Reversal of the Alignment Effect: Influence of Visualization and Spatial Set Size

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Abstract

When asked to engage in judgments of relative direction (JRD), subjects routinely show a performance benefit when the judgments are aligned with the perspective used at encoding. This alignment effect (Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998) has recently been shown to reverse itself when subjects rotate 180°(Waller, Montello, Richardson, & Hegarty, 2002), consistent with the predictions of egocentric spatial representation theories (Wang & Spelke, 2000). This study shows how the alignment effect is not only dependent upon individual differences in the quality of a subject's target visualization, but also that this benefit for latency, but not error, diminishes as target set size increases.

Keywords: spatial reasoning, representation, spatial updating, alignment, visualization, set size.

Introduction

The nature of spatial memories and their underlying representations have been the focus of research across many domains including not only cognitive (e.g. Presson & Montello, 1994; Shelton & McNamara, 2001; Wang & Spelke, 2000), development (e.g. Gouteux & Spelke, 2001; Newcombe, & Huttenlocher, 2000), and neuropsychological (e.g. King, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2002; O'Keefe, & Nadel, 1978), but even robotics and artificial intelligence (e.g. Burgess, Donnett, Jeffery, & O'Keefe, 1999; Hiatt, Trafton, Harrison, & Schultz, 2004). These studies consistently find that memories for the locations of objects are orientation dependent. Spatial judgments that are aligned with the encoding orientation are performed faster and more accurately than those that are misaligned (Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998). Investigations of orientation dependency often rely upon judgments of relative direction (JRD). In this methodology, subjects study a configuration of objects (figure 1). They are asked to imagine themselves standing at one target, facing a second, and then point to the third. The standing/facing target pair defines an imaginary heading. This imaginary heading can be *aligned* (i.e. parallel) to the encoding orientation or *misaligned*. In the case illustrated in figure 1, the JRD HYA would be faster and more accurate than the *contra-aligned* (180° rotation) EAH judgment.

Any representational theory must be able to account for this basic alignment effect. Egocentric theories, which encode the objects individually relative to the viewer, naturally encompass this phenomenon (e.g. Wang & Spelke, 2000). Allocentric theories, which represent the locations of objects relative to an external, stable frame of reference, handle the effect just as well and, in the case of geometrically regular configurations, present the possibility of multiple, non-viewer centered orientation preferences (Shelton & McNamara, 2001). Ignoring the special case of geometrically regular configurations, the two classes of theories are equivalent in their predictions. In order to differentiate these representational systems, one can look at the processes that operate on the representations while engaging in JRDs.

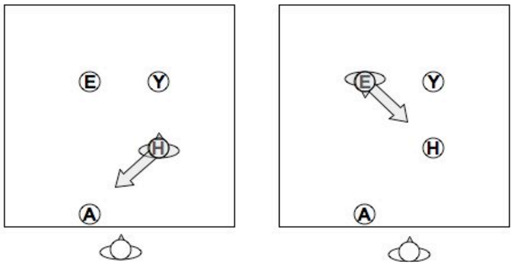

Figure 1. First training configuration used in this study. Left: *aligned* judgment HYA (i.e. "Imagine you're standing at H, looking at Y, point to A"). Right: *contra-aligned* judgment EAH (i.e. "Imagine you're standing at E, looking at A, point to H").

Egocentric representational theories necessarily depend upon some form of spatial updating in order to maintain a consistent representation of the spatial world across movement and time (Wang & Spelke, 2000). This updating can be performed automatically with subject movement by path-integration (Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Presson & Montello, 1994) or through effortful mental transformations (e.g. Shepard & Metzler, 1971). These processes operate on the individual egocentric representations such that after real or imagined movement, there should be some measurable representational change.

Theories of allocentric representation take a fundamentally different tack on path-integration and mental transformations. Instead of updating the object location representations, they serve to anchor a representation of the viewer within a stable allocentric network (e.g. King, et al., 2002; Mou, McNamara, Valiquette, & Rump, 2004; O'Keefe, & Nadel, 1978). An appropriate analogy would be the "you are here" arrow often seen on map kiosks. As the viewer moves or imagines moving through the space, the actual allocentric spatial representation remains unchanged; rather it is the viewer's position within it that is updated.

With these computational differences in mind, attention can be turned to a study conducted by Waller, Montello, Richardson, & Hegarty (2002). They were interested in exploring the changes to the alignment effect as a result of viewer movement. In their third experiment they examined the effect of a 180° rotation. After learning the target locations, if subjects were asked to rotate and visualize the locations of the objects relative to themselves (i.e. behind themselves) the alignment effect reversed itself: that is, *contra-aligned* judgments were now faster and more accurate than *aligned* judgments. When subjects were asked to rotate but ignore the locations of the objects relative to themselves (i.e. visualize the original learning view) they showed the standard alignment effect.

Interpreting these results from an egocentric perspective is quite straightforward. When the subjects rotated, they actively updated the locations of the targets in order to maintain spatial consistency. Those that were asked to visualize the new locations used the updated representations in solving the JRD. Those that had been asked to ignore the rotation merely retrieved and used the initially learned representations.

As a class of theories, allocentric representations have difficultly with this finding. Without a spatial updating mechanism, the allocentric network doesn't change with subject movement. The alignment effect should be immune to changes in the subject's position or orientation. However, two specific theories do address this phenomenon. May (2004) proposes that this is not an example of updating but rather interference between sensori-motor and cognitive object location estimates. In other words, the greater the difference between where you actually are and where you imagine you are, the greater the performance decrement. When subjects do not rotate, the interference will be greatest for *contra-aligned* judgments. On the other hand, when subjects do rotate interference will be greatest for *aligned* judgments. This explains the *rotate-update* results quite nicely, but not the *rotate-ignore* results, since for this group the average disparity between actual and imagined locations would be the same.

The model proposed by Mou, McNamara, Valiquette, & Rump (2004) explicitly addresses the Waller, et al. (2002) study. Their explanation rests upon two assumptions: 1) judgments aligned with 180° are roughly equivalent to those along 0° (i.e. *aligned* ≈ *contra-aligned*) and 2) the mental transformation necessary to align the imagined and actual headings introduces a roughly constant cost (as a function of disparity). If the first assumption were true, the reversal seen would be entirely due to the cost of mentally rotating in order to align the imaginary heading with the actual heading. Like May's proposal, this does explain the *rotate-update* but not *rotate-ignore* results for Waller, et al. (2002).

While the two previous allocentric theories make promising steps towards explaining the reversal of the alignment effect, there is an additional computational aspect that can help tease apart the predictions. If path-integration and mental transformations merely anchor the single representation of the self within a larger allocentric network, JRD performance should be relatively immune to set size effects. However, if spatial updating transforms individual egocentric representations, the efficiency of it should be constrained by working memory limitations (Harrison & Schunn, 2003; Hodgson & Waller, 2006; Wang, et al., 2006). Most recently, Wang, et al. has shown that egocentric pointing is sensitive to increases in set size for both latency and error (2006). However, Hodgson and Waller (2006) have only found latency effects across a much wider set size range. They conclude that this latency effect is the result of subjects engaging in mental transformations at testing and not during the rotation itself.

If rotation induces updates to egocentric representations, as suggested by the reversal of the alignment effect in JRDs, then as the number of targets increases, the magnitude of the alignment effect (or its reversal) should decrease both for latency and pointing error. Specifically, while there may be a main effect of set size (i.e. a serial search effect for latency), there should also be a significant interaction between set size, body position (*stay/rotate*) and imaginary heading (*aligned/contra-aligned*).

Methods

This study was effectively a set size variant of Waller, et al.'s third experiment (2002). Here subjects studied four-target configurations and made *aligned* and *contra-aligned* JRDs. Participants made these judgments on two configurations in each of three different conditions: *stay*, *rotate-update*, and *rotate-ignore*. For *rotate-update* and *rotate–ignore* conditions, participants turned 180° in place. During *rotate-update* subjects were asked to visualize the locations relative to their new position; that is, behind themselves. For *rotate-ignore* trials, subjects were asked to imagine that they had not moved at all.

This study introduced a few changes to Waller, et al.'s methodology. First, a between subjects manipulation of set size was added (*4,6,8*). Because of this, new configurations had to be generated for the six and eight target conditions. Geometrically regular configurations (i.e. grid-like configurations used by Mou & McNamara (2002)) were avoided in order to dissuade intrinsic alignments, which may mask changes to the alignment effects. Additionally, Waller, et al. (2002) had subjects point to each of the targets blindfolded before engaging in the JRDs. This was done to ensure that participants knew the target locations sufficiently after studying. In this experiment, a training-to-criterion study phase was used instead to ensure participants knew target locations. The egocentric pointing was moved to the end of the JRD pointing block in case it provided an additional rehearsal opportunity after rotating. Finally, the *rotate-ignore* group was not included; all subjects were asked to visualize the target locations relative to themselves as they rotated.

Participants Sixty-one students (29 female, 32 male) from Pittsburgh and Philadelphia universities participated for course credit or pay[1]. All participants were tested

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[1] No differences in performance were found between the student groups based on university or compensation.

individually in one-hour sessions. Two participants were omitted due to equipment failure, leaving a total of 59 participants (29 female, 30 male; 20, 19 & 20 in set sizes *4*,*6* & *8* respectively).

Materials Fifteen configurations of targets were generated for this study (three training sets and four testing sets for each set size). Configurations were assembled from 30.5cm (1ft) tall orange cones with 7.6cm (3in) reflective letter labels. Each configuration fit within a 3m square region, with a minimum of 0.5m separating each target. The initial pointing-training configuration was an 8-target diamond pattern, labeled alphabetically clockwise, with the subject position in the center. The remaining two training configurations were based on scaled versions stimuli used in Waller, et al. (2002). The testing configurations were pseudo randomly generated by computer with the following constraints: there must be at least two columns with two targets each, but no row or column can contain more than two targets. Labels were assigned to targets pseudo randomly to prevent label repetition in consecutive configurations and to minimize phonetic similarity of labels.

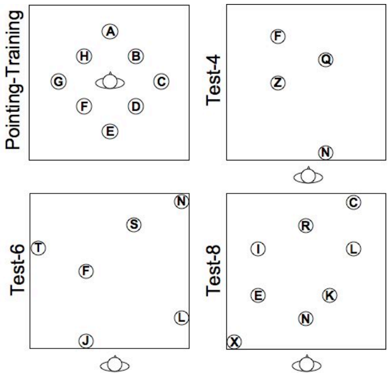

Figure 2. Sample training and testing target configurations.

Participants wore a pair of blacked-out wrap-around sunglasses, a pair of headphones (for probe presentation), and a high-precision joystick (for responding). Participants were blindfolded for the entire study except when studying the target configurations.

Procedure After obtaining informed consent subjects were randomly assigned to one of three target set size groups (*4*,*6*,*8*). Before testing, all participants completed the same three training configuration blocks.

Training The first training configuration (figure 2:*Pointing-Training*) gave participants practice using the joystick to respond and introduced them to the two pointing tasks: egocentric pointing (EGO) and judgments of relative direction (JRD). Subjects stood in the middle of an eight-target diamond configuration and were first asked to point (while sighted) to each of the targets in random order. For each target, if their pointing error exceeded 15°, they were provided with corrective feedback and asked to try again. After completing the sighted-EGO block, participants replaced the blindfold and were prompted to point to each of the targets again. As before, if their errors exceeded 15° they were provided corrective feedback, given 15 seconds additional time to study before replacing the blindfold, and asked to try again. Upon completion of the blindfolded-EGO block, the JRD task was explained to the participants. They were instructed that they would be provided with three target locations. They were to imagine themselves standing at the first, facing the second, and then point to the third. Like the EGO blocks, participants were asked to engage in four sighted and blindfolded JRDs. In this case the error threshold was a more liberal 45°. After completing the EGO and JRD training, participants received additional information. They were told that accuracy was more important than speed, but that they would have 8 seconds to complete each trial. If they were uncertain of their response, they were told to just let the time expire.

Participants were next introduced to second and third practice configuration blocks, which were structured like the actual testing configurations. Subjects entered the experiment area and began the study-phase of the block. During the study phase, participants were given 30 seconds to study the configuration (figures 1 & 2), after which time they replaced the blindfold and were tested. The study-phase repeated itself until participants passed this test. The test prompted them to point to each of the targets randomly three times. In order to pass the study test, their pointing error to *each* target had to be less than 15°. Upon exiting the study-phase there was a 30 second retention interval followed by the testing-phase. The testing-phase consisted of a block of eight randomly ordered JRD trials followed by a block of randomly ordered EGO trials (once per target) with a five second delay between each judgment. The eight JRD trials were composed of four *aligned* and four *contra-aligned* trials. The second practice configuration block introduced participants to the rotate instructions. Specifically, just before the retention interval, participants were instructed to turn 180° in-place. They were instructed to try to visualize the locations of the objects relative to themselves as they moved, since they would be asked to point to each of the targets at the end of the configuration block.

After the third practice configuration, the experimenter answered any questions and set up the first testing configuration block.

Testing Having completed the training, participants were exposed to the four testing configurations presented in random order (two each in *stay* and *rotate* conditions). The testing configuration blocks were structured almost identically to the second and third practice configurations. After the configuration was in place, the participant entered the experiment area and began the study-phase. Actual study times were different based on set size condition. Initial study times for the three conditions were 30, 50, and 70 seconds for set sizes *4*, *6*, and *8* respectively. If participants failed the study test, the additional study time was always 30 seconds regardless of set size. The testing-phase again consisted of eight randomly ordered JRD trials (four *aligned* & *contra-aligned*) followed by a block of EGO trials.

After the final configuration, participants filled out a brief questionnaire asking for general demographic information as well their subjective awareness of the frequency of various types of visual imagery, behaviors, and strategies. Of greatest interest here were the visual imagery questions. These questions were designed to probe the frequency of the use of egocentric (i.e. “When remembering the location of a target, I often *saw* it from the same perspective I studied it from”) or allocentric (i.e. “When remembering the location of a target, I often *saw* it from a top-down, map-like perspective”) visualizations. The responses for each were averaged to produce an estimated frequency of egocentric and allocentric imagery use.

Results

Each subject attempted 32 different JRDs, however the actual number completed might be less if the subject failed to respond in the allotted time for each judgment[2]. The reaction times and errors were averaged within each of the four conditions of concern (alignment x position). If any cell had less than four judgments, the data for the entire subject was excluded. All subjects completed at least half of the trials.

All of the analyses discussed here are based on repeated-measures ANOVA with viewer position (*stay*/*rotate*) and imaginary alignment (*aligned*/*contra-aligned*) as within-subject factors and target set size (*4,6,8*) as a between-subjects factor. These analyses were applied to absolute pointing error and reaction time. An additional between-subjects factor, allocentric visualization, was also used and will be discussed later.

While the alignment effect is solely dependent upon the imagined perspective of the subject, its reversal is additionally dependent upon the subject’s position (and the subjective quality of their visualization). It is the significant interactions that are of primary concern here. Therefore, while all significant effects will be touched upon, greater attention will be directed towards the interactions. Two specific interactions are predicted: the interaction of position and alignment, such that after *rotation contra-aligned* judgments are faster and more accurate than *aligned*; and the interaction of set size, position and alignment showing a decrease in the alignment effect (reversed or not) with increases in set size.

Alignment Effect

A significant main effect was found for alignment for both latency and pointing error. *Aligned* judgments were both faster (3.8s vs. 4.5s; F(1,53)=62, p<0.001) and more accurate (42.8° vs. 50.2°; F(1,53)=8.5, p<0.005) than *contra-aligned* judgments. A significant main effect of position on pointing error was also found, showing an increase when subjects were asked to turn around (F(1,53)=8.26, p<0.006); latency was unaffected. More importantly, the interaction between alignment and position was significant for both latency (F(1,53)=71.8, p<0.001) and pointing error (F(1,53)=12.5, p<0.001). In this case, while the alignment effect is present in the *stay* condition, when subjects are asked to *rotate*, the differences between *aligned* and *contra-aligned* judgments are eliminated (figure 3).

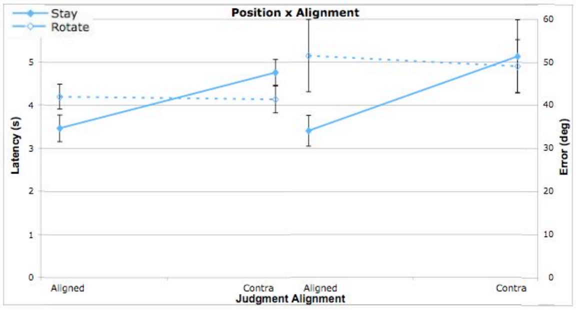

Figure 3. Latency (left) and error (right) as a function of alignment (*aligned/contra*) and position (*stay/rotate*). After rotating, the alignment effect is eliminated. Error bars are 95% CI.

Visualization and Alignment Reversal

While the previous results show a significant change due to rotation, it is far from the alignment reversal found by Waller, et al. (2002). It now becomes necessary to consider subjects’ response to the visualization questions. While over 90% of the subjects reported frequently engaging in egocentric visualizations, only half the subjects reported using allocentric visualizations frequently. The subjects were split into two groups: those that only used egocentric visualizations (*Ego*) and those that used both egocentric and allocentric visualizations (*EgoAllo*).

The interaction between position, alignment and visualization reveals a significant reversal of the alignment effect, but for *Ego* visualizers only. Those that engaged in both egocentric and allocentric visualizations (*EgoAllo*) just exhibit the basic alignment effect favoring *aligned* JRDs regardless of position (figures 4 & 5). This interaction was significant for both latency (F(1,53)=11.6, p<0.001) and pointing error (F(1,53)=10.3, p<0.002).

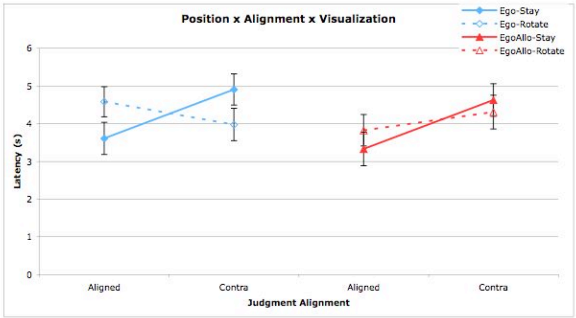

Figure 4. For latency, the alignment effect reversal (inverted slope) is seen only for *Ego*-visualizers (left). *EgoAllo*-visualizers (right) exhibit the basic alignment effect. Error bars are 95% CI.

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[2] Since subjects were under time pressure to respond, a speed/accuracy analysis was conducted on each subject’s raw data. Average r=0.1, with no group (set size & visualization type) less than r=-0.2.

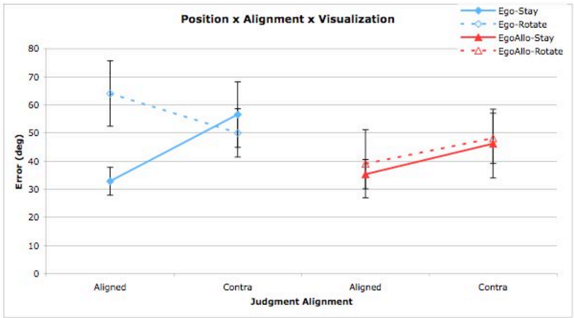

Figure 5. For pointing error, again, only *Ego*-visualizers show the reversal of the alignment effect. Error bars are 95% CI.

Set Size Effects

Having found the reversal of the alignment effect and its dependence upon the quality of subjects' visualizations, we can now explore the effect of set size. At the grossest level of analysis, there is a main effect of set size on latency (F(2,53)=4.9, p<0.01). However, post-hoc analyses[3] showed that it was only that four targets were significantly faster than six (p<0.01) and eight (p<0.002). The differences between six and eight targets were insignificant (p>0.5). There was no effect of set size on pointing error (F(2,53)=1.4, p>0.2).

Except for the four-way interaction with position, alignment and visualization, none of the other interactions with set size were significant. Because of the complexity of this interaction, it is presented in terms of difference scores between the *contra-aligned* and *aligned* judgments and can be viewed as the magnitude of the alignment effect. This interaction was significant for latency (F(2,53)=4.9, p<0.01), but not pointing error (F(2,53)=0.139, p>0.8).

An in-depth analysis of this interaction showed that it was being unduly influenced by the unequal distribution of visualizers in the set size *6* group (13:6, *Ego*:*EgoAllo*). As the result of three slower subjects, the average latency for *contra-aligned stay* judgments was significantly slower than it was for the equivalent cell in the set size *8* group.

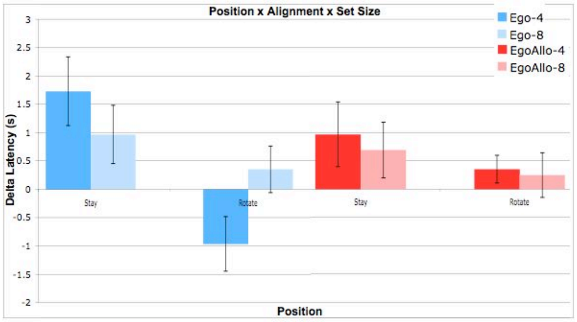

Figure 6. Decrease in the alignment effect (basic or reversed) for latency with increases in set size. Error bars are 95% CI.

If we exclude the set size *6* condition entirely, the significant interaction is maintained (F(1,36)=5.1, p<0.03) and is much easier to consider (figure 6). Here we can see that when set size increases from four to eight, not only does the basic alignment effect diminish for *EgoAllo* visualizers, but that the reversal diminishes as well for *Ego* visualizers. In other words, as set size increases the alignment effect decreases.

Discussion

It is well established that spatial representations have preferential orientations. If a spatial judgment is made that is consistent with that preferential orientation, it will be faster and more accurate than those that are inconsistent (Roskos-Ewoldsen, et al., 1998). Unfortunately, this basic phenomenon does not serve to differentiate contemporary theories of spatial representation; both allocentric (Mou & McNamara, 2002) and egocentric (Waller, et al., 2002) theories make similar predictions for this alignment effect. However, they do differ when one asks how, if at all, the alignment effect changes with movement and target set size.

The egocentric with spatial updating theory (Wang & Spelke, 2000) predicts that as a viewer moves through their environment, path-integration processes update the egocentric representations effectively moving the preferred orientation as well. In other words, the alignment effect would always benefit the alignment that was consistent with the viewer's current body position. In the case of judgments of relative direction, the alignment effect would favor *aligned* judgments when the subject did not move. However, if the subject rotated 180°, the alignment effect would reverse favoring *contra-aligned* judgments. This was precisely what seen for *Ego*-visualizers for both latency (figure 4, left) and pointing error (figure 5, left). Since this updating process will necessarily be computationally bounded, it should have a capacity limitation. Wang, et al. (2006) showed that both latency and error are adversely affected by increases in target set size. The data presented here only partially corroborates their results. While increasing set sizes do decrease the magnitude of the alignment effect, it is limited to just latency, pointing error is unaffected by set size (figure 6). While this only partially supports Wang, et al.'s theory, it is consistent with Hodgson and Waller's conclusions that the updating that is taking place occurs at testing not during rotation (2006).

Allocentric theories take a different perspective. Here path-integration processes serve to anchor the viewer within a larger allocentric representation of the space (e.g. Sholl & Kenny, 2005). As such, the alignment effect should remain relatively unchanged as the subject moves – precisely what was seen for the subjects who engaged in both egocentric and allocentric visualizations (*EgoAllo* in figures 4 & 5, right). Unfortunately, this particular design is unable to address the interference account put forward by May (2004). However, the results are consistent with Mou, et al.'s proposal (2004). If *aligned* and *contra-aligned* judgments

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[3] Bonferroni correction

are roughly equivalent, then the reversal seen is actually just the result of the cost of mental aligning the imagined heading with the actual heading.

If, as allocentric theories proposal, the spatial transformations merely act upon the representation of the self within the allocentric network, then increases in set size should have resulted in relatively little change. At most, one might expect increases in latency, as serial search processes would have to sift through more objects in search of a specific target. However, the effect of the serial search should be constant across conditions within any given set size. In other words, while average latency would increase with set size, the alignment effect should remain constant. What we see in the data, however, is that the alignment effect (difference between *contra-aligned* and *aligned* judgments) is decreasing with set size (figure 6).

Conclusions

This study set out to further differentiate egocentric and allocentric theories of spatial representation by looking at the effect of set size on the alignment effect. While the alignment effect was reversed after rotation, it was limited to those subjects who reported only engaging in *egocentric* visualizations. Participants who reported visualizing the targets both *egocentrically* and *allocentrically* showed no such reversal. Regardless of the nature of the alignment effect, as the number of targets studied increased, the magnitude of the alignment effect for latency decreased, contrary to allocentric predictions. This set size effect might account for the lack of updating seen in Mou, et al.'s nine target experiments (2004). That set size affected only latency and not pointing error suggests to some that the updating taking place isn't occurring during the rotation itself, but rather at testing and is driven by conscious mental transformations (Hodgson & Waller, 2006).

Acknowledgments

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