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THE ALLOCATION OF ATTENTION ON A PERPENDICULAR VISUAL DISPLAY DURING REACHING MOVEMENTS IN DEPTH

HIROSHI NAITO*†, TOSHIAKI MIURA, AND TAKAHIKO KIMURA

Graduate School of Human Sciences, Osaka University,
1-2, Yamadaoka, Suita, Osaka, 565-0871, Japan
**E-mail: naito@hus.osaka-u.ac.jp*

We investigated how visual attentional resources are allocated during reaching movements. Particularly, this study examined whether or not the direction of the reaching movement affected visual attention resource allocation. Participants held a stylus pen to reach their hand toward a target stimulus on a graphics tablet as quickly and accurately as possible. The direction of the hand movement was either from near to far space or the reverse. They observed visual stimuli and a cursor, which represented the hand position, on a perpendicularly positioned display, instead of directly seeing their hand movements. Regardless of the movement direction, the participants tended with quickly responding to the target stimuli located far from the start position as compared with those located near to the start position. These results led us to conclude that attentional resources were preferentially allocated in the areas far from the start position of reaching movements. These findings may provide important information for basic research on attention, but also contribute to a decrease of human errors in manipulation tasks performed with visual feedback on visual display terminals.
Key words: attentional resource; depth; representation; computer display

INTRODUCTION

In our daily lives, attention plays an important role in how we process stimuli around us. Although various visual stimuli may be present, we must select only a few stimuli to process at any one time because of our limited processing capacity. Known as selective attention, the spatial characteristics of this mechanism have been investigated for a number of years in two-dimensional space. A flanker paradigm is a method in which a target stimulus is presented with distractor stimuli (Eriksen and Eriksen, 1974). In this method, spatial characteristics of attentional resources allocation are examined by comparing the amount of interference effect of the distractor. A pre-cuing paradigm is another method (Posner et al., 1978; Posner et al., 1980). In this paradigm, a target position is indicated by a preceding cue. However, the cue sometimes indicates an incorrect position of the target (invalid trial). In invalid trials, participants might shift their attention from the cued position to the target appearance position. Spatial characteristics of attentional resources allocation are examined by comparing the efficiency of the shift.

In three-dimensional space, attentional resources allocation in depth has been examined by using the flanker paradigm, the pre-cuing paradigm and others. It has been shown that attentional resources may be preferentially allocated within near space, closer to the observer's body, as compared to far space (Andersen and Kramer, 1993; Downing and Pinker, 1985; Gawryszewski et al., 1987; Miura et al., 1994, 2002). This directional asymmetry in the allocation of attentional resources is called as a *viewer-centered representation*. Moreover, Miura et al. (1994, 2002) indicated that this asymmetry was more clearly shown when the observer was moving forward than in a static situation.

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The spatial allocation of attentional resources has also been examined in situations when a hand actively reached toward target objects (Tipper et al., 1992). Tipper et al. (1992) had participants reach out and press a target button while ignoring a distractor button, with buttons positioned in a three-by-three matrix approximately 11° off of the horizontal plane. A start button was positioned either in front of (in the near start condition) or beyond (in the far start condition) potential target buttons. The rationale was that if the distractor button served to draw attention, it should induce action, just like the target button. Therefore, to respond accurately, the participants needed to inhibit the action toward the distractor. As the attention directed toward the distractor increased, the effort required to inhibit the induced action would also increase, as would reaction times to the target button. Results showed that the near start condition considerably increased the reaction times when the distractor button was presented between the target button and the start button. The far start condition also increased the reaction times in the same situation. This effect implied that, regardless of the movement direction, attentional resources were preferentially allocated between the start and terminal positions of the hand movement. This pattern of attentional allocation is called as an *action-centered representation*.

Subsequent research has examined the action-centered representation (e.g. Lyons et al., 1999; Meegan and Tipper, 1998, 1999; Welsh and Elliott, 2004; Welsh et al., 1999). Lyons et al. (1999) examined how attentional resources are allocated during a reaching task on a graphics tablet with visual feedback on a computer display. The stimuli configuration was similar to the one used by Tipper et al. (1992), except that participants observed the stimuli and their hand movements indirectly on a computer display. In experiment 1, they observed their movement in a vertical direction, as indicated by a mouse cursor on the display positioned perpendicularly. In experiments 2 and 3, participants observed the mouse cursor movements as their hand movements in depth, which were indicated on the approximately horizontal plane on a mirror (Exp. 2) or semi-transparent mirror (Exp. 3) positioned between the tablet and their eyes. Only in experiments 2 and 3 did a distractor in the movement path cause interference effects on the initiation times of hand movements. These results suggest that the alignment of visual perception and action is an important factor, whether the distractor causes an interference effect or does not. However, some studies showed that distractor interference effects did not necessarily occur even when visual perception and action spaces were aligned (Welsh and Elliott, 2004; Welsh et al., 1999). Welsh and colleagues interpreted the absence of distractor interference effects as suggesting that participants might initiate their reaching movement before completing the processing of discrimination between target and distractor stimuli.

Even though Lyons et al. (1999) showed an absence of distractor interference effects on the initiation time, there has been little strong evidence to contradict the notion that hand reaching actions in depth change characteristics of attentional resources allocation in a vertical space. If individuals become familiar with well-suited relations between visual feedback on a vertical display and their own hand movement in depth, they will readily establish an internal representation of the perception-action spatial relationship. Thus, the present study aimed to investigate how visual attentional resources are allocated in a vertical space during reaching movement. In addition to the task adopted in experiment 1 by Lyons et al. (1999), we used a bi-directional paradigm in order to examine the effect of movement direction on attentional resources allocation. According to the action-centered representation hypothesis, it was expected that the duration to initiate hand reaching motion toward a target stimulus would become longer if a distractor stimulus was presented near to the apparent start position on a display in terms of hand reaching motion, regardless of the distance of actual start position relative to the body. A multitude of manual tasks are commonly performed in a workplace setting using an upright display. The present study has a potential to contribute to basic research on attention and applied research in such a workplace.

METHODS

Participants

Eight graduate and undergraduate students (four males and four females; 21.1 ± 2.2 years) participated. All the participants were right-handed and had either normal or corrected to normal binocular vision. Verbal informed consent was obtained from each participant.

Apparatus and stimuli

The experimental set-up is shown in Figure 1. During testing, the participant was seated in a dark room. Visual stimuli were presented on a 15-inch liquid crystal display (LCD-A15H, IO DATA) and a liquid crystal tablet (LCD Tablet PL-550, WACOM) under control of a PC. The display was positioned perpendicular to the table surface, approximately 65 cm in front of the participant. The tablet was tilted at approximately 12° off the table surface. Participants observed the stimuli on the display with their head positioned on a chin rest. They held the stylus pen with their right hand and moved it in contact with the surface of the tablet. A black wooden cover was positioned such that the participants could not see their hand. Two dimensional coordinates of the stylus pen on the tablet were recorded every 20 ms (50 Hz). The maximum spatial resolution of the tablet to detect displacements of a stylus pen was 0.05 mm with an error of ± 0.5 mm.

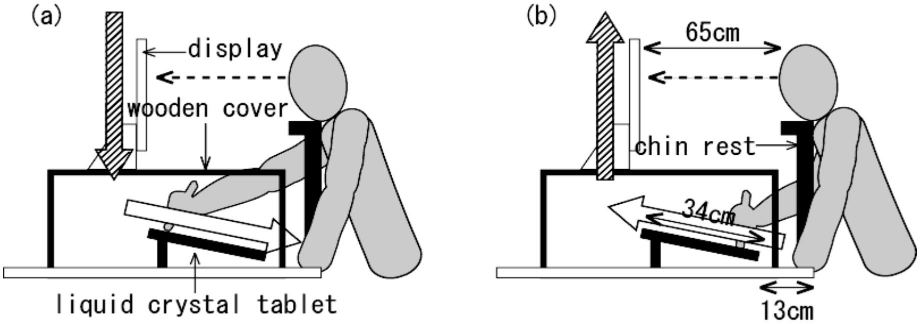

Fig. 1. Experimental set-up. (a) the far start condition and (b) the near start condition. The white arrows represent the movement direction of the hand. The slashed arrows represent the movement direction of the mouse cursor. The dashed arrows represent the visual directions.

Nine placeholders (blue discs, 7 mm (0.06°) in diameter) were displayed in three rows and three columns with a center-to-center distance of 4 cm (3.52°) between each rows and between columns (Figure 2). These placeholders indicated the explicit area in which visual stimuli such as a target and a distractor would appear. In addition, a red circle (8 mm (0.07°) in diameter) indicating the start position of hand movements and a green disc cursor (2 mm (0.02°) in diameter) representing the stylus pen position were shown on the display. Far to near movements were represented as bottom-to-top movement and vice versa on the display. The continuous displacement of the pen on the tablet produced the same displacement of the cursor on the display. The cursor motion upward or downward corresponded to the pen (hand) motion forward or backward in depth, respectively. The center-to-center distance from the start circle to the nearest placeholder disk was 5 cm. The background of the display was black.

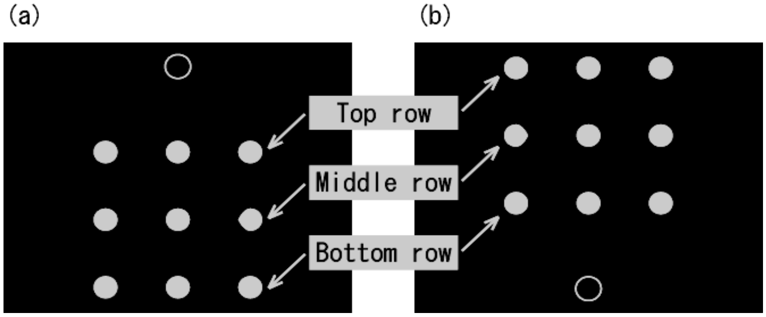

Fig. 2. Layout of the placeholders and the start positions. These were presented on the display (see Figure 1) at the beginning of each trial. Nine gray (actually blue in the experiment) discs represent the placeholders. The gray (actually red in the experiment) circles represent each start position. (a) the far start condition, (b) the near start condition (see the text for details). The actual sizes of stimuli are described in the text.

Procedures

Participants were instructed to move the cursor, by manipulating the stylus pen, from the start position to the target as quickly and accurately as possible while ignoring the distractor. At the beginning of each trial, they were required to place the cursor inside the start circle and then fixate on the center placeholder. Interviews after the experiment confirmed that all the participants fixated on it in the majority of trials (more than 80%). To initiate the trial, the participant pressed the enter key on a PC keyboard with their left index finger. Then, one of the placeholders turned red, indicating the target, at 2000, 2500, or 3000 ms after the enter key was pressed. The presentation of the target occurred simultaneously with another one of the remaining placeholders turning yellow, indicating the distractor. Two placeholder discs for the target and distractor remained lit until 1000 ms elapsed after the participants had placed the cursor on the target disc.

The target randomly appeared at one of the nine placeholders. In terms of the position of the distractor relative to the target's position as viewed from the bottom of the display, but not from the start position, there were four distractor conditions: (1) the distractor appeared in the lower row (LR) (the nearer row on LCD Tablet), (2) the distractor appeared in the same row (SR) (the same row on LCD Tablet), (3) the distractor appeared in the upper row (UR) (the further row on LCD Tablet), and (4) no distractor appeared (ND). It should be noted that for the ND condition, the target appeared only in the middle row, and that for the LR, SR, and UR conditions, the target and distractor could appear diagonally. Example layouts of the target and distractor in each of the four distractor conditions are shown in Figure 3.

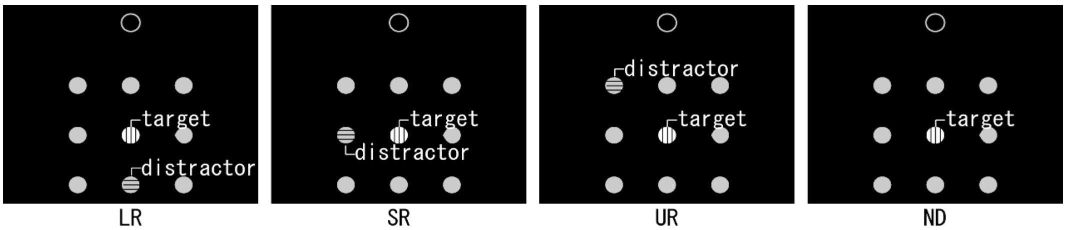

Fig. 3. Examples of each distractor condition. The conditions are shown below each figure; the far start position condition is indicated. As depicted in the figures, the white discs with vertical lines represent the targets (actually red) and the gray discs with horizontal lines represent the distractors (actually yellow). (Other placeholders were actually blue.) The actual sizes of any stimuli are described in the text.

In addition, in order to investigate the effects of movement direction on visual attention, the start circle was positioned either higher (further) than the placeholders (top start position) or lower (nearer) than the placeholders (bottom start position) on the display. Respective start positions required the participants to move their unseen hand from far to near space or from near to far space in depth. The condition regarding the start position was blocked, and the order of the two condition blocks was counterbalanced between the participants. Namely, half of the participants began the top start condition block first and the others did the bottom start condition block. The four distractor conditions were pseudo-randomly presented in each block. Prior to each block, the participants had two sets of 20 practice trials including all the four distractor conditions. Then, they performed 252 trials in each start condition block.

Data analysis

The present study aimed to examine the effects of the direction of reaching movements on the allocation of visual attention resources prior to motor execution. There was a possibility that attention might influence kinematic properties of reaching movements such as movement duration and movement speed. A preliminary analysis of the collected data did not demonstrate that the movement duration could reflect particular effects of the movement direction on the allocation of visual attention resources, at least in the experimental paradigm employed here. Thus, this paper focused on the analysis of reaction times.

The reaction time was defined as the time between the target appearance and the movement initiation. The movement initiation was determined by the displacement from an initial position of the stylus pen inside the start circle. A software programme automatically judged that if the pen's displacement was over 1 mm, the reaching movement would have started. To eliminate incomplete trials such as anticipatory responses, reaction times below 150 ms were excluded from the analysis.

RESULTS

Analysis of the interference effects

In fact, the target was presented on every placeholder. However, in order to examine the interference effects of the distractors on the reaction time, the data from which the target appeared in the middle row were selected for statistical analyses. This was because the cases of the middle row targets were necessarily included in all the four distractor conditions.

Reaction times were submitted to a two-way ANOVA, with the start position (top and bottom) and the distractor condition (LR, SR, UR, and ND). The main effect of the distractor condition was found ($F(3, 21) = 8.41$, $p < .001$). Neither the main effect of the start position ($F(1, 7) = 4.72$, $p > .05$) nor the interaction ($F(3, 21) = 1.64$, $p > .10$) were significant. Figure 4 shows the mean reaction times for each distractor condition. The post hoc Tukey's HSD test indicated that the mean reaction time for SR (369 ms) was shorter than those for LR and UR (382 and 383 ms, respectively). The mean reaction times for LR, SR, and UR did not significantly differ from that for ND (377 ms). These results suggest that the distractors had no interference effects and that the presence of the distractor might facilitate participants' reactions, particularly under the SR condition. This does not imply that characteristics of the attentional resource allocation can be further examined based on interference effects of the distracting stimuli.

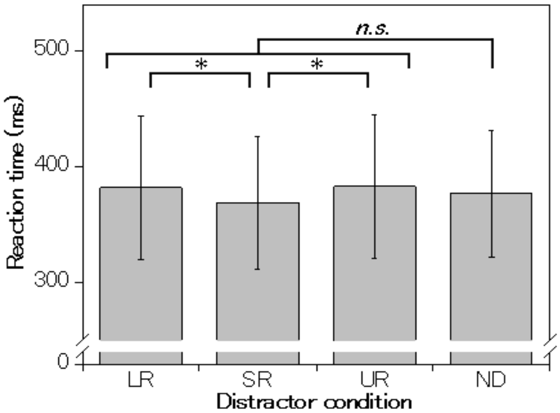

Fig. 4. Mean reaction times as a function of distractor condition. Error bars indicate standard deviations.

Analysis of the target appearance rows

The previous analysis revealed that simultaneous presentation of the distractor did not produce significant interference effects. Thus, the relationship between attentional resources allocation and reaching motion was further examined by using another approach. This was designed according to a theoretical assumption: the visual stimulus presented at a special location where a great quantity of attentional resources is allocated can decrease the reaction time. In order to minimize the possible influence of the distractor appearance position, we analyzed reaction time data only for SR condition trials. Under the SR condition, the target was presented at every placeholder and appeared in the same row as the distractor. The data collected under the SR condition were divided into three data categories for the target appearance row and then a difference in the reaction time was statistically tested between these three categories.

Figure 5 shows the mean reaction times for each of the three data categories (top, middle, and bottom rows) for each start position (top and bottom). The two-way ANOVA revealed a significant main effect of the target appearance row ($F(2, 14) = 15.48$, $p < .0005$). The main effect of the start position was not significant ($F(1,7)=1.85$, $p > .10$). This main effect was not interpreted, because there was a significant interaction between the start position and the target appearance row ($F(2, 14) = 26.49$, $p < .0001$).

Since the significant interaction was found, post hoc Tukey's HSD tests were carried out separately for respective start positions. In the case of the top start position, the mean reaction times for the middle row (359 ms) and lower row (372 ms) were shorter than that for the upper row (407 ms). Moreover, for the bottom start position, the mean reaction time for the middle row (379 ms) was shorter than that for the lower row (405 ms). The mean value for the upper row (395 ms) did not significantly differ from those for the other two rows. These results suggest that the participants tended to quickly respond to the visual stimuli located far from the start position, as compared to those located near to the start position, regardless of the movement direction.

DISCUSSION

Interference effects of distractors

Contrary to our expectation, this study did not demonstrate that the distractor stimuli definitely interfered in visual information processing of the target stimuli prior to the execution of reaching movements. This is consistent with the findings obtained from past studies (Lyons et al., 1999, Exp.1; Welsh and Elliott, 2004; Welsh et al., 1999). It is suggested that physical properties of the dis-

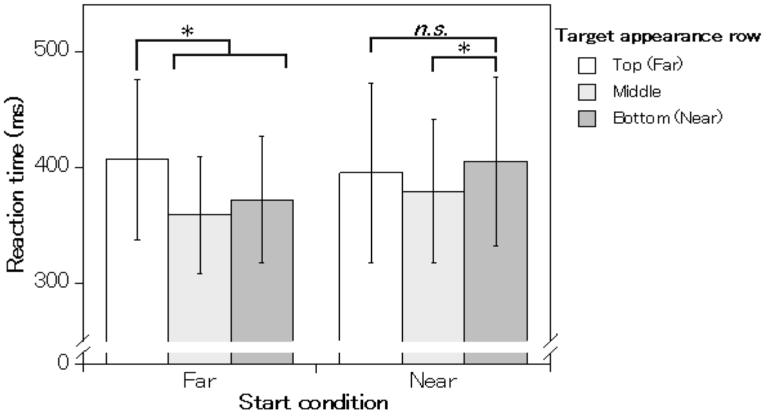

Fig. 5. Mean reaction times in each start condition as a function of the target appearance rows. Error bars indicate standard deviations.

tractor stimulus are responsible for no interference effects. In the present experiments, the distractor as well as the target, were visually presented on a flat surface of the computer display. Such a visual stimulus has a less obstructive effect on reaching movements (Welsh and Elliott, 1999). In contrast, the use of three dimensional objects (e.g., buttons) can obstruct movements, and participants must pay attention to obstacle objects in order to avoid a collision with them (Meegan and Tipper, 1998, 1999; Tipper et al., 1992). Thus, in the present study, the visual distractor stimuli on the computer display might not have acted as a distractor that required attention.

There is another possible reason for the lack of interference effects. Welsh and his colleagues hypothesized that a strategy to minimize the reaction time may be relevant to this issue (Welsh and Elliott, 2004; Welsh et al., 1999). Welsh et al. (1999) examined the temporal effects of distractor stimuli. In some trials, the disractor was presented before the target appearance. The results showed that in those trials, participants tended to initiate their hand movements to the target earlier than when the distractor appeared simultaneously or after the target appeared. That is, the participants tended to start their reaching movements before discriminating a target stimulus from a distractor stimulus and then correct the path of their hand trajectories toward the target to be reached. The results of our previous study (Naito et al., 2006) suggest that participants adopted this strategy in tasks similar to those by Welsh et al. (1999). The present study did not include any procedures to determine the timing of the movement initiation relative to the stimulus discrimination. Nevertheless, factors such as participants' strategy and special circumstances of the experimental setup appear to result in no interference effects.

Since there was no interference effect, we rejected the hypothesis that the presentation of the distractor was useful to explore characteristics of the attentional resources allocation. A newer paradigm specifically designed to elicit interference is needed in order to fully understand this issue.

The other important finding from the first analysis is that the mean reaction time for the SR was shorter than that for the LR and UR. This was obviously because one stimulus in the SR condition was positioned on the fixation point. If the participants did not discriminate the stimuli before initiating their reaching movement, the stimulus on the fixation point may have resulted in the participants detecting the stimuli (in this case the distractor) earlier in the SR condition than in the other conditions (including the ND condition).

Differences in reaction time: start position and distance

The major finding from the second analysis is that selective attention varies depending on the distance of reaching. Indeed, during the reaching movement in depth, the participants quickly responded to the targets' appearance in areas in the intermediate or longer distance from the movement starting positions, as compared to those in the shorter distance. These results are inconsistent with predictions according to the action-centered representation hypothesis (Meegan and Tipper, 1998, 1999; Tipper et al., 1992). Rather, the present results can be explained by assuming that the allocation of attentional resources is biased toward the fixation point and/or the areas further from the starting position. More importantly, this tendency seems to be notable if the hand is approaching from far to near space.

As discussed above, the distractor interference effects were absent in the present study. This means that the reaction times observed here were less restricted by temporal requirements to inhibit actions toward the distractors. It may be speculated that the differences in the reaction time between the targets' appearance areas reflect characteristics of the processing speed to shift the actors' attention from one point to another point. In this view, the increased time to shift attention from the fixation point (the center placeholder) to peripheral areas (i.e., the targets and/or distractor that appear in the lower and upper rows) would result in longer reaction times. The distance from the eye-fixation point to each of the lower and upper rows on the display is identical. Theoretically, if attentional resources were equally allocated over the lower and the upper rows, there should have been similar reaction times for the stimulus in each area. However, the present results showed that when the direction of attentional shift and hand movement was the same, the reaction times were shorter than when the direction was reversed. This suggests that there is an asymmetrical allocation of attentional resources between the nearer and the further area from the start position. We may assume that actions have synergistic effects on visual attentional shift when the direction of visual attentional shift and the hand movement is same.

Furthermore, in the bottom start condition, other factors might affect the allocation of attentional resources because there was no significant difference between the top row and bottom row target. Two reasons may be considered to explain why no significant difference was found. The first is that in peripersonal space (an area to which we can reach our hands without any transfer of standing position, within an approximately 2 m radius from the center of the body), attention is allocated more to the lower visual field (Previc, 1998). The second is that attention operates on a viewer-centered representation. Although the participants observed the target vertically, they performed the hand reaching movement in depth. Because the top on the computer display was positioned in the far row in depth, according to the viewer-centered representation, in space further from the participants' bodies, the attentional resource would be reduced as compared with the position nearer to the participants' bodies. According to both hypotheses, the attentional resources were allocated less to the upper field in this study, and it caused the reaction time to be longer than speculated if attention was evenly allocated. Taken together, attentional shift might be faster toward (1) the same direction of hand movement, (2) the lower area in the display, (3) the area nearer to the observers' bodies, and these tendencies might be additive.

Finally, our findings suggest a way to improve the efficiency of providing the signal or information to operators performing visual display terminal (VDT) tasks. For example, when an operator moves their hand from near space to far space when moving robot arms represented on a perpendicular display, information (e.g. what action to perform next) should be placed in the upper area of the display to decrease reaction times. In contrast, when the operator moves their hand from far space to near space, the information should be placed in the lower area of the display. Further studies based on the present study could lead to finding the appropriate ways to make the man-machine interaction safer and more efficient.

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