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# Shifts of Visual Attention: An Historical and Methodological Overview

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**Abstract** An historical overview of the study of visual attention shifts is presented. Contemporary research on this problem is outlined and models of attention shift mechanisms are briefly described. In addition, several methodological variables are described that warrant consideration when evaluating claims about shifts of visual attention.

Our ability to shift visual attention is apparent whenever we direct our eyes toward one object while attending to something else at a different location. This is commonly referred to as using our "peripheral vision" and we do so, for example, when driving a car and keeping our eyes on the road while attending to the sidewalks where pedestrians and children might appear. Undoubtedly, humans have been aware of this capacity for a good deal of our species' history but tools were not available to study this phenomenon scientifically until the 19th century. Helmholtz found that he could voluntarily shift the focus of his attention to identify groups of letters before he had sufficient time to execute an eye movement to those letters (see Warren & Warren, 1968). He demonstrated this by illuminating the display of letters with a spark. The brevity of the illumination precluded eye movements because they usually require approximately 220 ms for execution (Fischer & Weber, 1993). When Helmholtz kept his attention on a pinhole at the centre of the display where his eyes remained fixated, he could identify only those letters in the immediate area. On the other hand, when he voluntarily decided to attend to the letters at a different location and shifted his attention in advance of the spark, he could identify only those letters in the attended area. Thus, with the advent of technology for producing electrical sparks, voluntary shifts of attention made independently of eye movements were first studied in the laboratory.

Later in the 19th century, James (1890) described attention shifts as being under voluntary or involuntary control. Others conducting experiments around this time demonstrated that visual attention can be captured by the sudden

onset of a stimulus (e.g., Titchener, 1910). This work provided a framework for understanding one of the fundamental aspects of attentional control – shifts can be made in a goal-driven or in a stimulus-driven manner. Researchers have referred to goal-driven shifts as endogenous, voluntary, or intrinsic; and to stimulus-driven shifts as exogenous, reflexive, or extrinsic. Goal-driven attention shifts are initiated voluntarily on the basis of a computational goal (e.g., shift attention to the location indicated by the arrow cue presented in the centre of the visual field). Stimulus-driven shifts are initiated reflexively in response to abrupt-onset stimuli or visual transients somewhere in the visual field (Yantis & Jonides, 1984; Yantis & Gibson, 1994, this issue). The distinction between these two types of control will be discussed in more detail later in the article.

Very little research on attention was conducted during the behaviourist era in the first half of the 20th century until the pioneering work on auditory filtering by Broadbent (1952, 1958) and Cherry (1953). The evolution of visual attention research, as is usually the case with any scientific endeavour, was influenced by technological advances. In particular, just as the independence of attention shifts and eye fixation was not studied scientifically until the equipment required to ignite electrical sparks was developed, so it was that this phenomenon was not studied in more detail until the 1970s when eye movement monitoring technology was refined. Before this time, attention shifts could be studied only in the spirit of Helmholtz through the use of time-limited displays that were masked before eye movements could be made (i.e., displays with exposure durations less than 200 ms).

Another technique used regularly during the past 30 years to study the dynamics of visual attention shifts is location cueing. If a cue about a target's location is presented prior to the target's onset, it takes less time to detect or identify the target, and response accuracy is facilitated relative to an uncued trial. But this is true only when the cue accurately indicates the target's location (a valid cue). When the cue indicates a location other than the target's location (an invalid cue), response times are longer and accuracy is worse relative to cases in which cues are valid or no cue is presented. This discovery led to the development of cost/benefit analysis of location cueing effects (Posner, 1978). Cost/benefit analysis requires the use of a neutral cue that provides no information about target locations. The response time (RT) benefits of valid location cueing are determined by subtracting valid cue RTs from neutral cue RTs. Similarly, the RT costs of invalid cueing are determined by subtracting neutral cue RTs from invalid cue RTs. An RT benefit is thought to indicate that the perceiver is given a "headstart" in shifting attention to the target's location. An RT cost is thought to indicate a "headstart" in the wrong direction toward a nontarget location that must be followed by a realignment of attentional focus with the actual target location after target onset.

In addition to concerns about it described later in the article, the use of

cost/benefit analyses raised questions about whether the effect of location cueing is to increase perceptual sensitivity to targets presented at cued locations or instead is to influence an observer's response criterion for reporting the presence or identity of a stimulus presented at that location (Lappin & Uttal, 1976; Shaw, 1983). Signal detection theory (SDT) provides a way to measure perceptual sensitivity ( $d'$  in SDT terms) independently of the decision criterion ( $\beta$  in SDT terms) and is usually used to differentiate between these two possibilities (e.g., Green & Swets, 1966). Studies utilizing SDT have indicated that location cueing does affect perceptual sensitivity at the cued location and, therefore, that the dynamics of attention shifting can be examined fruitfully using a cueing procedure (e.g., Bonnel, Possamai, & Schmidt, 1987; Downing, 1988; Müller, 1994, this issue; Müller & Humphries, 1991; Possamai & Bonnel, 1991).

Questions have also been raised about the relationship between visual attention shifts and eye movements (e.g., Groner & Groner, 1989; Klein, 1994, this issue; Remington, 1980; Shepard, Findlay, & Hockey, 1986; Wright & Ward, 1994). Attempts to answer such questions have typically involved determining whether saccadic eye movements can be made with or without a concomittant attention shift to the saccade destination. There is a growing consensus that when a saccade is triggered by an abrupt-onset stimulus, a shift of attention accompanies and may even precede the execution of the saccade to the stimulus location. On the other hand, there is some disagreement about whether this is the case when a saccade is initiated voluntarily after an observer interprets a symbolic cue about where to make the eye movement (Klein, Kingstone, Pontefract, 1992; Remington, 1980; Shepard et al., 1986). In other words, while there appears to be a close relationship between stimulus-driven saccades and attention shifts, the relationship between goal-driven saccades and shifts may be less direct.

When saccades are triggered by an abrupt-onset stimulus that appears 200 ms after the offset of a central fixation point, saccade latency in humans is sometimes reduced to approximately 120 ms (as opposed to the 220 ms latency of regular saccades). Fischer and Weber (1993) referred to these rapid eye movements as *express saccades* and provided evidence that they occur only when there is a sufficiently long temporal gap between the offset of the fixation point and the onset of the target stimulus. The gap, they have argued, allows attention to be unlocked or disengaged from the fixation point prior to target onset. As a result, saccade latency is faster because attentional disengagement has been completed before the target appears. On the basis of this finding and several replications, it has been proposed that when stimulus-driven saccades are executed, they occur after an attentional disengagement operation (e.g., Fendrich, Hughes, & Reuter-Lorenz, 1991; Fischer & Breitmeyer, 1987; Fischer & Weber, 1993; Jüttner & Wolf, 1992; Wright & Ward, 1993). That is, when stimulus-driven saccades are made,

attention is first disengaged at the origin of the eye movement.

Posner, Petersen, Fox, and Raichle (1988) have proposed that attention is shifted from one location to another using a "disengage-shift-engage" sequence: Attention must be disengaged before the shift will occur, remains disengaged throughout the shift, and will be re-engaged at the shift destination. Posner et al. (1988) have also suggested that the posterior parietal cortex (disengage), superior colliculus (shift), and pulvinar (re-engage) work together to mediate these shifts. Their claim is supported by data indicating that prior to a shift, neural activity increases in the posterior parietal cortex in humans and that damage to this area causes an impaired ability to disengage attention (e.g., Petersen, Corbetta, Miezin, & Shulman, 1994, this issue; Posner, Walker, Friedrich, & Rafal, 1984, 1987). Neural activity in the superior colliculus also increases prior to and during shifts (e.g., Wurtz & Albano, 1980) and damage to this area decreases the speed of shifts (e.g., Posner, Cohen, & Rafal, 1982; Posner, Rafal, Choate, & Vaughan, 1985). Furthermore, studies indicate that neural activity increases in the pulvinar region of the thalamus when humans perform tasks requiring attentional engagement (LaBerge & Buchsbaum, 1990; Petersen, Robinson, & Morris, 1987) and that performance is impaired when this area is damaged (Petersen, Robinson, & Keys, 1987; Rafal & Posner, 1987). Although most of the supporting data were obtained from studies of stimulus-driven attention shifts, the "disengage-shift-engage" proposal is compelling.

Studies of the neurophysiology of attention also may provide information about the relationship between visual and auditory attention shifts (e.g., Ward, 1994, this issue). Shifts carried out within either modality appear to require spatial representations for their calibration and there are some indications that a polysensory or common representation used by visual and auditory processes exists. Wright and Ward (1994) have proposed that such a map may be located in the posterior parietal cortex.

Studies of the superior colliculus and other midbrain areas indicate that, in addition to mediating eye movements and attention shifts, they mediate a phenomenon referred to as *inhibition-of-return* or IOR (Posner & Cohen, 1984). This occurs when a direct stimulus cue (e.g., a barmarker) is presented at one location and then, 200 ms later, a second cue is presented at a different location. If, a further 200 ms later, a target is presented at the first cued location, detection RTs will be slower than if the target is presented elsewhere. Thus, there is said to be an IOR of visual attention to previously cued locations. IOR of visual attention is closely related to the execution of saccadic eye movements. In particular, IOR will not occur if the attention shifts are initiated by symbolic cues. Only direct stimulus cues produce this phenomenon. If a shift is initiated by a symbolic cue and a saccade accompanies it to the cued location, however, IOR will occur (Posner, Rafal, Choate, & Vaughan, 1985). Furthermore, if a shift is initiated by a symbolic cue and an

accompanying saccade is prepared but "canceled" before execution, IOR will also occur (Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Egly, & Rhodes, 1994, this issue). Another indication that IOR is related to eye movement programming is that IOR does not occur at eccentricities greater than those for which a saccade can be programmed. More specifically, Harman, Posner, Rothbart, and Thomas-Thrapp (1994, this issue) found that three-month-old humans are only capable of 10° saccades and also show IOR only for targets within 10° of central fixation. IOR also can occur at two locations at the same time (Posner & Cohen, 1984; Wright & Richard, 1993). This is consistent with claims that multiple locations can be simultaneously indexed even while a single focus of attention is currently located elsewhere in the visual field (e.g., Pylyshyn et al., 1994, this issue; Wright, 1994, this issue).

In addition to concerns about the degree to which attention can be shifted independently of eye movements and the relationship between these two processes, attempts have been made to determine the nature of the psychological mechanisms underlying attention shifts. A variety of proposals has been put forward that can be categorized as movement models, focussing models, and resource distribution models. Each model involves its own tacit assumptions. For example, movement models are based on the assumption that the focus of attention is shifted from one location to another in an analog or in a discrete manner (e.g., Posner, 1980). Focussing models are based on the assumption that the spatial extent of attentional focus can change to a broader, more diffuse state, and then back to a finer, more concentrated state at the destination of the shift (e.g., Eriksen & St. James, 1986). This process is similar to that of movement models but shifting is accomplished by defocussing from one location and refocussing at another. Resource distribution models are based on the assumption that the attentional alignment process does not involve a movement or focussing component (e.g., LaBerge & Brown, 1989). Instead, alignment occurs when sufficient processing resources accumulate at a particular location within a representation of visual space and cause a channel of focussed attention to be opened at that location. Each type of model is supported by some data and it remains to be seen which one most accurately describes operations of the attentional shift mechanism at the psychological level.

One reason why no single model has emerged is that many conflicting empirical claims about shifts of visual attention have been made over the past 15 years. For example, there is some debate about whether shifts are analog or discrete; about whether there is a unitary or multiple attentional foci; and about the closeness of the relationship between attention shifts and eye movements. We feel that these conflicts have arisen because several different methods have been used to study attention shifts. In fact, much of the data in the literature may be consistent with properties of a single attention shift

mechanism but, we believe, progress towards determining the nature of this mechanism will be hindered until order is imposed on methodological variables to ensure that different approaches are actually addressing the same aspect of attention shifting. The following factors appear to have differential effects on these shifts and should be considered when determining the validity of opposing claims in the literature.

### *Cue Type*

As mentioned previously, attention shifts can be initiated with two types of cues. One (e.g., a centrally presented arrow or digit) conveys symbolic information that observers must interpret to determine the probable target location. Another (e.g., an outline box, dot, bar) is presented with an abrupt onset near the probable target location and therefore indicates this location directly rather than symbolically. For reasons outlined elsewhere, we refer to them as *information cues* (symbolic cues) and *stimulus cues* (direct cues) (Wright & Ward, 1994). We pointed out earlier that while information cue use is voluntary, stimulus cue use appears to be reflexive (Jonides, 1981; Kröse & Julesz, 1989; Yantis & Jonides, 1990). That is, attention shifts initiated by stimulus cues appear to occur because these cues momentarily have the capacity to "pull" the focus of attention to their location. This distinction needs to be considered because the two types of cues cannot be assumed to have the same effects on response time and accuracy. One experiment that was interpreted on the basis of this assumption involved a double cue to determine whether the focus of attention could be divided between two locations (Eriksen & Yeh, 1985). Possible target locations in the display corresponded to the 3, 6, 9, and 12 o'clock positions of a circular array. A stimulus cue (bar marker) was presented adjacent to one of these locations and observers were told that the target was equally likely to be presented at this location or at the location diametrically opposite to it. The alternate location was therefore symbolically cued. It was assumed that the observer's optimal strategy would be to divide attention between the two cued locations and that, if this strategy were adopted, identification times would be equally fast for targets presented at either location. In reality, identification times were significantly faster for targets presented at the primary (stimulus cued) location than at the alternate (information cued) location. The subsequent conclusion that attention could not be equally divided between the two locations was based on the assumption that stimulus and information cues have the same effect on attention shifts. Stimulus cues, however, appear to reflexively "pull" attention to their location in a way that may have disrupted observers' attempts to voluntarily direct attention to the information cued location. The different effects of stimulus and information cues are also apparent in the context of the temporal parameters discussed in the next section.

### *Temporal Parameters*

The effectiveness of stimulus and information cues differs as a function of cue-target-onset-asynchrony (CTOA). Stimulus cue effectiveness increases rapidly as CTOA increases from 0 to 100 ms, peaks for CTOAs around 100 ms, and usually decreases with further CTOA increases (e.g., Müller & Findlay, 1988; Nakayama & Mackeben, 1989; Shepard & Müller, 1989). Information cue effectiveness, on the other hand, appears to increase more gradually as the CTOA is increased from 0 to 300 ms and to be sustained at a maximum level with further CTOA increases (e.g., Müller & Findlay, 1988; Shepard & Müller, 1989). In some cases, stimulus cue effectiveness also appears to be sustained at slightly lower than the maximum level with CTOAs larger than 100 ms (e.g., Cheal & Lyon, 1991a, b). This appears to arise from such cues serving as symbolic information cues after the initial "reflexive pull" subsides (cf., Weichselgartner & Sperling, 1987). The difference in the time course of stimulus and information cue effectiveness precludes using the two types of cues together to determine, for instance, whether attention can be simultaneously directed to two locations (e.g., Eriksen & Yeh, 1985).

Before the time course of cue effectiveness was directly examined in the late 1980s, researchers did not take the interaction between cue type and CTOA into consideration. For example, Jonides (1981) conducted experiments with stimulus and information cues and CTOAs ranging from 50 to 115 ms – a range in which stimulus cues are more effective than information cues. Posner, Snyder, and Davidson (1980) conducted experiments with stimulus and information cues and a CTOA of 1000 ms. In this case, information cues were more effective than stimulus cues because the reflexive pull of the latter would attenuate well before target onset. Whenever researchers conduct experiments involving stimulus cues and CTOAs exceeding 200 ms or experiments involving information cues and CTOAs that do not exceed 200 ms, claims about differences in cue effectiveness must take into account the differences in temporal parameters.

### *Task and Response Type*

Conflicting results might also be due to differences in the type of task or response used to measure a particular aspect of attention shifting. For example, varying cue/target distance affects discrimination and identification responses to a greater extent than it affects simple detection responses (e.g., Egly & Homa, 1991). Experiments with different response measures have been conducted to test the same effect but have produced different results. Tsal (1983) varied the distance between location cues and targets and concluded that attention is shifted from one location to another in the same manner as a constant-velocity spotlight. Remington and Pierce (1984) also varied the distance between cues and targets but concluded that attention is shifted either with a proportional velocity or in a discrete manner (i.e.,

attention is disengaged or "turned off" during the shift). Tsal's study involved identification responses while Remington and Pierce's study involved simple detection responses. Therefore, the interaction of response type with cue/target distance could also account for the difference in results. Note that Eriksen and his colleagues have also used identification response measures and concluded, like Remington and Pierce (1984), that attention shifts may be discrete (e.g., Eriksen & Hoffman, 1973, 1974; Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Pan & Eriksen, 1993). The generality of these findings may be limited, however, because most of the displays used by Eriksen et al. were entirely foveal. In contrast, most other investigations of shifts of visual attention involved nonfoveal cues and targets (e.g., Posner et al. (1980) presented targets with eccentricities as great as 25°). Therefore, Eriksen et al.'s conclusions may only be valid for intra-foveal attention shifts.

Differences between primary and secondary task performance may also lead to different patterns of data (e.g., Egly & Homa, 1984; Klein, 1980; LaBerge & Brown, 1989). That is, secondary task performance may be affected by primary task performance in some situations and, therefore, comparisons of data yielded by primary and secondary tasks should be made with caution. More generally, studies that differ in terms of task and response type may not be addressing the same aspects of attention shifting.

#### *Trial Presentation Order*

Conflicting claims about shifting may arise from differences in the order of trial presentation. More specifically, trials blocked by condition are thought to yield less reliable data than trials presented in a completely randomized order because the former are more likely to be biased by condition-specific strategies (Sperling & Doshier, 1986). For instance, in some experiments involving trials blocked by the distance between invalid cues and targets, the data did not indicate the occurrence of a cue/target distance effect (e.g., Posner, 1978; Remington & Pierce, 1984). In other experiments with a randomized trial presentation order, responses did vary with distance between the cue and target (e.g., Downing & Pinker, 1985). This suggests that the difference in trial presentation order could be responsible for the failure to find a distance effect in one case but not the other, and thus for conflicting claims about such effects.

#### *Subject Expertise*

Caution should also be exercised when comparing research involving differences in subject expertise. In particular, with several days of practise, subjects are able to develop focussing strategies such as attentional disengagement before target onset, that novice subjects do not have at their disposal (Fischer & Ramsperger, 1986). Hughes and Zimba (1985) conducted a study using expert subjects (including themselves) and found that valid cues did not



produce response facilitation. In contrast, Rizzolatti, Riggio, Dascola, and Umiltà (1987) replicated this experiment with novice subjects and found that valid cues did produce response facilitation. Although there were other differences between the two studies, the conflicting results may be attributable in part to differences in subject expertise as opposed to the obligatory processes underlying shifts of visual attention.

#### *Neutral Trials and Cost/Benefit Analyses*

Jonides and Mack (1984) outlined a number of ways in which cost/benefit analyses can be misleading. Cost/benefit analyses are based on the assumption that neutral and informative cues are similar in every way except for the target location information conveyed by the latter. However, this assumption is easily violated. For example, subjects may be more alert when responding to informative cues than when responding to neutral cues. The possibility of this occurring is greater when the two types of cues are physically different and also when they are presented in separate, homogenous blocks of trials (as in some of the experiments conducted by Hughes & Zimba, 1985). As a result, benefits may be reduced and costs may be inflated. In addition, neutral and informative cues may have different processing demands and may require different amounts of time to be encoded. Jonides and Mack (1984) have advised that neutral cues only be used when necessary, and then with caution. If they are used, neutral and informative cues should be as similar as possible in terms of physical appearance, potential to alert observers, and ease with which they can be encoded.

We began with an historical overview of research on shifts of visual attention. The descriptions of contemporary studies of this phenomenon indicate that a number of promising advances have been made. For example, investigations of the physiology of attention suggest that attention is disengaged prior to and during a shift under stimulus-driven control (i.e., stimulus-driven shifts appear to be discrete as opposed to analog). This work has also indicated that common brain areas mediate attention shifts, saccadic eye movements, and IOR. Finally, a number of methodological factors are now apparent and should be considered when designing experiments and evaluating opposing empirical claims about properties of visual attention shifts. The articles in this issue are an indication of the diversity of approaches being taken to a common problem – determining the nature of the mechanisms underlying shifts of visual attention.

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