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Covert Visual Attention and Distractibility

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COVERT VISUAL ATTENTION AND DISTRACTIBILITY

BY

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Abstract

Covert visual attention has been studied at several levels of observation and from several perspectives. Literature on covert attention, visual system information processing, and controlled and automatic information processing is reviewed and related to issues of attention, distraction and distractibility. A psychophysical experiment is described, in which speeded button press response was required to identify one of two target letters in a briefly presented four letter array. Cuing blinks appeared on the right or left side immediately prior to the array; depending on the experimental condition, subjects were informed that the blink (a) indicated the side on which the target letter would appear, (b) indicated the opposite side, or (c) was random and uninformative of target position. Results of analysis of variance and Attention Operating Characteristic (AOC) analysis are presented on the performance of 22 university undergraduate subjects. Cuing blinks appeared to "pull" attention automatically even when known to be uninformative; moreover, the voluntary use of blinks (during informative cue conditions) resulted in slower reaction times, consistent with a controlled processing account. The

covert attention effect is discussed with respect to distraction and individual differences, and comments are made on Shaw's (1980) argument that much of what has been regarded as attentional sensitivity may actually be the results of strategies and judgement criteria.

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The study of attention can be seen as a sort of core sample of the past hundred years of psychology, in which the strata are particularly clear. In the earliest stratum (the Subjective Era) are the origins of attentional study. The subjective experience of selective attention was the starting point, and figured prominently in discussions of awareness and thinking. Due to a change in climate unfavorable to "mentalistic" concepts, the subsequent stratum (the Behaviorist Era) is very thin, with discrimination training being a typical rubric under which issues of selectivity were addressed. Attention as a distinct area of study was virtually extinct (Dember & Warm, 1979). The next stratum (the Information Processing Era) has left a thick sediment, characterized by the use of performance (especially of concurrent tasks) as a research paradigm, and by controversy about how early or late in the sequence of cognitive processes attentional selectivity operates. The present period is noteworthy for the attempts to reintroduce conscious experience as a construct, and to integrate attentional theory with memory-oriented information processing theory, with performance data, and with knowledge about nervous system functioning (e.g., Posner, 1982).

The present study follows this trend toward integration, and concerns an attentional effect variously termed "covert attention," "the spatial attention system," "the functional fovea," or "the mind's eye." Just as overt shifting of visual attention (i.e., eye and body movements) functions to bring objects of interest onto the central (foveal) region of the retina and to maintain them there, shifts of covert attention appear to involve the movement of a region of increased sensitivity within visual space while the retinal image remains static. Previous studies have used covert attention effects -- inferred from performance data -- in connection with visual information processing and neurophysiology (Breitmeyer & Ganz, 1976), neuroanatomy and subjective experience (Posner, 1982), and automatic and voluntary/attended information processing (Bashinski & Bacharach, 1980; Jonides, 1980; Jonides, Note 2; Hoffman & Nelson, Note 1; Carr & Bacharach, 1976).

The range of these studies leaves the author with two impressions. First, it appears that we are approaching the ability to make confident and meaningful identifications of neural functioning with cognitive functioning in the case of covert attention. Second, several of psychology's classic controversies are at

issue here, most notably aspects of the mind body problem. Covert attention seems to be a point at which "biology" intrudes upward into "cognition," and "cognition" penetrates down into "biology."

The current study asks two general questions about covert attention: How does it coordinate with higher, voluntary cognitive processes? And can the nature of this coordination shed light on the subjective experience of distraction and the presumed trait of distractibility? Answers to these questions would help to specify the degree of "downward" influence (e.g., can covert attention shifting be attenuated or disabled?) and the consequences of "upward" influence (e.g., does covert attention control cooperate or compete with voluntary control?). In addition, a theoretical basis and operational definition for distractibility might be begun, and the issue of individual differences would be raised.

Covert Attention

A clear and dramatic demonstration of covert attention was done by Kaufman and Richards (1969). Using a technique called Haidinger's Brush, which produces with polarized light the illusion of a rotating propeller at the foveal center of vision, they found that subjects' reports of where they were looking deviated by as much as 2 degrees from the position of the "propeller." Their task involved extended viewing of geometric figures, and such variables as the acuteness of open angles were found to affect mean fixation positions (Kaufman & Richards, 1969).

Subsequent attempts to demonstrate covert attention effects (reviewed by Jonides, Note 2; Bashinski & Bacharach, 1980) had uneven success. Jonides (Note 2) observes that most of the successful attempts used visual marker cues at or near the location of the target which followed, while unsuccessful attempts tended to use instructional manipulations. Bashinski and Bacharach (1980) point out that this distinction does not hold in all cases, and that in addition to successfully producing the attentional effect, it is necessary to use a dependent measure capable of registering the effect.

To avoid contamination of covert attention effects by eye movement effects, most of the experimental procedures which have been developed rely on the presentation of cue and stimuli within the 250 msec or so typically required to complete a saccade. Speeded signal detection or identification response is usually required, with reaction time or error rates constituting the dependent variables. Compared to the technique used by Kaufman and Richards (1969), the use of rapid spatial cuing and speeded response differs in that (a) the 2 degree range of deviation found in spontaneous gaze may well not apply when fast spatial cues are used to manipulate covert attention actively, and (b) the measurement of covert attention effects does not focus on the position of a "functional fovea," but on the relative speed and efficiency of processing of information from attended or unattended locations. Whereas Kaufman and Richards' results conform to the fovea analogy of a focal center which moves around the visual scene, in later studies this geometrical model is exchanged for more abstract discussions of allocation and deallocation of attentional resources (Bashinski & Bacharach, 1980) and the costs and benefits to subsequent processing of cuing (Jonides, Note 2). Shulman, Remington, and McLean

(1979), however, have shown that covert attention shifts occur in analogue fashion, that is, passing through one point on the way to another. This revives the geometric model, in effect, with the functional fovea resembling a graded region of sensitivity (or prior entry), in contrast with the physical fovea, which is a sharply defined area of great acuity.

The procedure used by Jonides (Note 2) is typical, and will be described in some detail because his findings suggested the present study, and because his procedure most closely resembles that of this study. Subjects were tachistoscopically presented (for 50 msec) an array of four letters, one of which was always an "L" or "R," and their task was to make a speeded button-press response to identify which letter was present. Immediately before the stimulus array appeared, a cue was presented either centrally or peripherally, for a duration of 50 to 200 msec, which either was uninformatively neutral or correctly indicated the target letter's position 70 percent of the time. He reasoned that if the control of covert attention was mostly reflexive, then peripheral cues should produce greater benefit (when valid) and cost (when invalid) than central cues, on the assumption that peripheral cues should more automatically draw attention

than central cues can direct it. This hypothesis was supported by his results, he claimed, although the effect was seen only in greater costs, and not benefits. He proposed an explanation for this, according to which the benefits asymptote with a small increment of allotted attention, while costs continue to accrue with greater decrements of allocated attention.

A second experiment (Jonides, Note 2) was based on the assumption that cues which operate automatically should be difficult to ignore. Three types of cues were used: neutral and peripheral cues, as above, plus uninformative cues. The latter were peripheral markers which, instead of being accurate 70 percent of the time, were random (that is, valid only 25 percent of the time), and subjects were told so. The results showed the costs for the uninformative conditions -- when subjects were urged to ignore the cues -- to be as great as for invalid peripheral cues, indicating that peripheral cues were indeed difficult to ignore.

These findings -- that cues which produce covert attention shifts appear to be difficult to ignore, and that this effect is more apparent in the processing costs at noncued positions than in the processing benefits at cued positions -- directly raises the issues of

distraction and distractibility.

Distraction and Distractibility

In common usage the notions of distraction and selective attention are antagonistic: distraction is the failure to sustain selective attention. Jonides' (Note 2) findings suggest another conception of distraction, however. Rather than being the filtering through of random stimulation into consciousness (or into conflict with attended processing), distraction in this case looks more ordered and systematic. The allegedly automatic effect of spatial cues in producing covert attention shifts is far from random, being highly selective with respect to spatial location. In essence, then, we have two selective attention systems here: a relatively automatic system (the "spatial attention system," Hoffman & Nelson, Note 1) which is effective in moving around covert attention on the basis of rapidly presented spatial information, and a voluntary system (operationally identified with subjects' ability to follow verbal instructions) which appears to be relatively ineffective in shifting covert attention.

This phenomenon of visual distraction thus appears to involve the coordination of two systems -- one "automatic," the other "voluntary" -- and not the failure of a single system.

We might ask at this point whether there is corollary evidence from neural physiology and anatomy to support this picture of the spatial attention system, and whether any theoretical or experimental work has been done which might point to a more general context for this new conception of distraction.

Breitmeyer and Ganz (1976) present a seminal review and synthesis combining studies of visual masking, saccadic suppression, and neurobiology, in which the distinction between transient and sustained channels in visual pathways is the organizing schema. In brief, two different types of cells have been identified within the visual system on the basis of their speed of neural transmission and the type of visual information to which they respond. Sustained cells preferentially respond to slowly moving or static visual stimulation and transmit their signals relatively slowly, while transient cells are particularly sensitive to rapidly moving or suddenly appearing stimulation and transmit their signals rapidly. In addition, sustained cells are sensitive to high

spatial frequency input, while transient cells prefer low frequencies.

Since both transient and sustained cells are connected to their own kind from the retina to cortex, they seem to constitute semi-independent visual systems. Sustained channels specialize in fine discrimination, contour analysis, and figural information, and transient channels specialize in information about location and change in location (i.e., movement) with only crude response to form. Breitmeyer and Ganz (1976) associate transient channels, among other things, with the "early warning" signal about the location of a visual event which arrives at cortex 50-100 msec faster than sustained channel input, allowing attention (or the functional fovea) to be shifted accordingly. To rephrase, they believe that covert attention shifts are produced in response to transient channel activity, which conveys information only about location, movement, and sudden onset or offset of stimuli. The "decision" to shift covert attention, if this account is accurate, would not include information about what has appeared or moved in visual space, and would seem to be capable of no (non-spatial) selectivity in its response, only perhaps a general inhibition. In summary then, evidence exists

that the movement of covert attention is initiated by fast responding cells and in the absence of any information other than the location of some transient visual event. This is in substantial agreement with the view stated above, that the spatial attention system operates automatically and selectively with respect to location.

The second question, about a more general context for the new conception of distraction, is addressed in the work of Shiffrin and Schneider (1977; Schneider & Shiffrin, 1977) on controlled and automatic information processing. They propose a two factor model of information processing which subsumes the areas of visual search and attention, long and short term memory stores, and automatic processing. There are, they say, two different modes of human information processing, which correspond to the domains of short term and long term memory stores. Long term storage is conceived to be a very large number of nodes which permanently encode information. Those nodes which are activated at any particular moment constitute short term memory, and the portion of those which remain activated sufficiently long are included in conscious awareness (i.e., working memory). This last subset is the locus of "controlled

processing." Although severely limited in capacity, the controlled processing workspace is highly flexible, and temporary structures can be set up easily for operations such as serial comparisons. Through much consistent repetition of a task, nodes become associated with each other to the extent that one node, when activated, automatically and rapidly activates the next, so that a string of nodal activations may culminate in an overt response with little or no use of limited short term storage, and even without the subjective awareness of the person. This is "automatic" processing, and it generally operates in parallel fashion, as when many spatial locations are simultaneously monitored as efficiently as a few (e.g., Egeth, Jonides, & Wall, 1972). A great deal of consistent practice is required, however, for such automaticity to be developed (or "learned").

This framework readily accommodates the account of distraction developed above: distraction is not the consequence of stimulation from the (external or internal) environment of a random sort. Rather, the kind of stimulus which will commandeer attention is the kind which has, through long practice, laid down tracks in our long term store. Just as the spatial attention system is attuned to information about location and movement, and

responds to it apparently without voluntary effort, habitually associated nodes too may respond automatically to stimulation which is not relevant to the selective attention task at hand. In both cases, distraction occurs.

Although the same general model of automatic distraction seems to apply to both cases, there are major differences in the kinds of distraction effects each system is understood to produce. When a learned automatic process is initiated which includes as part of its activation sequence the emergence into conscious awareness, the limited capacity of controlled processing workspace is "forced" to admit an intruding item, which may "bump" one or more of the elements in a temporary processing structure, causing disruption of the controlled process. The distraction caused by covert attention shifting, in comparison, seems not to compete with or disrupt controlled processing, but only to delay the arrival and/or degrade the quality of visual information from points distant from the cued spot.

In what way, then, are the two similar? First, they both constitute systematic input to higher processes, and their effect may be negative (i.e., distracting) or positive, depending on the situation. To a hunter

scanning the horizon, for example, the rapid, automatic pull of covert attention toward moving objects would assist in the intentional task, while the same would not be the case for, say, a diamond cutter, who needs to maintain focused attention. Similarly, some learned automatic processes would be indispensable to a musician in sight-reading, but to a beginning musician who has not yet automatized musical encoding, most automatic processes would be distracting.

Another similarity follows from the first: since both apparently send input automatically to higher processes, for the higher processes to be freer of their influence, it would seem necessary either to decrease their activity or responsiveness, or to filter their input. This closely resembles Treisman's (1960) attenuation model of attention, with the difference that we do not assume that a single attenuation function would regulate all potential automatic inputs, nor even that both of the automatic processes being discussed are capable of attenuation.

This moves us from distraction into distractibility, and raises the issue of individual differences. It is an empirical question whether individuals vary in their susceptibility to distraction, and also whether this

might be due to differences in the activity of automatic processes, or in the strength of an attenuator function in suppressing them. One of the aims of the present study is to begin in a rough way to explore these questions.

Psychophysical approaches share a bias toward a nomothetic attitude, that it is the regularity of a phenomenon that is interesting, and that variability is "error variance." The recent exceptions to this trend (e.g., Cooper, 1976; Cunningham, Cooper & Reaves, 1982) have concerned individual differences in visual comparison strategies, and have attempted only to distinguish two groups.

Since Darwin and Galton (Watson, 1978), however, an ideographic tradition has found variability among individuals intrinsically interesting, particularly in areas such as personality, intelligence, and development. Bateson (1972) notes that in the past hundred years evolutionary theory has come to see the heterogeneous species as the unit of natural selection, rather than the individual organism. The variability within a species thereby gains new importance: "In other words, potentiality and readiness for change is [sic] already built into the survival unit. The heterogeneity of the

wild population is already one-half of that trial-and-error system which is necessary for dealing with environment." (Bateson, 1972, p. 451)

Questions of variability in attention are not of casual interest only. "Attention deficit disorder" is currently the approved diagnostic term for what had previously been called childhood hyperactivity (DSM-III, 1980), and "impaired attention" has long been regarded as a major feature of schizophrenia (Silverman, 1964). The use of the term attention in such cases is often imprecise and global, and would perhaps benefit from a more specific and articulated theoretical framework for considering attention and distraction. At the same time, consideration of the implications of individual differences for adaptation promises to enrich the normative psychophysical view.

The Experiment

The present experiment used a modification of Jonides' (Note 2) procedure. An array of four letters was presented for 50 msec, and subjects were to identify with a speeded button-press whether the array contained

an "F" or "L." The nature of the preceding cues differed in several respects from those of Jonides. A single type of cue was used, a blink on the right or left. Two types of trials occurred: the target could appear on the same side as the cuing blink, or on the opposite side. At the start of each set of trials, subjects were told (a) that the target letter would be on the same side as the blink 100 percent of the time, (b) that it would be on the opposite side 100 percent of the time, or (c) that the blink would be random, that is, 50 percent on the same side, 50 percent on the opposite.

The central question of the study is, How do the automatic spatial attention system and voluntary processes interact? The design of the study is such that equivalent cue-stimulus combinations were presented in two situations, namely, when cue position was informative, and when it was not. Furthermore, when the cue was informative with respect to voluntary control -- that is, when it was possible to try to use the blink -- voluntary effort could be either in the same direction as the spatial attention system's pull, or in the opposing direction. In uninformative cue trials, voluntary effort consisted in the possibility of "blocking out" the peripheral blinks.

Of the many possible patterns of results, several are of special interest because they would be consistent with plausible accounts of the interrelation of the voluntary and automatic processes and with previous findings. They are discussed in terms of AOC analysis, described in a later section.

The first, the Ineffective Volition Model, hypothesizes that voluntary effort will have no beneficial effect, whether it parallels covert attention shifting or opposes it. There are two possible patterns. In Pattern 1, the AOC lines for informative and uninformative cue conditions will not differ from each other: this is the null hypothesis for voluntary effort. In Pattern 2, the informative cue AOC line will be a "shifted out" version of the uninformative cue line. This would mean that voluntary effort uniformly slowed down responses, and would be understandable with reference to Shiffrin and Schneider's (1977) description of controlled (i.e., voluntary) processing, as a time consuming, serial process.

The second, the Non-interacting Model, portrays the spatial attention system as independent of voluntary control: voluntary effort is incapable of adjusting the gain of the spatial attention system, either to increase

or attenuate its effect. It predicts that the AOC line for informative cues will be a "shifted in" version of the uninformative cue line, indicating that voluntary effort yields faster reactions, but is transparent to the spatial attention system.

The third, the Interacting Model, proposes that advance knowledge about the nature of cuing blinks could allow the automatic pull of spatial attention to be increased and/or attenuated. A volitional augmentation of spatial attention shifting would appear in the data as informative cue points moving farther apart on the AOC line, while an attenuation would appear as uninformative cue points moving closer together on the AOC line. It should be noted that the present study is capable only of detecting an interaction and not of identifying whether it is augmentation, attenuation, or both.

The other major thrust of the study is to explore the construct of covert attention distractibility, specifically with respect to whether the model which emerges appears, on the one hand, normative, and on the other hand, variable. The former is relevant to the first research question discussed above, i.e., the nature of the interaction of the automatic and voluntary processes. The latter is relevant to the question of how

much individuals vary, both in how closely they fit the model, and in the magnitude of effects within the model.

METHOD

Subjects

Sixteen female and six male undergraduate psychology students served as volunteer subjects, and received extra course credit for their participation. All reported normal or corrected-to-normal vision. The range of ages was 17 to 42 years, with all but one being between 17 and 20. Seven were left-handed and fifteen right-handed. Surprisingly, seven reported mixed hand/eye dominance. None of the subjects reported previous experience in psychophysical studies.

Apparatus

Stimuli were presented on a standard video monitor driven by an Apple II+ microcomputer, which also constructed and ordered the stimulus arrays, timed response latencies, and tabulated the data. Subjects sat approximately 109 cm from the monitor screen. On the desk-arm of the chair in which they sat were two pushbuttons, positioned to be operated with two fingers of the right hand. The two buttons were identified as "P" and "L" responses by a card attached to the desk top.

The computer program which timed the stimulus sequence and the subjects' responses incremented a counter at an interval of 965 usec, and consequently reported time values are approximately 3.5 percent too large.

Stimuli

All stimuli appeared white against a dark background. Stimulus letters and white blocks which served as central fixation target and the peripheral cuing blinks were all approximately 30 minutes of visual arc in size. The four letters were at the corners of an imaginary square surrounding the center, and were approximately 2.5 degrees from the fixation target. The cuing blinks appeared approximately 5.4 degrees to the right or left of the fixation target. The stimulus arrays were automatically constructed by the computer, which placed either an F or L in one corner of the display, then filled the other three positions with random letters (sampling without replacement). A total of sixteen different stimulus array patterns were used: the two target letters could appear in four different screen positions after a blink on either the left or right periphery.

As a result of the raster-type CRT display and the

short presentation period, letters in the array may have appeared to subjects as slightly degraded images. Since the raster must scan the screen twice (at approximately 17 msec per pass) to refresh every screen point, a stimulus letter would be represented in full resolution from approximately 15 to 30 msec out of a 50 msec availability. Temporal summation was assumed to functionally neutralize this variability of image formation. Even if some letter images appeared more degraded than others, however, the effect was randomly distributed across trials, since the raster cycling and letter availability were temporally independent, and no systematic bias in the results should have occurred.

Procedure

Each subject participated in a single experimental session of about one hour. After receiving basic information about hand and eye preference, vision, etc., the experimenter described the task briefly to subjects and obtained informed consent. The task was then described in more detail and demonstrated, and the outline of the session was given: stimulus presentations were grouped into blocks of sixteen, with four blocks constituting a set. Rest periods of about three to five

minutes separated the five sets; subjects could also rest between blocks, although none did so. Screening was then done in two steps. First, subjects were instructed to fixate on a central target and verbally identify on which side a peripheral blink occurred. This ensured that visual field deficits did not render cuing blinks unperceivable. To ensure that visual field deficits or acuity problems did not interfere with the letter identification task, a high accuracy criterion was used during the training period. (This also served as the experimental control over accuracy as a source of reaction time variability.) Subjects were told that it was more important to be accurate than to be fast. The percentage of accurate responses was given as feedback to subjects after sixteen-trial blocks, and if after four blocks the subject was not able to achieve consistently high accuracy, further exhortation and up to three extra blocks of practice were permitted.

After screening and practice, the instructions were rehearsed again (with emphasis on the importance of fixating on the center target and of responding accurately), and the procedure for the session described: three kinds of blocks of trials would occur, and would be announced beforehand by the experimenter. Within a

block, the cuing blinks (a) could appear every trial on the same side as the target letter in the array that followed; (b) could appear every trial on the opposite side; or (c) could bear no consistent relationship to target letter position, that is, half of the time it would appear on the same side, and half on the opposite side.

Figure 1 shows the sequence and presentation times for a single experimental trial. The central fixation target appeared on the screen, and a chirping sound from the computer signalled the beginning of the trial. About one second later a peripheral block appeared on the right or left for 100 msec, followed by the offset of fixation target and peripheral block and the onset of the array of four letters. The offset of the array after 50 msec and the onset of the fixation target marked the beginning of timing of the subject's reaction. Another chirp indicated that the subject's button press had been registered by the computer. After about a second, another trial automatically ensued.

Each set comprised two observations of each of 32 cells (sixteen stimulus patterns, as above, at two cuing conditions), grouped into four blocks of sixteen trials (one block each with same-side and opposite-side cues,

and two blocks with uninformative cues). Each subject completed five sets, yielding ten observations per cell. The sequence of block types for each set and across the five sets was determined with a modified Latin square procedure to control for order effect. Twelve different such protocols were constructed, and no more than two subjects followed the same protocol.

The Attention Operating Characteristic (AOC)

Although the attention operating characteristic (AOC) and the equivalent performance operating characteristic (POC) have been the subject of several theoretical discussions (Sperling & Melchner, 1978; Kinchla, 1980; Navon & Gopher, 1979), they have not yet been widely used, and are not universally known. This section will serve as a brief introduction for readers unfamiliar with the approach.

The AOC was developed as one solution to the problems of understanding, interpreting, and modeling the attentional phenomena underlying empirical data. The performance of dual tasks is represented by plotting performance at Task A against performance at Task B. A curve (the AOC) is fitted to the plotted points corresponding to different attentional manipulations

(e.g., "Task A is twice as important as Task B"; "The word 'cupcake' is three times as likely to be heard in your left ear as your right."), and that curve is assumed to describe the attentional selectivity which operates between the two tasks. Kinchla (1980) states that a single reservoir of attentional resources is expressly not an assumption of AOC analysis, but rather that many resources and structures must underly observed trade-off functions. Navon and Gopher (1979) go further and reject the use of the term "attention" as a general descriptor of selectivity. The term is retained here, however, since in the case of covert attention it is well specified and commonly used.

Kinchla (1980) points out that the "sources of information" which constitute the dual tasks can be variously designated, depending on the kind of analysis to be done. In the present study, the dual tasks are taken to be the simultaneous monitoring of right- and left-side screen positions for the occurrence of a target letter. It is assumed that if the two tasks are indeed competing with each other for limited (attentional) resources, then improved right-side monitoring will be at the expense of left-side monitoring, and vice versa. The use of AOC analysis here is aimed at seeing whether

different AOC functions are produced by informative-cue and uninformative-cue conditions, and whether peripheral blinks produce the same movement along the AOC function(s) (i.e., produce the same shifts of covert attention) in both conditions.

RESULTS AND DISCUSSION

To examine the effects on the sample as a whole of the four factors (informative or uninformative cue; blink on the same or opposite side as the target letter; position of the target letter; and identity of the target letter), a four-way analysis of variance with repeated measures was performed on the 32 cell means ($2 \times 2 \times 4 \times 2$) of the 22 subjects. The assumption of homogeneity of variance was tested and found not to be violated ($F_{\max}(31,21)=3.18, p>.05$). The results of the analysis of variance are summarized in Table 1. Of the four main effects, both of the effects of interest were significant at an alpha level of .01: uninformative cue conditions were faster than informative ($F(1,21)=15.0, p<.001$); and blinks on the same side produced faster reactions than opposite side blinks ($F(1,21)=25.1, p<.001$). In addition, a significant effect of letter ($F(1,21)=51.3, p<.001$) was found, whose interpretation was superceded by a significant interaction of position and letter ($F(3,63)=21.15, p<.001$).

Since the interacting terms were not of major interest, formal follow-up procedures were not used, but

TABLE 1
Summary Table for Four-way Analysis of Variance with
Repeated Measures (n=22) of Letter Identification
Reaction Times (in Milliseconds)

SOURCE	df	MEAN SQUARE	F
CUE	1	183890.4	14.96**
CUE x S	21	12289.9	
BLINK	1	142671.1	25.08**
BLINK x S	21	5688.2	
CB	1	5946.1	1.13
CB x S	21	5275.5	
POSITION	3	96180.8	2.63
POSITION x S	63	36502.1	
CP	3	3561.8	0.99
CP x S	63	3611.5	
BP	3	5429.2	0.68
BP x S	63	7935.8	
CBP	3	6106.5	1.37
CBP x S	63	4471.9	
LETTER	1	669124.4	51.34**
LETTER x S	21	13033.4	
CL	1	93.0	0.01
CL x S	21	7183.7	
BL	1	8.2	0.00
BL x S	21	4927.1	
CBL	1	3011.2	0.58
CBL x S	21	5158.9	
PL	3	188198.1	21.15**
PL x S	63	8896.3	
CPL	3	10472.0	3.06
CPL x S	63	3422.4	
BPL	3	8917.8	1.79
BPL x S	63	4986.7	
CBPL	3	10661.2	2.89
CBPL x S	63	3689.4	

* $P < .01$

** $\bar{P} < .001$

-

TABLE 2

Mean Reaction Times (in Milliseconds) for 22 Subjects

blink:	<u>INFORMATIVE CUE</u>				<u>UNINFORMATIVE CUE</u>			
	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>
tqt:	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>
1	528	573	585	636	497	486	547	494
2	657	719	774	689	643	646	739	596
3	971	1064	929	981	913	944	876	864
4	865	828	936	690	865	705	898	741
5	661	638	659	608	598	597	543	613
6	683	669	665	592	648	626	642	605
7	620	665	644	630	602	598	576	586
8	746	699	722	711	714	671	744	696
9	714	719	755	681	701	665	675	651
10	1024	1063	1085	1078	1049	1121	1155	1016
11	918	851	905	898	948	1004	977	851
12	785	761	811	795	767	798	678	707
13	888	834	950	936	802	890	800	754
14	672	706	730	701	645	691	672	658
15	848	814	928	840	813	913	805	696
16	665	678	650	682	616	693	668	624
17	668	751	748	692	686	675	741	724
18	742	720	695	721	771	732	848	674
19	601	605	698	561	577	586	691	565
20	494	572	521	579	496	546	494	540
21	593	686	582	664	575	619	568	614
22	578	614	614	527	555	570	609	557
MEAN	727	746	756	729	705	719	730	676

Figure 2. Conventional graphic representation of letter identification data. (a) Target on right side of display. (b) Target on left.

Figure 3. Attention Operating Characteristic (AOC) representation of letter identification data. Dotted lines represent the trade-off model described in the text.

informal follow-up showed that the letter "L" produced faster reaction times, and that this effect was specific to the right-hand screen positions.

Further analysis of the aggregate data utilized graphical representations as Attention Operating Characteristics (AOC), described in a previous section. Graphs were constructed using the subjects' cell means as listed in Table 2, that is, collapsed across letter and upper/lower target positions. Figure 2 shows in conventional graphical form that uninformative cue trials produced faster responses, and that a peripheral blink caused faster responses to target letters appearing on the same side of the display as the blink, whether or not the blink was an informative cue. Figure 3 presents the same information in AOC form, and leads to a slightly different reading of the results: the position of the blink shifts performance in favor of same-side targets even when the blink is not informative as to target position, and the cue-informative conditions are more difficult for subjects.

The difference is that in the AOC-inspired account, the pairs of points are assumed to lie along a line (i.e., the attention operating characteristic) which is characteristic of the simultaneous performance of the two

tasks; and attentional manipulations are assumed to "pull" performance in one direction or the other along the line. We have only two points for each operating characteristic here, and are thus restricted to very simple characterizations of the attentional trade-off function. Also, since the analysis of variance showed no significant interaction of cue with blink, the two lines in Figure 3 can be considered to be parallel.

Since left-handed subjects were required to press the response buttons with their non-preferred hand, it was expected that this disadvantage might lead to slower reactions. To assure that the pattern of their performance was not also affected, AOC graphs were prepared for both right- and left-handed groups. The unexpected finding that left-handed subjects performed somewhat faster and in closer conformity to the aggregate model than the right-handed group is evidence that handedness is not a confound in the data.

There are two reasons for assuming that the "true" slope of both lines is -1 . First, it defines a simple and parsimonious trade-off relationship which can be interpreted easily. Second, there are two pieces of evidence that this model fits the data well. The observed slopes of the two lines ($-.58$ and -1.72) are

relatively close to -1 , considering that the range of slopes is minus infinity to infinity. Also, when the best-fit lines with slopes of -1 are drawn for the two pairs of coordinates, the points lie quite close to the lines: informative and uninformative condition points lie 4.2 and 6.3 msec from their respective lines in AOC space. These values, called Distance Scores, are reported in Table 3, and their calculation demonstrated in Appendix A.

Analysis of individual subjects' performance was aimed at assessing how well individuals fit the AOC pattern seen in the sample as a whole, and at tentatively exploring whether the covert attention effect might plausibly be considered to reflect individual differences in visual distractibility.

Of the four derived measures given in Table 3, the two Distance Score terms have already been described. They correspond to the amount of deviation of the observed points in the AOC graph from the best fitting line with slope of -1 , and are therefore indicators of individuals' similarity to the pattern identified in the aggregate data. If the aggregate pattern is a valid model for the trade-off functions of individual subjects, then the distribution of Distance Scores should show most

of the sample with small error values, with increasingly large errors being decreasingly frequent. Figure 4 shows that the two Distance Score measures (for informative- and uninformative-cue conditions) do in fact show this pattern, with about half the sample deviating less than 15 msec.

It appears, then, that the pattern seen in the aggregate sample is a reasonably good representation of individuals' performance. This pattern may be interpreted as follows: The attempt to capitalize on the informativeness of cues was (a) costly in time, consistent with relatively slow, nonautomatic controlled processing, and (b) shows no evidence of altering the effect of the spatial attention system. In other words, the pull of the spatial attention system was not able to be either "turned up" or "turned down." This corresponds to the Ineffective Volition Model, Pattern 2, as elaborated in the Introduction above.

The third derived measure shown in Table 3 is the distance between the two (parallel) best fit lines. This value represents the measured difference in difficulty between the informative- and uninformative-cue tasks, and its calculation is demonstrated in Appendix A. Nineteen of twenty-two subjects show a positive difference,

TABLE 3
Descriptive Statistics and Derived Measures (n=22)

	OVERALL	STANDARD	ACCURACY	DERIVED MEASURES*			
	MEAN	DEVIATION	(PERCENT)	1	2	3	4
1	531	93	95	42.4	20.5	105	50
2	683	165	98	30.7	16.2	76	108
3	943	209	98	44.1	41.3	123	88
4	816	185	88	23.6	24.4	38	48
5	615	116	83	11.3	13.7	76	57
6	641	166	95	33.5	9.5	31	21
7	615	139	86	3.8	13.4	69	28
8	713	116	99	4.2	19.4	18	39
9	695	169	87	1.0	14.1	62	29
10	1074	268	95	26.8	0.3	-32	149
11	919	236	91	12.0	43.8	-73	155
12	763	151	97	21.2	63.6	71	127
13	857	186	97	57.9	48.7	128	136
14	685	121	99	18.7	2.1	50	42
15	832	255	91	37.4	79.5	71	217
16	660	140	93	3.8	6.0	26	86
17	711	149	84	7.4	36.7	11	73
18	738	219	97	16.2	6.7	-51	96
19	611	121	99	18.7	32.8	16	115
20	530	105	92	12.0	2.8	31	6
21	613	130	99	11.6	4.2	52	8
22	578	128	98	18.0	14.5	14	55
	723		94	4.2	6.3	45	49

*Derived measures:

- 1 Distance Score, informative cue - distance in AOC space between informative cue points and the line with slope of -1 best fitting those points
 - 2 Distance Score, uninformative cue - as above, for uninformative cue points
 - 3 Cuing effect - distance in AOC space between the two best fit lines (see 1 and 2)
 - 4 Covert attention effect - distance in AOC space between uninformative cue points
- (Calculation of derived measures shown in Appendix A)

Note: The values in the bottom row are taken from the aggregate AOC, and are not means. See Appendix A.

Figure 4. Distributions of Distance Score measures. (a) Informative cue conditions. (b) Uninformative cue conditions.

indicating greater difficulty for the informative-cue conditions. Although the performance of the three other subjects requires comment, the substantial agreement within the sample constitutes additional support for the adequacy of the aggregate pattern as a normative model.

During the experiment, between blocks of trials, some subjects remarked that the "informative" cues seemed not to be helpful, and that they had adopted the strategy of ignoring the cuing blinks for all trials. Although it was not possible to compare self-report with performance in a systematic way (because the remarks were spontaneously offered, not consistently solicited), of the six subjects who stated unambiguously that they ignored all blinks, only one (subject 22) produced AOC points which appeared visually to lie along a single line. Still, even though the reported differences in strategy could not be detected in subjects' actual performance, the assumption that all subjects used the same strategy in utilizing cue information must be considered weakened. The distance between AOC lines for each subject, then, might reflect individual differences in processing speed, or differences in processing strategies, or both. The three subjects who showed greater difficulty for uninformative cue reactions, in

particular, are suspect of having used a different strategy. This is supported by the observation that only one subject showed a higher standard deviation of reaction times over all trials than these three (see Table 3).

The third derived measure, then, would not appear to be a good choice for exploration of individual differences effects. The same argument would apply to the distance separating the informative-cue points in AOC space. This value was not calculated, and does not appear in Table 3. The distance between uninformative-cue points, however, escapes these particular objections, and should constitute an estimate of the magnitude of the covert attention effect for a subject. Its calculation is demonstrated in Appendix A. As Table 3 shows, the range of estimated covert attention effects (derived measure 4) is rather large (6-217 msec), with the value for the aggregate sample (49 msec) indicating a positively skewed distribution. The large range suggests that real individual differences may exist. Several transformations were applied to the data, and a square root transform was found to produce a distribution which appeared normal, and to place the aggregate value near the mid-range. Figure 5 shows the

distribution of the square root transform of the data.

Subjects' accuracy rates (see Table 3) were not as high or as uniform as those often reported for similar experiments in which accuracy is not included as a manipulated or outcome variable (e.g., Jonides, Note 2). A positive consequence of this variability in error rates is that relationships can be explored between subjects' accuracy and other aspects of their performance. On the negative side it is possible that, on one hand, the inclusion of reaction times from error trials would bias the data, while on the other hand, their exclusion might seriously reduce the observations in some cells. As a check on the biasing effect of error trials, the data of the two lowest-accuracy subjects (numbers 5 and 17) were investigated in detail. In both cases, no pattern could be found in the distribution of error trials, and AOC graphs (described above) representing only accurate response trials showed no meaningful differences in pattern from graphs representing all trials (i.e., both accurate and inaccurate). At least on a gross level, therefore, error trials were indistinguishable from equivalent trials in which the target letter was correctly identified, and on the strength of this evidence subsequent analysis used the total data set,

with error trials included.

Finally, bivariate correlations were computed to explore relationships within the data, specifically to probe the character of the covert attention effect (derived measure number 4), and of accuracy rates. It should be emphasized that correlations in a sample as small as the present one are unstable, and only the roughest sorts of conclusions are justified. Even these must be considered very tentative.

Accuracy correlates low with mean reaction time ($r=.05$), indicating that subjects with faster reactions were generally not more prone to errors in letter identification. This is not necessarily inconsistent with our stated assumption that errors were the result of rushed responses, since subjects may differ in the degree to which they can speed their responses without losing accuracy. This notion that accuracy rate reflects a decision criterion, rather than some such characteristic as processing efficiency or ability to focus on the task, is further supported by the low correlations of accuracy with standard deviation of reaction times ($r=-.04$) and with covert attention effect ($r=.10$).

Standard deviation and covert attention effect, on the other hand, correlate highly ($r=.71$) with each other.

If we assume that overall variance is typically inflated by error variance, and if we consider that the covert attention effect is, loosely speaking, "error variance" in the sense that the cuing blinks were irrelevant to the identification task in the irrelevant-cue condition, then two possibilities present themselves. First, the correlation could reflect the greater variability consequent to the covert attention effect itself: in other words, subjects who show a larger covert attention effect would ipso facto also show larger variance. Second, the degree to which subjects are susceptible to covert attention shifting might be associated with a general susceptibility to distracting effects. The distance score measures should, in principle, reflect the non-covert attention extraneous effects, assuming that the trade-off model developed above is valid. These might be expected to include other distraction effects: for example, a subject might be distracted by an automatic tendency to move covert attention rightward, perhaps as a result of reading habits. If there is a general distractibility, then Distance Scores should correlate more strongly with covert attention effects than with standard deviation. And in fact, Distance Score correlates highly with covert attention effect

($r=.70$) and moderately with standard deviation ($r=.37$). The concept of a general distractibility, therefore, appears to be a plausible one. It must be re-emphasized, however, that the power of the foregoing correlational analysis is very low, and the analysis is furthermore suspect of being tainted by nonindependence of the measures from each other.

CONCLUSION

The present study has two chief findings. First, for the stimuli, intervals and tasks used, rapid peripheral blinks appeared to exert an irresistible "pull" on subjects' covert attention. Second, the opportunity to make strategic use of the blinks as cues resulted in reaction times which were uniformly longer, not shorter, than equivalent trials with uninformative blinks. No interaction was found between the speeding effect of the blinks and the slowing effect of informative cuing: the pull of the spatial attention system appears to be temporally or functionally prior to the (presumed) voluntary processes of strategy and judgement.

Shiffrin and Schneider's (1977) paradigm provides a useful framework for these findings. The sharp contrast between the fast, automatic functioning of the spatial attention system and the slowing effect of voluntary, strategic processing closely resembles their account of automatic and controlled human information processing. A notable divergence, however, is between Shiffrin and Schneider's emphasis on (over-)learned nodal activation

sequences and Breitmeyer and Ganz's (1976) evidence for "wired in" spatial information processing. Future research might address the question of the developmental course of the spatial attention system.

A secondary finding is that individual differences may exist in the spatial attention system's functioning. An index of covert attention effect strength was derived from the AOC representation of the data, and the range was seen to be quite large. Previous investigators have tended to report only aggregate results, in cost/benefit form, and to use few subjects. Future investigations might profitably explore the character and significance of individual differences in covert attention.

Finally, Shaw (1980) has raised an important issue which, in a general way, is addressed by the findings of the present study. She points out the difficulty and importance of distinguishing the effects of attentional shifts, which affect the quality of information processing at one location at the expense of another, from the effects of strategic changes, in which information (regardless of its quality) is differentially weighted by the subject as a result of "attentional" manipulations. Shaw (1980) seems not to believe in non-capacity limited automatic encoding, as discussed by

Shiffrin and Schneider (1977), and her own approach to distinguishing attention from strategy reflects that attitude. Without arguing with Shaw's assumptions, we wish to point out that the present study seems to have driven a wedge between attention and strategy, with automatic attention shifts resulting in faster responses, and strategic effort resulting in slower responses. The same pattern might not obtain with different intervals, particularly longer ones. Moreover, other tasks may mask rapid attentional effects with slower controlled processes required in the response. It would seem that in order to settle the controversy, systematic investigation is needed to establish the construct validity of non-capacity limited automatic processes, and to specify the conditions under which they are and are not demonstrable.

APPENDIX A

Calculation of Derived Measures

The derived measures are based on the AOC graph for a subject of for the aggregate sample (refer to Figure 3). In each case two pairs of points are plotted, representing performance for informative and uninformative cue conditions; and the derived measures describe patterns in the data, and the "goodness of fit" of a trade-off function suggested by the aggregate data. Calculations will be demonstrated using the data for Subject 1 (see Table 2).

Before the derived measures themselves can be calculated, the lines representing the trade-off model must be fitted to the pairs of points. The model specifies lines with a slope of -1. Any line in two dimensional space is completely described by an equation of the form

$$Y=AX+B$$

in which A is the slope and B is the Y intercept. Since the slope here is known, only the Y intercepts must be specified. One method of finding the best fit line with a slope of -1 is to find the Y intercepts of the lines with slopes of -1 which pass through each of the two points, and take their mean. Rewriting the equation,

$$B=Y-AX$$

For informative cue points, therefore, the Y intercept of the best fit line may be found thus:

$$\begin{aligned} B &= 573 - (-1) (538) = 1101 \\ B' &= 636 - (-1) (585) = 1221 \\ B(\text{best fit}) &= (1101 + 1221) / 2 = 1161 \end{aligned}$$

Likewise for uninformative cue points:

$$\begin{aligned} B &= 486 - (-1) (497) = 983 \\ B' &= 494 - (-1) (547) = 1041 \\ B(\text{best fit}) &= (983 + 1041) / 2 = 1012 \end{aligned}$$

Derived Measures 1 and 2: Distance Scores

The first two derived measures describe the "goodness of fit" of the two fitted trade-off lines. They constitute the shortest distance of the plotted points from their respective lines. (This contrasts with the least-squares approach usually used in bivariate analysis.) The three Y intercepts for each condition found above allow the simple calculation of the vertical distance between a line and either of its observed points:

$$\begin{aligned} D(\text{informative}) &= 1221 - 1161 \text{ or } 1161 - 1101 = 60 \\ D(\text{uninformative}) &= 1041 - 1012 \text{ or } 1012 - 983 = 29 \end{aligned}$$

The vertical distance can be shown to represent the hypotenuse of an isocetes right triangle whose short side is the desired goodness of fit measure. It is calculated thus:

$$\begin{aligned} \text{Distance score (informative)} &= 60 / \sqrt{2} = 42.4 \\ \text{Distance score (uninformative)} &= 29 / \sqrt{2} = 20.5 \end{aligned}$$

Derived Measure 3: Cuing Effect

The third derived measure describes the magnitude of the effect that informative cuing had on performance. It assumes that the trade-off function of the best fit lines represents the true values underlying the observed points, and is described graphically as the distance separating the two (parallel) best fit lines. The calculation follows that of Derived Measures 1 and 2 above:

$$D = 1161 - 1012 = 149$$

$$\text{Cuing effect} = 149 / \sqrt{2} = 105.3$$

Derived Measure 4: Covert Attention Effect

The fourth derived measure describes the effect within the uninformative cue condition of a peripheral blink occurring on the right or left. Graphically it is the distance between the uninformative cue points. It uses the simple formula for the distance of points in two dimensional space:

$$D = \sqrt{(486-494)^2 + (497-547)^2} = 50.6$$

Note: For convenience sake, all final results reported in the tables were rounded downward.

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