Attentional scanning and space errors

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Using the method of paired comparisons, pairs of simultaneous horizontal or vertical lines, with one line above and one below or one on the left and one on the right of a fixation point, respectively, were presented tachistoscopically for length comparison. Space errors were found to have a pattern similar to that of time errors. The tendency to guess the comparative response from the absolute magnitude of stimuli is proposed as a basis for time and space errors. Manipulation of attentional scanning, which implies a more frequent usage of this guessing strategy for one of the two lines in a pair, was shown to affect space errors.

Using the method of paired comparisons, we investigated the possible role of attentional scanning in the comparative judgment of brief, simultaneous stimuli. First, let us consider an overview of this method and the judgment errors inherent in it.

The method of paired comparisons uses two sets of variable stimuli, with each set the identical copy of the other. These variables vary with respect to a single attribute. Let A_i ($i = 1, 2, \dots, n$) and B_j ($j = 1, 2, \dots, n$) denote the variables in the two sets, in which i and j increase with the varied attribute. Each A_i is paired with each B_j . For each ensuing pair, subjects usually report whether $A_i < B_j$ or $A_i > B_j$.

Each A_i or B_j may be taken as a variable or standard. When A_i is the standard, the variables are B_1 to B_n . When B_j is the standard, the variables are A_1 to A_n . Each standard involves one point of subjective equality (PSE), which is the physical value of the varied attribute that has a 50% probability of being reported as larger than the physical value of the standard. Let PSE_i and PSE_j be the PSEs for A_i and B_j , respectively. The differences $PSE_i - A_i$ and $PSE_j - B_j$ are called either *time errors* or *space errors* when the stimuli in a pair are either successive or simultaneous, respectively (Guilford, 1954).

When A_i and B_j are successive and A_i follows B_j , the PSE_i tends to be larger than the PSE_j , for large standards, and smaller than the PSE_j , for small standards. That is, with PSE as the dependent variable, there is an interaction between the factors value of A_i , or B_j , and (temporal) order of A_i and B_j in a pair (Masin & Agostini, 1990). Here, this interaction is called the *value-order interaction*.

When they are compared, two successive stimuli seem to receive a code proportional to the absolute magnitude of the comparison attribute. The two codes are then matched to produce the comparative response (Bower, 1971). The retrieval of the first stimulus code for matching with the second requires time. In addition, this retrieval may occasionally fail. Consequently, the comparative response may occasionally be produced on the basis of only the second stimulus code. It has been suggested that when the second stimulus code is "large" ("small") and the first stimulus code is not used, the "larger" ("smaller") comparative response tends to be guessed (Masin, 1988; Masin & Fanton, 1989). As we shall see, this bias implies the occurrence of the value-order interaction.

Let us now consider the comparative judgment of two simultaneous tachistoscopic stimuli, one on the left and one on the right of a fixation point. Horizontal letter arrays presented tachistoscopically tend to be scanned from left to right (White, 1969). We hypothesize that the task of comparing two horizontal, simultaneous visual stimuli activates this attentional scanning tendency. That is, at the onset of two horizontal, simultaneous stimuli presented for comparison, there is a greater probability that the left stimulus would be attended to first. Consequently, left tachistoscopic stimuli would be encoded at a higher rate more often than right stimuli (Downing, 1988; LaBerge & Brown, 1989; Reinitz, 1990), and premature termination of encoding would be more frequent for right than for left stimuli (Klein & Farrell, 1989). It follows that for short stimulus durations, the comparative response would be produced, at least occasionally, on the basis of only the left stimulus code.

As we did for time errors, we suggest that when the left stimulus code is large (small) and the right stimulus code is not used, the larger (smaller) comparative response tends to be guessed. Thus, it may be predicted that the value-order interaction occurs for both time and space

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errors, with the left stimulus in a pair of simultaneous stimuli equivalent to the last stimulus in a pair of successive stimuli. The following experiment tested this prediction.

EXPERIMENT 1

Method

Subjects. Eighty students from the Faculty of Foreign Languages and Literature at the University of Udine participated. Their reported vision was either normal or corrected to normal by lenses.

Stimuli. Stimuli were pairs of black vertical lines displayed for 125 msec on a light-gray 22×30 cm IBM 8514 color-display screen controlled by an IBM 80 computer. These pairs were all combinations of five lines that varied in 0.12-cm steps, the shortest being 8.38 cm. Line width was 1 pixel. Viewing distance was 65 cm. The lines in a pair were placed symmetrically at 8 cm (7°) from the fixation point, 1 yellow pixel always present in the middle of the screen. This pixel and the centers of the two lines lay on an imaginary horizontal line. Each stimulus was signaled 1.4 sec before its appearance by a very brief sound. Each pair of lines appeared 2.7 sec after a response was typed.

The experimental room was lighted at a constant, normal illumination level by neon tubes on the ceiling. The subjects viewed the stimuli through an 8.5×14.5 cm rectangular cutout in a black 70×100 cm cardboard placed 49 cm from the screen. Eye level was adjusted by a chin-and-head-rest.

Procedure. The method of paired comparisons was used. Let the variables on the left and the right of the fixation point be A_i and B_j , respectively, with the integers i and j increasing from 1 to 5 with length. Each A_i was paired with each B_j . To each subject, the ensuing 25 A_i/B_j pairs were shown randomly twice consecutively, that is, one set of 25 after the other set, in a single session with no rest period. The subjects did not know that lines were to be named "A" or "B."

The subjects were asked to focus on the fixation point at the acoustic signal. It was explained to them that avoiding eye movements during fixation would optimize performance and permit equal visibility of the lines in a pair. The subjects were asked to verbally identify the longer line in a pair. The "equal" or "don't know" responses were forbidden. Each subject gave 50 responses in total.

Results

For $i = j$, $A_i = B_j$. Consequently, for each $i = j$, two PSEs derive from a single application of the method of

paired comparisons—one when A_i is taken as the standard and one when B_j is taken as the standard.

Figure 1 shows the mean PSEs as a function of size of standard, for left (A_i , open circles) and right standards (B_j , filled circles). The mean PSEs are means of 160 individual PSEs (two replicates) computed by the simplified version of the method of transitions (Masin, 1989; Masin & Vidotto, 1984); they correspond substantially to those obtained by the weighted least-squares procedure. A 2 (spatial order of stimuli in a pair) $\times$ 5 (value of standard) analysis of variance (ANOVA) with two replicates showed that the main effects caused by spatial order were significant [$F(1,79) = 5.1, p < .05$], indicating an overestimation of left lines (Brown, 1953; Ogle, 1950; Takala, 1951). The value-order interaction was significant [$F(4,316) = 92.8, p < .0001$], which suggests that time and space errors might have a common basis.

Discussion

The value-order interaction in Figure 1 could be explained as follows. For simplicity, let us consider only the extreme values of A_i and B_j . When A_1 is compared with the shortest variable [$B_1 (=A_1)$], the observed probability to respond "shorter" to A_1 is greater than the expected or theoretical probability (P), because A_1 has a high probability to be coded as "short" and is more likely to be attended to first. Therefore, the proportion of "longer" responses to B_1 tends to be higher than P . This higher proportion implies a shift of the psychometric function (and PSE_1) away from the middle of the range of variables. When A_5 is compared with the longest variable [$B_5 (=A_5)$], the probability to respond "longer" to A_5 is greater than P , because A_5 has a high probability to be coded as "long" and is more likely to be attended to first. The proportion of "longer" responses to B_5 tends, then, to be lower than P , again implying a shift of the psychometric function (and PSE_5) away from the middle of the range of variables. Analogous reasonings show that PSE_1 and PSE_5 shift toward the middle of the range of variables when B_1 or B_5 are right standards. This interpretation is strengthened by the finding that the left line in a pair has greater weight on the comparative response (Hellström, 1990).

However, it is also possible that the value-order interaction in Figure 1 depends on a difference in cerebral hemisphere specialization for spatial judgment.¹ In fact, Kosslyn et al. (1989; see also Kosslyn, 1987) found faster finger reaction times in evaluations of visual distance when stimuli were initially presented in the left visual hemifield.² To examine this possibility, Experiment 1 was repeated with the simultaneous lines in a pair now placed above and below the fixation point.

EXPERIMENT 2

Method

Subjects. Twenty different students, recruited according to the criteria used in Experiment 1, participated.

Stimuli. Stimuli and stimulus conditions were the same as in Experiment 1, except for the following changes. The lines varied in

Figure 1. Mean point of subjective equality (PSE) as a function of left (A_i) or right (B_j) standards.

Figure 2. Mean point of subjective equality (PSE) as a function of upper (A_i) or lower (B_j) standards.

0.09-cm steps, the shortest being 9.57 cm. The lines in a pair were horizontal and placed symmetrically at 4 cm (3.5°) from the fixation point. The centers of the two lines and the fixation point lay on an imaginary vertical line.

Procedure. Let the upper and lower lines in a pair be A_i and B_j , respectively. The procedure was the same as it was in Experiment 1, except that now the 25 A_i, B_j pairs were presented six times consecutively, with a 1–2 min rest period between the second and third and between the fourth and fifth sets of presentations.

Results

Figure 2 shows the mean PSEs as a function of size of standard, for upper (A_i , open circles) and lower standards (B_j , filled circles). The mean PSEs are means of 120 individual PSEs (six replicates) computed as they were in Experiment 1. A 2 (spatial order) $\times$ 5 (value of standard) ANOVA with six replicates showed that the main effects caused by spatial order were significant [$F(1,19) = 320$, $p < .0001$], in agreement with the well-known overestimation of the upper half of visual stimuli in normal viewing conditions (Robinson, 1972, p. 104). The value-order interaction was significant [$F(4,76) = 22.0$, $p < .0001$].

Discussion

On the basis of the present data, the possibility that a hemispheric asymmetry for spatial judgment contributes to space errors cannot be excluded. However, the occurrence of the value-order interaction with lines in the upper and lower visual hemifields indicates that some factor other than cerebral hemifield specialization is operating. We suggest that this other factor is attentional scanning. That is, the value-order interaction in Figure 2 would be the result of a slight tendency to start the comparison from the lower line in a pair.

If attentional scanning is a basis of space errors, then a manipulation of this scanning should affect the value-order interaction. Accordingly, Experiments 3 and 4 tested the hypothesis that space errors are affected when the probability of attending first to one line in a pair is varied. In Experiments 3 and 4, the probability of focusing attention first on one line in a pair was maximized

by having the subjects rate the length of that line before producing the comparative response.

EXPERIMENT 3

Method

Subjects. Subjects were 96 different university students recruited according to the criteria used in Experiment 1. They were divided into two groups of 48 (X and Y).

Stimuli. Stimuli were the same as in Experiment 1.

Procedure. The method of paired comparisons was used. The 25 A_i, B_j pairs were presented randomly four times consecutively in a single session, with a 1–2 min rest period between the second and the third sets of presentations. As in Experiment 1, the subjects were carefully instructed to focus correctly on the fixation point. For each pair, subjects were asked to rate the length of one line as soon as possible and, immediately after the rating, to compare the length of the rated line with that of the other line in the same pair. Initially, the two groups were shown the five lines (half of each group of subjects in ascending order and half in descending order) in the middle of the screen, one every 1 sec. The integers from 1 to 9 were used for the rating, with 1 corresponding to the shortest line and 9 to the longest line. For each pair, Group X (Y) rated only left (right) lines in the first two sets of presentations, and only right (left) lines in the second two. The instructions for the comparative response were the same as they were in Experiment 1. Each subject produced 100 absolute and 100 comparative responses.

Results

Figure 3 shows the mean PSEs as a function of A_i and B_j taken as left and right standards, respectively. These mean PSEs are means of 192 individual PSEs (two replicates) computed as they were in Experiment 1. Open squares (filled circles) show the results when left (right) lines were rated.

A 2 (spatial order) $\times$ 2 (direction of scanning) $\times$ 5 (value of standard) ANOVA with two replicates showed that the main effects caused by spatial order and direction of scanning were statistically significant [$F(1,95) = 306$, $p < .0001$, and $F(1,95) = 7.67$, $p < .01$, respectively]. These results confirm that left lines are overestimated and indicate that deployment of attention on left lines contributes slightly to this overestimation (Coren &

Figure 3. Mean point of subjective equality (PSE) as a function of left (A_i) and right (B_j) standards, for left and right rated lines.

Girgus, 1972; Fraisse, Ehrlich, & Vurpillot, 1956; Jordan & English, 1989; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990).³ The significant interactions between spatial order and direction of scanning [$F(1,95) = 4.33$, $p < .05$], spatial order and value of standard [$F(4,380) = 235$, $p < .0001$], direction of scanning and value of standard [$F(4,380) = 11.5$, $p < .0001$], and spatial order, direction of scanning, and value of standard [$F(4,380) = 237$, $p < .0001$], confirm the occurrence of the value-order interaction found in Experiment 1 and show that space errors vary with the probability of focusing attention first on one line in a pair. Thus, the value-order interaction is affected when attentional scanning is manipulated.

EXPERIMENT 4

Experiment 4 was a repetition of Experiment 3, with the simultaneous lines in a pair now placed above and below the fixation point.

Method

Subjects. Subjects were 24 university students from the Department of General Psychology at the University of Padua. Their reported vision was either normal or corrected to normal by lenses.

Stimuli. Stimuli were the same as in Experiment 2, except for the following changes. Lines were displayed for 30 msec on a 22×35 cm light-gray background on an EIZO 9400 color-display screen controlled by an ASEM 9030 computer. The lines varied in 0.11-cm steps, the shortest being 11.84 cm. The distance of a line from the fixation point was 6.2 cm (6.5°). Viewing distance was 55 cm.

Procedure. The procedure was the same as in Experiment 3. Groups X and Y were now made up of 12 subjects each.

Results

Figure 4 shows the mean PSEs as a function of the upper (A_i) and lower (B_j) lines in a pair taken as standards.

Figure 4. Mean point of subjective equality (PSE) as a function of upper (A_i) and lower (B_j) standards, for upper and lower rated lines.

The mean PSEs are means of 48 individual PSEs (two replicates) computed as they were in Experiment 1. Open squares (filled circles) show the results when upper (lower) lines were rated.

A 2 (spatial order) $\times 2$ (direction of scanning) $\times 5$ (value of standard) ANOVA with two replicates showed that the main effects due to spatial order and direction of scanning were statistically significant [$F(1,23) = 1,672$, $p < .0001$, and $F(1,23) = 35.4$, $p < .0001$, respectively]. The results confirm that upper lines are overestimated and indicate that attention to upper lines contributes slightly to this overestimation.⁴ The significant interactions between spatial order and direction of scanning [$F(1,23) = 61.5$, $p < .0001$], spatial order and value of standard [$F(4,92) = 43.0$, $p < .0001$], direction of scanning and value of standard [$F(4,92) = 35.0$, $p < .0001$], and spatial order, direction of scanning, and value of standard [$F(4,92) = 73.3$, $p < .0001$] confirm that the value-order interaction changes markedly when attentional scanning is induced artificially by focusing the subject's attention first on one line in a pair. These results seem difficult to interpret in terms of a hemispheric asymmetry for spatial judgment.

CONCLUSION

Without excluding the possibility that space errors may also depend on a hemispheric asymmetry for spatial judgment, the present results favor the following conclusion: Time and space errors seem to have one common basis—the tendency to guess the comparative response from only one of the compared stimuli when the code of the other stimulus cannot be used. In a set of stimuli, large (small) stimuli have a high probability of being larger (smaller) than another unknown stimulus from the same set. It is plausible that subjects intuitively use this knowledge to guess the comparative response.

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NOTES

1. For the suggestion of two concurrent judgmental factors in time errors, see Masin and Agostini (1990, p. 492).

2. Kosslyn et al. (1989) had subjects respond with both hands to amoeba-like figures with a dot on either the contour or the outside of the figure. The interpretation of their results is difficult, because (1) there is evidence of an interaction between overall attributes of visual stimuli and hemispheric-processing differences in visual search (Polich, DeFrancesco, Garon, & Cohen, 1990), (2) there are complex and partly unknown reciprocal influences of the attentional and intentional systems (Verfaellie & Heilman, 1990), and (3) judgments of nonverbal visual stimuli involve a shift in hand preference (Hampson & Kimura, 1984; Wünscher, Jordan, Gille, & Roth, 1990). In agreement with Points 2 and 3, Masin, Fanton, & Crestoni (1988) obtained data showing that space errors resulting from a manual response are different from space errors resulting from a verbal response, and Masin & Agostini (1991) found that the patterns of space errors in left- and right-handed subjects who respond with both hands are specular.

3. Line ratings were asked only as a means to direct attention toward one of the two lines in a pair. The grand mean ratings of left and right line lengths were 6.82 and 6.68, respectively. The information conveyed by these means is uncertain, because each line rating lacked the corresponding rating of the other line in the same pair for proper comparison.

4. The grand mean ratings of upper and lower line lengths were 6.90 and 6.74, respectively. See Note 3.

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