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INFLUENCE OF HAND POSITION ON THE NEAR-EFFECT IN 3D ATTENTION

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Abstract

Voluntary reorienting of attention in real depth situations is characterized by an attentional bias to locations near the viewer once attention is deployed to a spatially cued object in depth. Previously this effect (initially referred to as the 'near-effect') was attributed to access of a 3D viewer-centred spatial representation for guiding attention in 3D space. The aim of this study was to investigate whether the near-bias could have been associated with the position of the response-hand, always near the viewer in previous studies investigating endogenous attentional shifts in real depth. In Experiment 1, the response-hand was placed at either the near or far target depth in a depth cueing task. Placing the response-hand at the far target depth abolished the near-effect, but failed to bias spatial attention to the far location. Experiment 2 showed that the response-hand effect was not modulated by the presence of an additional passive hand, whereas Experiment 3 confirmed that attentional prioritization of the passive hand was not masked by the influence of the responding hand on spatial attention in Experiment 2. The pattern of results is most consistent with the idea that response preparation can modulate spatial attention within a 3D viewer-centred spatial representation.

INTRODUCTION

Over the last twenty years, evidence for a depth aware representation underlying spatial attention has accumulated. Studies investigating the nature of selective attention in 3D space have reported reliable effects of location cues to 'near' and 'far' locations on performance measures in real depth situations (Gawryszewski, Riggio, Rizzolatti & Umiltá, 1987; Downing & Pinker, 1985; Couyoumdjian, Di Nocera & Ferlazzo, 2003), in stereoscopic displays (e.g. Atchley, Kramer, Anderson & Theeuwes, 1997; Atchley & Kramer, 1998; Theeuwes, Atchley & Kramer, 1998; Bourke, Partridge & Pollux, 2006) in perceived space (Han, Wan & Humphries, 2005) and within pictorial scenes (Parks & Corballis, 2006). Particularly in 'real depth' experimental situations, deployment of attention is characterized by an asymmetric effect of spatial cueing, first referred to as the 'near-effect' by Gawryszewski et al. in 1987. In this study spatial attention was cued at fixation with high probability to one of two target LEDs, one located near the viewer and the second at a depth beyond fixation but still within reaching space. Their results showed that detection times were greater when the target was presented at the un-cued location, but this effect of cueing varied with direction. Detection times for targets at the far location when attention had been cued to the near LED were greater than when attention was cued to the far location and the target was presented at the near LED (Gawryszewski et al., 1987). Comparable asymmetric effects have been observed within pictorial scenes (Parks & Corballis, 2006) and in stereoscopic depth where reorienting from near to far locations is associated with greater error costs (Atchley, et al., 1997, but see Atchley & Kramer, 1998, for an exception). A few studies have further shown that the distribution of attention in depth is characterized by a gradient which is maximal at attentional focus and declines at more peripheral locations (Andersen, 1990; Downing & Pinker, 1985). Andersen (1990) presented random-dot stereograms of horizontal or vertical bars at the centre with distractor bars presented at the either the same or different depths as the centre bars, and found that performance declined as a function of distance from attentional focus. In real space, Downing & Pinker (1985) also showed that the cost of reorienting to stimuli at un-cued locations (varying in horizontal distance and in depth) was greater when the un-cued target was at a different depth. Their analysis of reorienting 'cost' in relation to distance from attentional focus further showed that attention seems to decline as a function of a gradient defined in terms of visual-angle separation, and that this decline is stronger for stimuli presented at a different depth than the attentional focus.

While the number of studies reporting the near-bias is increasing in the literature, little is known about the processes underlying the effect. In Gawryszewski et al.'s (1987) original explanation, the near-effect was associated with a viewer-centred spatial representation accessed for guiding attention in 3D space. They proposed that an attentional space is dynamically created between the attended object and the viewer in response to the spatial depth cue. More specifically, when attention is cued to the near location, Gawryszewski et al. (1987) argue that attention spreads from the maximal focus of attention to the observer. As a result, spatial awareness is enhanced at the near relative to the far location when the target is presented in this condition. When attention is cued to the far location, the attentional space extends from the far location to the body, resulting in equal spatial awareness of the near and far LED when the target is presented. Consequently, reorienting attention from the cued near location to far target LED is relatively slower (associated with longer target detection times) than reorienting from the cued far location to the target near the viewer.

The idea that the near-effect may reflect a general attentional bias towards near stimuli is not supported by existing findings, as detection times to near and far targets are generally comparable when the cue predicts the target location correctly in real depth situations (Gawryszewski et al., 1987; Couyoumdjian et al., 2003). Couyoumdjian et al. (2003) further showed that the near-effect seems to be independent of the boundary between peripersonal and extrapersonal space. Although the authors found that cueing effects on target detection times were greater in a condition where cued and target locations were separated by the boundary between peripersonal and extrapersonal space (1 meter), as compared to the situation where both cued and target locations were either within peripersonal or extrapersonal space, this boundary effect did not interact with reorienting direction. A comparable near-effect was observed across all conditions, suggesting that the reorienting bias is independent of the proposed functional specialisation of 3D space (Couyoumdjian et al., 2003; Previc, 1998).

Although explanations to date assume that near-effect is associated with access to a viewer-centred representation for guiding attention in 3D space (e.g. Downing & Pinker, 1985; Gawryszewski et al., 1987; Atchley et al., 1997; Parks & Corballis, 2006), converging evidence suggests that the distribution of spatial attention in peripersonal space can be influenced by the position of the viewer's hand when performing tasks involving manual responses (e.g. Mattingley, Robertson & Driver, 1998; Eimer, Forster, van Velzen, & Prabhu, 2005, Eimer & van Velzen, 2006). In a neuropsychological investigation of visual extinction, Mattingley et al. (1998) showed for example that extinction of stimuli within left space was reduced when stimulus presentation was initiated by a key-press with the patient's left hand. ERP findings reported by Eimer et al. (2005) further showed that when one hand was cued for responding (lift of index finger), somatosensory ERP components elicited by (task irrelevant) tactile stimuli presented between cue-onset and a 'go' or 'no-go' signal were enhanced. Both findings were considered consistent with the idea that preparation of manual responses is associated with shifts of attention to the response hand (Eimer et al., 2005, Eimer & van Velzen, 2006) or with enhanced spatial awareness within the visual field where the response hand is located (Mattingley et al., 1998).

A different line of evidence suggests that under certain task conditions attention is prioritized to the location of the viewer's hand, even when this hand is not used for responding (Reed, Grubb & Steel, 2006). Reed et al. (2006) used a horizontal cueing task (presented on a computer screen) with highly predictive cues for target location. Participants were instructed to place one hand in close proximity to one of the two possible target locations whilst responding with the other hand (positioned away from the screen) at detection of the targets. Across five experiments, detection times to targets presented close to the passive hand were found to be faster than to targets presented at the alternative location, independent from cue validity. This attentional prioritization effect persisted when the hand was hidden from view and when replaced by a fake rubber glove, but was absent when replaced by a visual anchor. It appears that proprioceptive information received from the hand is sufficient for attentional prioritization of space around the hand, but visual information is not sufficient unless a connection is made between the visual input and the actual hand. Reed et al further showed that the extent of the prioritized area around the passive hand was relatively small, as the effect disappeared when the hand was placed towards the side of the computer screen, increasing horizontal distance between stimulus and hand to 11 cm. The consistency between this pattern of results and characteristics of bimodal neurons in peripersonal space (e.g., Graziano & Gross, 1995) suggests the attentional prioritization effect is likely to reflect the influence of bimodal hand-centred representations on spatial attention (Reed et al., 2006).

The accumulating evidence for hand-centred attention in peripersonal space raises the question of whether allocation of spatial attention in the depth cueing task is influenced by the position of the response hand. As the hand was always positioned near the viewer in previous studies investigating attention in real depth situations, the near-effect could have been associated with a bias to the response hand instead of a bias to viewer-centred near space. The present study aims to investigate this question by varying the position of the responding hand whilst performing the depth cueing task. In Experiment 1, participants placed their response hand at the same depth of either a 'near' or 'far' target LED. If the near-bias in reorienting of attention reflects a bias towards the response hand, then placing the hand at the same depth as the far LED may reverse the reorienting bias to the far target location. Alternatively, if the near-effect reflects the influence of a 3D viewer-centred spatial representation on spatial attention, as suggested by Gawryszewski et al. (1987), the bias should be unaffected by response-hand position.

EXPERIMENT 1

METHOD

Twenty-eight right-handed volunteers participated in Experiment 1. Fourteen volunteers were allocated to the ‘Hand-Far’ Condition (mean age = 24 , sd = 5.6) and 14 participant to the ‘Hand-Near’ condition (mean age = 23, sd = 4.5). All participants were right handed, had normal or to normal corrected vision and reported no problems of colour vision or depth perception.

Subjects were seated in a comfortable chair with their head placed in a chin rest, looking down a rail at three LEDs mounted on rods. Distances of the near, middle and far LED from the viewer position were 19, 31 and 43 cm, respectively. All testing took place in a fully lit room under binocular viewing conditions and participants were instructed to maintain fixation on the centre LED. To maximise control over luminance differences between the LEDs, a small cap was placed on each light with a hole drilled in the middle of the front face of the cap. The diameter of this hole was 2 mm for all three caps (visual angle was 0.6° and 0.27° for the near and far target stimulus, respectively). Luminance of the LEDs was measured with a light photometer (Hagner Universal, Model S3) positioned on a tripod at a distance of 30 cm from the LED. Luminance levels of the 2 red target LEDs (with the caps on) were adjusted to approximately 21 CD/m^2, and to 58 CD/m^2 for the colours green and blue at the centre LED.

To ensure that the LEDs were viewed at eye-level, an ‘eye-level marker’ was constructed, consisting of a transparent plastic square fixed to two rods, both attached to a base. A horizontal line was marked across the plastic square. This marker was placed between the chin rest and the LEDs. Chin rest and chair were adjusted until participants reported that the marker line crossed the midlines of all three LEDs. Participants were subsequently asked to describe the visual experience associated with fixating at the centre LED. All participants reported symmetric diplopic images of the near and the far LED.

For the experimental tasks, subjects were required to respond to the onset of a red target light presented at the near or far location by pressing a key on a button box affixed to the rail behind the far rod in the Hand-Far condition and behind the near rod in the Hand-Near condition. The hand was placed around the button box and the rod: The thumb was placed to the front of the rod, the index finger (used for responding) was placed on the response key, and the remaining three fingers were placed around the back of the button box, resting against the box and on the rail. Distance between the response-key and the LED was 9 cm. Two cardboard boxes were fixed to the table to ensure a comfortable position of the arms. Participants were instructed to place their left (non-responding) arm on the left box (placed away from the target scene) and to not move this arm beyond the depth of fixation. Both arms were visible for the duration of the Experiment.

[Figure 1 approximately here]

The probable location of the target was cued by lights presented at the central LED (green or blue light). The cue-light was presented until the target appeared and targets were presented for 70 ms. In both groups of fourteen people, seven participants were instructed to attend ‘near’ in response to the blue cue-light, and to attend ‘far’ in response to the green cue-light in the depth cueing task. Cue-location mapping was reversed for the remaining 7 participants within each group. Probability of valid vs. invalid cued trials was 80:20 and the task consisted of four blocks of 240 trials. Each block consisted of 160 valid cued trials, 40 invalid cued trials and 40 catch trials. These catch trials were included to prevent anticipatory responses. A neutral cueing condition was not included given the concerns raised about the use of this condition as a baseline for measures of ‘facilitation’ and ‘inhibition’ in covert visual spatial orienting tasks (Gawryszewski et al., 1987; Jonides & Mack, 1984). Based on previous findings showing that effect of endogenous horizontal cueing on detection times tend to reach a maximum around 300 ms after cue-onset (e.g., Müller & Rabbitt, 1989), stimulus-onset asynchrony (SOA) was varied randomly between 300 or 600 ms.

As retinal regions covered by the near and far target light were not the same, detection times were measured in a control task (Target-Control task), where red lights illuminated at random at the two target locations. Subjects were instructed to respond as quickly as possible on detection of the red light whilst maintaining gaze at the centre LED. A warning tone was presented 300 or 600 ms before presentation of the red light. Delay between response (or the 1000ms cut-off in the case of catch trials) and onset of the cue was 500 milliseconds. The same task parameters were used to measure detection of the cue lights in a second control task (Cue-control task). Both tasks consisted of 112 trials in addition to 16 catch trials, where the warning tone was not followed by a light.

Participants were introduced to the depth cueing task in two practice blocks, each consisting of 40 trials. To allow familiarisation with the cue-colour/location mapping, the first practice block consisted of valid cued trials only. The second block consisted of 32 valid, 8 invalid and 8 catch trials. Experimental blocks of trials were paused automatically after every 40 trials for a time determined by the participant. Errors (RT $\leq$ 100 ms or $\geq$ 1000 ms, and responses on catch trials) were repeated after each block of 240 trials. Control tasks were presented at the end of the testing session.

To be able to exclude trials in which eye-movements were made between onset of the cue-light and offset of the target light, HEOG and VEOG were recorded with Ag/AgCl electrodes placed on the outer canthi of the left and right eye, and below and above the left eye, referenced to two mastoid electrodes placed behind the two ears. The EOG was digitised at 256 Hz per channel and amplified with a bandpass of 0.1 – 35 Hz. To establish whether eye-movements could be detected in the EEG, a short test was developed consisting of 40 trials. Participants were requested to move their eyes (in blocks of 5 trials) to the near and far LED. Each trial was initiated by a warning tone. Testing on four participants revealed clearly detectable waves in response to horizontal eye-movements and divergent/ convergent eye-movements on all 40 trials when the signals from the electrodes placed around the eyes were compared to signals from mastoids (below the eyes for VEOG, outer canthi for HEOG). All trials where the amplitude exceeded 70μV between cue-onset and target-onset were tagged during testing. Final rejection of eye-movement trials occurred off-line after testing by manual inspection of all tagged trials.

RESULTS AND DISCUSSION

Depth cueing task: Error trials were excluded from RT analysis of the depth cueing task. Means of median response times (RT) were entered in a Mixed Repeated Measures ANOVA, with the factors SOA, Target Location (near vs. far) and Cue (valid vs. invalid cue). Response Hand Position (RHP: near vs. far) was entered as the between subjects factor. Only significant effects are reported here (Table 1 shows the results for all effects in the depth cueing task). The analysis revealed a significant main effect of Target Location [$F(1,26) = 71.58$; $p < 0.001$], with longer RT to targets presented at the far target location. The main effect of Cue was also significant [F(1,26) = 54.57; p < 0.001], reflected in longer RT to invalid cued as compared to valid cued targets. The effect of cueing was greater at the far as compared to the near target location, indicated by the significant interaction effect between Cue and Target Location [F(1,26) =10.73; p = 0.003]. Post-hoc analysis (Bonferrroni adjustment) showed that the effect of Cue was significant at both target locations (p < 0.001 for both comparisons) and that the effect of Target Location was significant in both Cue conditions (p < 0.001 for both comparisons). To allow a comparison between cueing effects at the near and far target location, difference RT values due to cueing (RT invalid – RT valid) were calculated. Comparison of these difference values confirmed that that the effect of cueing was significantly greater at the far as compared to the near target location [t(27) = 3.02; p = 0.005]. More importantly however, was the significant interaction effect between Cue, Target Location and Response Hand Position [F(1,26) = 5.72; p = 0.024]. Figure 2 shows that the cueing effect in the RH-near condition is asymmetric, whereas this asymmetry is absent in the RH-far condition. Post-hoc analysis showed that this result was due to the effect of RHP on detection times to invalid cued targets at the far target location. RT in this condition was significantly longer in the RH-near condition than in the RH-far condition (p = 0.013), whereas RT to invalid cued targets at the near location were not significantly different in both response hand conditions (p = 0.26). The difference between the RH-near and RH-far condition was also not significant for valid trials (Valid-near: p = 0.44; Valid-far: p = 0.36). The effect of SOA was significant, with longer RT at SOA300 [F(1,26) = 6.06; p = 0.021], but this effect was different for the valid and invalid cue conditions [SOA x Cue: F(1,26) = 38.16; p < 0.001]. Post-hoc analysis showed that the effect of SOA was observable on valid trials but not on invalid trials.

In the valid cue condition, RT at SOA300 were significantly longer than at SOA600 ($p = 0.006$), whereas this difference was not significant on invalid trials ($p = 0.53$), resulting in enhanced cueing effects at SOA600.

[Figure 2 here]

Control tasks: For analysis of the Target Control task, means of median RT were analysed with the factors Target Location and Response Hand Position. The main effect of RHP was not significant [$F(1,26) = 1.02$; $p = 0.32$], but RT to lights presented at the far location were significantly longer than RT to near targets [$F(1,26) = 24.2$, $p < 0.001$]. This effect of Target Location was similar for both RHP conditions [$F < 1$]. Mean of median RT (SE in brackets) to near and far targets was 261 *(7)* and 276 *(8)* ms (respectively) in the RH-near group, and 275 *(7)* and 289 *(7)* ms (respectively) for the RH-far group. Analysis of the Cue Control Task with the factors Cue-light (blue or green) and RHP yielded non-significant results for all three effects [Cue-colour: $F < 1$, RHP: $F < 1$; Cue-colour x RHP: $F < 1$]. Mean RT to green and blue cue-lights presented at the centre LED were 234 *(5)* and 236 *(6)* ms in the RH-near group, and 251 *(6)* and 251 *(5)* ms in the RH-far group.

To summarize, the analysis of Experiment 1 revealed significant effects of endogenous cueing at 300 ms after presentation of the cue, which were characterized by the near-effect when the response hand was positioned near the viewer. Specifically and consistent with previous findings, the effect of invalid cueing on detection times was greater for targets at the far compared to near target location when the hand was positioned at the near target depth. Placing the responding hand at the far depth failed to reverse the near-bias to the far target location, suggesting that the reorienting bias observed here and in previous studies was not simply due to the position of the response hand. The finding that the far hand eliminated the asymmetry in cueing effects suggests however that spatial attention is influenced by hand-position in the depth cueing task. This effect seems to be restricted to invalid cued targets presented at the far target location. Neither the valid conditions nor the invalid condition at the near target location were affected by position of the response hand.

Overall, the results of Experiment 1 seem to suggest that reorienting of attention to a target beyond fixation is associated with a reduction in detection time ‘cost’ when the hand is positioned at the far target depth. It remains to be established whether elimination of the near bias is due to the mere presence of the hand at the far location or due to the fact that an active manual response had to be made. The possible contribution of a passive hand in the near-effect is explored in Experiments 2 and 3. Experiment 2 investigates whether addition of a passive hand in the visual scene will influence the effect of the response hand observed in Experiment 1. Participants were instructed to place one hand on a response key at the near location and the other hand on the key at the far location for the duration of the experiment. Manual responses were either made with the left or right hand in an alternating fashion across blocks, allowing comparison of ‘passive-hand’ and ‘response-hand’ effects on spatial attention whilst maintaining the visual scene and proprioceptive information equivalent across conditions. One possible outcome is that the presence or absence of the near-effect is dependent on the position of the response hand (consistent with Experiment 1), which would suggest that the hand-effect observed in Experiment 1 is predominantly associated with the response requirement, and not with a passive hand. Alternatively, if both the passive- and the response-hand influence shifts of attention, possibly in an additive fashion, then the near-effect should be (at least partly) reinstated when the passive hand is placed at the near location, and should be reduced when the passive hand is placed at the far target location.

EXPERIMENT 2

METHOD

Sixteen volunteers participated in Experiment 2 (mean age = 21, SD = 3.87). All participants were right handed, had normal or to normal corrected vision and did not report any problems with colour vision or depth perception.

The following changes were made to the set-up and to the design for Experiment 2: A second button-box (identical to the button-box used in Experiment 1) was affixed to the rail. One button-box was placed at the far depth, and the other button-box was placed close to the near rod. Positioning of the button-box relative to the rod at each depth was identical to the positioning used in Experiment 1. Eight participants placed the right hand on the button box at the far depth and the left hand on the button box at the near depth. This was reversed for the remaining eight participants. Positioning of the hands on the button-boxes was the same as the positioning in Experiment 1.

Testing took place in two sessions, each consisting of four block with 240 trials. In each block, participants responded either with the right or the left hand. Four out of eight participants whose left hands were placed at the near depth responded with the left hand in blocks 1 and 3 of session 1, and with the right hand in blocks 1 and 3 in session 2. This was reversed for the remaining four participants. The same counterbalancing procedure was applied to participants whose right hands were placed in proximity to near rod.

Participants were instructed to keep the index finger of both the response hand and the passive hand on the response keys for the duration of each block to ensure similarity of proprioceptive information received from both hands before target presentation. Based on the finding that cueing effects were not maximal at SOA 300 ms in Experiment 1, stimulus-onset asynchrony was increased for Experiment 2. To maximise unpredictability of target onset, SOA was varied at random in steps of 50 ms between 550 and 900 ms. The warning tone in the Control tasks was removed and the response-stimulus interval in the Target Control task was adjusted to the SOA used in the depth cueing task. The Target Control task was presented in both sessions: Eight participants responded with the hand positioned at the far location in session 1 and with the near hand in session 2. The reverse order was applied for the remaining eight participants.

RESULTS AND DISCUSSION

Depth cueing task: Means of median RT were entered in a Mixed Repeated Measures ANOVA with the factors Response Hand Position (RHP near vs. far), Target Location (near vs. far) and Cue (valid vs. invalid cue). The factor 'Hand' (either left or right hand placed at the far LED) was entered as the between subject factor. The results revealed a significant effect of Target Location [$F(1,14) = 32.2$; $p < 0.001$], reflected in longer RT to far compared to near targets, and a significant effect of Cue [$F(1,14) = 26.7$; $p < 0.001$], with longer response times to invalid cued targets. Consistent with the results of Experiment 1, cueing effects were greater at the far as compared to the near target location [$F(1,14) = 8.5$; $p = 0.011$]. Post-hoc analysis showed that the effect of Target Location was significant in both Cue conditions ($p < 0.001$ for both comparisons), and that the effect of Cue was significant at both target locations ($p < 0.001$ for both comparisons). To confirm that asymmetry in cueing effect was significant, RT difference values were calculated (RT invalid – RT valid). Comparison of these difference values showed that cueing effects were greater at the far as compared to near target location [$t(15) = 3.009$; $p = 0.009$]. The interaction between Target Location and RHP was significant [$F(1,15) = 9.2$; $p = 0.009$], but this interaction effects is explained by the more important significant 3-way interaction effect between Cue, Target Location and RHP [$F(1,15) = 8.06$; $p = 0.012$]. Figure 3 shows a pattern of results consistent with the results of Experiment 1: The near-effect is present in the RH-near condition but is abolished by the response hand when this hand is positioned at the far target location. Post-hoc analysis revealed that RT to invalid cued targets presented at the far target location were significantly faster in the RH-far compared to the RH-near condition ($p = 0.006$), whereas this difference was not significant for invalid cued targets presented at the near target location ($p = 0.12$). The difference between RH-far and RH-near conditions was also not significant for valid cued trials ($p > 0.09$).

[Figure 3 here]

<u>Control tasks</u>: The Target Control task was analyzed using ANOVA with the factors Response Hand Position (RHP), Target Location and the between subjects factor Hand (either left or right hand at far depth). This analysis revealed a significant effect of Target Location [$F(1,14) = 51.1$; $p < 0.001$], but all other effects were not significant [$F < 1$]. Means of median RT to near and far targets (SE in brackets) were 229 *(6)* and 242 *(6)* ms (respectively) in the RH-near condition, and 232 *(8)* and 245 *(8)* ms (respectively) for the RH-far condition. Analysis of the Cue Control task using ANOVA with the factors Cue-colour (green vs. blue) and the between subjects factor Hand revealed non-significant results for all effects [$F < 1$]. Mean RT to green and blue cue-lights were 218 *(5)* and 221 *(5)* ms, respectively.

To summarize, Experiment 2 revealed the near-effect when responses were made with the hand near the viewer, even when a passive hand was positioned at the same depth as the far LED. The finding that the near-effect was absent when the response hand was placed at the far target depth, despite a passive hand placed at the near depth, seems to suggest that shifts of attention were not affected by the passive hand. The effect of the responding hand at the far target depth was restricted to the condition where shifts of attention were made from the invalidly cued near location to the far target LED. Consistent with the results of Experiment 1, detection times to valid cued targets and to invalid cued targets presented at the near location were not affected by response hand position. As the location of both hands was the same for the duration of the testing session in Experiment 2, it is unlikely that the abolishment of the near-effect in Experiment 1 was associated with differential attentional saliency effects due to dissimilar visual scenes. Hand-dominance was shown not to be a relevant factor either, as the effect of the response hand at the far location was the same for right and left handed responses.

The finding that the response hand effect on the reorienting bias was not influenced by the presence of an additional passive hand does not necessarily imply that spatial attention was not influenced by the passive hand. Reed et al. (2006)

showed that when attention is cued along the horizontal dimension and only the non-responding hand is horizontally aligned with one of the two target locations, spatial attention is biased towards this hand's location, resulting in an overall benefit in detection times to the proximal target (independent from cue-validity). In Experiment 2 of the present study, detection times to valid targets, and to invalid cued targets at the near target location did not vary as a function of passive hand position. This finding could suggest that the passive hand was not prioritized for spatial attention, or alternatively, that passive hand effect on spatial attention can only be revealed when potentially more dominant effects of the responding hand are eliminated. Experiment 3 aims to investigate whether passive hand influences on spatial attention were masked by effects of the response hand in Experiment 2. The non-responding hand is placed at either the near or far target depth whilst the responding hand is moved away from the target scene. If alignment in depth of the passive hand and the target is sufficient for attention to be prioritized to the passive hand in the depth cueing task, then an overall detection time bias (independent from cue-validity) may be revealed at the target location most proximal to passive hand, in line with the attentional prioritization effect observed in horizontal cueing tasks (Reed et al., 2006).

EXPERIMENT 3

METHOD

Sixteen participants were recruited for Experiment 3 (mean age was 22, sd = 4.8). All participants were right handed and had normal or to normal corrected vision without any reported problems with colour vision or depth perception.

The following modifications to the experimental procedure of Experiment 2 were made for Experiment 3: All participants responded by pressing a response key placed on the table below the rail close to the viewer (actual distance between the hand and the near target light was ~52 cm, distance in depth between the hand and the near LED was 17.5 cm, horizontal distance was 10 cm, vertical distance 50). The other hand was placed on either the near or far button-box placed on the rail (depending on the condition) but was never used for responding. Due to malfunction, two LEDs had to be replaced. Luminance of the cue-lights and target lights were adjusted to 24 CD/m^2 for the green and blue cue-lights, and 54 CD/m^2 for the red target lights. Eight participants responded with their left hand and placed the right hand on the button box fixed at either the near or far target depth. The remaining 8 participants responded with their right hand and placed the left hand on the button box close to either the near or far LED. The experimental task consisted of 4 blocks of 240 trials. For eight participants, the passive hand was placed on the button box at the far target depth during the first two blocks and at the near depth during the last two blocks. This order was reversed for the remaining eight participants. The target control task was presented after the first two blocks and at the end of the experimental task.

RESULTS AND DISCUSSION

Depth cueing task: Means of median RT were entered in a Mixed Repeated Measures ANOVA, with the factors Target Location, Cue and Passive Hand Position (PHP: near vs. far). The factor Hand (responses made with either the left or right hand) was entered as the between subject factor. Significant main effects were found for the factors Cue [$F(1,14) = 41.5$; $p < 0.001$] and Target Location [$F(1,14) = 35.9$; $p < 0.001$]. The interaction effect between Cue and Target Location was also significant [$F(1,14) = 23.7$; $p < 0.001$]. Post-hoc analysis showed that the effect of Cue was significant at both target locations ($p < 0.001$), and that the effect of Target Location was significant in both Cue conditions ($p \leq 0.04$). Pair-wise comparisons of the difference values (RT invalid – RT valid) as a function of Target Location showed that the effect of cueing was significantly greater at the far compared to the near target location [$t(15) = 5.04$; $p < 0.001$]. Most important was the findings that the three-way interaction effect between Cue, Target Location and PHP was not significant [$F < 1$], suggesting that the asymmetric cueing effect was comparable in both PHP conditions.

[Figure 4 here]

Control tasks: The Target Control Task was analysed with the factors PHP (near vs. far), Target Location and with the between subjects factor Hand (responding with right vs. left hand). The effect of Target Location was significant [$F(1,14) = 5.7$; $p = 0.032$], but the interaction effect between Target Location and PHP was not [$F < 1$]. Mean RT to near and far targets (SE in brackets) were 248 *(8)* and 260 *(9)* ms (respectively) in the PH-near condition, and 244 *(8)* and 254 *(7)* ms (respectively) in the PH-far condition. All remaining effects were also not significant [PHP: [$F(1,14) = 2.1$; $p = 0.16$; Hand: $F < 1$; PHP x Hand: $F < 1$], suggesting that neither hand-dominance nor the position of the passive hand influenced detection times in the Target Control task. Analysis of the Cue Control Task with the factors Cue-light and

Response Hand (left vs. right) revealed non-significant results for all three effects [$F < 1$]. Mean RT to green and blue cue-lights were 222 *(7)* and 223 *(6)* ms, respectively.

Further analysis

Target Location effects: The difference between RT to valid far and valid near targets was consistent across all three experiments, irrespective of response-hand or passive-hand position. The assumption was that this difference is associated with the different sizes of the retinal regions covered by the near and far target light (approximately twice as large for the near light), as suggested by the effect of Target Location in the Target Control task. To establish if the Target Location effect observed on valid trials in the depth cueing task is comparable to the effect of Target Location in the Target Control task, RT to valid cued trials and to targets in the Target Control task were analysed with the factors Target Location (near vs. far) and Task (Valid cued condition in the depth cueing task vs. Control task), separately for each Experiment. Significant results were found for the effect of Target Location in all three Experiments [$F \geq 10.39$; $p \leq 0.006$] and for the effect of Task in Experiments 1 and 3 [$F \geq 7.8$; $p \leq 0.013$] (faster RT to targets in the control task), although the latter effect was not significant in Experiment 2 [$F(1,15) = 3.51$; $p = 0.081$]. Most important was the finding that the interaction effect between Task and Target Location was not significant [$F < 1$ in all three Experiments], suggesting that difference in detection times for near and far targets was the same in the Target Control task and on valid cued trials in the depth cueing task.

The near-effect across Experiments: A final analysis on RT was conducted to explore if the cueing effect, and the ‘near-effect’ (Cue x Target Location) was comparable in all conditions where the response hand was placed near the viewer, whether a passive hand was placed in proximity to the far target LED (Experiments 2 and 3) or not (Experiment 1). ANOVA was used with the factors Cue and Target Location. The factor 'Experiment' was entered as the between subjects factor. Results of this analysis revealed significant main effects of Target Location [$F(1,43) = 77$; $p < 0.001$], Cue [$F(1,43)$; $p < 0.001$], and a significant effect of Cue x Target Location [$F(1,43) = 36.7$; $p < 0.001$], consistent with the main analyses per Experiment. The main effect of Experiment was not significant [$F(1,43) = 1.8$; $p = 0.17$], and, more crucially, the interaction effects between Experiment, Cue and Target Location was also not significant [$F(1,43) = 1.6$; $p = 0.21$]. The latter result suggests that the passive hand at the far location did not modulate the near-bias in reorienting of attention when the response hand was placed near the viewer.

Errors: Percentage trials rejected based on the amplitude cut-off was 5.92% and 6.12% in the Response-hand 'far' conditions (for Experiment 1 and 2, respectively), and 5.45% and 6% in the Response-hand 'near' conditions (Experiment 1 and 2, respectively). For Experiment 3, Percentage trials rejected was 4.76% and 5.32% for the Passive Hand 'Far' and 'Near' conditions, respectively. Omissions and Anticipatory errors were made infrequently (less than 2% across all conditions in all three Experiments). As the variance in several conditions was zero or close to zero for all three types of errors, only main effects were analysed for each Experiment. Analysis of percentage eye-movement trials, omissions and anticipations revealed non-significant results for all comparisons in all three Experiments ($t \leq 1.5$; $p \geq 0.14$).

In sum, placement of only a passive hand at either the near or far target depth did not affect detection times in Experiment 3. It is therefore unlikely that the absence of possible attentional prioritization effects associated with the passive hand were somehow masked by more dominant response-hand effects in Experiment 2. The presence of the near-effect in both passive hand position conditions supports the idea that the response requirement of the hand at the far target location is crucial for the abolishment of the reorienting bias to occur. Irrelevance of passive hand position for shifts of attention in the present study is further supported by analysis across experiment, showing that the near-effect was not significantly influenced by the presence (Experiment 2 and 3) or absence (Experiment 1) of a passive hand at the far depth when the response hand was placed near the viewer.

Response times to near targets were consistently faster than to targets emitted from the far LED in the depth cueing task. Although this difference could be interpreted as a general viewer-centred bias in endogenous shifts of attention to all targets presented in viewer-centred near space, it is more likely that the effect is associated with the different retinal sizes of the two stimuli. The target location effect observed on valid cued trials was comparable to the location effect in the control task, where endogenous shifts of attention are not required. Further support for this assumption can be inferred from Gawryszewski et al.'s study (1987) who adjusted the size of the target lights for distance from the viewer in a depth cueing task and found no location effect in response times to valid cued targets. Both findings seem inconsistent with the idea that voluntary shifts of attention may be biased to all targets near the viewer.

GENERAL DISCUSSION

The aim of the present study was to investigate whether the near-effect, previously associated with a 3D viewer-centred reorienting bias to near space, could be explained in terms of a bias to the responding hand, always positioned near the viewer in previous studies investigating spatial attention in real depth situations. The results of Experiment 1 excluded this explanation, as the near-effect was not reversed to a far-bias when the hand was positioned at the far depth. Instead the hand reduced detection time 'cost' associated with reorienting of attention from the near to the far target location, resulting in symmetric effects of cueing at the near and far LED. Shifting attention in response to valid depth cues was left unaffected by response-hand position, as was reorienting of attention from the far to the near target location. Experiment 2 and 3 further showed that the response requirement was crucial for the hand-effect to occur. Placement of only a passive hand at one of the target locations had no effect on detection times (Experiment 3), and placing a passive hand at the target depth not occupied by the responding hand did not influence the effect of the response-hand on the reorienting bias (Experiment 2).

One aspect of our results that may seem inconsistent with Reed et al.'s (2006) findings (who cued attention along the horizontal dimension) is the absence of any passive-hand position effect on detection times in the depth cueing task. Although this could suggest that attentional prioritization of the passive hand is restricted to situations where attention is cued along the horizontal dimension, an alternative explanation may be that this inconsistency is related to the difference in proximity between the passive hand and the target stimulus in the two studies. The passive hand was proximal to the target along all three dimensions in the Reed et al.'s study, whereas the vertical distance between the response key and the LED was 9 cm in the depth cueing task. Reed et al. (2006) showed that the attentional prioritization effect depends on close proximity between the target and the hand (as the effect was not observed when the distance was 11 cm), consistent with the idea that the attentional prioritization effect reflects modulation of spatial attention within a bimodal (visual-tactile) hand-centred spatial representation (Graziano & Gross, 1995; Fogassi, Gallese, Fadiga, Luppino, Mattelli & Rizolatti, 1996; Duhamel, Colby & Goldberg, 1998). Whether an overall bias in spatial attention to the passive hand would have been detected if the hand had been more proximal to the target cannot be excluded. It remains clear however, that the position of the passive hand cannot account for the presence or absence of the near-effect in the depth cueing task.

Although the present findings clearly suggest that the response requirement is a necessary condition for hand-position effects to occur in the depth cueing task, it is less clear whether spatial attention was modulated within 3D viewer-centred or within a hand-centred spatial representation. Gawryszewski et al (1987) originally explained the near-effect as reflecting 3D viewer-centred enhancement of spatial attention in the region between the viewer and fixation after cueing of the near LED, resulting in prolonged detection time when reorienting of attention to the far target location is required. When the far LED is cued, the attentional focus is shifted to the far target location and attention spreads towards the viewer, resulting in equal awareness of all information within this viewer-centred area of space. One possible explanation within this framework for the abolishment of the near-effect is that the 3D viewer-centred attentional space is extended to the depth of the far response hand on all trials during response preparation, even when attention is initially cued to the near LED. This would result in equal awareness of both target locations when the target is presented and could account for the symmetric cueing effects when the hand is positioned at the far depth. An alternative explanation for the response-hand effect is that a hand-centred spatial representation is accessed when preparing the manual response in addition to an already active 3D viewer-centred representation. When the hand is placed at the far position and attention is cued to the near LED, response preparation may enhance spatial awareness around the hand to an equal level of the attentional space created within a 3D viewer-centred spatial representation between the viewer and fixation. Assuming that the attended region around the hand includes the target LED, the pattern of results across the two hand-position conditions would reflect additive influences of viewer-centred and hand-centred spatial representations on spatial attention in this explanation.

Whilst both explanations could account for the abolishment of the near-effect by the response hand at the far target depth, it could be argued that the two explanations would predict different results on valid cued trials. Consistent with the observed pattern of results, the 3D viewer-centred explanation would predict that valid cue conditions should be left unaffected by hand-position as the cued locations always fall within attended space, whether the hand is positioned close to the near or the far LED. In contrast, if spatial attention is enhanced within both spatial representations, additive effects of the response hand would be expected in all conditions, including valid cued trials. The only caveat would be if spatial attention was maximally enhanced within a viewer-centred spatial representation in terms of observable behavioural effects. A few neuropsychological findings have previously been explained in this way (e.g., Frassinetti, Rossi & Làdavas, 2001; Mattingley et al., 1998). Mattingley et al. (1998) showed for example that spatial awareness of stimuli presented in right space was not further enhanced by right-handed trial-initiating keypresses in a patient with left visual extinction. Although spatial awareness in these studies was predominantly measured in terms of the number of stimuli reported, detection times may be similarly restricted in their sensitivity to uncover additional effects of the response hand. While this question clearly requires further investigation, additive effects in attention (e.g. location-based and object-based attention) have been successfully revealed within the third dimension using manual response times as the behavioural measure (Bourke et al., 2006).

Even though the specific pattern of results observed in the present study seems most consistent with a 3D viewer-centred explanation for the abolishment of the near-effect, this preliminary conclusion may warrant further verification in future studies, particularly given the accumulating evidence for modulation of attention from hand-centred representations in peripersonal space. One question raised by the present findings is whether the beneficial effect of the response hand at the far target depth is restricted to situations where the response hand is aligned with the direction of the viewer's gaze. It may be possible that the 'boundary' of 3D viewer-centred enhancement in spatial attention returns to fixation when the response hand at the far target depth is moved further away from gaze direction. When the hand is positioned close to a target in the periphery, proprioceptive information received from the hand and limb may become more relevant for determining the location of the hand for shifts of attention to response hand, previously associated with response preparation (Eimer et al., 2005; Eimer & van Velzen, 2006). Adding LEDs to the left and right could allow investigation of the relative importance of these two types of information about hand position. The potential influence of a (bimodal) hand-centred representation on shift of attention may result in horizontal biases when the hand is placed in the periphery, instead of (or possibly in addition to) a 3D viewer-centred reorienting bias to near space.

A second question that could be investigated further is whether the influence of hand-centred representations on spatial attention could be manipulated by the complexity of the manual response. Studies investigating the effect of reaching responses on spatial attention have shown that reaching seems to be associated with action-based shifts of attention to the starting position of the hand (Tipper, Lortie & Baylis, 1992). In a study investigating distractor interference on reaching response times, Tipper et al. (1992) showed that response time interference was strongest from distractors presented at locations in the middle and front of the 3D target display when the starting position was close to the observer. More crucially, this effect reversed when the hand was positioned beyond all stimuli, with stronger interference from distractors furthest from the viewer but closest to the starting position of the reaching hand. Interference from distractors close to the hand have also been shown to affect reaching trajectories (e.g., deviating away from the distractors), supporting the assumption that distractor inhibition operates on representations centred on the hand in goal-directed reaching (Tipper, Howard & Jackson, 1997). Perhaps a similar action-based bias to the far hand could be revealed when the behavioural response requires movement planning in the depth cueing task.

In conclusion, the results of this study demonstrate that the near-effect observed in the depth cueing task can be eliminated by placing a response hand close to the far target location. As the hand only influenced spatial attention when used for responding (and not when passively placed at the far target depth), the abolishment of the near-effect seems to be associated with preparation of the manual response, resulting in equal spatial awareness of the near and far target location when the hand is positioned at the far depth. The pattern of results across the three experiments is most consistent with the idea that spatial attention can be modulated by the response-hand within a 3D viewer-centred spatial representation when the hand is aligned with the direction of gaze.

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Table 1: ANOVA results of detection time analysis in the depth cueing task:

Experiments 1-3. See text for explanations of factors and levels.

Experiment 1					
Effect	*F*	*p*	*Effect*	*F*	*p*
RHP	< 1		Target Location x RHP	1.93	0.17
SOA	***6.06***	***0.021***	***Target Location x Cue***	***10.73***	***0.003***
Target Location	***71.58***	***< 0.001***	***Target Location x Cue x RHP***	***5.72***	***0.024***
Cue	***54.57***	***< 0.001***	SOA x Cue x RHP	2.1	0.15
SOA x RHP	< 1		SOA x Target Location x RHP	< 1	
SOA x Target Location	1.74	0.19	SOA x Target Location x Cue	< 1	
SOA x Cue	***38.16***	***< 0.001***	SOA x Target Location x Cue x RHP	< 1	
Cue x RHP	2.47	0.13			
Experiment 2					
RHP	< 1		***Target Location x RHP***	***9.17***	***0.009***
Hand	< 1		***Target Location x Cue***	***8.46***	***0.011***
Target Location	***32.17***	***< 0.001***	***Target Location x Cue x RHP***	***8.39***	***0.012***
Cue	***26.71***	***< 0.001***	Hand x Cue x RHP	< 1	
Hand x RHP	< 1		Hand x Target Location x RHP	< 1	
Hand x Target Location	< 1		Hand x Target Location x Cue	< 1	
Hand x Cue	< 1		Hand x Target Location x Cue x RHP	1.63	0.22
Cue x RHP	< 1				
Experiment 3					
PHP	< 1		Target Location x PHP	< 1	
Hand	1.35	0.26	***Target Location x Cue***	***23.76***	***< 0.001***
Target Location	***41.54***	***< 0.001***	Target Location x Cue x PHP	< 1	
Cue	***65.96***	***< 0.001***	Hand x Cue x PHP	< 1	
Hand x PHP	< 1		Hand x Target Location x PHP	1.9	0.19
Hand x Target Location	< 1		Hand x Target Location x Cue	< 1	

Hand x Cue	2.86	0.11	Hand x Target Location x Cue x PHP	2.6	0.09
Cue x PHP	< 1				

Figure 1: Schematic illustration of the experimental set-up for Experiment 2. See text for further explanation of variations per Experiment.

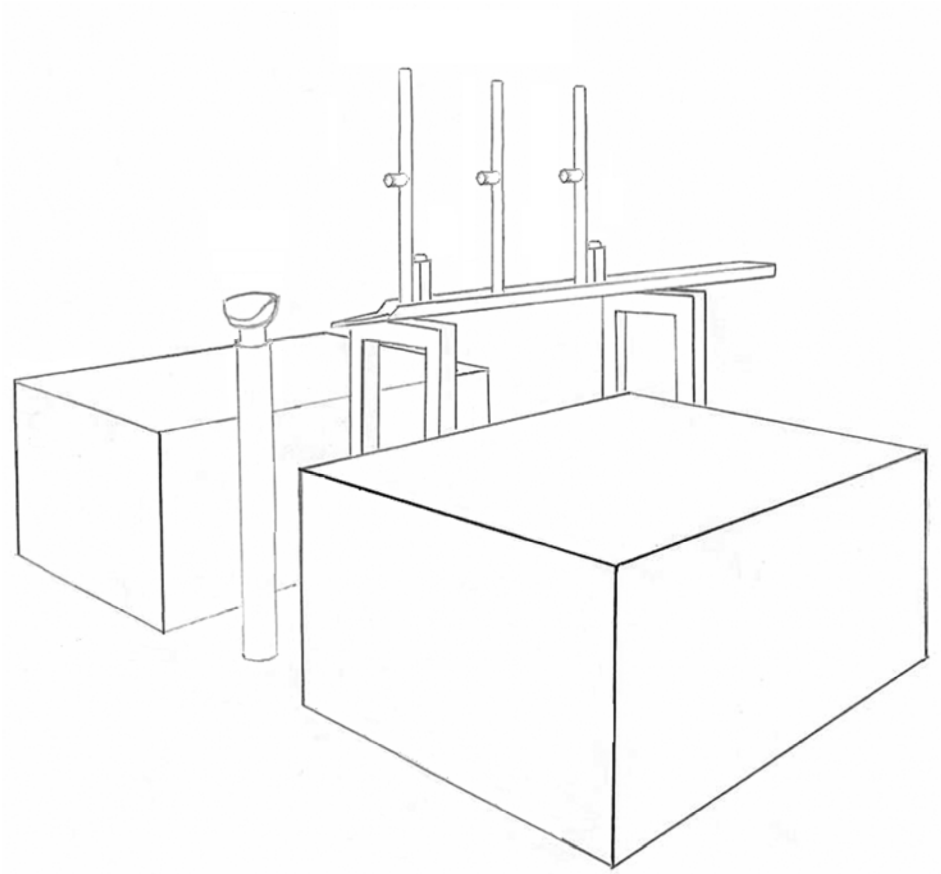


Figure 2: *Experiment 1*: Means of median RT (in Millisecond) as a function of Response Hand Position (RH-near and RH-far), Cue (Valid and Invalid) and Target Location (TL).

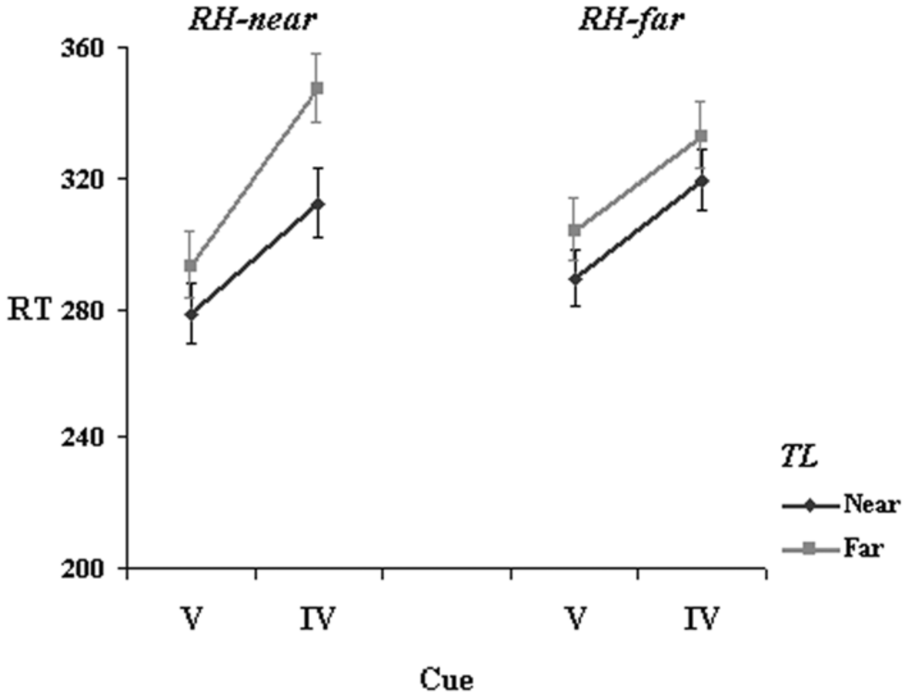

RH-near
RH-far
360
320
RT 280
240
200
V
IV
V
IV
Cue
TL
Near
Far

Figure 3: *Experiment 2*: Means of median RT (in Millisecond) as a function of Response Hand Position (RH-near and RH-far), Cue (Valid and Invalid) and Target Location (TL).

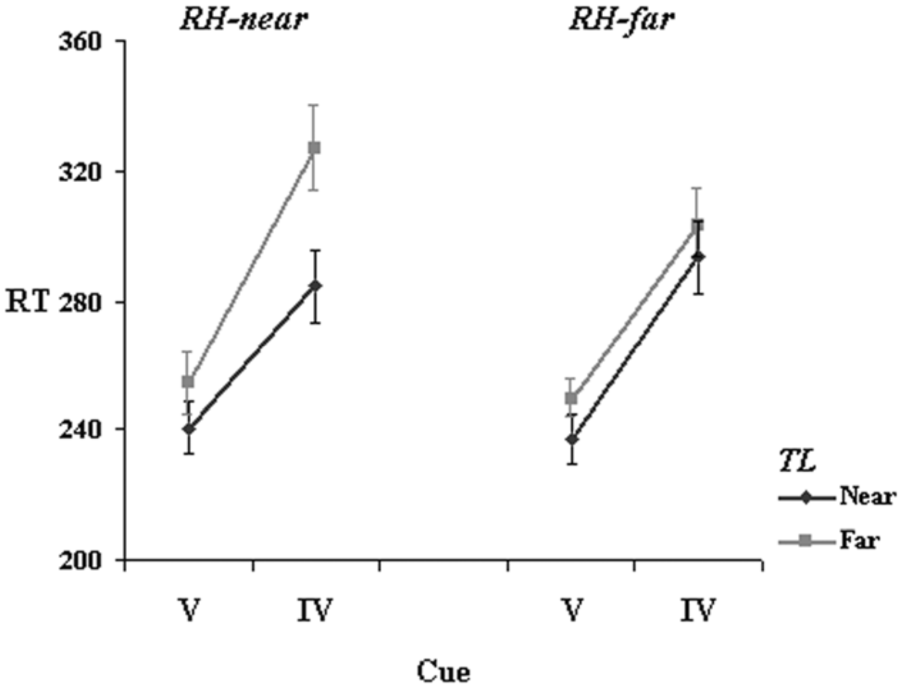
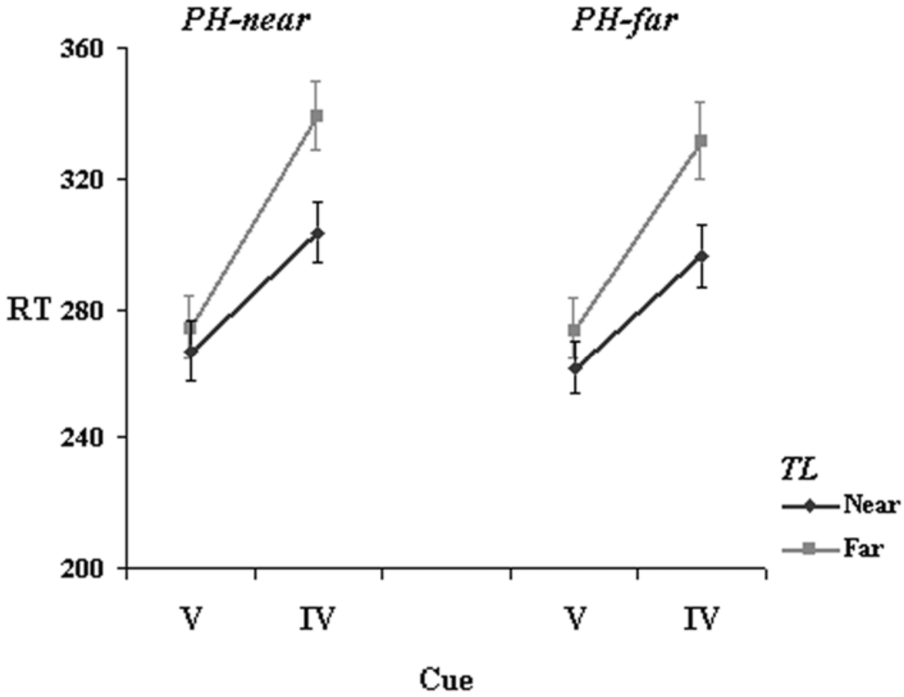

RH-near
RH-far
360
320
RT 280
240
200
V
IV
V
IV
Cue
TL
Near
Far

Figure 4: *Experiment 3*: Means of median RT (in Millisecond) as a function of Passive Hand Position (PH-near and PH-far), Cue (Valid and Invalid) and Target Location (TL).


PH-near
PH-far
360
320
RT 280
240
200
V
IV
V
IV
Cue
TL
Near
Far