



# Relating the mechanisms of orienting and alerting

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**Abstract**—Cues provide two types of information: information about where the target will occur and when it will occur. We hypothesized two underlying processes related to cues, orienting (to location) and alerting. Using a covert orienting task under different conditions of alertness, we found evidence of independence between orienting and alerting (Experiments 3–4). The alerting mechanism is spatially broad and seems common for auditory and visual input (Experiments 1–2). In Experiment 1, visual cues at four locations occur simultaneously to prevent orienting; response facilitation was the same for targets occurring near or far from a cue. In Experiment 2, adding a visual alerting signal to an auditory signal provided no additional benefit. In Experiment 3, an auditory signal was used to modulate the alertness level during a covert orienting task. Orienting, measured by the validity effect, was independent of the level of alertness in this simple reaction task. Experiment 4 extended those results to a choice task. These studies indicate separate mechanisms of alerting and orienting. The global mode of alertness is consistent with the broad axonal distribution of the noradrenergic system. In contrast, human and animal data suggest that the orienting mechanism may be modulated by the basal forebrain cholinergic system. © 1997 Elsevier Science Ltd. All rights reserved.

**Key Words:** attention; alertness; orienting; cueing; transmitter functions; warning signal effects.

## Relating the mechanisms of orienting and alerting

Orienting is the selective allocation of attention to a particular part of the visual field [23]. Covert orienting of attention can be spatially quite precise even to a single letter within a word [12]. Orienting to a visual location affects target processing at that location by improving reaction time, reducing threshold, and increasing blood flow and electrical activity in the relevant parts of the visual system [26]. There is good evidence that a portion of the control mechanism for orienting to visual locations lies in the parietal lobe. Lesions of the parietal lobe produce an inability to disengage a current location of orienting in order to shift its location in the contralateral direction [24].

Alerting involves a change in the internal state that follows the presentation of a warning signal. A warning signal tells the subject that a target will occur but usually provides little or no information about where it will be [23, 26]. Orienting and alerting may be carried out by separate internal mechanisms, one operating with spatial precision at a selected visual area and the other operating

broadly to influence signal to noise ratio over the visual field. While mechanisms of orienting and alerting may be separate in some senses, it is clear that most stimuli can influence both kinds of operations. This idea is very similar to the arousal and cue function of stimuli suggested by D.O. Hebb [9]. For example, a cue in a covert orienting experiment is thought to orient the organism to the location of the cue and to change the level of alertness.

The first experiment develops a method to produce alerting in the absence of orienting. Cues at four locations occur simultaneously so they provide no information about where to orient. Reaction time is compared for subsequent targets either near or far from the alerting cue. Facilitation of near targets under these conditions would suggest that there is a spatially precise effect of alerting independent of orienting. In contrast, lack of differential effect of near targets would indicate the alerting effect is homogeneous across the visual field.

The second experiment examines whether a visual warning signal uses the same alerting mechanism as an auditory warning signal. We assume that the auditory signal will act via alerting to produce a uniform effect in the visual field. If visual and auditory cues use the same mechanism, combining them should produce no improvement in performance over the more effective of the two.

The third experiment examines whether a single cue

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that orients the subject toward a visual location will operate differently depending upon the level of alertness at the time it is presented. Does orienting occur more rapidly during high states of alertness? The fourth experiment extends these results to a condition in which the target requires a choice response. Taken as a whole, these studies seek to determine to what extent alerting and orienting can be seen as separate mechanisms and how they combine to influence the speed of responding to targets.

## Experiment 1

In Experiment 1, we measured the spatial properties of visual warning signals. Cues at four locations occurred simultaneously and were not predictive of the target location. Subjects could not orient endogenously because the warning signal was uninformative about the target location. Exogenous orienting was not possible either, because the display included symmetric cues simultaneously at four locations.

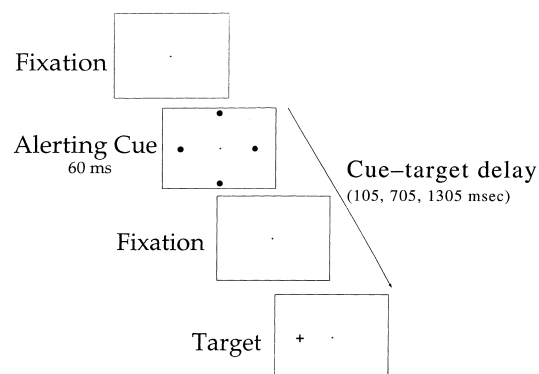
The target could occur at a location near one of the cues, or far from any cue. If alerting produced a uniform benefit across the visual field, responses to targets occurring near a cue should not differ from responses to targets distant from the cues. In contrast, if there was a mechanism of alerting based on the spatial aspect of the cue, performance should improve only when the target appeared near the cue. Finally, a combination of a spatially precise and a spatially broad mechanism would benefit all the visual field, but it would benefit most areas near the cues.

## Method

**Subjects.** Thirteen undergraduates from the University of Oregon participated in the experiment and were paid \$5 for their participation in a single session lasting approximately 40 min. All were right-handed and had normal or corrected to normal vision.

**Apparatus and materials.** The stimuli were displayed on a Macintosh II 24 × 17.5 cm monitor. The laboratory was dimly illuminated. Viewing distance was maintained at 50 cm by use of a chin rest. A response was made by pressing a key with the right index finger.

The visual display is shown in Fig. 1. Four white circles constituted the alerting cues. Circles were equidistant from the fixation point. The center of each circle was 7.8° of visual angle away from fixation. The set of four circles was displayed in a square or a diamond configuration. Circle diameter was 0.8°. Each circle was as bright as the target. The stimulus used as a target was a white cross 0.8° in size. The target was always displayed at an eccentricity of 7.0°. There were eight possible locations where the target was presented. The spatial layout of the display ensured that the cross was presented either near to one of the alerting cues, or far from all the alerting cues. In the near condition the cross appeared adjacent to one of the circles, the distance from the center of the circle to center of the cross being 0.8°. In the distant condition, the cross appeared relatively distant from any circle, the distance from the center of a circle to center of the cross being 5.7°.



## Major conditions

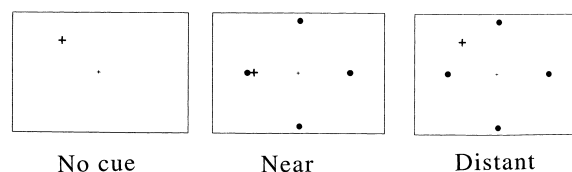


Fig. 1. Examples of the display used in Experiment 1. After a variable ITI (600–1000 msec), a set of four equidistant circles (warning signal) flashes for 60 msec. Following the warning signal after a variable delay (105, 705, 1305 msec), a target is displayed. The target can be displayed at eight positions around an imaginary clock. *Near* refers to trials where the target appears adjacent to one of the circles. *Distant* refers to trials where the target appears spatially distant from all circles. *No Cue* trials are control trials in which the warning signal is not displayed. Target and cue never overlap in time; they are depicted in a same figure for illustrative purposes only.

**Design.** A within-subject design was used, the dependent variable being reaction time (RT). In a  $3 \times 3 \times 8$  factorial design, cue-to-target delay (105, 705, 1305 msec) was crossed with cue-to-target spatial relation (no cue, near, distant) and target location (upper, upper-right, right, lower-right, bottom, lower-left, left, upper-left). The design allowed 10 identical trials for each of the 72 conditions. The spatial layout of the display allowed the alerting cue to have a square or a diamond configuration. The square or diamond configuration of the alerting cue was determined by two other factors: the cue-to-target spatial relation and the target location. Given that the pattern of the alerting cue was determined by two other factors, it was not included in the design as a separate factor.

To study the spatial properties of the alerting effect, the most important factor to be analyzed was the cue-to-target spatial relation; this factor had three conditions: (1) near: the target appeared adjacent to the alerting cue. It assessed both nearby and distant alerting effects; (2) distant: the target appeared spatially distant from the alerting cue. It assessed spatially homogeneous alerting effect; (3) no-cue: the target appeared without a prior alerting cue. It served as a control condition to determine the alerting effect of the cue.

**Procedure.** There were 792 trials per subject, randomly distributed in four blocks. A plus sign in the center of the screen, indicating the fixation point, remained through the whole block. In one-third of the trials a target was presented without warning signal; in two-thirds of the trials, the warning signal preceded the target. Trials with warning signal have the following sequence: after a random delay of 600–1000 msec, the warning signal flashed for 60 msec. Following the warning signal after a variable delay (105, 705, 1305 msec), a target was displayed (see Fig. 1). After the subject's response a new trial began

automatically. If the subject did not press the key, the target remained for 1,500 msec, after which a new trial began. Anticipatory responses were followed by a tone signal which informed the subjects about the error. Trials without warning signal have the same sequence, but no warning signal was flashed.

Ten percent of trials were catch trials in which no target followed the alerting cues. The purpose of the catch trials was to minimize anticipatory responses. As expected, subjects seldom made a response in catch trials. Therefore, no data was collected from these trials. The subjects were given written instructions describing the task. The instructions emphasized the importance of maintaining fixation on the plus sign in the center of the screen. Subjects were instructed to press the response key as quickly as possible, while avoiding making anticipatory responses. Subjects were tested individually. Each subject completed one practice block of 40 trials in the presence of the experimenter, and four test blocks of 198 trials each, in the absence of the experimenter. Between blocks, subjects were allowed to rest for approximately 2 min.

## Results

The mean RTs for each condition were calculated for each subject. All RTs less than 100 msec or greater than 1000 msec were excluded. They represented 2.5% of trials, mostly anticipatory responses, uniformly distributed across conditions. The alerting cue configuration (diamond, square) was not included as a factor after a preliminary analysis had shown no significant effects. Mean RTs were analyzed in a series of planned comparisons using repeated measures analysis of variance (ANOVA).

Figure 2 shows the RT as a function of cue-to-target

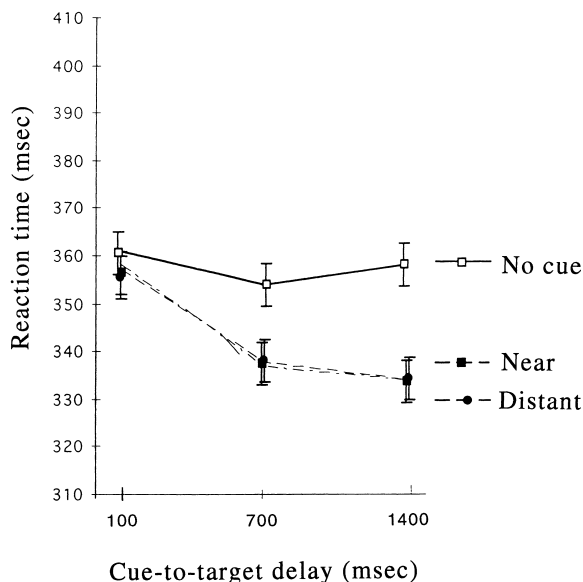


Fig. 2. Mean RTs as a function of cue-to-target spatial relation and cue-to-target delay for Experiment 1. *No Cue* denotes trials in which no cue was displayed. *Near* denotes trials in which the target occurred adjacent to one of the cues. *Distant* denotes trials in which the target occurred distant from any cue. RTs are plotted against cue-to-target delays, although in *No Cue* trials there was no cue denoting the onset. Vertical bars represent standard errors of the mean.

delay and cue-to-target spatial relation. Response was faster in cued trials ( $M = 343$  msec) than in uncued trials ( $M = 359$  msec), [ $F(1,24) = 19.5$ ,  $P < 0.0002$ ], revealing that target detection was sensitive to changes in alertness. In contrast, no significant difference was found between near and distant conditions, [ $F(1,24) = 0.05$ ,  $P < 0.82$ ], indicating that the alerting effect was not affected by the cue-to-target distance. The near condition, in which the target appeared adjacent to the cue, assessed both spatial and non-spatial alerting effects; the distant condition assessed non-spatial alerting effect only. The results suggest that the alerting effect is homogeneous across the visual field tested.

A different approach to the spatial properties of alerting is to examine the visual field of the target. To do this the eight target locations were grouped into right visual field, vertical meridian, and left visual field. There was a significantly larger alerting effect in the left visual field ( $M = 18.1$  msec) than in the right visual field ( $M = 9$  msec), [ $F(1,48) = 7.68$ ,  $P < 0.008$ ]. However, this effect might have been related to the fact that all subjects responded with the right hand.

Finally, we investigated horizontal hemifield asymmetries. Target locations were grouped into upper visual field, horizontal equator, and lower visual field. Upper visual field was slower ( $M = 351$  msec) than lower visual field ( $M = 346$  msec), [ $F(1,24) = 10.8$ ,  $P < 0.003$ ], but there was no interaction between alertness and horizontal visual hemifield, [ $F(1,48) = 0.35$ ,  $P < 0.55$ ]. A lower visual field superiority without evidence for a differential effect of the alerting cue is consistent with previous reports [27].

## Discussion

In Experiment 1 we attempted to design a visual cue that had an alerting effect, and did not evoke an orienting response. An overall alerting effect was found, suggesting that the experiment was sensitive to changes in alertness. The responses to near and distant targets were almost identical, indicating that alertness was homogeneous.

It is possible that the warning cue benefits not only by alerting but also by specifying a time of response. However, the use of variable cue-target delays minimizes the contribution of temporal information. Moreover, in previous studies a strong alerting effect was found even when a non-aging foreperiod was used [39]. Therefore, a reduction of temporal uncertainty cannot be the only explanation for the warning cue benefit.

It remains possible that methodological limitations prevented observation of a spatial alerting effect. For example, masking effects are dependent on spatial proximity between masking stimulus (i.e. cue) and target. Other variables that affect masking are the duration and intensity of the target and cue [31]. To minimize the masking effect the target was made very salient and the room was not very dim. Also, the target was presented adjacent to the cue, instead of overlapping it. The alerting

cue was designed to be as bright and large as the target, because it was assumed that luminance was an important physical property that could modulate the alerting effect. However, this luminance might have had a detrimental effect in contributing to masking. Forward masking in the shortest delay condition is likely, but not in the long intervals.

A second methodological issue is the one of eccentricity. It is possible that a display with a different eccentricity would have revealed a spatial alerting effect. Ideally, one would like to have target and cue within the same receptive field in the close condition and in different receptive fields in the distant condition. It is more likely for cue and target to be within the same receptive field when they are presented to peripheral vision, because receptive fields are larger in the periphery than in the central visual field [36].

The final methodological concern is whether subjects used a specific strategy, by always orienting attention to the same part of the visual field. This is unlikely because the cue was uninformative about the future location of the target. Furthermore, the instructions emphasized the importance of maintaining fixation on the plus sign in the center of the screen.

In summary, Experiment 1 strongly indicates an alerting effect based in the cue-to-target temporal relation, independent of their spatial relation.

## Experiment 2

Experiment 2 was designed to test whether visual and auditory warning signals use the same alerting mechanism. We assumed that auditory warning signals would produce an alerting effect homogeneous across the visual field, and we tested the hypothesis that visual warning signals acted exclusively in this fashion too. Our strategy was to manipulate non-spatial alertness up by using an auditory warning signal, and to study the effectiveness of a visual alerting cue in those conditions. If the visual cues had only a global alerting effect, they should be ineffective if the auditory cue had already produced a maximal global alerting. More specifically, we tested the hypothesis that adding a visual cue to an auditory (non-spatial) cue does not provide additional benefit in RT.

## Method

**Subjects.** Twelve undergraduates from the University of Oregon participated in the experiment and were paid \$5 for their participation in a single session lasting approximately 40 min. All were right-handed and had normal or corrected to normal vision. None of the subjects had participated in the first experiment.

**Apparatus and materials.** The visual display was identical to Experiment 1. The warning signal was played through the Macintosh's internal speaker at a sound pressure level of 50.8–53.3 dB(A), measured at the subject's head.

**Design and procedure.** A within-subject design was used. In a

$4 \times 3 \times 4$  factorial design, four cue conditions (no cue, auditory, visual, both) were crossed with three stimulus onset asynchronies (105, 405, 705 msec) and four target locations (upper, lower, right, left). For each of these 48 possible conditions there were 20 identical trials, randomly distributed. The auditory cue was displayed for 15 msec, immediately before the beginning of the visual cue. The subjects completed 960 real trials and 96 catch trials distributed in four blocks.

Besides the existence of an auditory cue, Experiment 4 differed from Experiment 1 in several respects. First, only four target locations were used, with the target always occurring near to an alerting visual cue. Second, cue-to-target delays were shorter than in Experiment 1 (105, 405, and 705 msec). The replacement of the long delay of Experiment 1 (1305 msec) by a 405 msec delay, was an attempt to study early changes in more detail. Third, Experiment 2 had more trials (960) than Experiment 1 (720), although the total time of a session remained roughly equal (40 min). Finally, the visual cue was displayed only in the diamond configuration, after preliminary analysis in Experiment 1 had shown no effect due to the cue configuration (diamond, square).

## Results

The mean RTs for each condition were calculated for each subject. All RTs less than 100 msec or greater than 1000 msec were excluded. Anticipatory responses occurred in 3.9% of the trials, mostly in trials with visual cue. Data were cast into a three-way within-subjects ANOVA (Type of Cue  $\times$  Delay  $\times$  Target Location), followed by Tukey *post-hoc* tests.

A statistical analysis of the overall data showed significant effects of type of cue, [ $F(3,33) = 46.3$ ,  $P < 0.0001$ ], of cue-to-target delay, [ $F(2,22) = 7.7$ ,  $P < 0.003$ ], and of the interaction of type of cue with cue-to-target delay, [ $F(6,66) = 2.6$ ,  $P < 0.02$ ].

Figure 3 shows RTs for each of the four types of cue, for each of the cue-to-target delays. At all the delays there was a visual alerting effect ( $P < 0.05$ ), RTs being faster in trials with visual cue than in trials without cue. The auditory alerting effect also was present at all delays ( $P < 0.01$ ), RTs being faster in trials with auditory signal than in trials without signal. Although both auditory and visual cues had alerting effects, the auditory cue was always more effective than the visual cue ( $P < 0.01$ ). The auditory alerting effect developed very fast and remained very stable, as evidenced by a lack of interaction between auditory cue and cue-to-target delay. In contrast, the visual alerting effect was not fully developed until the 400-msec delay ( $P < 0.05$ ), replicating results found in Experiment 1.

The main question of the experiment was whether the visual alerting effect would further contribute to the auditory alerting effect. Not only did the visual cue not increase the auditory alerting effects, but at the 105-msec delay the auditory cue was more beneficial when displayed alone than when combined with the visual cue ( $P < 0.01$ ). Finally, the alerting visual field asymmetry found in Experiment 1 was not replicated in this experiment, [ $F(9,99) = 0.87$ ,  $P < 0.55$ ].

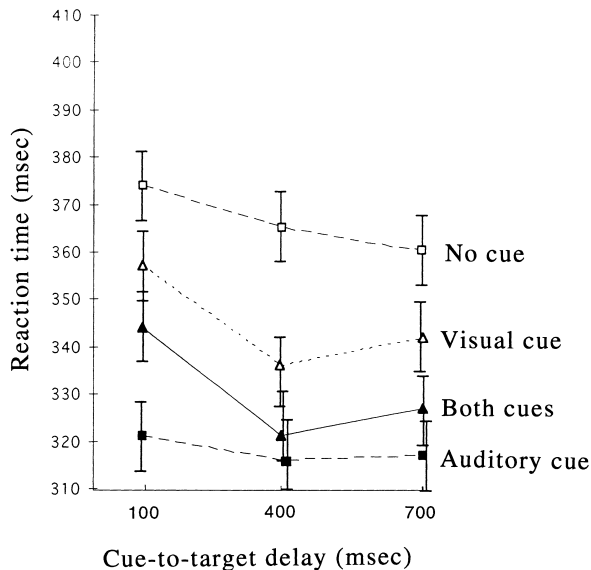


Fig. 3. Mean RTs as a function of type of cue and cue-to-target delay for Experiment 2. *No Cue* denotes that neither auditory nor visual cue was displayed. *Auditory Cue* denotes that only auditory cue was displayed. *Visual Cue* denotes that only visual cue was displayed. *Both* denotes that both auditory and visual cue were displayed. RTs are plotted against cue-to-target delays, although in *No Cue* trials there was no cue denoting the onset. Vertical bars represent standard errors of the mean.

### Discussion

Results in Experiment 2 supported a common mechanism for visual and auditory alertness. A visual cue benefited when displayed alone, but it was never beneficial when displayed together with an auditory cue. If the visual cue had acted through a modality specific mechanism, adding a visual cue to an auditory cue should have improved performance. Because the visual cue did not provide an extra benefit, we conclude that the visual cue acted upon the same mechanism as the auditory cue. Under the assumption that auditory alertness is homogeneous across the visual field, Experiment 2 favors a non-spatial mechanism of visual alerting.

Adding an auditory cue to the visual cue improved RT over having a visual cue alone, consistent with previous literature showing that auditory cues have a larger alerting effect than visual cues [22]. However, this does not explain why adding a visual cue to the auditory cue leads to slower RT than having an auditory cue alone. The cost of adding a visual cue to the warning cue was maximum at the short cue-to-target delay, so forward masking is a possibility. Alternatively, the presence of a visual cue may have decreased the auditory effect by increasing the difficulty of the task. When a visual cue was displayed, the subject had to identify the cue as such, without mistaking it for a target. If the target occurred briefly after the visual cue, subjects might have been in an attentional blink, due to cue identification. This explanation is further supported by the relatively large number of anticipatory responses after presentation of a visual cue.

Presumably, in those trials subjects mistook the cue for a target.

### Experiment 3

Experiments 1 and 2 showed that visual and auditory signals act upon a common alerting system which is homogeneous across the visual field. Posner [23] argued that alerting influenced the speed at which orienting to information about the stimulus could occur, but did not influence the rate of buildup of information about stimulus identity. His evidence was that warning signals improved speed but reduced accuracy. It was as though the organism was responding to a lower quality of information. In Experiment 3 we studied the influence of the alerting system on orienting more directly. We used a covert orienting task under increasing levels of alertness. We asked whether high levels of alerting facilitate orienting. Three different levels of alertness were probed by displaying the orienting cue alone, together with an auditory cue, or 400 msec following the auditory cue.

A second goal of this experiment was to replicate the interaction found in Experiment 2 between visual alerting effect and auditory alerting effect. If visual and auditory cues act upon a common alerting system, once alerting is established visual cues should have no alerting effect. Thus, under ceiling levels of alertness, an orienting cue will have a pure spatial effect.

The visual alerting effect was estimated by subtracting trials with invalid cue from trials with no visual cue. The spatial effect of the orienting cue was estimated by the validity effect. If the spatial benefit is independent of alertness, the validity effect should remain invariant across different levels of alertness. In contrast, if alertness facilitates disengagement from an invalid location the validity effect will be smallest during high states of alertness.

### Method

**Subjects.** Twelve undergraduates from the University of Oregon participated in the study. Each received \$5 for her participation in a single session lasting approximately 40 min. All subjects were right-handed and had normal or corrected to normal vision. None of the subjects had participated in the previous experiments.

**Apparatus and materials.** The auditory stimulus was identical to that used in Experiment 2. The visual stimulus was identical to Experiment 2, except that the visual cue was one circle instead of the set of four circles used in Experiment 2.

**Design and procedure.** In a  $2 \times 3 \times 2 \times 4$  factorial design, auditory alerting cue (present, absent) was crossed with visual cue (no cue, valid, invalid), two cue-to-target delays (105, 405 msec) and four target locations (upper, lower, right, left). The design allowed 16 identical trials for each valid condition, 4 identical trials for each invalid condition, and 20 identical trials for each condition without visual cue. Experiment 3 differed from Experiment 2 in the following respects. First, there were not four but one visual cue, which predicted target location with an

80/20 probability (i.e. orienting cue); in each trial, the orienting cue remained until occurrence of the target. Second, there were only two cue-to-target delays (105, 405 msec). Third, we added a new type of trial, in which the auditory cue preceded the visual cue by 400 msec (trials with cue-to-cue asynchrony). Finally, there were no catch trials.

Five major cue displays were included in this experiment, each occurring in 160 trials. A trial could have (1) no cue, (2) auditory cue, (3) visual cue (valid/invalid) (4) both cues in a simultaneous display or (5) auditory cue followed by a visual cue after a 400-msec cue-to-cue delay.

### Results and discussion

The mean RTs for each condition were calculated for each subject. All RTs less than 100 msec or greater than 1000 msec were excluded. These represented 6.8% of trials, mostly anticipatory responses in trials with an auditory cue. Table 1 shows the mean RT for each cell. The overall data was regrouped into two data sets. The first data set excluded trials in which the auditory cue preceded the visual cue. The second data set excluded trials in which the auditory and visual cue were displayed simultaneously. Each data set was cast into separate ANOVAs, followed by Scheffe *post-hoc* comparisons. The sphericity assumption was not violated.

A statistical analysis of the first data set showed significant effects of auditory cue [ $F(1,11)=27.0$ ,  $P<0.0003$ ], of visual cue [ $F(2,22)=22.6$ ,  $P<0.0001$ ], of cue-to-target delay [ $F(1,11)=86.7$ ,  $P<0.0001$ ], of target location [ $F(3,33)=4.3$ ,  $P<0.01$ ], of the interaction of auditory cue with visual cue [ $F(2,22)=11.4$ ,  $P<0.0004$ ], of the interaction of visual cue with cue-to-target interval [ $F(2,22)=15.6$ ,  $P<0.0001$ ] and a three way interaction of auditory cue and visual cue with cue-to-target delay [ $F(2,22)=5.2$ ,  $P<0.01$ ].

We were most interested in possible interactions within the alerting system, as well as possible interactions between the alerting system and the orienting system. Three effects were relevant in these analysis: the auditory alerting effect, the visual alerting effect and the validity effect. The auditory alerting effect was estimated by subtracting trials with auditory cue from trials without audi-

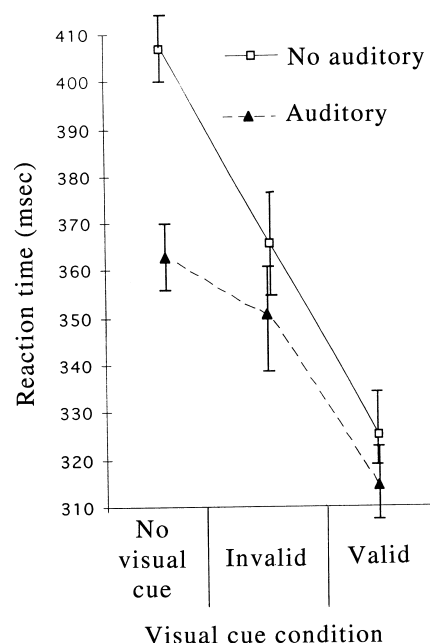


Fig. 4. Mean RTs as a function of auditory cue and visual cue conditions, with cue-to-cue synchrony, for Experiment 3 (collapsed across cue-to-target delay). The validity effect was calculated as the difference in RT between the invalid and the valid condition. The visual alerting effect was the difference in RT between no visual cue condition and invalid condition. The auditory alerting effect was the difference in RT between no auditory cue condition and auditory condition. The visual alerting effect was reduced in presence of an auditory cue. The validity effect did not interact with the auditory cue. Vertical bars represent standard errors of the mean.

tory cue. Figure 4 shows that RTs were fastest in trials with auditory cue, revealing an auditory alerting effect. The visual alerting effect was estimated by subtracting from invalid trials the no-cue trials. The validity effect was estimated by subtracting valid trials from invalid trials. Valid trials were those in which the cue correctly predicted the future location of the target; they constituted 80% of the trials with visual cue. The remaining 20% were invalid trials, in which the target occurred in any of the uncued locations. There was both a visual alerting effect ( $P<0.05$ ) and a validity effect ( $P<0.01$ ), as revealed by *post-hoc* tests of the visual main effect (see Fig. 3). The visual alerting effect was modified by an interaction with auditory cue. The validity effect was not modified by an interaction with auditory cue.

The most important questions addressed by this experiment were the influences that an auditory alerting cue had over the visual alerting effect and over the validity effect. Figure 3 shows that presence of an auditory signal reduced the visual alerting effect ( $P<0.05$ ) suggesting that visual and auditory cues acted through a common alerting mechanism. In contrast, the validity effect was not affected by the presence of auditory cue.

In the second data set trials with simultaneous cue presentation were replaced by trials with cue-to-cue asynchrony. We were most interested in finding how visual alerting effect and validity effect were affected by an audi-

Table 1. Mean RTs for Experiment 3

Alerting Condition	Valid	Visual Invalid	No Cue
No Auditory			
105 msec	362(8.4)	393(12.5)	410(8.9)
405 msec	287(8.2)	339(13.1)	404(9.7)
Auditory			
105 msec	347(7.7)	369(12)	378(8.1)
405 msec	281(7.7)	332(17)	349(8.3)
Auditory(cue-to-cue delay)			
105 msec	313(8.8)	339(14)	
405 msec	279(8.4)	326(13)	

Note: Values enclosed in parenthesis represent standard errors of the mean.

tory cue. Adding an auditory cue 400 msec prior to the visual cue did not affect the validity effect, [ $F(1,22)=0.33$ ,  $P<0.57$ ]. This result further supports the independence between auditory alerting effect and orienting effect. Also consistent with the previous analysis, the visual alerting effect was smaller when occurring after an auditory cue than when occurring alone, [ $F(1,22)=2.48$ ,  $P<0.10$ ].

Figure 5 indicates that a visual cue has both a visual alerting and a visual spatial effect. When only an auditory cue is displayed, there is an auditory alerting effect that is substantial at the short cue-to-target delay, and that increases slightly over time. When the orienting cue is displayed under conditions of maximum alertness (i.e. 400 msec after the auditory cue), RT at the 100-msec cue-to-target delay reveals both alerting and spatial effects; the extra benefit at the long delay is due to a development of the validity effect. Finally, an orienting cue displayed alone has visual alerting and spatial effects. Both visual alertness and spatial effects are incomplete at the short delay, and achieve maximum levels at the long delay.

#### Experiment 4

In Experiment 4, we used a choice task in an attempt to conceptually replicate the results found in Experiment 3. By using a choice task we tried to minimize anticipatory responses, as well as preventing responses based in cue-to-target interval. We also used a more central display to

minimize eye movements and to study whether the effects of Experiment 3 generalize to other eccentricities.

#### Method

**Subjects.** Sixteen undergraduates from the University of Oregon participated in the experiment and were paid \$5 for their participation in a single session lasting approximately 40 min. All were right-handed and had normal or corrected to normal vision. None of the subjects had participated in the previous experiments.

**Procedure and design.** As an attempt to minimize eye movement, stimulus was displayed at a central location. Subjects viewed the computer monitor from a distance of 85 cm. The orienting cue,  $0.86^\circ$  in size, had its center at an eccentricity of  $2.17^\circ$  of visual angle. A dot,  $0.43^\circ$  in size, was used as fixation point. The target,  $0.86^\circ$  in size, was displayed adjacent to the cue, its center being at an eccentricity of  $1.31^\circ$ . The target was either a plus sign or the capital letter X. The response panel was positioned in the midline, parallel to the screen; there were two response keys, one being 15 cm closer to the subject's body than the other one. We used this key disposition to prevent benefits due to congruent stimulus-response location. Response was counterbalanced between subjects for hand position.

A mixed design had hand position as the between-subjects condition and auditory alerting cue (present, absent), visual cue (no cue, valid, invalid), cue-to-target delay (105, 405 msec) and target location (upper, lower, right, left) as the within-subject variables. Target type (capital letter X, plus sign) was not included after a preliminary analysis showed no main effect of target type. The design allowed 16 identical trials for each valid condition, 4 identical trials for each invalid condition, and 20 identical trials for each other condition. In all other respects, Experiment 4 was identical to Experiment 3.

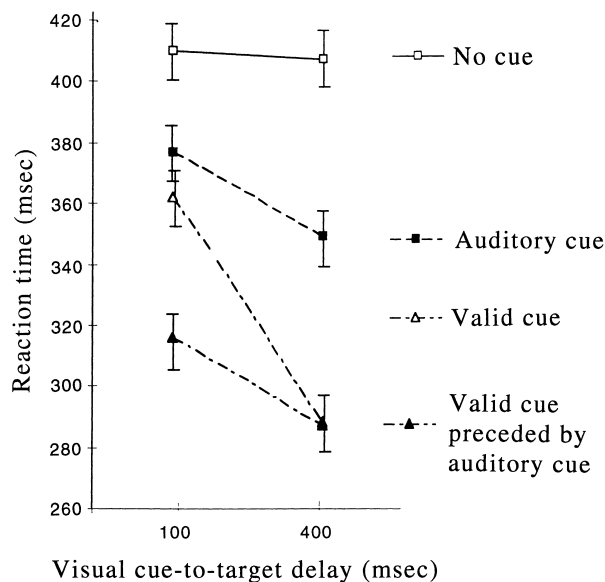


Fig. 5. Major results of Experiment 3. *No Cue* denotes that neither auditory nor visual cue was displayed. *Auditory* denotes that only auditory cue was displayed. *Valid* denotes trials in which a valid visual cue was displayed without an auditory cue. *Valid preceded by Auditory* denotes trials in which an auditory cue was displayed followed by a valid visual cue after a 400 msec delay. RTs are plotted against cue-to-target delays, although in *No Cue* trials there was no cue denoting the onset. Vertical bars represent standard errors of the mean.

#### Results and discussion

The mean RTs for each condition were calculated for each subject. All RTs less than 100 msec or greater than 2000 msec were excluded. These represented less than 1% of trials. Table 2 shows the mean RT for each cell. The treatment of the data was similar to Experiment 3. The sphericity assumption was not violated. The major results

Table 2. Mean RTs for Experiment 4

Alerting Condition	Valid	Visual Invalid	No Cue
No Auditory			
105 msec	510(8.8)	559(13.4)	560(9.6)
405 msec	491(8.4)	536(12.4)	549(7.5)
Auditory			
105 msec	511(8.1)	542(11.1)	531(8.4)
405 msec	472(7.7)	542(13.2)	522(8.0)
Auditory(cue-to-cue delay)			
105 msec	503(7.0)	547(12.5)	
405 msec	484(8.0)	554(13.7)	

*Note:* Values enclosed in parenthesis represent standard errors of the mean.

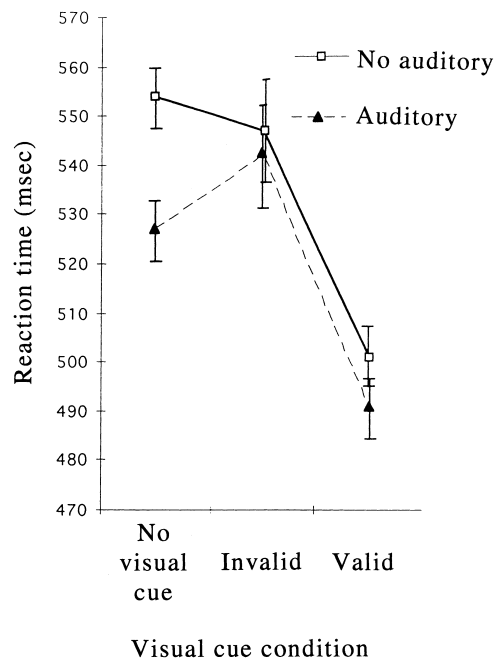


Fig. 6. RTs as a function of auditory cue and visual cue conditions, with cue-to-cue synchrony, for Experiment 4 (collapsed across cue-to-target delay). The labels are used in the same way as in Figure 3 (Experiment 3). There was an interaction between visual alerting effect (no visual cue minus invalid) and auditory alerting effect (no auditory cue minus auditory cue). In contrast, the validity effect (invalid minus valid) did not interact with the auditory condition, suggesting independent systems for alerting and orienting.

of this experiment are shown in Fig. 6, where RTs are shown as a function of auditory cue condition and visual cue condition.

The first data set excluded trials with cue-to-cue asynchrony. The analysis of variance showed significant effects of auditory cue [ $F(1,14) = 14.8$ ,  $P < 0.002$ ], of visual cue [ $F(2,28) = 36.5$ ,  $P < 0.0001$ ], of cue-to-target delay [ $F(1,14) = 19.8$ ,  $P < 0.0005$ ], of target location [ $F(3,42) = 5.1$ ,  $P < 0.004$ ], of the interaction of auditory cue with visual cue [ $F(2,28) = 6.7$ ,  $P < 0.004$ ], of the interaction of visual cue with cue-to-target interval [ $F(2,28) = 3.5$ ,  $P < 0.04$ ] and a triple order interaction of auditory cue and visual cue with cue-to-target delay [ $F(2,28) = 3.7$ ,  $P < 0.04$ ].

The pattern of results was largely similar to the Experiment 3. There was a main auditory alerting effect. Moreover, adding an auditory cue was more beneficial in trials without visual cue than in trials with invalid visual cue ( $P < 0.05$ ), suggesting that visual and auditory cues trigger a common alerting mechanism. This result is consistent with Experiments 2 and 3. Furthermore, in trials without auditory signal there was a non-significant trend toward a visual alerting effect. Most important, the validity effect was independent from the auditory effect. Adding an auditory cue did not change the validity effect, [ $F(1,28) = 0.4$ ,  $P < 0.53$ ].

The analysis of the second data set, in which trials with simultaneous cue presentation were replaced by trials

with cue-to-cue asynchrony, showed largely the same results. We were most interested in finding how visual alerting effect and validity effect were affected by the auditory cue. Therefore, we ran planned comparisons to test the results revealed by the other data set. Consistent with the previous analysis, the visual alerting effect was reversed by the occurrence of an auditory cue, [ $F(1,28) = 13.5$ ,  $P < 0.0001$ ]. There was no evidence of interaction between auditory alerting effect and validity effect. The validity effect was not affected by adding an auditory cue 400 msec previous to the visual cue, [ $F(1,28) = 1.26$ ,  $P < 0.21$ ]. However, a tendency to increase validity effect after presentation of the auditory cue must be acknowledged. It is possible in this case that data failed to reach significance due to a lack of statistical power.

Subjects made errors in only 4.17% of the trials. An analysis of variance using error rate as a dependent variable did not reveal any significant difference of conditions. The simplicity of the task and the saliency of the targets might account for the low rate of errors, as well as for the lack of differences across conditions.

In summary, Experiment 4 replicated the major results found in Experiment 3. In this experiment overall RT was approximately 100 msec slower than in Experiment 3 reflecting greater task difficulty. Albeit this difference, the relation between alerting and orienting in the choice task seems to be the same as in a simple reaction task.

## General discussion

Data from the present experiments suggest alerting is subserved by a neural system independent from the orienting system. The alerting mechanism is relatively homogeneous across the visual field and seems common for auditory and visual warning signals. The most likely mechanisms of this effect lie in the subcortical nor-adrenergic system arising in the locus coeruleus. The nor-adrenergic system, which has been proposed to mediate alerting as well as sustained attention [2, 3, 7, 10, 29, 32], has distributed projections, with each neuron innervating large areas of cerebral cortex [29]. This broad axonal distribution is likely to affect cortex in a diffuse fashion, increasing signal to noise ratio over extended areas of the brain [7]. That broad modulation of cortical areas is consistent with the spatially broad alerting effect reported in our study. NE is likely to have its major impact on parietal lobe, which is densely innervated by nor-adrenergic cells [15] and plays a major role in vigilance, alerting and attention [25].

In contrast to the alerting mechanism, the orienting mechanism operates with spatial precision over a localized visual area. It remains an important issue to determine which subcortical pathways have an effect over the orienting system. Modulatory pathways that densely innervate posterior parietal lobe should be considered, due to the important role of this area in orienting. Lesion



of posterior parietal lobe produces an abnormally slow response to the uncued location. This has been interpreted as a difficulty in disengaging attention from an invalid location [24]. The basal forebrain cholinergic system projects abundantly to the parietal lobe [11] and when lesioned in animals it produces a pattern of response similar to the one in parietal patients, suggesting that cholinergic input to parietal cortex favors disengagement [16, 17, 20, 37, 38, 40, but see 28]. Moreover, cholinergic stimulation enhances disengagement during covert orienting tasks in monkeys and humans [14]. Patients with Alzheimer disease, who have deficit in basal forebrain cholinergic system, also have deficit in disengagement [8, 19, 21, 33]. The attentional deficits in Alzheimer patients are diminished by cholinergic agonists [18, 30]. Taken as a whole, these studies suggest a central cholinergic modulation of disengagement process at the level of posterior parietal lobe.

Our study indicates that the mechanisms of alerting (most likely NE) and of orienting (most likely Ach) make independent contributions to the efficiency of responding as measured by reaction time. Ideas and data have been reported that are contrary to this view. In 1978 Posner suggested that the speed of orienting was improved at high level of alertness and used this to account for the speed accuracy trade off with warning signals in his data [23]. In addition Clark *et al.* [6] showed facilitation in disengagement from an invalid location, following a reduction in central NE. According to those results, a high state of alerting should reduce the time for disengagement and thus the validity effect. Several factors may account for discrepancies between the current data and previous results. In the experiments reported by Clark and collaborators, NE activity was reduced by using clonidine, an alpha-adrenergic agonist that reduces central NE activity. Although clonidine dampens noradrenergic coeruleo-cortical activity [1, 4, 5, 35] it also acts post-synaptically as an agonist, boosting noradrenergic function on cortical neurons [29]. Because in human psychopharmacology the administration of a drug is systemic, it is impossible to define its initial site of action. Thus, it is unclear whether the net effect of clonidine over the orienting system simulates an increase or a decrease of the noradrenergic activity. A second difference between the studies is that all conditions used by Clark and collaborators (valid, invalid, neutral) had an alerting component. Thus, it is not possible to directly assess the alerting effect. Third, those researchers used central cues, which might trigger a different system than the peripheral orienting system studied here [13]. Finally, the cue-to-target interval was fixed in their paradigm, but variable in ours. In summary, while both studies address the same conceptual issues, the differences in methodology prevent a comparison between them.

The ultimate goal of this line of research is to build the bridges that link arousal and attentional processes to their neurochemical substrata. The results of this paper suggest that specific transmitters can be associated with

a class of cognitive operations despite the well known complexity of interactions among transmitters. Studies in clinical populations (e.g. Alzheimer disease) and human psychopharmacology could be used to test the hypothesis postulated here. Electrochemical methods exist that allow the measurement of catecholamines in cerebral cortex with high temporal and spatial resolution [34]. In the future, it might be possible to measure changes of these substances during behavioral tasks involving attention and alerting. Parietal lobe, because of its role in alerting and attention, appears to be a good place to search for these changes.

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