Research Article

# VISUAL PRIOR ENTRY

David I. Shore,[1] Charles Spence,[2] and Raymond M. Klein[3]

[1]*McMaster University, Hamilton, Ontario, Canada;* [2]*Oxford University, Oxford, England; and* [3]*Dalhousie University, Halifax, Nova Scotia, Canada*

**Abstract—***It has long been claimed that attended stimuli are perceived prior to unattended stimuli—the doctrine of prior entry. Most, if not all, studies on which such claims have been based, however, are open to a nonattentional interpretation involving response bias, leading some researchers to assert that prior entry may not exist. Given this controversy, we introduce a novel methodology to minimize the effect of response bias by manipulating attention and response demands in orthogonal dimensions. Attention was oriented to the left or right (i.e., spatially), but instead of reporting on the basis of location, observers reported the order (first or second) of vertical versus horizontal line segments. Although second-order response biases were demonstrated, effects of attention in accordance with the law of prior entry were clearly obtained following both exogenous and endogenous attentional cuing.*

The doctrine of prior entry—that attended stimuli are perceived earlier than unattended stimuli—has a long history in experimental psychology, stretching back to the very origins of the study of perception (Boring, 1929; James, 1890; Mollon & Perkins, 1996; Spence, Shore, & Klein, 2001; Titchener, 1908). Some of the most compelling evidence demonstrating that attention influences the perception of arrival times comes from recent studies using temporal-order judgment (TOJ) tasks (e.g., Hikosaka, Miyauchi, & Shimojo, 1993; Stelmach & Herdman, 1991).

In a typical study, attention is oriented to the left or right of fixation, and observers are required to indicate which of two subsequent stimuli, one presented on the left and one on the right, was presented first. In most studies, the interval between the two stimuli is varied, and the point of subjective simultaneity (PSS) is determined for each type of cue. The PSS represents the interval for which the observer perceives the stimuli as simultaneous and is computed as the interval at which "left first" and "right first" responses are reported equally often; that is, the PSS is the point at which observers are maximally uncertain as to the correct response.

The accelerative effect of attention that is presumed by prior entry is indicated by a shift in the PSS. We believe genuine prior entry should be defined as a perceptual effect on arrival times attributable to attentional modulation (cf. Titchener, 1908) once the opportunities and incentives for response- and decision-level contributions to the measured PSS have been minimized. One such postperceptual mechanism that has recently been highlighted (Frey, 1990; Jaskowski, 1993; Pashler, 1998; Spence et al., 2001; Stelmach & Herdman, 1991) is the contribution of response bias.

## RESPONSE BIAS IN PREVIOUS RESEARCH

A simple response-bias account of the shift in PSS postulates that observers may simply report the side to which they had been instructed to attend (Frey, 1990). Many previous studies of prior entry are subject to such an account of the data (Abrams & Law, 2000; Enns, Brehaut, & Shore, 1999; Hikosaka et al., 1993; Jaskowski, 1993; Robertson, Mattingley, Rorden, & Driver, 1998; Rorden, Mattingley, Karnath, & Driver, 1997; Stelmach, Campsall, & Herdman, 1997; Stelmach & Herdman, 1991; Stelmach, Herdman, & McNeil, 1994; Zackon, Casson, Stelmach, Faubert, & Racette, 1997; Zackon, Casson, Zafar, Stelmach, & Racette, 1999). Some researchers, aware of the potential problems of response bias, attempted to minimize this bias by allowing observers a third, "simultaneous" response (cf. Jaskowski, 1993; Stelmach & Herdman, 1991). Stelmach and Herdman (1991), for example, demonstrated a robust effect of prior entry in an experiment using precisely this methodology, whereas Jaskowski (1993) failed to show any prior-entry effect.

It is important to note that independent of any response-bias confound, Stelmach and Herdman (1991) also used different stimulus onset asynchronies (SOAs) for the attend-left and attend-right conditions, so that an observer's tendency to report the two response options equally often (Sekuler & Erlebacher, 1971) could have produced the prior-entry effects reported. Further, Stelmach and Herdman's observers chose to make the "simultaneous" response on less than 5% of trials, whereas Jaskowski's (1993) observers used this option on the majority of trials when the SOA was close to zero. These mixed results from studies that have incorporated an "uncertain" response option may therefore reflect differential success in encouraging observers to use it. It is unlikely that the mere use of this option is sufficient to rule out a response-bias account, and even if it were, because of the mixed results when it was used, response bias remains a potential explanation of the positive results reported in the majority of previous prior-entry studies. Indeed, in a recent review of the psychology of attention, Pashler (1998) stated that "at present the empirical evidence for prior entry is unconvincing . . . future demonstrations of prior entry, if they are to be convincing, will have to include careful precaution to minimize response biases" (p. 260). Thus, the goal of the present study was to reduce and assess the influence of this potential confound.

## CONTROLLING AND ASSESSING RESPONSE BIAS

In order to reduce the impact of response bias, we recommend using a methodology in which attentional-cuing and response dimensions are orthogonal (cf. Cairney, 1975; Drew, 1896; Spence et al., 2001). We implemented this strategy by using a peripheral flash or a central arrow to orient attention to the left or right while our observers indicated whether a vertical or horizontal line segment was presented first. There is no obvious reason why "horizontal" or "vertical" responses should be preferentially activated by a left or right cue (whereas it is easy to see that "left" and "right" responses might be), and hence response biases obtained with this method should be smaller than those in the nonorthogonal designs used previously. However, even with this design, it is possible for an observer to engage a second-order response bias by reporting, when uncertain, the orientation of the line segment presented on the attended side. For this reason, we included a second task, so we

Address correspondence to David I. Shore, Department of Psychology, McMaster University, Hamilton, Ontario, Canada L8S 4K1; e-mail: dshore@mcmaster.ca.

  

would have results from two tasks that should have opposite effects on response bias and yet not affect the perceptual influence of prior entry. Specifically, different observers were asked which target was presented first (the typical judgment used in the TOJ literature) and which target was presented second (e.g., Allik & Kreegipuu, 1998, Experiment 2; Frey, 1990). If, as Frey (1990) has claimed, observers simply report the attended side (or in our case, the attribute of the line segment on the attended side), then the PSS should shift in opposite directions under these different instructions.

Further, we provide converging evidence for the magnitude and existence of prior entry by analyzing the distribution of reaction times (RTs) across SOAs (cf. Heath, 1984). This novel use of RT relies on the conventional wisdom that observers should be slowest when they are least certain of their response (i.e., at the PSS). This form of analysis should provide a bias-free measure of prior entry because the point of maximum uncertainty should depend solely on the products of perceptual processing. Response bias should simply influence which alternative will be reported at this point of maximum uncertainty.

Shifts of attention involve an internal adjustment of selection schedules whereby some regions of space or particular objects are processed preferentially over others. Attentional orienting can be directed either by environmentally generated or by observer-generated signals. Following Posner (1980; see also Klein, Kingstone, & Pontefract, 1992; Klein & Shore, 2000), we refer to these sources of control as exogenous (coming from outside the organism; this source is also referred to as bottom-up, reflexive, or automatic) and endogenous (coming from within the organism; this source is also referred to as top-down, voluntary, or strategic). Previous research on prior entry has used both, and sometimes a combination, of these two cuing methods. For example, Jaskowski (1993) used a purely endogenous (verbal instruction) manipulation, whereas Hikosaka et al. (1993) used a purely exogenous (spatially unpredictive) cue. Stelmach and Herdman (1991) used a hybrid cue consisting of a spatially informative peripheral flash, likely to engage both exogenous and endogenous orienting mechanisms. Given that these two methods of attentional cuing may recruit different neural mechanisms (Briand, 1998; Briand & Klein, 1987; Klein, 1994; Posner & Petersen, 1990), and have been shown to have different behavioral consequences (e.g., Spence & Driver, 1994; see Klein & Shore, 2000, for a review), it is important to assess their relative roles in mediating prior-entry effects separately. Therefore, in separate sessions, we manipulated attention using either spatially uninformative peripheral flashes (purely exogenous orienting) or predictive central arrows (purely endogenous orienting). This manipulation was performed for both tasks. One might think that response bias would play a larger role with endogenous than exogenous cuing, because both response bias and endogenous cuing operate in a voluntary fashion. We had no a priori predictions concerning whether response bias would be different with these two types of cues; however, given the mixed nature of previous research, we felt that it was important to assess this question empirically.

## METHOD

### Observers

Nine right-handed graduate and undergraduate students (6 females) from Dalhousie University, Halifax, Nova Scotia, Canada, participated in this experiment. They were naive as to the purpose of the experiment and varied in their previous experience of psychophysical procedures. The majority were given either extra credit in a psychology course or $12 for their participation. Three of the observers (J.S., T.B., and A.B.) participated in both the endogenous-cuing and the exogenous-cuing conditions of the "which came first?" task, whereas the other 6 observers were divided equally between the two different cuing conditions for the "which came second?" task. That is, the cuing manipulation was within-observers for the "which first?" task and between-observers for the "which second?" task.

### Apparatus

A Macintosh 8500 computer was connected to a 1710 Apple monitor with a resolution of 640 × 480 pixels. Black-on-white stimuli were displayed and responses collected using the Psyscope Software package. Observers sat with their heads in a chin rest located 57 cm in front of the computer monitor. They used the "8" and "2" keys on the numeric keypad to make "vertical target" and "horizontal target" responses, respectively.

### Stimuli and Procedure

The display (see Fig. 1) consisted of three boxes (the entire array subtended 16° × 3°) that remained on the screen throughout the trial. The first display, which contained a fixation cross in the center box, remained on the screen for 300 ms and was followed by the cue. For exogenous cuing, this consisted of the line making up one of the outside boxes (or the central box for neutral cues) thickening (to 8 pixels) for 45 ms and then returning to its original size (2 pixels); for endogenous cuing, the central fixation cross changed to an arrow pointing to the left or right, or to a double-headed arrow pointing in both directions, until a response was made. After a short interval (60 ms for exogenous cuing, 405 ms for endogenous cuing), the first stimulus—a horizontal line, a vertical line, or a small black dot (0.5°)—was presented. The small black dot was presented on 4% of the trials so we could assess the effectiveness of exogenous and endogenous cuing independently of the TOJ task itself (for similar methodologies, see Cairney, 1975; Vanderhaeghen & Bertelson, 1974). Observers were instructed to make a speeded response to the dot with their left hand, and no further stimuli were presented on these trials.

On 41% of trials, a second line segment (with opposing orientation) was presented in the same spatial location as the first line segment after a variable interval (15, 45, 90, 135, or 240 ms). Following exogenous cues, the locations of these same-location target pairs were evenly divided between the cued and uncued sides (i.e., the cue was spatially uninformative). By contrast, all of the same-location target pairs were presented on the cued side following endogenous cues. These unilateral trials were included to provide a strong incentive for observers to attend to the cued side under endogenous cuing. They were also included for the exogenous condition to make the two conditions as comparable as possible. On the remaining 55% of trials, the second line segment was presented on the opposite side of the display at one of the same intervals used on the unilateral trials. On trials on which two line segments were presented, observers made unspeeded temporal-order discriminations regarding which orientation was presented either first or second, depending on the task. Response latencies from the onset of the first line segment were also recorded.

There were three parts to the experiment, repeated in two sessions

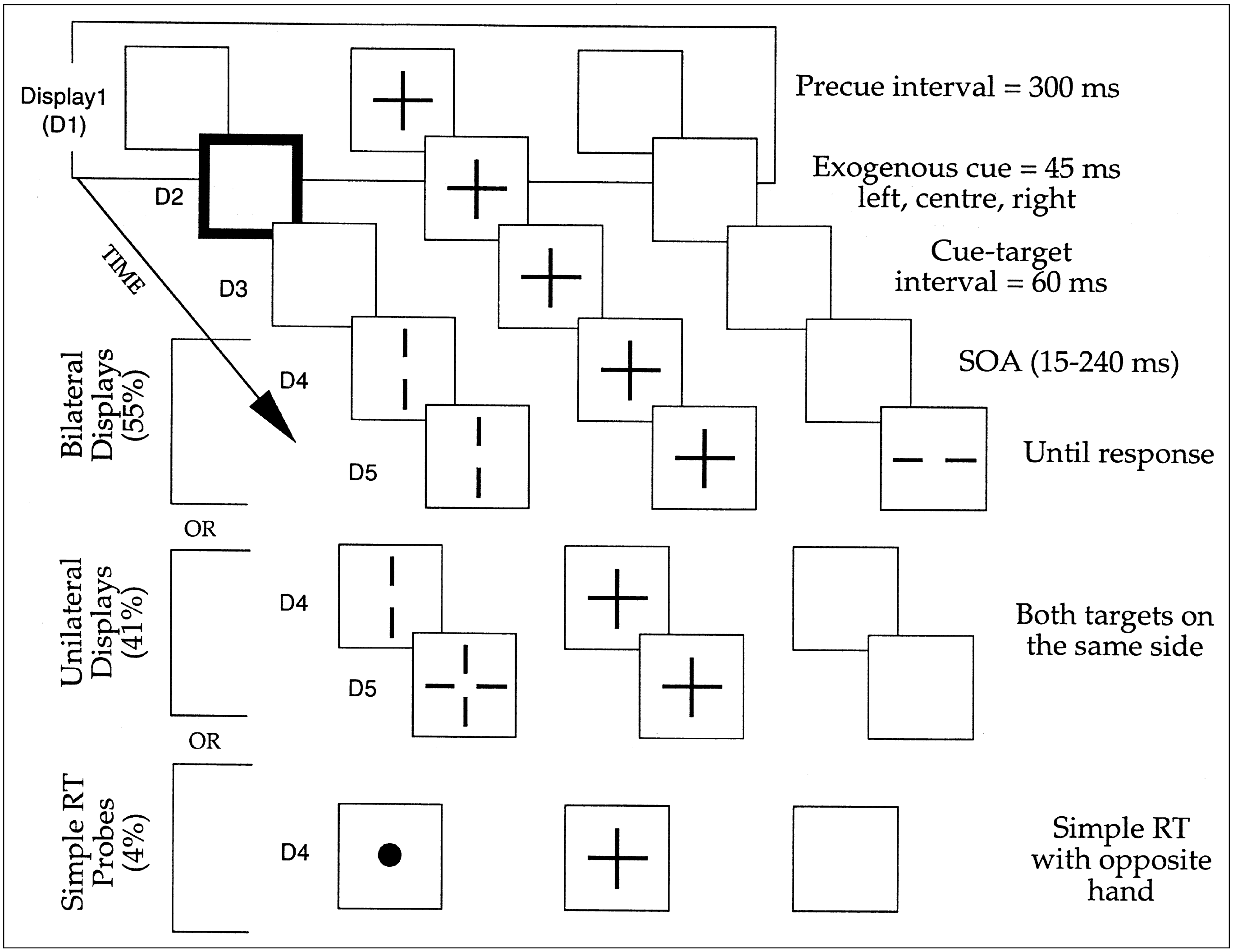


**Fig. 1.** Sample displays for the exogenous-cuing condition. The displays in the endogenous-cuing condition differed in that the cue consisted of an arrow in the center box; the arrow remained on the screen from the second display (D2) until the observer responded. In the unilateral trials, the two items always appeared on the cued side in the endogenous condition, but appeared equally often on the right and left in the exogenous condition. For the simple reaction time (RT) probes, the black dot was equally often on the right or left side, regardless of the cued location. SOA = stimulus onset asynchrony.

on separate days. The first part consisted of 30 trials of response learning, during which observers simply reported which of two orientations was presented on the left or right of the screen. The second part consisted of 30 trials of practice using SOAs that were twice the magnitude of those used in the actual experiment. The final part of each session consisted of 10 blocks of 70 trials with the SOAs mentioned earlier. Auditory feedback, presented from the computer loudspeaker located under the table, followed an incorrect response in the first two parts of the experiment only.

## RESULTS AND DISCUSSION

Data from the speeded simple RT trials (RTs greater than 2 standard deviations of the mean were excluded) following the presentation of a target dot confirm that observers were affected by the cue. A one-tailed paired *t* statistic for each of the four cells in the design (Cue Type × Task) revealed significant differences in RT when the cue and target were on the same versus different sides: for endogenous cuing, *M*s = 566 and 591 ms, respectively, for "which first?" $t(2) = 9.0$, and *M*s = 518 and 537 ms, respectively, for "which second?" $t(2) = 3.1$; for exogenous cuing, *M*s = 513 and 555 ms, respectively, for "which first?" $t(2) = 5.9$, and *M*s = 554 and 587 ms, respectively, for "which second?" $t(2) = 5.2$; all $ps < .05$ (for the neutral conditions, *M*s = 577, 536, 572, and 546 ms, respectively). A liberal one-tailed *t* test was warranted given our a priori expectations, the low probability of simple RT probe stimuli (4%), and the small number of participants in the analysis.

The proportion of responses implying that the horizontal segment was perceived first is shown in Figure 2 for each observer; averages across observers are shown in the right-hand panels. Note that in order

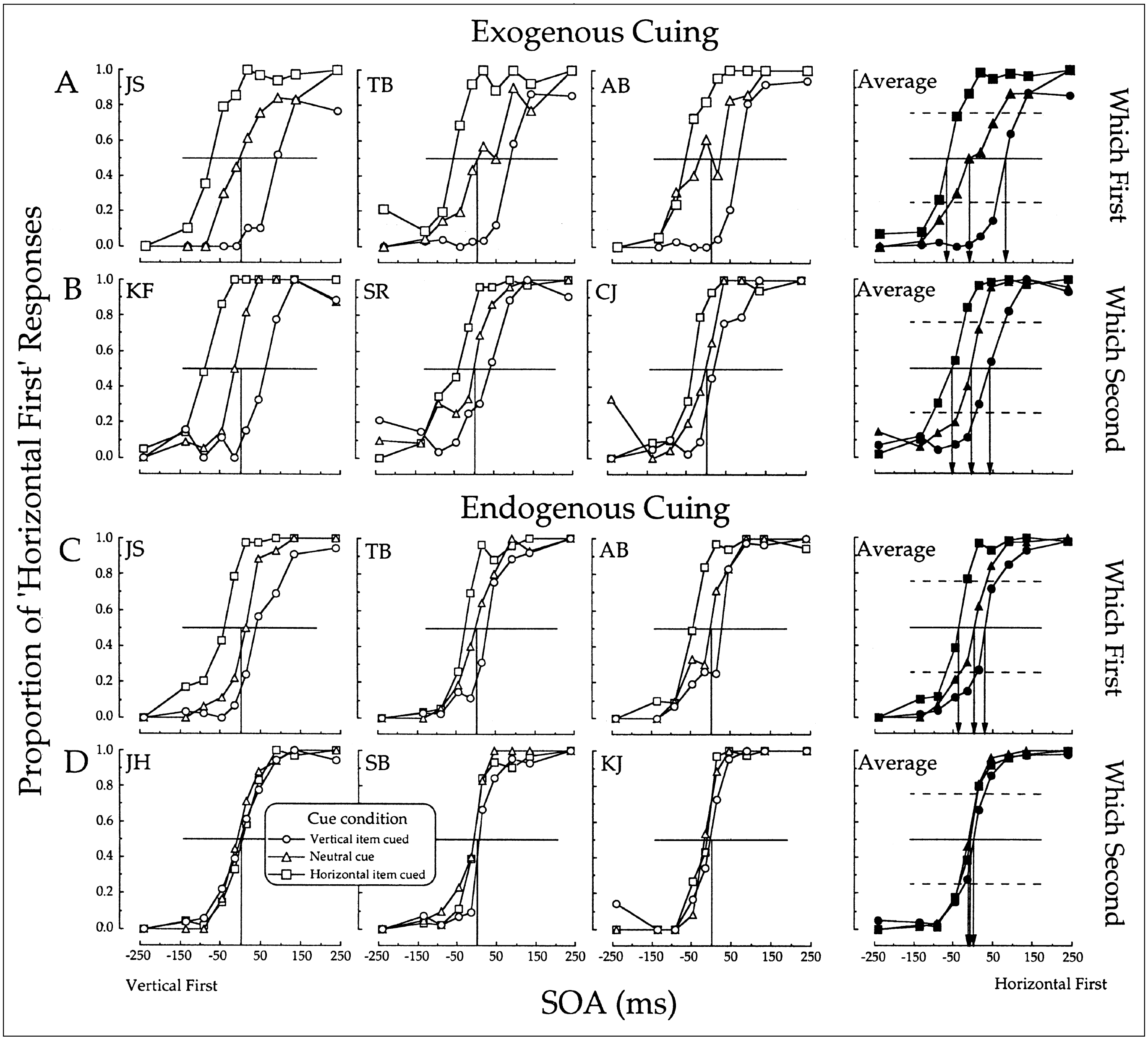


**Fig. 2.** Proportion of "horizontal first" responses as a function of stimulus onset asynchrony (SOA) between vertical and horizontal stimuli. Cues were either exogenous (a, b) or endogenous (c, d), and the observer indicated which orientation was presented first (a, c) or second (b, d). Results for individual observers and averages across observers are shown separately. On nonneutral trials, the left or right side was cued, but for ease of presentation, cue conditions in the figure indicate either the item (vertical or horizontal) at the cued location or that neither item was cued (neutral cue). Negative SOAs indicate that the vertical item was presented first, whereas positive SOAs indicate that the horizontal item was presented first. The solid horizontal and vertical lines in the graphs for the individual observers indicate the points at which they reported "horizontal first" half of the time and the zero-SOA point, respectively. The arrows in the right-most graphs, which show averages across observers, indicate the point of subjective simultaneity for each of the cue conditions; the horizontal lines in these graphs indicate the points at which .75, .50, and .25 of the responses were "horizontal first."

to plot the data in terms of proportion of "horizontal first" responses, it was necessary to convert the cued location into a cued orientation, even though orientation was not cued. Only this way could the effect of attention be clearly seen in the graphed results. As indicated on the bottom of Figure 2, negative SOAs refer to those situations in which the vertical item was presented first, whereas positive SOAs indicate that the horizontal item was presented first.

The PSSs for the bilateral conditions are presented in Table 1. These SOA values were calculated using linear interpolation between the two points (one above and one below) nearest the value at which 50% of the responses were "horizontal first." The effect of prior entry is evident in Figure 2 as the horizontal shift to the left for the horizontal-cued condition and to the right for the vertical-cued condition. The magnitude of the effect was calculated as half of the difference be-

**Table 1.** *Points of subjective simultaneity for individual observers and averaged across observers*

| | Cue condition | | |
|---|---|---|---|
| Task and subject | Vertical | Neutral | Horizontal |
| **Exogenous cue** | | | |
| "Which first?" | | | |
| J.S. | 88 | −6 | −75 |
| T.B. | 82 | 0 | −62 |
| A.B. | 67 | 2 | −66 |
| Mean | 79 | −2 | −68 |
| "Which second?" | | | |
| K.F. | 62 | −15 | −87 |
| S.R. | 40 | −1 | −40 |
| C.J. | 20 | −1 | −34 |
| Mean | 41 | −6 | −54 |
| **Endogenous cue** | | | |
| "Which first?" | | | |
| J.S. | 39 | 15 | −39 |
| T.B. | 28 | −3 | −29 |
| A.B. | 28 | 0 | −16 |
| Mean | 32 | 4 | −28 |
| "Which second?" | | | |
| J.H. | 0 | −9 | 5 |
| S.B. | 6 | −8 | −8 |
| K.J. | −3 | −17 | −11 |
| Mean | 1 | −11 | −5 |

tween these two conditions. This effect was larger following exogenous than endogenous cuing and was clearly moderated by the task performed (i.e., "which first?" vs. "which second?"). Prior-entry effects were smaller (by about 27 ms) for the "which second?" task than for the "which first?" task for both exogenous cuing (74 ms vs. 48 ms, respectively) and endogenous cuing (30 ms vs. 3 ms, respectively; see Table 1).

If the PSS (prior-entry effect) for "which first?" judgments were due entirely to response bias, then the effect would be completely reversed for the "which second?" judgments, whereas if there were absolutely no bias, the prior-entry effect with the two judgments would be identical. Thus, averaging the values from the two tasks yields an estimate of prior entry from which bias has been removed. Thus, the true perceptual prior-entry effect (with the contribution of response bias removed) was approximately 61 ms for exogenous orienting and 17 ms for endogenous orienting. Note that the contribution of response bias can be estimated as 13 ms, which is half the difference between the "which first?" and "which second?" judgments. This shows that even with our design in which cuing and response dimensions were orthogonal, there was still some response bias.

The data from the unilateral conditions are not presented here because observers were at a ceiling in detecting the temporal order of stimulus presentation in this condition. Just-noticeable differences were less than 15 ms, and PSSs were always within 5 ms of zero. Several observers reported using a motion cue—the second stimulus appeared to grow out of the first one—that provided an unambiguous signal to the correct response on these same-location trials. This is clearly related to the phenomenon of illusory line motion (Schmidt & Klein, 1997). Regardless, these trials were important to motivate observers to attend to the endogenous cues (see the Method section).

One might ask how robust the small prior-entry effect for endogenous cuing was—particularly for the "which second?" task, shown in Figure 2d. Two pieces of evidence indicate that prior entry, although small, was indeed operating for this cue type. First, if the effect in the "which first?" task had been due entirely to response bias (i.e., if the prior-entry effect did not exist), then the effect in the "which second?" task should have been completely reversed in sign (cf. Frey, 1990, Experiment 7), but this was not the case. The lack of a cuing effect on TOJs in the "which second?" task with endogenous cues implies that the response-bias effect and the prior-entry effect were both operating, at different stages of processing, and approximately canceling each other out.

The second piece of evidence indicating that prior entry was present with endogenous cuing comes from the following novel analysis of the RT data collected from the temporal-order trials. Although observers were explicitly instructed that the TOJ was unspeeded, their RTs were not uniform across the different SOAs used. On the assumption that the point of maximal uncertainty should produce the largest RT, an analysis of RT as a function of SOA should provide a bias-free index of the PSS.

RT as a function of SOA on bilateral TOJ trials is presented in Figure 3 for each of the four combinations of task and cue type. The results clearly provide converging evidence for prior entry under endogenous orienting. For both tasks, the point of maximum RT is

 

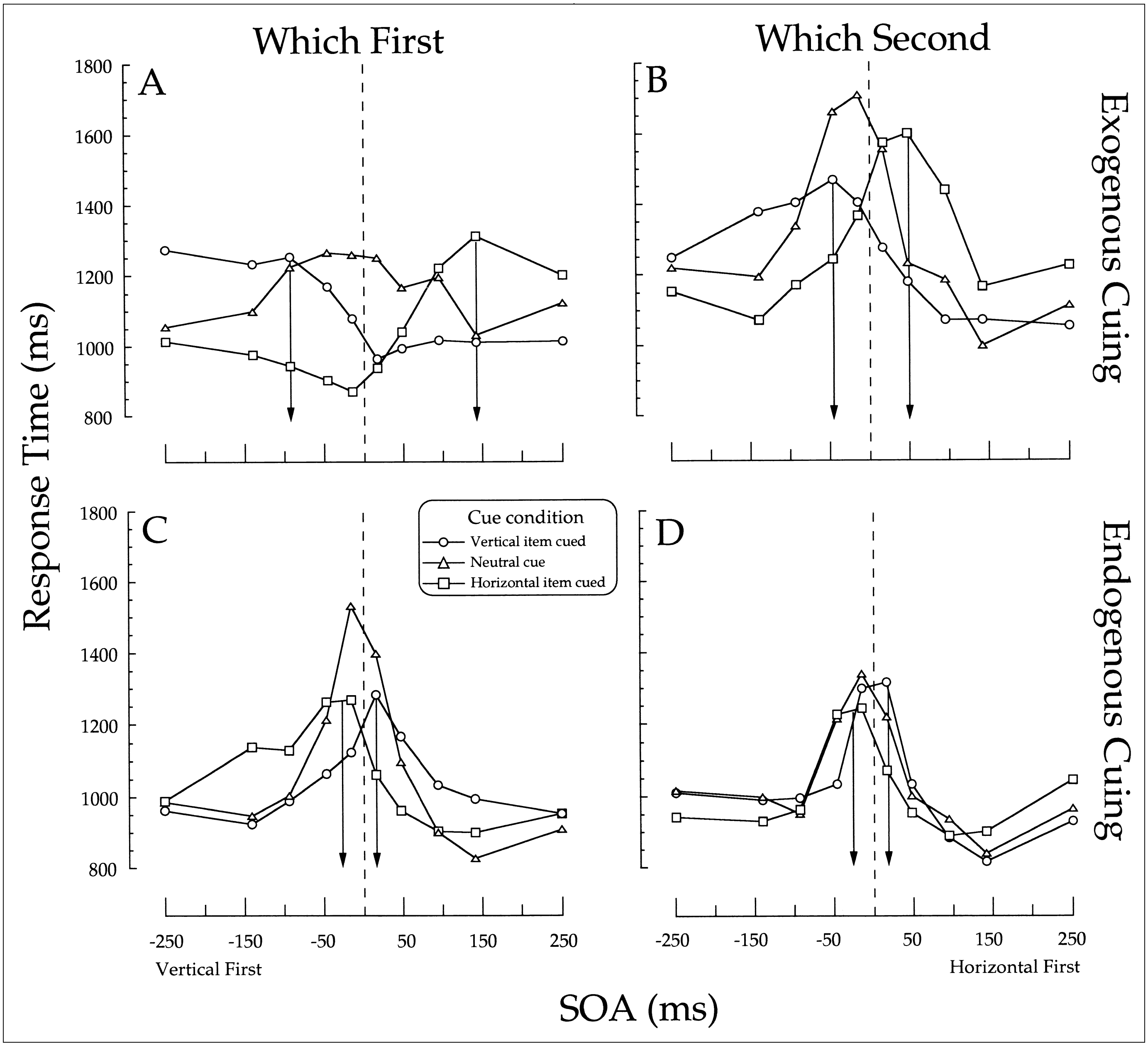


**Fig. 3.** Response latencies as a function of stimulus onset asynchrony (SOA) for exogenous (a, b) and endogenous (c, d) cues for the “which came first?” (a, c) and “which came second?” (b, d) tasks. On nonneutral trials, the left or right side was cued, but for ease of presentation, cue conditions in the figure indicate either the item (vertical or horizontal) at the cued location or that neither item was cued (neutral cue). The data are means of the individual observers’ means. The arrows indicate the approximate SOAs of the maximum response times. Negative SOAs indicate that the vertical item was presented first, whereas positive SOAs indicate that the horizontal item was presented first.

shifted in the direction that would be expected if perceptual arrival times were accelerated by attention. Critically, for the endogenous arrow cues, the magnitude of the shift (15–20 ms) is the same for the two tasks and similar to the prior-entry effect derived earlier from the PSS analysis (17 ms), supporting the claim that this value represents a bias-free measure of prior entry. The data for the exogenous cues are encouraging, but not as clear-cut. Although there is a large shift in the functions as a result of the cuing for the “which first?” task, there is no clear peak in RT, which remains slow once the maximum is reached. In the “which second?” task, there is a clear maximum that shifts about 45 ms in a direction consistent with the cue. This estimate of the prior-entry effect is comparable with the value calculated using the PSSs from both the “first” and “second” judgments to index prior entry. This type of analysis of unspeeded RT data can therefore be used to provide converging evidence for the existence of prior entry. We suggest that in future work using this method, a greater emphasis on the speed of TOJ responses might lead to less noisy RT distributions than we obtained in the exogenous-cuing conditions, and hence to greater consistency between the PSS as inferred from the TOJs and from the point of maximum RT.

## IMPLICATIONS AND FUTURE DIRECTIONS

The major goal of the present research was to assess the doctrine of prior entry (the claim that attended stimuli are perceived prior to unattended stimuli; Titchener, 1908) in a design that both reduced and assessed the role of response bias. We accomplished this by using a novel experimental design in which attention was manipulated in a dimension (space) orthogonal to response demands (orientation; cf. Spence et al., 2001). Furthermore, any residual effect of response bias was assessed by comparing performance in the "which first?" and the "which second?" tasks. Finally, converging evidence for the existence of prior-entry effects was provided by an analysis of RT as a function of SOA.

Prior-entry effects were observed for both exogenous and endogenous orienting, though they were larger following exogenous orienting. Converging evidence for such a difference in the effect of these two modes of orienting on perceptual arrival times can be gleaned from the literature on illusory line motion (for a review, see Schmidt, 2000). With both types of cue, the size of the prior-entry effect was moderated by the response requirements, indicating some residual response bias, even in our orthogonal design. The RT analysis and a comparison across the two tasks rule this out as the sole explanation of our results and converge on the conclusion that prior entry is a real perceptual phenomenon. We believe that the methodology described here addresses Pashler's (1998, p. 260) criticism of previous prior-entry studies and counters his charge that evidence in favor of prior entry is "unconvincing" by providing converging evidence of prior entry when response bias does not provide a viable explanation.

The present findings have clear implications for the interpretation of previous research using TOJ tasks to make claims about the existence of prior entry. Although the role of response bias has been discussed in this literature (cf. Jaskowski, 1993; Stelmach & Herdman, 1991), no definitive resolution has yet been provided (see the introduction). The present data corroborate the concern raised by these previous researchers and provide a novel methodology to address it. Consider that even with the orthogonal design we used, there was some influence of response bias. Tentative support for the claim that response bias was reduced in the present experiment comes from a comparison with previous work by Frey (1990), who first introduced the use of opposing response demands in a nonorthogonal design with endogenous cues. He observed a 58-ms effect for the "which first?" task and a −62-ms effect in the "which second?" task. Thus, according to the logic we have outlined, there was a −4-ms prior effect and a 120-ms response-bias effect. The 13-ms response-bias effect found in the present experiment with an orthogonal design represents a clear reduction. The magnitude of the prior-entry effect cannot be compared between the two experiments given their methodological differences. A more direct comparison should be made in future research.

Given these results, it is reasonable to wonder how large the influence of response bias has been in the majority of previous studies using a nonorthogonal design. The tools introduced here are well suited for making this assessment. For example, consider the report by Robertson et al. (1998). They tested patients who had right parietal lesions and exhibited signs of left neglect using a TOJ task in which the required response was "left" or "right." Given the severe neglect of the left side of space by these patients, it was not surprising that Robertson et al. found a very large (almost 500 ms) PSS favoring stimuli on the right side of space. They claimed that this large asynchrony was a result of the attentional deficit typical of these patients. However, it may have been that these patients were simply unsure which stimulus came first and were biased to respond that the first stimulus was presented in their "good" field when there was any degree of uncertainty. Given that neglect patients may have a temporal-processing deficit independent of a spatial asymmetry (e.g., Husain, Shapiro, Martin, & Kennard, 1997), the range of SOAs for which these patients are uncertain may be large. Moreover, strong biases to respond to stimuli on the ipsilesional side are commonly found with patients of this type (Driver, 1998). Future research should readdress this interesting and important issue using an orthogonal design and a "which second?" task to be sure that the effects observed are attentional in nature, reflecting a genuine prior-entry effect, rather than simply a pathological response bias.

There has been a great deal of interest recently in the use of TOJs in human experimental psychology (e.g., Klein, Schmidt, & Müller, 1998; Rorden et al., 1997; Shimojo, Miyauchi, & Hikosaka, 1997; Spence et al., 2001; Stolz, 1999; Zackon et al., 1997, 1999), and there are several very good reasons for this methodology to be preferred to the more typical RT measures when questions dealing with perceptual levels of processing are being addressed (cf. Klein et al., 1998; Schmidt, 1996). First, there is no need for speeded responding, which carries with it a great deal of baggage concerning the effects of response selection and execution on performance measures (cf. Watt, 1991, p. 213). By removing the pressure to respond quickly, this procedure may provide a more accurate index of the perceptual component of information processing. Second, the use of TOJs may provide a more accurate temporal assessment of relative processing times because the critical comparison is within-trial and is not based on the assumption that differences in response time are due solely to differences in perceptual processing. Finally, this task has obvious appeal to researchers working with patients who tire easily and may become stressed and anxious because of the need to respond quickly under difficult task constraints (e.g., Riese et al., 1999).

**Acknowledgments—**This research was supported by the Rotman Research Institute and by the Killam Trust Funds (Dalhousie University) by way of postdoctoral fellowships to the first author, and by the Natural Sciences and Engineering Research Council of Canada by way of an operating grant to the last author. Also, we thank the Faculty of Graduate Studies at Dalhousie University for supplying travel funds to the first author so that these data could be presented at the 39th Annual Meeting of the Psychonomic Society, Dallas, Texas, November 1997. Finally, we would like to thank Salvador Soto-Faraco, Lew Stelmach, Jim Enns, and two anonymous reviewers for comments on an earlier draft of this article.

## REFERENCES

Abrams, R.A., & Law, M.B. (2000). Object-based visual attention with endogenous orienting. *Perception & Psychophysics, 62,* 818–833.

Allik, J., & Kreegipuu, K. (1998). Multiple visual latency. *Psychological Science, 9,* 135–138.

Boring, E.G. (1929). *A history of experimental psychology.* New York: Appleton-Century.

Briand, K.A. (1998). Feature integration and spatial attention: More evidence of a dissociation between endogenous and exogenous orienting. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1243–1256.

Briand, K.A., & Klein, R.M. (1987). Is Posner's "beam" the same as Treisman's "glue"?: On the relation between visual orienting and feature integration theory. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 228–241.

Cairney, P.T. (1975). Bisensory order judgement and the prior entry hypothesis. *Acta Psychologica*, *39*, 329–340.
Drew, F. (1896). Attention: Experimental and critical. *American Journal of Psychology*, *7*, 533–572.
Driver, J. (1998). The neuropsychology of spatial attention. In H. Pashler (Ed.), *Attention* (pp. 297–340). East Sussex, England: Psychology Press.
Enns, J.T., Brehaut, J.C., & Shore, D.I. (1999). The duration of a brief event in the mind's eye. *Journal of General Psychology*, *126*, 355–372.
Frey, R.D. (1990). Selective attention, event perception and the criterion of acceptability principle: Evidence supporting and rejecting the doctrine of prior entry. *Human Movement Science*, *9*, 481–530.
Heath, R.A. (1984). Response time and temporal order judgement in vision. *Australian Journal of Psychology*, *36*, 21–34.
Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. *Vision Research*, *33*, 1219–1240.
Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature*, *385*, 154–156.
James, W. (1890). *Principles of psychology* (Vol. 1). New York: Holt, Rinehart & Winston.
Jaskowski, P. (1993). Selective attention and temporal-order judgement. *Perception*, *22*, 681–689.
Klein, R.M. (1994). Perceptual-motor expectancies interact with covert visual orienting under conditions of endogenous but not exogenous control. *Canadian Journal of Experimental Psychology*, *48*, 167–181.
Klein, R.M., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 46–65). New York: Springer-Verlag.
Klein, R.M., Schmidt, W.C., & Müller, H.K. (1998). Disinhibition of return: Unnecessary and unlikely. *Perception & Psychophysics*, *60*, 862–872.
Klein, R.M., & Shore, D.I. (2000). Relations among modes of visual orienting. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 195–208). Cambridge, MA: MIT Press.
Mollon, J.D., & Perkins, A.J. (1996). Errors of judgement at Greenwich in 1796. *Nature*, *380*, 101–102.
Pashler, H.E. (1998). *The psychology of attention*. Cambridge, MA: MIT Press.
Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.
Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.
Riese, H., Hoedemaeker, M., Brouwer, W.H., Mulder, L.J.M., Cremer, R., & Veldman, J.B.P. (1999). Mental fatigue after very severe closed head injury: Sustained performance, mental effort, and distress at two levels of workload in a driving simulator. *Neuropsychological Rehabilitation*, *9*, 189–205.
Robertson, I.H., Mattingley, J.B., Rorden, C., & Driver, J. (1998). Phasic alerting of neglect patients overcomes their spatial deficit in visual awareness. *Nature*, *395*, 169–173.
Rorden, C., Mattingley, J.B., Karnath, H.-O., & Driver, J. (1997). Visual extinction and prior entry: Impaired perception of temporal order with intact motion perception after unilateral parietal damage. *Neuropsychologia*, *35*, 421–433.
Schmidt, W.C. (1996). Inhibition of return is not detected using illusory line motion. *Perception & Psychophysics*, *58*, 883–898.
Schmidt, W.C. (2000). Endogenous attention and illusory line motion reexamined. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 980–996.
Schmidt, W.C., & Klein, R.M. (1997). A spatial gradient of acceleration and temporal extension underlies three illusions of motion. *Perception*, *26*, 857–874.
Sekuler, R., & Erlebacher, A. (1971). The invalidity of "invalid results from the method of constant stimuli": A common artifact in the methods of psychophysics. *Perception & Psychophysics*, *9*, 309–311.
Shimojo, S., Miyauchi, S., & Hikosaka, O. (1997). Visual motion sensation yielded by non-visually driven attention. *Vision Research*, *12*, 1575–1580.
Spence, C., Shore, D.I., & Klein, R.M. (2001). *Multisensory prior entry.* Manuscript submitted for publication.
Spence, C.J., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms facilitate sound localization. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 555–574.
Stelmach, L.B., Campsall, J.M., & Herdman, C.M. (1997). Attentional and ocular movements. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 823–844.
Stelmach, L.B., & Herdman, C.M. (1991). Directed attention and perception of temporal order. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 539–550.
Stelmach, L.B., Herdman, C.M., & McNeil, K.R. (1994). Attentional modulation of visual processes in motion perception. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 108–121.
Stolz, J.A. (1999). Word recognition and temporal order judgements: Semantics turns back the clock. *Canadian Journal of Experimental Psychology*, *53*, 316–322.
Titchener, E.B. (1908). *Lectures on the elementary psychology of feeling and attention.* New York: Macmillan.
Vanderhaeghen, C., & Bertelson, P. (1974). The limits of prior entry: Nonsensitivity of temporal order judgements to selective preparation affecting choice reaction time. *Bulletin of the Psychonomic Society*, *4*, 569–572.
Watt, R.J. (1991). *Understanding vision*. London: Academic Press.
Zackon, D.H., Casson, E.J., Stelmach, L., Faubert, J., & Racette, L. (1997). Distinguishing subcortical and cortical influences in visual attention. *Investigative Ophthalmology and Visual Science*, *38*, 364–371.
Zackon, D.H., Casson, E.J., Zafar, A., Stelmach, L., & Racette, L. (1999). The temporal order judgement paradigm: Subcortical attentional contribution under exogenous and endogenous cuing conditions. *Neuropsychologia*, *37*, 511–520.

(RECEIVED 1/21/00; REVISION ACCEPTED 9/15/00)