Neutral Location Cues and Cost/Benefit Analysis of Visual Attention Shifts

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Abstract The effects of location cuing on target responses can be examined by comparing informative and neutral cuing conditions. In particular, the magnitudes of costs of invalid location cuing and of benefits of valid location cuing can be determined by comparing invalid and valid cue responses to location-nonspecific neutral cue responses. Cost/benefit analysis is based on the assumption that neutral baseline measures reflect a general warning effect about the impending target's onset but no other specific target information. The experiments we report were carried out to determine the appropriateness of two baseline measures for cost/benefit analyses of direct (nonsymbolic) location cuing effects. We found that a multiple-cue baseline attenuated the benefits of valid cuing, and that a background-flash baseline arbitrarily attenuated costs or benefits depending on flash intensity. It is proposed that a background flash is the more suitable neutral cue because it is target-location-nonspecific, but that its intensity should be adjusted to elicit a target-onset warning signal of the same magnitude as the location cues with which it will be compared.

Résumé Les effets de repérage d'indices sur des cibles réponses peuvent être examinés en comparant les conditions de repérage informatives ou neutres. Plus particulièrement, l'importance des coûts d'un repérage incorrect d'emplacement et les avantages d'un repérage valide peuvent être déterminés en comparant les réponses valides et erronées sur l'emplacement d'indices à des réponses neutres faisant abstraction de l'emplacement. L'analyse coût/avantage se base sur la prémisse que des mesures de base neutres reflètent un effet général d'avertissement sur le déclenchement de la cible, mais aucune autre information propre à la cible. Les expériences dont nous faisons ici état ont été menées pour déterminer le bien-fondé de deux mesures de base pour les analyses coûts/avantages des effets directs (non symboliques) des indices d'emplacement. Nous avons constaté qu'une base d'indices multiples atténuait les avantages d'un indice valide et qu'un éclair lumineux sur le fond atténuait arbitrairement les coûts ou les

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avantages selon l'intensité de l'éclair. On suggère qu'un éclair de fond est un indice neutre plus approprié car il ne donne pas d'indice sur l'emplacement de la cible, mais que son intensité devrait être réglée de manière à ne pas nuire à un signal d'avertissement de déclenchement de cible de même intensité que les indices d'emplacement auxquels il sera comparé.

Visual attention shifts can be studied in the laboratory by determining how the accuracy and latency of responses to targets is affected by location cuing. In particular, location cuing appears to initiate a shift of focused attention to the expected target location prior to its onset, which gives the visual system a "headstart" on target detection and discrimination processes (e.g., Posner, Snyder, & Davidson, 1980). Target detection response times are typically faster when cues are *valid* indicators of target location than when they are not, and cost/benefit analysis is often used to examine cuing effects as a function of cue validity (e.g., Posner, 1978). This involves comparing valid and invalid cue effects with the effect of a neutral cue that serves only as a target-onset warning signal. More specifically, a valid-cue benefit is the difference between mean valid-cue and neutral-cue response times, and an invalid-cue cost is the difference between mean invalid-cue and neutral-cue response times. Note that the processing complexity of neutral and location cues must be highly similar in a given experimental situation to ensure that costs are not inflated by a relatively simple neutral cue, and that benefits are not inflated by a relatively complex neutral cue (Jonides & Mack, 1984). Thus, while cost/benefit analysis is a useful technique, similarity of the neutral and location cues involved is essential (see Wright & Ward, 1994, for an overview of the visual attention shift literature).

Using cost/benefit analysis to determine nonsymbolic (direct) stimulus cuing effects is more challenging than using it to determine symbolic cuing effects because abrupt-onset stimulus cues appear to elicit visually-triggered visual capture (e.g., Yantis & Jonides, 1990). In particular, if attention is not actively engaged, an abrupt-onset stimulus cue appears to reflexively trigger an increase in perceptual sensitivity at that location for 100-200 ms (Müller & Findlay, 1988; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Shepard & Müller, 1989). Thus, cost/benefit analysis of stimulus cue effects must involve a neutral cue that also elicits a visually-triggered effect.

One cue condition that does so and, according to some researchers, preserves target-location-nonspecificity is the simultaneous cuing of all possible target locations. The general rationale is that no one location can be singled out because all are cued. The multiple-cue condition is also based on a subtle assumption that target responses are influenced only by the "purely attentive" processing that follows cue onset. To elaborate, it is assumed that responses to targets appearing at one of a number of simultaneous abrupt-onset cued locations will be unaffected by preattentive, sensory processing associated with cue onset, and will show a cuing effect only if the unitary channel of focused attention is aligned with that location. On the basis of evidence that the channel of focused attention is unitary and indivisible (Kiefer & Siple, 1987; McCormick & Klein, 1990; Posner et al., 1980), it follows that focused attention will be aligned with perhaps only one cued location on a multiple-cue trial. Over the course of many trials, though, the costs and benefits of multiple cuing are assumed to balance out, and by virtue of this averaging process, provide a target-location-nonspecific neutral baseline measure.

We take issue with the multiple-cue neutrality assumption because a growing body of evidence indicates that target responses can be influenced by visual processing that is independent of the channel of focused attention (e.g., Müller & Humphreys, 1991; Pylyshyn, 1989, 1994; Yantis, 1992; Yantis & Johnson, 1990). Furthermore, when one or more locations are cued simultaneously with abrupt-onset stimuli and the target then appears at one of the them, the magnitude of response-time facilitation and inhibition is independent of the number of cues (e.g., Posner & Cohen, 1984; Wright, 1994; Wright & Richard, 1994). This appears to hold for as many as four simultaneous abrupt-onset cues (Wright & Richard, in press). In other words, target responses appear to be influenced by preattentive, sensory processing of abrupt-onset cues that is not constrained to a single location. If true, then the multiple-cue condition is not an appropriate neutral baseline measure for cost/benefit analysis of valid and invalid stimulus cue effects.

Experiment 1

The first experiment was a direct comparison of valid, invalid, and multiple cuing effects on target response times to determine the appropriateness of multiple cuing as a neutral baseline measure. We expected, on the basis of previously described findings, that the multiple cue would lead to perceptual sensitivity increases at both cued locations, making it, in effect, a "double valid cue". If so, then the failure of multiple cuing to satisfy the target-location-nonspecificity criterion would cause attenuated benefits and inflated costs.

METHOD

Fifty Simon Fraser University students with normal or corrected-to-normal vision participated in this experiment. Stimuli were displayed on a black (unlit) computer screen at a distance of 60 cm. Experimental control, timing, and data collection were carried out with a 386-based microcomputer interfaced to a response-button mechanism. A white ($0.4 \times 0.4°$) fixation cross was visible at the centre of the display throughout the experiment, and subjects were required to keep their eyes directed toward it at all times. Each trial began with a 1000 ms delay during which only the central fixation point

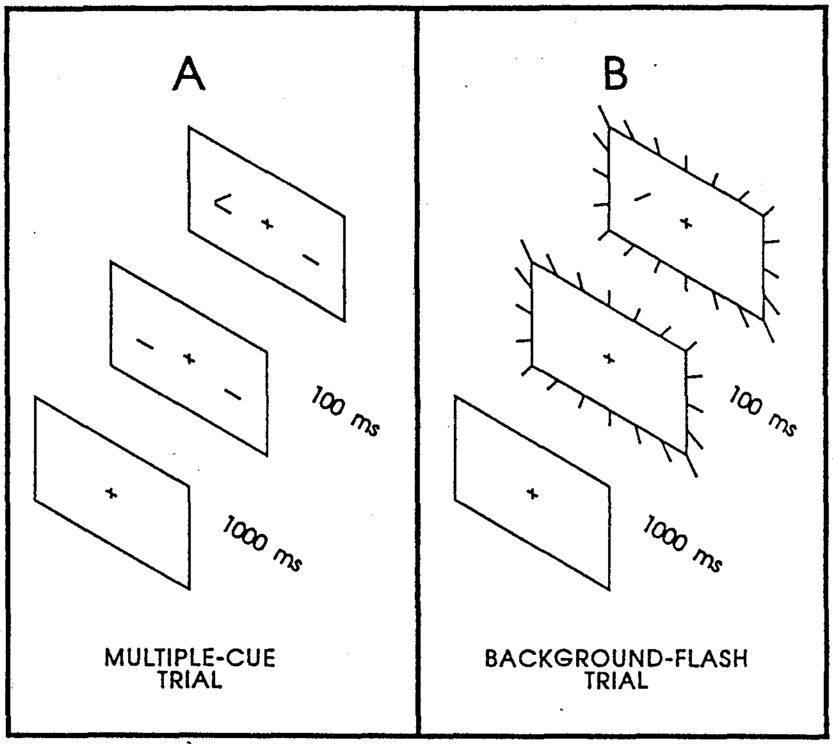

Figure 1. (A) Neutral cue used in Experiment 1. (B) Neutral cue used in Experiment 2.

was visible (see Figure 1). Then the target location was cued for 100 ms. Following this, a white (0.95 x 0.95°) diagonal target line was presented and subjects were required to detect its onset as quickly as possible with a button-press response. A 100 ms cue-target-onset-asynchrony (CTOA) was chosen because this appears to be the delay following cue onset at which perceptual sensitivity at the cued location is maximal (e.g., Müller & Findlay, 1988; Shepard & Müller, 1989). It is also short enough to preclude the occurrence of saccadic eye movements (regular or express) before the target onset (Fischer & Weber, 1993).

White (0.01 x 1.9°) horizontal underline cues were presented at locations 7.6° on either side of the central fixation point. Valid-cue trials involved the presentation of an underline cue beneath the target location 100 ms before the target appeared there; invalid-cue trials involved the presentation of an underline cue at the location on the opposite side of centre to that of the target; and multiple-cue trials involved the presentation of underline cues at both locations. Each type of trial was presented an equal number of times in a completely random order so that, over the course of the testing session, subjects received 30 practice trials, 288 data trials, and 96 catch trials with a

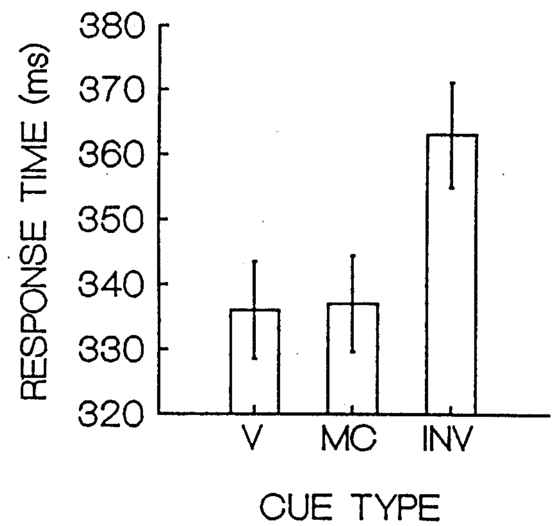

Figure 2. Mean response times on valid cue (V), multiple cue (MC), and invalid cue (IV) trials in Experiment 1. The error bars are standard error.

1500 ms CTOA randomly interspersed among the other trials to reduce response anticipation errors.

RESULTS AND DISCUSSION

All response times less than 100 ms or greater than 1000 ms, and all response times three standard deviations greater than or less than the mean response time for a particular condition were removed as outliers (1.3% of trials). A repeated measures ANOVA indicated that cue type (valid cue, multiple cue, or invalid cue) affected response times, $F(2,98) = 98.2$, $MS_e = 121.03$, $p < .0001$. Paired comparisons of means using t-tests indicated that the mean response time on valid-cue trials was not significantly faster than that on multiple-cue trials, $t(49) = 0.28$, $p > .78$. On the other hand, the mean response times on both valid-cue and multiple-cue trials were significantly faster than that on invalid-cue trials, $t(49) = 11.44$, $p < .0001$, and $t(49) = 11.27$, $p < .0001$, respectively (see Figure 2). Outlier removal was unaffected by cue type and, therefore, a speed-outlier tradeoff did not occur.

The results suggest that multiple stimulus cuing is not an appropriate baseline measure for cost/benefit analysis because it is not target-location--nonspecific. The multiple-cue baseline in the current experiment inflated costs relative to benefits as though it was a double valid cue. This is consistent with other reports of significant costs but substantially smaller benefits when a multiple-cue baseline was used for cost/benefit analyses. of stimulus cue effects (e.g., Enns & Brodeur, 1989; Zimba & Hughes, 1987).

Experiment 2

The second experiment was a systematic examination of background flashes as neutral cues for cost/benefit analysis. These were brief (17 ms) uniform increases in display background intensity for 100 ms before target onset to provide a warning signal but, unlike multiple cuing, no information about target locations (cf. Mackeben & Nakayama, 1993). Background flash intensity ranged from just noticeable to very noticeable. We expected that if response times varied as a function of flash intensity, benefits would be largest with the just-noticeable flash. and smallest with the very-noticeable flash.

METHOD

Eight Simon Fraser University students with normal or corrected-to-normal vision participated in this experiment. The procedure was identical to that of Experiment 1 except that there were more trials (240 practice, 900 data, and 300 catch trials), speeded discrimination responses were made (top-right/bottom-left vs. top-left/bottom-right diagonal line target), there were four different types of background flashes that varied in intensity, and there were no multiple-cue trials (see Figure 1). Neutral condition N1 involved an increase in intensity of 0.08 lux, N2 involved an increase of 1.70 lux, N3 involved an increase of 7.15 lux, and N4 involved an increase of 19.80 lux.

RESULTS AND DISCUSSION

Response time outliers were removed in the same manner as in Experiment 1. A repeated measures ANOVA indicated that cue type (valid cue, N1, N2, N3, N4, or invalid cue) affected response times, $F(5,35) = 14.97$, $MS_e = 74.0$, $p < .0001$. Paired comparisons of means using t-tests indicated that the mean response time for invalid-cue trials was significantly slower than those for all background-flash intensities (N1, N2, N3, & N4), but that the mean response time for valid-cue trials was significantly faster than that of only N1, $t(7) = 6.5$, $p < .001$), and N2, $t(7) = 2.7$, $p < .05$ (see Figure 3). A repeated measures ANOVA carried out on the mean error rates indicated that cue type had no effect on response accuracy, $F(5,35) = 2.15$, $MS_e = 6.4$, $p > .05$. In particular, the mean response accuracy differed by 1% or less across the six cue conditions, indicating that a speed-accuracy tradeoff did not occur. In summary, there was a systematic change in response-time costs and benefits as a function of background-flash intensity. The benefits of valid cuing decreased and then were no longer significant when the intensity of the comparison background flash was increased to 7.15 lux or more.

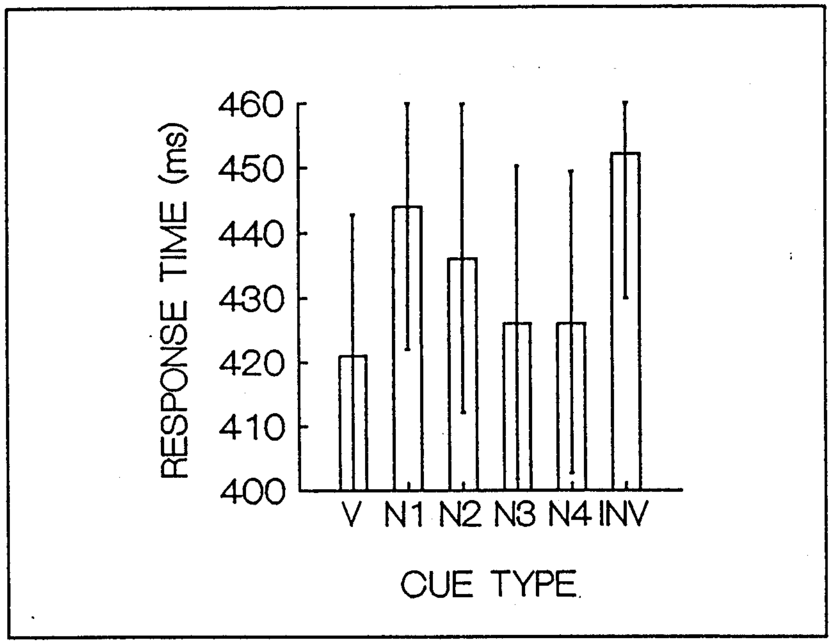

Figure 3. Mean response times on valid cue (V), Neutral1 (N1), Neutral2 (N2), Neutral3 (N3), Neutral4 (N4), and invalid cue (IV) trials in Experiment 2. The error bars are standard error.

Conclusions

The current experiments indicate that multiple stimulus cuing provides target location information, and therefore is not an appropriate cost/benefit analysis baseline measure. Furthermore, the use of a target-location-nonspecific background flash as the neutral cue can lead to variations in costs and benefits as a function of flash intensity. Therefore, if an experimenter is unaware of the intensity/response-time relationship and does not control for location-cue-flash intensity differences, cost/benefit analyses with a background flash baseline are arbitrary at best. We concur with Jonides and Mack (1984) that cost/benefit analysis should be used with caution, and suggest that when examining stimulus cue effects, researchers should determine, a priori, the background-flash intensity that has the same warning signal strength as a location cue (cf. Ross & Ross, 1980). When this flash intensity is used as a neutral baseline measure, costs and benefits are attributable only to the location information conveyed by valid and invalid stimulus cues.

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