THE ATTENTIONAL REPULSION EFFECT IS INFLUENCED BY NON-PERCEPTUAL MANIPULATIONS

by

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Abstract

The Attentional Repulsion Effect (ARE) refers to the phenomenon whereby a central target consisting of two aligned lines is misperceived to be offset in the direction opposite a preceding peripheral visual event. The prevailing explanation is that the ARE results from a transient change in the visual receptive fields. In a series of three experiments, the present investigation tests and lends initial support to a different explanation: that the ARE arises from a comparison between different spatial reference frames. Without altering the task, we found that the ARE can be eliminated by simply introducing some trials where the top line is unambiguously located to the left or right of the bottom line. Changing the task from a directional to a non-directional one caused the classic ARE to disappear as well, although a new form of the ARE was discovered.

Preface

The following research was all conducted in the Brain and Attention Research Laboratory at the University of British Columbia. In collaboration with Alan Kingstone, my supervisor, I programmed the experiments, collected data or supervised data collections, analyzed the data, and wrote any work that resulted from the research. Ethical approval for this research was provided by UBC's Behavioural Research Ethics Board under the approval number of H10-00527.

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Acknowledgements

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1 Introduction

What is the attentional repulsion effect?

In 1997, Suzuki and Cavanagh discovered that briefly presented stimuli appear displaced away from the focus of attention. They coined this finding 'the attentional repulsion effect' (ARE). The task they employed included a brief peripheral cue appearing in either the top left or top right quadrants of the screen, while participants fixated on a cross in the centre of the display. Subsequently, a brief Vernier stimulus was presented along the vertical meridian and was followed by the appearance of a random dot mask. In a two-alternative forced choice task, participants indicated whether the Vernier was offset leftward or rightward by pressing keys on a computer keyboard. Interestingly, when the cue was in the top left quadrant, participants reported an offset in the clockwise direction and when the cue appeared in the top right quadrant, participants reported an offset in the counter clockwise direction. Essentially, the Vernier was most often perceived to be displaced in the direction opposite from where the peripheral cue captured attention.

Pratt and Turk-Browne (2003) and Pratt and Arnott (2008) later confirmed the finding that a shift in attention to the periphery results in a misjudged localization of visual objects in the direction opposite of the shift. Pratt and Arnott (2008) provided evidence to suggest that the ARE is indeed attentional in nature, and also demonstrated that it affects one's perceptions of an object's true location. They did this by comparing well-known effects of attention on reaction times (RTs) with the effects of attention on spatial perception. Their reasoning was that if the patterns were comparable for RTs and spatial perception, the same attentional processes might underlie both. The effects on RTs in each of the following three cue-setting scenarios - onset versus offset cues, simultaneous appearance of onset and offset cues in different locations, and pop-out cues - are well-known (Godjin & Theeuwes, 2004; Pratt & Hirshorn, 2003; Pratt & McAuliffe, 2001; Rauschenberger, 2003): in the case of either onset or offset cues RTs are comparable, but when both appear simultaneously, the onset cues are accompanied by faster RTs. Additionally, RTs in tasks that use pop-out cues are significantly slower than when either a single onset or offset cue is used. Pratt and Arnott (2008) showed that the same pattern applies to spatial repulsion effects, implying that the same attentional processes underlie the temporal and spatial consequences of orienting attention. Further support for the ARE comes from Pratt and Turk-Browne (2003), who found that not only does the ARE influence perceptual judgments, it affects tasks that assess computer mouse-pointing and hand-pointing responses. This is significant as it suggests that the locus of the ARE lies in the early visual processing stages of the visual stream, likely in the primary visual cortex, and before the object-perception and object-action pathways separate into different streams.

Receptive field account

The current leading explanation for the existence of the ARE comes from the original authors, Suzuki and Cavanagh (1997), and has to do with receptive field modulation. The finding is described as the cue attracting attention and then causing a misperception of the target in the opposite direction of the cue, as a result of receptive fields being altered. To account for why the ARE occurs, Suzuki and Cavanagh (1997) suggest that the repulsion effect represents the cost of orienting attention in order to enhance perception at a peripheral location, a hypothesis that is based on several assumptions. The first one is that spatial locations are represented by a population of ‘position-coding’ neural units that have spatially localized receptive fields. Suzuki and Cavanagh also state that these neural units could be composed of cells from any visual area that preserves retinotopy. Further, they put forth that the target display (Vernier) will be coded in terms of the centroid of these position-coding neural units. Presumably, without peripheral cues the population centroid representing the perceived Vernier location would correspond to the veridical location. Conversely, the appearance of a peripheral cue would shift the focus of attention to the cued location, adjusting the centroid of the distribution such that the Vernier appears displaced away from the focus of attention (i.e., the cued location). Thus, Suzuki and Cavanagh suggest that the ARE occurs because the position of the centroid of the response distribution of receptive fields will be skewed away from the focus of attention.

How could a modulation of the distribution of reception fields generate an ARE? Suzuki and Cavanagh (1997) propose three possible mechanisms. One mechanism is surround suppression, where the cell activity surrounding the focus of attention could potentially be suppressed by lateral inhibition, resulting in the attended location receiving greater spatial selectivity due to inhibition of interference from neighboring cells. Another mechanism is receptive field (RF) recruitment, whereby RF's near the attended location presumably shift towards it and as a result, respond less than usual to stimuli in the area bordering the focus of attention. The final mechanism is RF shrinking, where RF position tunings sharpen (i.e., shrink) around the focus of attention and, similar to the recruitment mechanism, these shrunken RF's respond less than they normally would to stimuli surrounding the focus of attention, resulting in the population response being skewed away from the attended location.

The present investigation

The current body of research assumes that the ARE reflects the consequences of a faulty visual perception: that is, that one inaccurately perceives and reports an object's location. The overarching goal of this thesis is to test the possibility that non-perceptual factors could be contributing to this incorrect discrimination. Central to Suzuki and Cavanagh's (1997) explanation for the ARE is the notion that attention can modulate receptive fields. This is undoubtedly the case, as several physiological studies have shown that voluntary attention can adjust a cell's response to certain stimuli (e.g. Bushnell, Goldberg, & Robinson, 1981; Mountcastle et al., 1987; Spitzer & Richmond, 1991), and even more compellingly, that attention can alter the spatial properties of individual RFs in various brain regions (Anton-Erxleben, Stephan, & Treue, 2009; Ben Hamed et al., 2002; Connor, Gallant, Preddie & Van Essen, 1996; Connor, Gallant, & Van Essen, 1994; Connor, Preddie, Gallant, & Van Essen, 1997; Desimone et al., 1990; Moran & Desimone, 1985; Womelsdorf et al., 2006).

While this RF theory is certainly plausible, it neither speaks to the idea that locating objects in space requires anchoring to other objects (Gibson & Kingstone, 2006), nor to the idea that terms like "left" and "right" are relative in nature. In other words, the process of receptive fields encoding visual percepts is not the only variable that influences how we actually internalize an object's location. We do not code space in absolute terms. Even when we discuss the location of objects in a room, for example, our descriptions reveal our dependence on relativity –"the lamp is *on the desk*", or "the chair is *to the left of the filing cabinet*". How would one even describe the absolute location of an object? The closest one might get is by saying '*it is there*', a statement that clearly lacks precision and requires the aid of an action, such as pointing, for the object's location to be adequately conveyed. In addition to their physical perception, our localization of objects in space is based on their position relative to other objects and thus we are required, to compute multiple reference frames upon which to base these decisions (Logan, 1995). Not only are object locations themselves contingent on other object locations, there is a distinct relativity embedded within the very language we use to describe these locations. If the alphabet were written out on a piece of paper, for example, the letter ‘C’ would be considered to be *on the right* only in relation to the letters ‘A’ and ‘B’. With respect to a letter like ‘Z’, on the other hand, it would seem ridiculous to say that ‘C’ was *on the right* because it is clearly on the leftmost portion of the alphabet spectrum. The fact that our internalization of the essence of location and space is inextricably linked to both the surrounding environment and to the language we use to describe it suggests that these factors merit consideration if the process of visual spatial attention is to be discussed. In the specific context of the ARE, this means that we cannot rule out the possibility that the language of the task (e.g. is the top line to the left or to the right of the bottom line?) or the environment of the task (e.g. the bilateral presence of cues on the screen), or some combination of both could be introducing a response bias of sorts that compromises the results.

In Experiment 1, I investigated the resilience of the ARE by manipulating the location of targets. The aim was to see whether the notion of a vulnerability to directional bias was more than just a conceptual concern. Could it be introducing a practical issue as well? If so, where could the bias be coming from?

The classic ARE emerges when the top target line is directly above the bottom target line – this is where we can see whether there has been a distortion in the perception of the lines. From here on I will refer to this situation as the *test position* (when the top line is presented directly above the bottom line). In the typical task, the lines are sometimes physically misaligned slightly, and this serves as an opportunity to ensure that participants are paying attention (as they should respond “left” when the top line actually is located to the left, and vice versa). In Experiment 1, instead of just presenting the top line only slightly to the left or right of the bottom line, I added another condition where the top line could be presented to the far left or far right of the bottom line. The rationale was to provide an unambiguous anchor for what constituted 'left' and for what constituted 'right' in this task. If the far left and far right targets can influence the response to the top line when it appears directly above the bottom line, I would expect the ARE to be diminished or eradicated. This follows from the reasoning that perhaps people would be less willing to call a top line "left" in the *test position*, if they had an unambiguous understanding of what left and right could be in the experiment. If, on the other hand, the ARE task is not vulnerable to directional biases or changing reference frames, then introducing the far targets should have no effect on the ARE, and it should be preserved.

As mentioned previously, because the terms "left" and "right" are such relative judgments, their use could potentially be affecting one's response in the spatial discrimination task. If reference frames are indeed influencing participant's responses, what could the reference object or spatial referent be in the original ARE task? Unlike far targets, the classic targets where the top line is presented only slightly to the left or right of the bottom line are unlikely to be serving as extreme spatial references because their position in space is quite close to the *test position*. Although reference frames involving the targets are not likely to introduce a significant bias, Danziger, Kingstone, and Ward (2001) suggest that peripheral cues may serve as spatial references. Findings from their study on spatial reference frames lends empirical support to the possibility that collecting left and right responses may muddy the waters when it comes to inferring one's perception of spatial locations for centrally presented targets. Specifically, Danziger et. al. present evidence for cue-induced spatial coding where a target's spatial code is relative to the preceding cue. Participants were presented with a diamond shaped cue on either the left or right side of the screen. This was followed by an arrow head target that was presented in the centre of the screen. The task was to indicate with a keypress whether the arrow head was pointing to the left or to the right. Participants were faster at responding to right pointing arrows after seeing left cues, and faster at responding to left pointing arrows after seeing right cues. This indicates that the spatial code of a target is affected by the relative location of the preceding cue, with targets appearing to the right of a cue acquiring a 'right-ness' and targets appearing to the left of a cue possessing a 'left-ness'.

The central aim of Experiment 2 was to design a task that removed, or at least reduced the potential for a directional bias, and thus create an opportunity to more objectively assess whether the ARE actually exists as a distortion of visual perception. To attempt this, I changed the dependent variable from left/right judgments to aligned/misaligned judgments. Inherent to the former question is a component of directionality, because subjects are being asked to determine whether one object is to the left or to the right of another object. As mentioned previously, this is potentially contaminating, as there are multiple bases on which "left" and "right" might be assessed. An assessment of spatial locations is relative by nature, as it is based on the relative location of something else, so a potentially "cleaner" measure of the ARE might be attained by using language that reduces the possibility of comparing a target's position to objects other than the one the task set out to measure. In some ways, asking about alignment versus direction creates its own internal anchor, because the reference frame is contained within the question (i.e. in order to determine whether lines are aligned, one must compare them). The main aim of Experiment 3 was to replicate and extend the findings from Experiment 2.

2 Experiment 1: Evaluating the Persistence of the ARE by Introducing Object Anchors

Introduction

The paradigm used here is similar to the one used in DiGiacomo and Pratt (2012), which was itself a modified version of Suzuki and Cavanagh's (1997) landmark study. In the present study, two peripheral cues were presented simultaneously (either in the top left and bottom right or top right and bottom left corners of the screen) before a brief Vernier stimulus consisting of two lines was presented and then masked. There were three between subject conditions: the top line was always directly above the bottom line; the top line could be either slightly left, slightly right, or directly above the bottom line; the top line could be either to the far left, far right, or directly above the bottom line.

The rationale for Experiment 1 was two-fold: first, I simply wanted to explore the possibility that the ARE task might be vulnerable to directional biases, and secondly, if so, to get a sense for where these biases were coming from. At this point one cannot speak to whether or not the concern that objects are coded relative to the location of other objects is simply a theoretical one or whether it has actually influenced existing ARE data. The aim here is therefore to assess whether or not the ARE is at all sensitive to there being different reference frames upon which we establish an object's location. I decided to look into this by introducing an unambiguous standard for what constitutes left and right and seeing whether this would diminish or disrupt the ARE. The underlying assumption of the ARE task is that when participants are asked to determine whether the top line is to the left or right of the bottom line, the response reflects solely the visual perception of the top line compared to the bottom line. By adding in a condition where flanker targets are unambiguously left or right of the bottom line, I can assess whether introducing a new reference frame influences the ARE, as assessed in the *test position*. It could be that in the near target (NT) condition participants are uncertain about whether the location of the top line actually ever changes. When the far targets (FT's) are presented, these may serve as an anchor for a true 'left' and a true 'right', on the basis of which to compare the case where the top line is presented directly above the bottom line. If the FT condition results in a diminished ARE or even in a lack of ARE, it would lend credence to the possibility that the original ARE task may not reflect a visual misperception. Here I aim to determine whether changing the location of the flanker targets will have an effect on the ARE, and thus, whether the task, as it is currently implemented, is indeed vulnerable to these types of anchoring effects.

If reference frames do play a role in the ARE, how could they explain it? That is, if the ARE task is not solely reflecting of a visual misperception, how could the concept of a reference frame give rise to the systematic reporting of a line as 'right' after the presentation of a left cue and as 'left' after the presentation of a right cue in the *test position*? Danziger *et al* (2001)provide the possible explanation that participants could be basing their decision on the location of the target relative to the cue, and they suggest that the spatial code of a target is affected by the relative location of the preceding cue, with targets appearing to the right of a cue acquiring a 'right-ness' and targets appearing to the left of a cue possessing a 'left-ness'. It is possible, of course, that there are other ways of making this judgment, and that additional factors come into play that could bias the response.

Methods

Participants

Twenty-five undergraduate students from the University of British Columbia participated in this experiment for course credit. All had normal or corrected-to-normal vision, were naïve as to the purpose of the study, gave their informed consent prior to participating, and were debriefed by the experimenter. The task lasted approximately 30 minutes.

Apparatus

The experiment was conducted on 21.5inch iMac computer. A head and chin rest was used and the viewing distance was 60 cm. Each participant was tested individually in a dimly lit, quiet room.

Stimuli

All stimuli appeared in white on a black background, and the basic trial sequence is illustrated in Fig 1. The initial screen displayed a central fixation cross (each line was 8 pixels by 4 pixels) that remained for 1000 ms. Following this, two cues appeared for 30 ms in either the top-left and bottom-right areas of the screen or the bottom-left and top-right areas of the screen. Each cue was a circle, 40 pixels in diameter, and the centers were displaced 245 pixels in the horizontal and vertical directions from the fixation cross. After the cues were removed, there was a delay of 180 ms during which the fixation cross remained on the screen. At this point the target appeared, which consisted of two vertically aligned lines. Each line was 34 pixels long and 3 pixels wide and the midpoint of each line was displaced 167 pixels in the vertical direction from the centre of the screen. In all conditions, the bottom line always appeared directly below the centre of the screen. In the single aligned target (SAT) condition, the top line was always located directly above the bottom line. In the near target (NT) condition, the top line was equally likely to occupy one of three positions: either directly above the centre of the screen, or slightly to the left (13 pixels) or to the right (13 pixels) of the centre of the screen. In the far target (FT) condition, the top line was randomly and equally likely to occupy one of three positions: either directly above the centre of the screen, or to the far left (133 pixels) or to the far right (133 pixels) of the centre of the screen. All targets were displayed for 60 ms and then replaced by a pattern mask that was shown for 250 ms. Participants were assigned to one of these conditions.

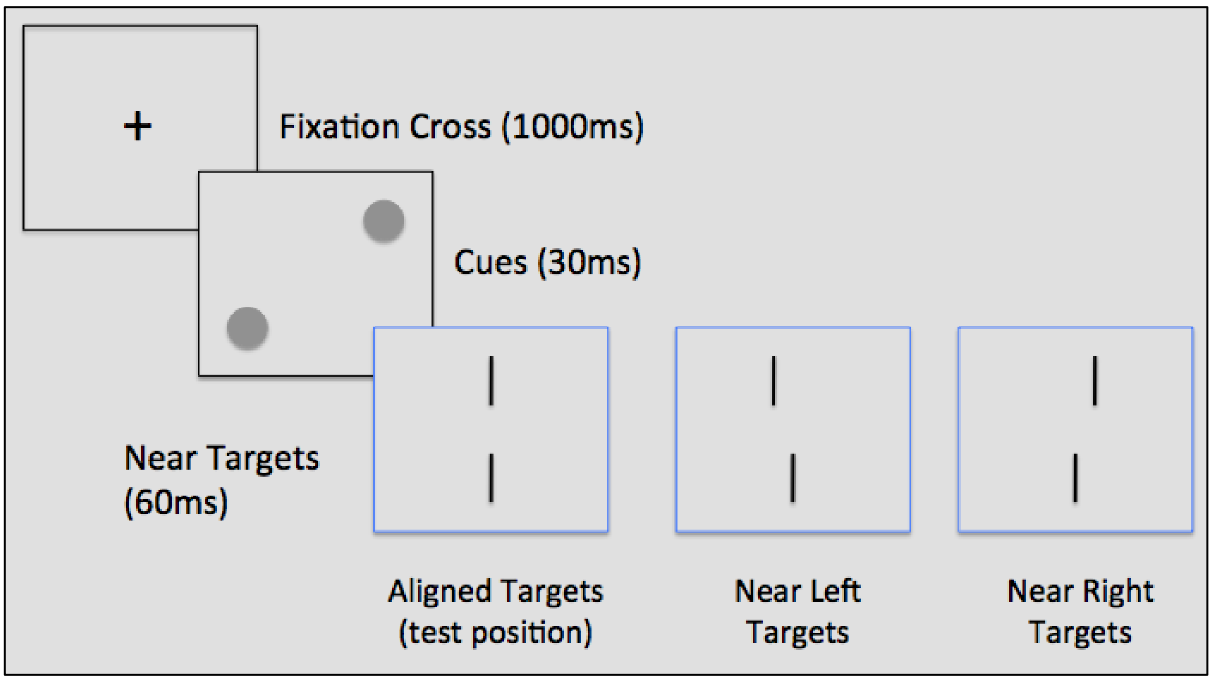

Figure 2. 1 Standard trial sequence for the NT condition

Procedure

Participants were told to focus on the cross at the center of the screen for the duration of each trial and to determine whether the top target line was to the left or right of the bottom target line. In all three conditions the bottom line always appeared centered and it was only the top line that could appear in differing locations. If they thought that the top line was to the left, they were told to press the ‘z’ key on the keyboard and if they thought that the top line was to the right, they were told to press the ‘/’ key on the keyboard. After each response, there was a 750ms intertrial interval.

Results

Data handling

There were 216 near target (NT) trials, 216 far target (FT) trials, and 180 single aligned target (SAT) trials. For the NT and the FT conditions, there were 6 unique cue-target combinations (i.e. top left cue and top left target, top left cue and top aligned target, top left cue and top right target; and so forth). There were 36 trials for each cue-target combination, yielding 216 trials in total. Figure 2.2 shows only the percentage of left responses for each condition in the *test position.* Percentage of left responses was calculated based on how many times a participant reported that the top line was to the left of the bottom line out of the 36 trials in each unique set. For the SAT condition, there were 90 left cue and 90 right cue trials, for a total of 180. Here, the percentage of left responses was calculated based on how many times the participant reported “left” over the course of the 180 trials.

Percentage of left responses

A 3 (condition) x 2 (cue) between-within analysis of variance was conducted on the percentage of left responses at the *test position*. There was a main effect of cue, $F(1,22) = 26.46$, $p < .001$, such that there was a higher percentage of left responses with right cues (69%) than with left cues (25%). There was no main effect of condition, $F(1,22) = .037$, $p = .964$, such that the average of the percentage of left responses between the left and right cues did not differ across conditions (47% for FT, 45% for NT, and 45% for SAT). There was a significant cue by condition interaction, $F(2,22) = 4.08$, $p = .03$, and the difference between the percentage of left responses for left and right cues was 14% for the FT condition, 49% for the NT condition, 71% for the SAT condition.

Three follow-up paired samples t-tests were conducted on the cue types in each condition. As expected, this revealed a significant ARE in the NT condition, $t(6) = 3.52$, $p = .013$, suggesting that right cues (70%) yield a higher percentage of left responses than left cues (21%). There was no ARE in the FT condition, $t(10) = .93$, $p = .374$, with both cue types yielding a similar percentage of left responses (40% and 54% for left and right cue types respectively). In the SAT, there was an even larger ARE present than was found in the NT condition, $t(6) = 5.69$, $p = .001$. The percentage of left responses for the right cue type (83%) was overwhelmingly greater than for the left cue type (12%).

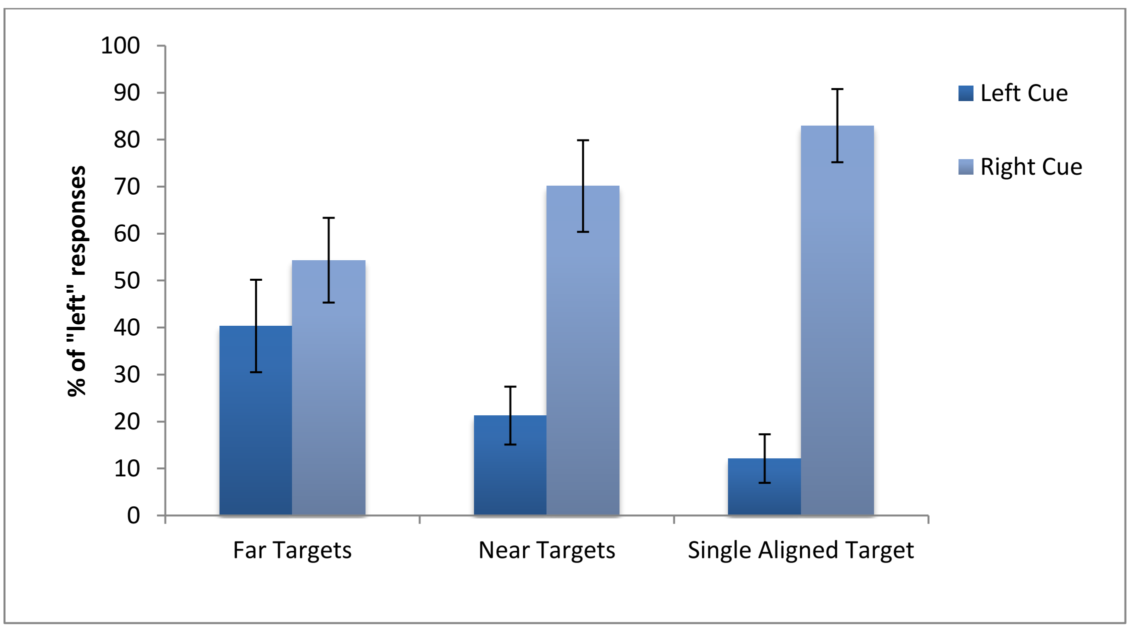

Figure 2. 2 Percentage of left responses in the *test position* (when the top target line is directly above the bottom target line) in the far target (FT), near target (NT), and single aligned target (SAT) condition. Error bars represent the standard error of the mean

Discussion

Experiment 1 shows that the classic ARE first discovered by Suzuki and Cavanagh can be altered (either magnified or overridden) by changing the location of flanker targets in separate trials. In other words, participants respond differently to the *test position* depending on whether they are in the NT, FT, or SAT condition. As expected, the NT case which presents the three typical possibilities for the top line location (centre, slightly left and slightly right), reveals an ARE (Figure 2.2), such that there are fewer left responses for left cues than there are for right cues. The ARE literature suggests that the presence of the left cue repels the top line so that it is perceived as being to the right of the bottom line even when it is aligned, and vice versa (Suzuki and Cavanagh, 1997; DiGiacomo and Pratt, 2012). In the FT condition, with the top line located unmistakably to the left or to the right of bottom line, the ARE disappears, and there are statistically the same number of left responses for left cues as for right cues. Cues that had been thought to instigate the ARE in the NT have no effect in the FT, such that in the *test position*, participants report the top line as being left of the bottom line equally as often as they report it being right of the bottom line.

Interestingly and surprisingly, Figure 2.2 illustrates that the SAT condition reveals a magnified ARE. Right cues almost always result in left responses and left cues almost never results in left responses. Not only does introducing FTs modify the percentage of left responses for each cue, but presenting participants only with the *test position* in the absence of other target types results in a greater magnitude of ARE. It is clear from this set of data that the ARE is indeed quite vulnerable to decision biases inherent to the task.

Because there is no reason to suggest that the same *test position* could be differentially activating receptive fields in the three conditions and contributing to three different perceptions, it is safe to say that the very nature of the task is vulnerable to reference frame effects and thus may not be an effective task for assessing one's perception of line locations. It appears that since the dependent variable reflects a relative construct (i.e. 'left' or 'right' depends on what one considers to be left and right), one cannot be sure that the responses reflect solely a visual misperception.

Now that the ARE has been shown to be vulnerable to reference frame changes, the questions becomes: what could be serving as the reference object in the NT condition? As mentioned previously, data from Danziger et al's 2001 study shows that targets appearing to the right of a cue are associated with a certain 'rightness' and targets appearing to the left of a cue are associated with a certain 'left-ness'. It is plausible that in the ARE task, target locations are being specified with respect to the cue locations, and that this could explain why there are more left responses after right cues and fewer left responses after left cues.

The ARE could potentially be reflecting a reference frame based upon the cues, but it also may be an actual perceptual effect. One way to gain insight into this possibility is by removing the left/right directionality from the task, and then seeing whether the ARE persists. By changing the question to one that does not imply a direction, then, the potential for reference frame "contamination" may be reduced. Asking about alignment does not lend itself to anchoring the lines to the cue locations, and it could be that responses to the question: "are the top and bottom lines aligned or misaligned?" will reflect a 'truer' representation of one's perception of the line locations. If the task were to be based on alignment, however, the traditional way of measuring the ARE (i.e. by the difference between the percentage of left responses for left and right cues) would not be applicable. This is due to the fact that asking about alignment means that one cannot expect differences in the percentage of aligned or misaligned responses across cue types. One therefore has to infer the presence of the ARE in the *test position* based on magnitude of misaligned responses instead of the difference between cue types. Looking at the NT condition in Experiment 1 and taking the difference between the percentage of left responses for left and right cues, it appears that the magnitude of the ARE is approximately 50%. It is also possible to arrive at an estimate of the magnitude by looking at the percentage of left responses for each cue type in the NT condition separately. For left cues, for example, there were approximately 20% left responses, which implies that 20% of the time there was no ARE and 80% of the time there was an ARE. Looking at right cues, there were approximately 70% left responses, which implies that 70% of the time there was an ARE and 30% of the time there was no ARE. Using this approach, we arrive at an average of a 75% ARE rate. So, a conservative estimate would suggest that an ARE is observed 50% of the time, while a more liberal approach puts the estimate at around 75%.

When the lines are actually aligned, then, in the *test position*, if there is an ARE operating one would expect there to be upwards of 50% to 75% misaligned responses. If there is no ARE in the *test position*, one would expect there to be fewer than 50% misaligned responses.

3 Experiment 2: Does the ARE Persist When the Task is Altered?

Introduction

The current experiment uses the same general paradigm as Experiment 1 except that the dependent variable was changed to 'percentage of misaligned responses'. Using a within-subjects design, there were two conditions, NTs and FTs, that were identical to Experiment 1.

The central aim of this experiment is to assess whether an ARE persists in the *test position* when the task is intended to be more objective in that it could be less susceptible to directional biases due to the fact that asking about alignment has nothing to do with whether the cues are presented to the left or to the right.

Methods

Participants

Fourteen undergraduate students from the University of British Columbia participated in this experiment for course credit. All had normal or corrected-to-normal vision, were naïve as to the purpose of the study, gave their informed consent prior to participating, and were debriefed by the experimenter. The task lasted approximately 60 minutes.

Apparatus

The apparatus used here was the same as in Experiment 1.

Stimuli

The stimuli used here are the exactly the same as in Experiment 1.

Procedure

Participants were required to determine whether the lines were aligned or misaligned. If they thought that the lines were aligned, they were told to press the ‘z’ key on the keyboard and if they thought that the lines were misaligned, they were told to press the ‘/’ key on the keyboard. After each response, there was a 750ms intertrial interval.

Results

Data handling

There were 216 NT trials and 216 FT trials and the data reported is within-subjects. For both conditions, there were 6 unique cue-target combinations (i.e. top left cue and top left target, top left cue and top aligned target, top left cue and top right target; and so forth). There were 36 trials for each cue-target combination, yielding 216 trials in total. The percentage of misaligned responses was calculated based on how many times a participant reported that the lines were aligned out of the 36 trials in each unique set. The order of condition was counterbalanced but since there were no order effects, the result reported are collapsed across condition.

It should be noted that because the response decision concerns alignment and not left/right, to get a sense of any directional nature of the ARE, such as a left cue pushing on a left target or a right cue pushing on a right target, the percentage of misaligned responses will be shown for each possible target location.

Percentage of misaligned responses for far targets (FTs)

A 2 (left/right cues) x 3 (far left target, aligned target, far right target) repeated measures analysis of variance (ANOVA) was conducted on the percentage of misaligned responses in the FT condition. As illustrated in Figure 3.1 was a main effect of target, $F(2,36) = 96.70$ $p < .001$, such that the percentage of misaligned responses increased as the magnitude of the actual target misalignment increased (96% for far left targets, 12% for aligned, and 97% for far right targets). There was no main effect of cue, $F(1,18) = 0.06$, $p = .816$, such that there was a similar percentage of misaligned responses with left cues (72%) as with right cues (73%). There was no significant cue by target interaction, $F(2,36) = 1.14$, $p = .331$.

Three follow-up paired samples t-tests were conducted between the cue types for each target type. These were no significant AREs for any condition, suggesting that there was no difference between the reported percentage of misaligned responses across the cue types for each of the three targets. Each cue type yielded a similar percentage of misaligned responses, $t(18) = 1.53$, $p = .143$ (far left targets), $t(18) = 1.40$, $p = .176$ (far right targets), and $t(18) = .81$, $p = .427$ (aligned targets).

A one-sample t-test was conducted on the percentage of misaligned responses at the *test position* (aligned targets), revealed that the relatively low 12% of misaligned responses was significantly below 50%, $t(37) = 5.15$, $p < .001$, with 50% representing the minimum percentage of misaligned responses that should be seen if there is an ARE operating at the *test position.*

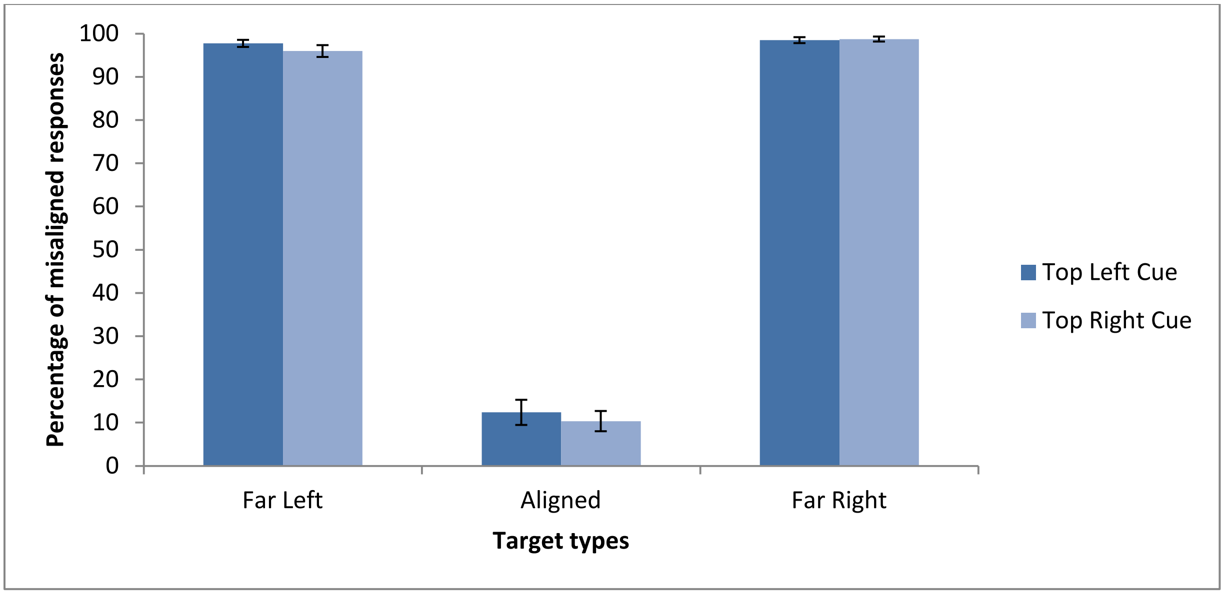

Figure 3. 1 Percentage of misaligned responses in the far target (FT) condition. Error bars represent the standard error of the mean

Percentage of misaligned responses for near targets (NTs)

A 2 (left/right cues) x 3 (near left target, aligned, near right target) repeated measures analysis of variance (ANOVA) was conducted on the percentage of misaligned responses in the NT condition. The data are illustrated in Figure 3.2. There was a main effect of target, $F(2,26) = 13.70$, $p < .001$, such that the percentage of misaligned responses increased as the magnitude of the actual target misalignment increased (52% for near left targets, 29% for aligned targets, and 40% for right targets). There was no main effect of cue, $F(1,13) = 2.58$, $p = .13$, such that there was a similar percentage of misaligned responses with left cues (40%) as with right cues (44%). There was a significant cue by target interaction, $F(2,26) = 9.10$, $p = .001$, and the difference between the percentage of misaligned responses for left and right cues was 25.6% for near left targets, 20.4% for near right targets, and 6.6% for aligned targets.

Three follow-up paired samples t-tests were conducted between the cue types for each target type. These revealed a significant AREs for the near left, $t(13) = 3.94$, $p = .002$, and near right, $t(13) = 3.26$, $p = .006$ target types, suggesting that for near left targets, left cues (39%) yield fewer misaligned responses than right cues (64%), but for near right targets, left cues (58%) yield more misaligned responses than near right cues (38%). Interestingly, there was no ARE in the *test position* (aligned targets), $t(13) = .89$, $p = .389$, with both cue types yielding a similar percentage of misaligned responses (25% and 32% for left and right cue types respectively).

A one-sample t-test was conducted on the percentage of misaligned responses at the *test position* (aligned targets), revealed that only 29% were misaligned responses which is significantly less, $t(31) = 4.26$, $p < .001$, than 50%, with 50% representing the minimum percentage of misaligned responses that should be observed if there was an ARE at the *test position.*

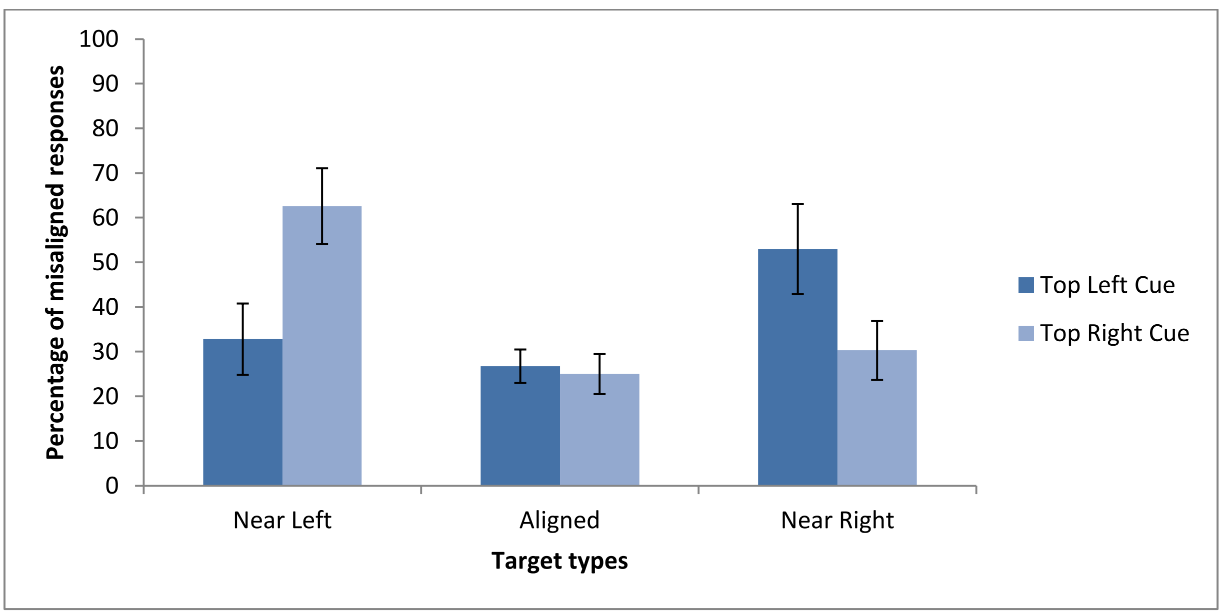

Figure 3. 2 Percentage of misaligned responses in the near target (NT) condition. Error bars represent the standard error of the mean

Percentage of misaligned responses in the near target (NT) condition. Error bars represent the standard error of the mean.

Discussion

Because the dependent variable no longer involves directionality, I cannot infer the presence of an ARE in the *test position* the same way as before – with a difference in left responses for left and right cues. In this case, even if there were an ARE present, I would expect the magnitude of misaligned responses for the left and right cues to be similar. This is because both leftward-perceived misalignments and rightward-perceived misalignments would both be coded as simply "misaligned". One can however discern the presence of the ARE by observing the actual magnitude of the misaligned responses. If there was an ARE, I expected the percentage of misaligned responses in the test position to be equal to or greater than 50%. This is because, as discussed previously, a conservative estimate of the magnitude of the ARE is 50%.

Looking at the far left and far right target types in Figure 3.1, it is apparent that these misaligned lines are reported as such almost 100% of the time. Looking at the *test position*, it appears that there is no ARE. The test position lines are aligned and are rarely reported as being misaligned. Specifically, the aligned test position lines were reported as being misaligned only 12% of the time, which is significantly less than the 50% estimate predicted for an ARE.

The purpose of using the aligned/misaligned task instead of the left/right task was to attain a more objective measure of whether or not an ARE exists at the *test position.* Nevertheless, one must consider the possibility that even the aligned/misaligned task is being affected by anchoring to the far left and right targets. One could argue that although we have dealt with the concern that the cues are serving as a spatial referent, the far targets may still be somehow making participants less willing to say that the *test position* consists of misaligned lines. It could be that if the flanker targets were NT instead of FT that there would be an ARE revealed at the *test position*. Looking at the NT data, however, one sees that while there was a small increase in the percentage of misaligned responses (from 12% to 28%) consistent with the concern that there was an anchoring effect in the FT condition), the 28% of misaligned responses in the *test position* was still significantly less than the minimum of 50% that was predicted by an an ARE, $t(31) = 4.26$, $p < .001$. In summary, for both the far targets and near targets, an ARE does not occur at the test position when the response is aligned/misaligned rather than left/right.

Although there is no evidence of the classically defined ARE in this Experiment 2, I did observe a modified ARE at both the left and right target locations, as shown in Figure 3.2. Because the lines presented are actually misaligned, we can go back to assessing the ARE based on the difference in the percentage of misaligned response for left and right cues. In a manner consistent with what the ARE would predict, when the top line is left and there is a left cue, participants are less likely to report that the lines are misaligned, presumably because the left cue is pushing the top line over to the right, into alignment with the bottom one. Similarly, when the top line is right and there is a right cue, participants are less likely to report the lines as being aligned, presumably because the right cue is pushing the top line into alignment with the bottom one. Indeed, this ARE results in misaligned responses (32%) that closely approximate, and are statistically equivalent ($p = .51$) to the low rate (28%) observed for the aligned lines in the test position.

If, then, the misaligned/aligned task is succeeding in being a less biased measure for assessing the ARE, it appears that while the ARE does not push the aligned lines so that they are perceived as being misaligned, it does push misaligned lines so that they are perceived as being aligned.

4 Experiment 3: Replication of Alignment Task with Five Locations Instead of Three

Introduction

The current experiment serves as a replication and extension of Experiment 2. Here, all five possible target locations (far left, near left, test position, near right, and far right) are mixed into the same experiment. If there really is no ARE at the test position, but there is a new type of ARE at the NT conditions, these outcomes should persist even when the far targets trials are interspersed with near target trials.

Methods

Participants

Sixteen undergraduate students from the University of British Columbia participated in this experiment for course credit. All had normal or corrected-to-normal vision, were naïve as to the purpose of the study, gave their informed consent prior to participating, and were debriefed by the experimenter. The task lasted approximately 60 minutes.

Apparatus

The apparatus used here was the same as in Experiment 1.

Stimuli

The stimuli used here are the same as in Experiment 1, but they are arranged slightly differently. Here, the FT and NT conditions of Experiment 1 are combined together, such that all of the five line locations are equally likely to appear on a given trial.

Procedure

The task is identical to Experiment 2. After each response, there was a 750ms intertrial interval. There were 380 trials.

Results

Data handling

There were 10 unique cue-target combinations, (i.e. top left cue and top far left target, top left cue and top near left target, top left cue and aligned target, top left cue and top near right target, top left cue and top far right target; and so forth). There were 38 trials for each cue-target combination, yielding 380 in total. The percentage of aligned responses was calculated based on how many times a participant reported that the lines were aligned out of the 38 trials in each unique set.

Percentage of misaligned responses

A 2 (left/right cues) x 5 (far left/near left/aligned/near right/far right targets) fully-within analysis of variance was conducted on the percentage of misaligned responses. The data are illustrated in Figure 4.1. There was a main effect of target, $F(4,60) = 193.95$, $p < .001$, such that the percentage of misaligned responses increased as the magnitude of the actual target misalignment increased (91% for far left targets, 23% for near left targets, 13% for aligned targets, 22% for near right targets, 97% for far right targets). There was a main effect of cue, $F(1,15) = 5.90$, $p = .03$, such that there was a lower percentage of misaligned responses with left cues (48%) than with right cues (51%). There was a significant cue by target interaction, $F(4,60) = 11.79$, $p < .001$, and the difference between the percentage of misaligned responses for left and right cues was 4% for far left targets, 19% for left targets, 3% for aligned targets, 14% for right targets, and 1% for far right targets.

Five planned contrasts were conducted between the cue types for each target type. Only the near left and near right target types reached significance, with near left targets yielding fewer misaligned responses with left cues (14%) than right cues (33%), $t(15) = 3.62$, $p = .003$, and near right targets yielding fewer misaligned responses with right cues (15%) than left cues (33%) $t(15) = 4.05$, $p = .001$. This is the new ARE.

There was no classic ARE in the *test position*, $t(15) = 1.56$, $p = .140$, with both cue types yielding a similar percentage of misaligned responses (11% and 14% for left and right cue types respectively), with the mean (12.5%) significantly less than 50%, $t(31) = 15.07$, $p <.001$. Note the misaligned response rate at the test position was the same as the misaligned response rate for near left targets preceded by left cues ($p = .51$) and near right targets preceded by right cues, ($p = .29$)

For far left targets there was no effect of cue, $t(15) = 1.40$, $p = .182$ (90% misaligned responses for left and 94% for right cues) and far right targets, $t(15) = .48$, $p = .639$ (96% misaligned responses for left and 97% for right cues).

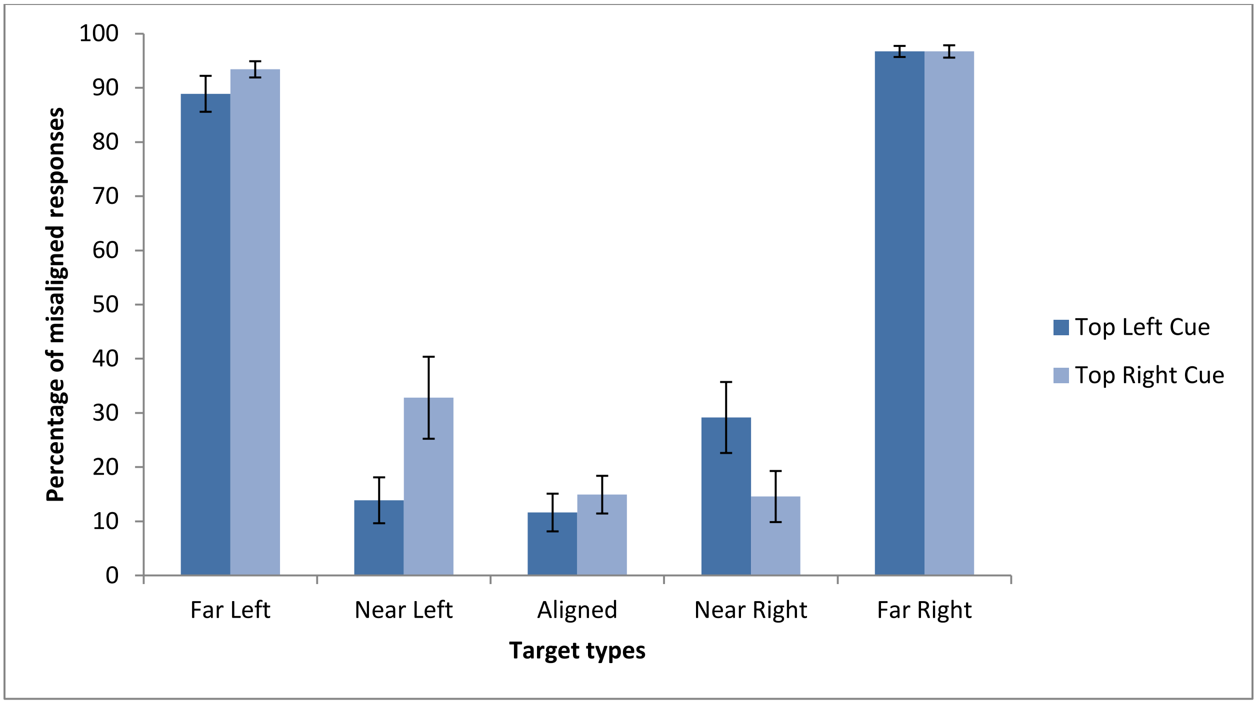

Figure 4. 1 Percentage of misaligned responses across five line positions. Error bars represent the standard error of the mean

Discussion

The purpose of this experiment was to see whether the lack of an ARE in the *test position* and the presence of the new type of ARE in the near left and near right target positions would persist when all of the possible target locations were presented within a single experiment. It appears that having all of the target types mixed together does not change the results from Experiment 2.

In the far left and far right positions, when the lines are very obviously misaligned, they are reported as being misaligned almost all of the time. In the *test position,* when the lines are aligned, that are only reported as being misaligned about 10% of the time. As discussed previously, a conservative estimate of the magnitude of the classic ARE is 50%, and there was no evidence of that here. However, the near left and near right target positions exhibited the new ARE first observed in Experiment 2. When the top line is left and there is a left cue, participants are less likely to report that the lines are misaligned, presumably because the left cue is pushing the top line over to the right, into alignment with the bottom one. Similarly, when the top line is right and there is a right cue, participants are less likely to report the lines as being aligned, presumably because the right cue is pushing the top line into alignment with the bottom one. Indeeded, the rate of misaligned responses in these situations were the same as the rate of aligned responses in for the test position

This experiment reveals the robustness of the finding that there is no ARE in the test position and replicates the finding of a new type of ARE at the near target positions.

5 General Discussion

In Experiment 1, I sought to discover whether the ARE is vulnerable to changes in reference frames, which are sets of coordinate axes that define a three-dimensional space (Logan, 1995). Specifically, I wondered whether the ARE would reduced or eliminated simply by changing what could constitute a left and right target. Given the extant receptive field-based explanation of the ARE (Suzuki & Cavanagh, 1997) it seemed unlikely that changing the location of targets that were not in the test position would influence performance in the test position.

Nevertheless, it seemed that there was a theoretical possibility that the task itself could be compromised by directional biases, given that the very nature of the concept of left and right is relative, that is, dependent on reference frames that are relative to other objects. If relative judgements of left and right do exert an influence on responses in the ARE task, then the effect itself might be altered when relative comparisons are adjusted. I decided to create an unambiguous standard for what the definition of left and right was, in hopes of introducing a new reference frame that was anchored to this standard. The manipulation entailed moving the flanker targets that had been positioned offset slightly from the aligned target to the far left and far right. If participants came to understand that the targets could appear in regions of space that were very obviously to the left or right of the aligned position, they might be unwilling to report that the *test position* was offset.

The results from this experiment were clear: the classic ARE left/right judgement was vulnerable to shifts in what constituted a left/right target on trials that did not probe the test position. Creating reference objects that appeared on the far left and far right resulted in the disappearance of the ARE in the test position. Note that this finding does not mean that the ARE does not exist, nor that the receptive field theory is inaccurate. It simply means that the standard left/right task that yields an ARE may not *only* be measuring the misperception of two misaligned lines that are actually aligned. For instance, the top line in the aligned test position might have a 'right-ness' when it occurs to the right of a left cue, and the top line in the test position might have a 'left-ness' when it occurs to the left of a right cue.

The goal of Experiment 2 was to use a task that was not vulnerable to such a left/right bias, and see whether the ARE is still observed. One way to remove directionality from the task but still get an assessment from participants in terms of the line locations, is to ask about line alignment. Thus the task was changed from "is the top line to the left or to the right of the bottom line?" to "are the two lines aligned or misaligned?" The intention was that the latter question would prevent the left/right cues from serving as reference objects, and therefore that the results would reflect a purer estimation of the ARE.

The findings were somewhat surprising, as they suggested a lack of ARE at the *test position*, which classically provides a setting that elicits the ARE. There was still, however, evidence that the cues may be causing perception of the targets to be inaccurately offset in the opposite direction from the cue. This came from the fact that misaligned near targets were reported as being misaligned less frequently when the cue appeared on the same side as the top target, as if the cue was pushing the top line into alignment, in a manner consistent with what the ARE would predict. Experiment 3 replicated these findings.

Limitations

One limitation of this set of experiments is that I was unable to definitely show that there was no ARE in the aligned condition. This problem arises from two different issues. The first is that the aligned/misaligned task does not allow one to directly measure a perceived shift of a target stimulus in the test position. The second is that I may not have a reliable estimate of the magnitude of the ARE. The reason I switched from a left/right task to an aligned/misaligned task is that I needed to remove the directionality bias that contaminated the left/right responses. By doing this, however, I lost an important piece of information – that is, did participants see the lines as misaligned to the left or misaligned to the right? I do not know for sure. It is possible that the *test positions* in Experiments 2 and 3 are concealing an ARE. Without having a clear conception of what error rates should be at the *test position*, it is impossible to definitely state whether or not an ARE is present. It is unlikely that there would be zero error, and this is supported by the fact that even in the FT conditions we still don't see 100% accuracy, so there is good cause to reason that the percentage of misaligned responses observed in the *test position* are indeed reflecting error. Our estimate of ARE magnitude came largely from Experiment 1, where we used the left/right task that is vulnerable to bias. Because we are asserting that the left/right task is faulty, we cannot use the current ARE literature to gauge the magnitude of the ARE, to aid us in predicting the absolute percentage of misaligned responses that we should see. If we had a clearer idea of the ARE magnitude, we would be able to more definitely suggest that the fact that we don't see zero misaligned responses in the *test position* is simply due to error. That said, if there is an ARE in the test position, it is fairly trivial and small, i.e., in Experiment 3 if one assumes that all misaligned responses are true misperceptions (i.e., an ARE), the magnitude of the effect is less than 15%.

Future questions and directions

In Experiments 2 and 3 I concluded that there was no evidence for the ARE at the *test position*, based on a comparison of the percentage of misaligned responses to an estimate of ARE magnitude. The ambiguity about how many misaligned responses should be expected could be cleared up if I had a reliable error rate measurement. This could be obtained by running a condition where there are no cues, and participants perform the same task: reporting whether the lines in the *test position* are aligned or misaligned. By removing the cues, the presumable "source" of the ARE is removed, and there is no reason to expect that participants would not see the lines as being aligned. Therefore, any departure from zero misaligned responses could be attributed to error. This could then be compared with the percentage of misaligned responses that are seen with the cues, to see if there are significantly more misaligned responses that cannot be attributed to error. Additionally, it would be very informative to run a sort of master experiment with the three possible cue types (left, right, and none) and gather the basic aligned/misaligned information but to then also after each trial ask participants to specify whether, if they pressed misaligned, they thought the line was misaligned to the left or to the right.

Another idea to explore would be the fact that there is a type of ARE observed when the targets are actually misaligned. Why is there no ARE at the *test position* but an ARE at the NT positions? Why would the ARE function to push lines together into alignment but not push them apart out of alignment? It could be that the *test position* presents a visual event that looks more like a cohesive object, and that object-like representations are more difficult to distort than items that do not look like they fit together. To explore whether the ARE truly affects misaligned lines and not aligned lines, one could conduct an experiment where the *test position* is presented closer to the cues, in the position of the NTs, for example. As it stands now, the *test position* always appears furthest from the cues, because the bottom line is always presented in the centre. It could be that the ARE does influence aligned lines, but not when they are so far away from the cues.

Finally, to gain some insight about the mechanism underlying the ARE, it would be informative to see whether an ARE could be elicited when the source of the ARE -- the peripheral cues -- are presented in a nonvisual modality, e.g., as auditory sounds coming from either the left or the right.

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