remained unconscious to the subjects: when asked to press a key at the end of each trial in which they recognized an erratic saccade to the stimulus, up to 70% of the erratic trials escaped the subject's attention. The mean values of 10 subjects were: error rate = 20.9%, mean recognition rate = 48.6% (Fischer & Mokler, unpublished observation). Even extremely well trained subjects (like HW and BF) were unable to suppress the unwanted glances or to recognize all of them. Again, most of the reflexive saccades were of the express type, and most were corrected extremely quickly, within about 100 msec or less (= average for unrecognized errors) or 30 msec later (= average for recognized errors). If, on the other hand, the cue and the stimulus for the antisaccade were presented on the same side, the latencies of the antisaccades and the error rates were decreased as compared to the control situation without cueing (Fischer & Weber 1996).

These findings require an explanation that takes into account the notion of the existence of *two* attentional components, as proposed by Nakayama and Mackeben (1989): With valid cueing, that is, attention target and saccade target at identical locations, sustained voluntary attention allocation inhibits express saccades, whereas transient attention capture facilitates them, as shown schematically by the graph in Figure 1. The automatic involuntary nature of the transient component becomes evident from the experiment with valid anti-cues: the knowledge that the

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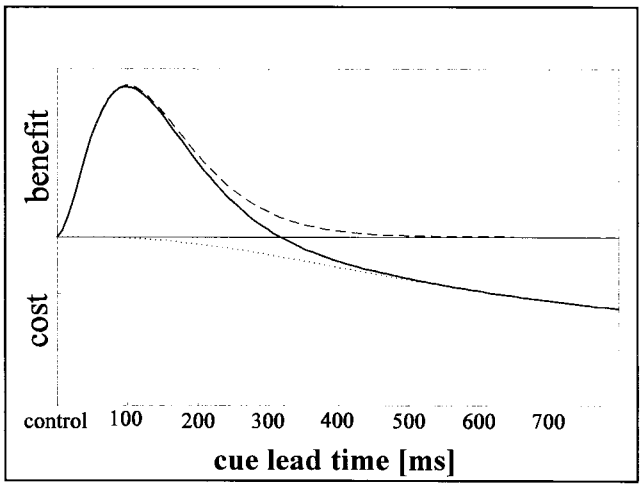


Figure 1 (Fischer & Weber). Schematic drawing of the combination (solid line) of transient orienting (dashed line) and sustained attention (dotted line) components as proposed in the text. With valid cueing the transient component facilitates and the sustained component inhibits the generation of express saccades.

cue always indicates the occurrence of the saccade target on the opposite side provides no benefit for the subjects' reaction times. By contrast, the automatic attention capture summoned by the transient cue leads to a cost for the reaction times of the subsequent saccade toward the target on the opposite side, since attention must be disengaged from the cued location before the saccade to the mirror imaged position can be executed. The results from the experiments with cueing of antisaccades imply, moreover, that the orienting mechanism elicited by the transient cue relates to the decision to make an antisaccade: in this case the cue elicits *anti-orienting* and facilitates saccades to the opposite side, whereas saccades toward the location of the cue are delayed.

In conclusion, we want to emphasize that it may be misleading to stay with the notion of only one attention system and to argue in favor of or against reaction time costs or benefits due to attentional engagement. Most of the controversial experimental data are in agreement with the concept of two attentional components, one facilitating, the other inhibiting saccade generation. The inhibition acts top-down to prevent reflexive saccades to the attended location, but not necessarily to unattended locations. The automatic component would appear as a bottom-up orienting mechanism that helps to guide the fovea from one salient stimulus to the next, providing an optomotor cycle of "saccade–fixation–saccade" that usually does not need our conscious control.

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