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Stevens, Christopher; Carlson, Rich

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Are You Sure the Library Is That Way? Metacognitive Monitoring of Spatial Judgments

Christopher A. Stevens and Richard A. Carlson
Pennsylvania State University

Many studies have examined how people recall the locations of objects in spatial layouts. However, little is known about how people monitor the accuracy of judgments based on those memories. The goal of the present experiments was to examine the effect of reference frame characteristics on metacognitive accuracy for spatial judgments. Reference frame characteristics include the alignment of one's viewpoint with the structure of the environment (allocentric alignment), direction of the target with respect to one's current viewpoint (egocentric direction), and the type of perspective used to solve the task (egocentric vs. allocentric). Participants were tested on their knowledge of a well-known location in which they had experience navigating. They were asked to orient themselves toward a particular heading and point to target landmarks from this heading. They then rated their confidence in their pointing judgments. Confidence judgments were sensitive to the effects of allocentric alignment and egocentric direction on performance. However, they underestimate the magnitude of these effects. Follow-up regression analyses indicate that confidence in individual landmarks was a stronger predictor of confidence than reference frame characteristics. Overall, the results suggest that people use reference frame features and landmark confidence when monitoring performance in directional judgments.

Keywords: metacognition, spatial cognition, metamemory, reference frames, perspective taking

Whether learning a new space or navigating in a familiar one, it is important to know when one's knowledge of that space is likely to be accurate. Despite an abundance of research on spatial memory and the factors that influence spatial memory accuracy, little is known about how people monitor their spatial knowledge and judgments. In these experiments, we examine the hypothesis that individuals' confidence in their spatial judgments will be sensitive to factors known to affect the accuracy of spatial judgment. One such factor is the choice of spatial reference frames. A reference frame refers to a set of axes or coordinates used to define spatial locations. Reference frames influence the information available for spatial judgments, and may therefore affect the information used for confidence judgments as well.

Spatial Reference Frames

Making a spatial judgment requires one to establish a reference frame. Reference frames can be centered on the observer's body (egocentric) or on the environment (allocentric; Easton & Sholl,

1995). Many theories of spatial cognition postulate that two separate systems exist for processing information from these two types of reference frames (Easton & Sholl, 1995; McNamara, 2013; Mou, McNamara, Valiquette, & Rump, 2004; Wang & Spelke, 2002). Previous research has shown that the reference frame used to make a spatial inference can have a strong effect on the accuracy and latency of the inference (Kelly & McNamara, 2009; Shelton & McNamara, 2001; Sholl, 2000; Werner & Schmidt, 1999). However, the effect of these reference frames on metacognitive monitoring of performance has not yet been considered.

In this paper we examine a particular type of spatial judgment that requires the use of information from both egocentric and allocentric reference frames: judgments of relative direction (JRDs; Sholl, 1987). In a JRD task, a participant must assume a particular heading within an environment and indicate the direction of a target given this heading. In the following section, we review empirical effects associated with egocentric and allocentric reference frames in the JRD task and discuss how these effects might also influence metacognitive monitoring.

Metacognitive accuracy refers to the correspondence between confidence and performance. Metacognitive accuracy may be measured in absolute and relative senses (Koriat, 2012). Ideal metacognition would provide perfect knowledge as to the correctness of a judgment in both senses. Absolute accuracy means the extent to which confidence predicts performance (Koriat, 2012; Nelson & Dunlosky, 1991). For instance, if a person believes that they are off by no more than 10° in pointing to a target, but they are actually 60° off, the person has poor absolute accuracy. Relative accuracy means the extent to which confidence judgments can discriminate between items that are likely to be remembered or correct from those that are not. Relative accuracy is high when performance

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Christopher A. Stevens and Richard A. Carlson, Department of Psychology, Pennsylvania State University.

Christopher A. Stevens is now at the University of Groningen.

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Correspondence concerning this article should be addressed to Christopher A. Stevens, University of Groningen, Nijenborgh 9, 9747 AG Groningen, The Netherlands. E-mail: c.a.stevens@rug.nl

increases with confidence, even if that confidence is too high or too low in absolute terms (Yaniv, Yates, & Smith, 1991). Both of these measures of metacognitive accuracy may be influenced by the reference frame factors discussed in this section.

Egocentric System

Information in the egocentric system is organized along body-centered axes: front-back, left-right, and up-down (Franklin & Tversky, 1990). Of these axes, the front-back axis shows a particular importance. Many studies have demonstrated that people are faster and more accurate when pointing to the front than when pointing to the back (Kelly & McNamara, 2009; Shelton & McNamara, 2001; Sholl, 1987, 2000; Werner & Schmidt, 1999). Kelly and McNamara (2009) argue that this is because information in the front hemifield of the egocentric reference frame is more active than information in back hemifield. This hemifield is presumably the one most relevant for the planning of movement and navigation. It is also the half of space toward which sensory and motor organs are oriented. This asymmetric activation likely has implications for metacognition. First, if targets in the front half of space are more active than those in the back half, more information about these targets may be available for monitoring. This may include perceptual information about the target and information about nearby landmarks and paths. The ability to retrieve more of this information may increase confidence in one's knowledge of the target. Thus, people should be more confident when pointing to the front half of space than to the back half. In addition, the increased availability of information should make it easier to discriminate between well-known targets and lesser-known targets. Therefore, we expected absolute and relative metacognitive accuracy to be better for front targets than for back targets.

Allocentric System

The allocentric system stores enduring information about object and landmark layouts. Shelton and McNamara (2001) propose that this information is stored in specific preferred orientations. These orientations are usually aligned with intrinsic geometric properties of the environment (Mou & McNamara, 2002). Spatial updating requires integrating information from the allocentric system with the egocentric system. When the retrieval viewpoint is aligned with the preferred orientation, object locations can be retrieved directly. However, when viewpoints are not aligned, object locations must be inferred. This inference is time-consuming and error-prone. As a result, spatial judgments are less accurate when the viewpoint is misaligned with the environment (Mou et al., 2004; Shelton & McNamara, 2001; Werner & Schmidt, 1999).

Reconciling information from the egocentric and allocentric reference frames could have implications for metacognitive monitoring. There is some evidence that people have difficulty detecting the effects of allocentric properties on performance. Stevens and Coupe (1978) showed that relative directional judgments between cities are biased by geopolitical group membership and that confidence judgments fail to detect these biases. Brewer and Sampaio (2012) replicated this finding and further found that confidence judgments are negatively related to performance when geopolitical group membership is a misleading cue. Similarly, Yerramsetti, Marchette, and Shelton (2013) found evidence that

people select suboptimal viewpoints when making spatial judgments. Instead of selecting viewpoints aligned with the preferred orientation, participants selected viewpoints that maximized field-of-view (FOV). This suggests that information about optimal orientations may not be accessible to metacognitive processes.

The extent to which people utilize egocentric and allocentric reference frames is flexible. In an egocentric perspective, the observer imagines him or herself within the environment. In an allocentric perspective, the observer's viewpoint is external to the environment. Several studies indicate that it is possible to manipulate the perspective adopted by participants without harming performance. This is typically done by instruction or visual displays (Bryant & Tversky, 1999; Gramann, Müller, Eick, & Schönebeck, 2005). Although perspective does not affect performance, we expected that it would influence confidence. Perceptual detail has been shown to be an important factor in confidence judgments (Heaps & Nash, 2001; Johnson, Raye, Wang, & Taylor, 1979; Robinson, Johnson, & Robertson, 2000) and in viewpoint selection (Yerramsetti et al., 2013), and local perceptual details may be easier to retrieve from an egocentric perspective. Thus, we expected participants to be more confident when using the egocentric perspective.

Overview of Experiments

The aim of the present experiments is to investigate the effect of spatial reference frames on metacognitive monitoring of spatial judgments. We tested participants on their existing knowledge of a space, the Pennsylvania State University campus. Three reference frame factors were of interest: egocentric direction, allocentric alignment, and perspective. Egocentric direction was manipulated by selecting targets such that participants were pointing to the front hemi-field on half the trials and to the back hemi-field on the other half. Alignment was manipulated by selecting headings such that half were aligned with the intrinsic axes of campus and half were misaligned. Perspective was manipulated by instructions, and this manipulation was enhanced in Experiment 2 using visual displays.

Participants were asked to indicate the direction of the target and then indicate their certainty in the target's direction by giving a 90% confidence interval and then indicating the probability that the true direction was within 20° of the pointing direction. In Experiment 1, we used a typical JRD paradigm. We asked participants to orient toward specific buildings on campus to establish headings. In Experiment 2, headings were established and perspective manipulated through the use of visual displays. Photographs were used to induce an egocentric perspective and maps were used to induce an allocentric perspective.

Measuring Spatial Metacognition

An interesting feature of spatial reasoning is that it can vary in precision. Very little is known about the extent to which metacognitive processes can accurately track the precision of spatial memory (but see Pfohl, Barrera, Living, & Biegler, 2013). The JRD task is well suited to this question because it provides a continuous measure of the precision of a participant's spatial memory (Mou, McNamara, Valiquette, & Rump, 2004).

The most common method for measuring confidence in continuous quantities is the fractal method (Alpert & Raiffa, 1982; Soll

& Klayman, 2004). In this method, participants are asked to construct a confidence interval for a given uncertain quantity (e.g., the population of China). Absolute accuracy is measured as the distance between the confidence level of the confidence interval and the actual percentage of trials in which the true quantity falls within the interval (within-range percentage). For example, if an individual with perfect absolute accuracy is asked to construct a 90% confidence interval for his or her answers, 90% of the constructed intervals should contain the correct answer. A caveat of this method is that participants are often somewhat overconfident due to anchoring and adjustment and random error in the interval estimates (Block & Harper, 1991; Lichtenstein, Fischhoff, & Phillips, 1982; Soll & Klayman, 2004; Teigen & Jørgensen, 2005).

Relative accuracy is commonly measured by gamma correlations or discrimination indexes (Goodman & Kruskal, 1954; Masson & Rotello, 2009; Nelson, 1984). Both of these measures reflect the extent to which an increase in confidence predicts in an increase in the likelihood of a correct response. However, both measures rely on classifying responses as either correct or incorrect. Spatial directional judgments are continuous, and it is not clear when a JRD response is "correct." We resolve this issue in the present study by using linear correlations between confidence intervals and pointing error as a measure of relative accuracy.

An alternative, more continuous method of measuring confidence is the search time method proposed by Pfuhl, Barrera, Living, and Biegler (2013). According to this method, more time spent searching for a target means less confidence in the precision of memory. However, this method does not allow for measuring absolute accuracy, only relative accuracy.

Gender and Spatial Cognition

Gender differences in spatial cognition are well documented. For reasons yet to be fully understood, males show a consistent advantage over females in a variety of spatial reasoning tests (see Voyer, Voyer, & Bryden, 1995 for a meta-analysis). Moreover, in navigation tasks, females seem to prefer using an egocentric, "route-based" strategy while males tend to focus on allocentric features of the environment such as Euclidian distances and cardinal directions (Chen, Chang, & Chang, 2009; Dabbs, Chang, Strong, & Milun, 1998; Lawton, 1994). These differences in performance and strategy could complicate any interpretation of metacognitive effects observed in this experiment, so we carefully controlled the distribution of males and females in all experimental conditions and treated gender as a covariate in data analyses.

The Present Experiments

Measuring metacognition requires three types of dependent variables: performance, confidence, and metacognitive accuracy. Performance refers to the participant's objective level of performance in the current task, and in the present context includes pointing error, orientation time, and response time. Pointing error means the distance (in degrees) between the participant's pointing judgment and the true direction of the target. Higher pointing error means a less accurate judgment. Orientation time refers to the amount of time participants use to visualize a new heading. Response time is the time elapsed between the revelation of a target

and the completion of the participant's pointing judgment. Faster response times typically imply more efficient processing and less conflict between spatial representations (Werner & Schmidt, 1999).

Confidence measures capture a participant's subjective estimate of their own performance. Here we use confidence interval, which refers to the width (in degrees) of the confidence intervals provided by participants. Wider confidence intervals imply lower confidence because the true direction could be within a larger area. For example, a confidence interval of ± 20 degrees means that the participant expects their pointing error to be no more than 20 degrees. Metacognitive accuracy refers to the extent to which confidence successfully predicts performance. Here we use within-range percentage and over/underconfidence. Within-range percentage means the percentage of judgments in which the participant's confidence interval actually does include the true target direction. Over/underconfidence is a measure of the extent to which individuals are too conservative or too liberal in their confidence judgments. If a participant gives a confidence interval of ± 20 degrees but the target is actually 40 degrees from the pointing judgment, the participant is 20 degrees overconfident.

Hypotheses

It is known that allocentric alignment and egocentric direction affect performance in spatial judgments, and we expected to replicate these performance effects. There are several possible bases for confidence judgments in this task: the ease or fluency with which spatial knowledge is retrieved (e.g., Koriati, Nussinson, Bless, & Shaked, 2008), the consistency or amount of spatial knowledge retrieved (Koriati, 2012; Pleskac & Busemeyer, 2010), metacognitive experience accompanying the inference process (e.g., Brewer & Sampaio, 2012), and metacognitive beliefs concerning one's spatial ability or the influence of reference frame factors. With respect to our central questions concerning the sensitivity of metacognitive judgments to reference frame factors, we expected that egocentric direction and allocentric alignment would each affect confidence judgments. Egocentric direction should influence metacognitive experience of the inference process, with participants noticing the greater difficulty of making JRDs in the back half of the environment. Allocentric alignment could affect confidence either by metacognitive experience or by affecting the consistency of information retrieved to support the judgment. Finally, we expected that the egocentric perspective would result in higher confidence because of increased availability of perceptual information. We further hypothesized that both alignment and egocentric direction would affect metacognitive accuracy, because we expected that individuals would not adjust confidence sufficiently to account for the effects of misalignment and of pointing to targets in the back half of the field.

Experiment 1

In Experiment 1, participants imagined pointing to various target buildings on a familiar college campus. Perspective was manipulated by asking participants either to imagine themselves standing within the campus (egocentric) or to imagine viewing the campus from above (allocentric). Allocentric alignment was manipulated by asking participants to assume one of four headings.

Two of these headings were aligned with the intrinsic structure of the environment and two were not. Finally, targets were selected so that half would be in front of the participant's current viewpoint and half would be in back, thus manipulating egocentric direction.

Penn State's University Park campus (see Figure 1) was selected as the environment on which participants were tested. All participants were students on this campus and had attended classes for at least several months, and pilot testing guided the selection of landmarks familiar to students. The campus lies along four main roads: Park Avenue, Curtin Road, Pollock Road, and College Avenue. These roads are not parallel to one another but run roughly in the same direction (east–west). Campus buildings are placed primarily along these roads and campus maps are typically aligned so that these roads generally travel along the east–west axis of the map. The overall layout of the campus is roughly rectangular (see Figure 1). Note that “campus north” is not aligned with geographic north; the horizontal axis in Figure 1 runs approximately southwest to northeast.

Throughout the experiment, the student union (the HUB) was used as the origin because of its central location. Those in the egocentric condition were asked to imagine themselves standing at the origin in front of the union. Those in the allocentric condition were asked to assume a top-down view of campus, as if they were looking at a map or satellite photograph. They were instructed to keep the origin building in the center of their mental image.

Egocentric direction and allocentric alignment were manipulated in a similar manner as Sholl (1987) and Werner and Schmidt (1999). In an egocentric-front trial, the target is in the front hemifield of the participant's imagined position. In an egocentric-back trial, the target is in the back hemifield. A viewpoint is allocentrically aligned if it is approximately parallel or perpendicular to an environment's intrinsic axes. Past research has shown a performance advantage for both the primary axis and for axes that are perpendicular to it (Marchette, Yerramsetti, Burns, & Shelton, 2011). Pilot work suggested a major intrinsic axis of the Penn State campus is the campus west–east axis, approximately parallel to

Figure 1. Penn State's campus as typically displayed on maps available to students. Arrows indicate the direction of headings adopted by participants in Experiment 1. The origin used for all trials (the student union) lies at the intersection of the arrows. Penn State University Park campus map copyright 2010 by the Gould Center for Geography Education and Outreach. Reprinted with permission.

most of the major roadways on campus. Pilot work indicated that people are most accurate when their viewpoint was aligned with this axis. This is consistent with research suggesting that knowledge of real-world environments is often organized allocentrically along roadways (Montello, 1991; Werner & Schmidt, 1999) and is often aligned with map directions (Frankenstein, Mohler, Bülhoff, & Meilinger, 2012; Marchette et al., 2011).

Selection of Targets

When measuring metacognitive reasoning, it is important to have items that vary in difficulty. If all items are equally easy (or difficult), participants cannot use their confidence judgments to distinguish them (see, e.g., Brewer & Sampaio, 2012). For this reason, we deliberately selected targets that offered a wide range of difficulty for participants (based on performance in pilot experiments).

Method

Participants. Fifty-four undergraduate students from Penn State University (28 females, 26 males) participated in this experiment and were compensated with partial course credit. Because of prior documented effects of gender on spatial cognition, we strove to recruit and assign an equal number of males and females to each experimental condition. In the egocentric condition, there were 15 females and 14 males. In the allocentric condition, there were 13 females and 12 males.

Design. Experiment 1 was a 2 (perspective) $\times$ 2 (alignment) $\times$ 2 (direction) mixed factorial design. Perspective (egocentric, allocentric) was a between-subjects variable and alignment (aligned, misaligned) and direction (front, back) were within-subjects variables.

Stimuli and apparatus. On every trial, the names of three locations were displayed on the screen. The first location was the origin (the student union building), the central point from which the directional judgment was to be made. The second location was the heading, the location the participants were to imagine facing. Four buildings on campus were selected as heading locations. Two of these headings were approximately aligned with the east–west axis of campus typically portrayed on the campus map. The other two headings were offset from this axis by about 45–55°. The third location was the target. Sixteen campus buildings were selected as targets. They were selected so that on half of the trials, the target was located in front of the subject's imagined viewpoint (front trials). On the other half of the trials, the target was behind the imagined viewpoint (back trials). These trial types are illustrated in Figure 2. Participants pointed to each target from each of the four headings, yielding a total of 64 trials. Spatial judgments were made with the use of a Logitech Extreme Pro 3D computer joystick. The joystick was placed on the desk directly in front of the participant.

Procedure. Participants were randomly assigned to either the egocentric or allocentric perspective condition. Participants in the egocentric perspective condition were instructed to imagine themselves standing at the HUB and to try to visualize what they would see as they faced each new direction. Those in the allocentric condition were instructed to visualize the campus from a top-down perspective, as if they were looking at a map or satellite picture. They were told to always imagine that the HUB was at the center

Figure 2. An illustration of the trial types in the three experiments. All viewpoints parallel or perpendicular to the campus east-west axis are aligned. Other viewpoints are misaligned.

of the map, with the map rotated so that the heading building was at the top. After the perspective instructions, participants were given eight practice trials using origins and headings that were not used in the experiment.

On each trial, a large black circle was displayed on the screen (see Figure 3). The origin location was displayed in the center of the circle, and the heading at the top. A black line was displayed underneath the circle. The name of the target was displayed under the black line. Additional text reinforced the perspective manipulation. In the egocentric condition, “you are standing at:” appeared next to the origin, “you are facing” appeared at the top, and “point to” appeared next to the target. In the allocentric condition, “is at the center of the map” appeared next to the origin, “is at the top of the map” appeared next to the heading, and “point to” appeared next to the target. Participants were instructed that the top of the circle always represented “straight ahead.”

The cursor started at the center of the screen. To make their judgments, participants used the joystick to move the cursor to a part of the black circle and click on it. A thin blue line appeared on the screen connecting the center of the circle to the point at which the participant clicked. This gave visual feedback of the direction of the participant's response. This screen disappeared after 1 s.

After making each judgment, participants were asked two confidence questions. The first question asked participants how confident they were that the true direction fell within $\pm 10^\circ$ of their response (a 20 degree interval). Participants typed in a percentage from 0% to 100%. The second question asked participants to indicate their 90% confidence interval. They were instructed that their chosen intervals should contain the true direction on 90% of the trials. Participants could select intervals in 10-degree increments starting at $\pm 10^\circ$ and ending at $\pm 90^\circ$. Participants could also select “greater than $\pm 90^\circ$.”

Upon completion of the experimental trials, participants completed a postexperiment questionnaire. Participants were asked to indicate how familiar they were with each of the landmarks mentioned in the experiment. They were also asked about their relative

Figure 3. Example trial display in the egocentric condition. The center location is the origin. The top is the heading. And the top-right is the target.

use of egocentric and allocentric perspectives during the task, and about their everyday navigational experience and strategies.

Results

ANCOVAs were used to analyze all dependent variables. Except where noted, these were $2 \times 2 \times 2$ ANCOVA's that included perspective as a between-subjects factor, alignment and direction as within-subjects factors, and gender as a covariate. For all post hoc t tests, a Bonferroni correction was applied. The angular error, confidence intervals, and over/underconfidence measures were positively skewed, so means of participant medians were used for analysis of these variables. Overall, the analyses suggest that alignment and direction have similar effects on performance, confidence, calibration, and overconfidence.

Questionnaire responses. To ensure group equivalence, participants' answers to questions on the postexperiment questionnaire were compared between groups using t tests. No significant differences between groups were found on any of the everyday navigational experience variables or self-rated spatial ability (see Table 1).

Performance.

Pointing error. The main effects of alignment and direction did not reach significance (both $ps > .1$). However, there was a significant alignment $\times$ direction interaction, $F(1, 51) = 5.594$, $p = .022$, $\eta_p^2 = .099$, illustrated in Figure 4. Post hoc t tests were conducted to probe the interaction. They indicate that this interaction is driven by a stronger direction effect on misaligned trials (front = 36° , back = 42°); $t(53) = 2.394$, $p = .04$, than on aligned trials (front = 38° , back = 36°); $t(53) = .690$, ns . There was a nonsignificant trend such that the allocentric perspective led to

Figure 4. Pointing error by alignment and direction in Experiment 1.

larger errors ($M = 43^\circ$, $SE = 4^\circ$) than the egocentric perspective (34° , $SE = 4^\circ$). As is typical in the literature, males made smaller pointing errors ($M = 33^\circ$, $SE = 4^\circ$) than females ($M = 44^\circ$, $SE = 4^\circ$), $F(1, 51) = 4.131$, $p = .047$, $\eta_p^2 = .075$.

Response time. Orientation time and response time were measured on every trial. Orientation time is the time between the appearance of the heading instruction and when the participant pressed the spacebar to reveal the target. Orientation times were submitted to a 2 (perspective) $\times$ 2 (alignment) mixed ANCOVA with gender as a covariate. A different ANCOVA design was used for the variable because orientation occurred before the target was known, making target direction meaningless for this dependent variable. The only significant effect was a marginal main effect of perspective, $F(1, 51) = 3.057$, $p = .086$, $\eta_p^2 = .057$. Participants in the egocentric condition had slightly longer orientation times ($M = 2.0$ s) than people in the allocentric condition ($M = 1.7$). This could reflect extra time taken to imagine nearby perceptual details. Alignment had no significant effect on orientation time.

Response time was defined as the length of time between the onset of the target and the completion of the JRD response. This variable was analyzed using the same ANCOVA design as the other dependent variables: 2 (perspective) $\times$ 2 (alignment) $\times$ 2 (direction). Response times were shorter on the aligned trials ($M = 7.8$ s) than on the misaligned trials (8.7 s), $F(1, 51) = 5.246$, $p = .026$, $\eta_p^2 = .093$. Participants were also marginally faster when pointing to targets in front ($M = 7.9$ s) than to targets in back ($M = 8.6$ s), $F(1, 50) = 3.560$, $p = .065$, $\eta_p^2 = .065$. This reflects the greater difficulty of these conditions, and suggests that the pointing error results were not caused by a speed/accuracy tradeoff. Finally, alignment and direction both participated in a marginal three-way interaction with perspective, $F(1, 51) = 3.806$, $p = .057$, $\eta_p^2 =$

Table 1
Questionnaire Averages for Participants in Experiment 1

Group	Campus map use	GPS use	General map use	Spatial ability	Semesters on campus	Year in school	Years exp. in navigation
Egocentric	2.1	2.7	2.2	72	2.1	1.6	1.9
Allocentric	1.9	2.9	1.8	68	1.9	1.6	3.3

Note. GPS = Global Positioning System.

.069. This interaction suggests that the effect of target direction on response time was weaker when using the allocentric perspective, especially when misaligned. When misaligned, participants were actually slower for front targets ($M = 8.1$ s) than back targets ($M = 7.4$ s). This may suggest that the responses of people in the allocentric group may be mediated by the egocentric reference frame to a lesser extent than those in the egocentric condition. However, this is a statistically weak effect and should be interpreted with caution.

Confidence.

Confidence intervals. Confidence intervals were coded in terms of degrees. For example, when the reported interval was $\pm 10^\circ$, the confidence interval was coded as 10. The intervals were submitted to an ANCOVA with the same design used for the performance data. Participants gave narrower confidence intervals on aligned trials ($M = 31^\circ$, $SE = 2^\circ$) than misaligned trials ($M = 34^\circ$, $SE = 2^\circ$), $F(1, 51) = 4.600$, $p = .037$, $\eta_p^2 = .083$. Further, confidence intervals were narrower for front targets ($M = 30$, $SE = 2$) than for back targets ($M = 34$, $SE = 2$), $F(1, 51) = 25.529$, $p < .0005$, $\eta_p^2 = .334$. Figure 5 displays these effects. Post hoc t tests confirmed that there was a significant direction effect for both alignment conditions, aligned: $t(53) = 3.579$, $p = .002$; misaligned: $t(53) = 4.492$, $p < .0005$. Perspective had no effect on confidence intervals ($p = .798$). Taken together, these results suggest that participants used both alignment and direction as confidence cues when forming their confidence judgments.

Metacognitive accuracy—absolute.

Within-range percentage. Whereas confidence interval refers to the width (in degrees) of the confidence intervals provided by participants, within-range percentage is the number of times those intervals actually contained the true target direction. Thus, the former is a measure of confidence while the latter is a measure of the correspondence between confidence and performance. Overall, within range percentages were comparable to those reported in other research using this method ($M = 49.3\%$; Alpert & Raiffa, 1982; Block & Harper, 1991; Lichtenstein, Fischhoff, & Phillips, 1982; Teigen & Jørgensen, 2005). When people are asked to give 90% confidence intervals, they typically make them too narrow, resulting in within-range percentages closer to 50% (Teigen & Jørgensen, 2005).

The ANCOVA on this variable indicated that within-range percentage was better on aligned trials ($M = 52.7\%$) than on

misaligned trials ($M = 46.1\%$), $F(1, 51) = 5.048$, $p = .029$, $\eta_p^2 = .094$. Further, there was a significant alignment by direction interaction, $F(1, 51) = 6.296$, $p = .015$, $\eta_p^2 = .110$. Post hoc t tests confirm that the interaction is driven by a larger effect of alignment for backward pointing trials, $t(53) = 3.308$, $p = .008$. Finally, there was a marginally significant effect of perspective, such that those in the egocentric group ($M = 54\%$) had higher within-range percentages than those in the allocentric group ($M = 44\%$), $F(1, 51) = 3.480$, $p = .068$, $\eta_p^2 = .064$. Figure 6 summarizes this data.

Over/underconfidence. To compute over/underconfidence scores, pointing errors were organized into the same bins used for confidence intervals (e.g., 0–10; 11–20; 21–30 etc.). Then these errors were subtracted from the confidence interval for the trial. Positive scores indicate overconfidence and negative scores indicate underconfidence. Overall, participants were somewhat overconfident ($M = 12^\circ$, $SE = 3^\circ$). The only significant effect on this variable was an interaction between alignment and direction, $F(1, 51) = 6.180$, $p = .016$, $\eta_p^2 = .108$. For aligned viewpoints, participants were more overconfident when pointing to the front. For misaligned viewpoints, participants were more overconfident when pointing to the back (see Figure 7). This is likely the result of the fact that participants' confidence judgments predicted a front-facilitation effect for the aligned viewpoints. But this effect did not actually occur. This substantially raised overconfidence for the aligned headings. Perspective had no significant effect on over/underconfidence.

Metacognitive accuracy—relative. Within-subject Pearson correlations between confidence interval and pointing error were computed for each subject and for each within-subject condition (all combinations of levels of alignment and direction). These correlations were then transformed using Fisher's Z-transformation (Cohen, Cohen, West, & Aiken, 2013). Overall, participant confidence was predictive of performance ($r = .29$) and this correlation was significantly different from zero, $t(53) = 7.961$, $p < .0005$. The z-scores were then submitted to the same ANCOVA used for the other analyses. This analysis revealed an overall metacognitive advantage for front targets ($r = .35$) over back targets ($r = .24$), $F(1, 51) = 6.952$, $p = .011$, $\eta_p^2 = .120$.

Regression analysis. In order to better understand the information participants used to make their confidence judgments, we performed a linear mixed effects (LME) regression analysis on the confidence and pointing error data. There are several possible sources of information participants may have been using to guide their confidence judgments, and the aim of this analysis was to find out which ones participants were actually using. In addition to the reference frame factors we manipulated in this experiment, participants may also have based their confidence on their familiarity with individual targets, or on the time it took them to make the judgment. LME analysis allows us to take these predictors into account while also analyzing the effects of the independent variables. We hoped to answer two key questions with this analysis. First, do target familiarity and response fluency affect JRD confidence? Second, do the independent variables explain any additional variation in confidence beyond that explained by the familiarity and fluency?

In this experiment, we deliberately selected items that varied in difficulty. To confirm that we were successful, we fit an LME model to the pointing error data using subject number and target

Figure 5. Average confidence intervals by condition in Experiment 1.

Figure 6. Within-range percentages in Experiment 1.

identity as random effects. A likelihood ratio test confirmed that the effect of target identity is significant, $\chi^2(1) = 25.8, p < .001$, $R^2 = .045$, meaning that the average pointing error for some targets is consistently higher than others. We then ranked the targets according to their pointing error (higher rank means higher error) and used these ranks as a predictor of confidence in the following analysis.

To properly separate the effects of item difficulty, response fluency, and the independent variables, it was necessary to use a stepwise regression approach. The logic of this approach was as follows. First a null model was specified which contained only demographic variables: the participant's subject number and their gender. Subject was modeled as a random effect while gender was modeled as a fixed factor. In the next step, judgment fluency (response time in seconds) and target difficulty were added to assess their effects on confidence. Both of these variables were entered as fixed effects. Response times greater than 1 min were omitted from the regression (less than 1% of the trials). Next, the independent variables (alignment, direction, and perspective) were added. Our hypothesis was that people use reference frame factors in addition to target identity and response fluency to determine confidence. If this

Figure 7. Over/underconfidence in Experiment 1.

hypothesis is correct, adding the independent variables should significantly improve the fit of the model.

The models were fit using the lme4 package in the R software environment (Bates, Maechler, Bolker, & Walker, 2015; R Core Team, 2015). Each model was tested against the previous one using a likelihood ratio test. R^2 values for each model were computed using Nakagawa and Schielzeth's $R^2_{GLMM(conditional)}$ method (Johnson, 2014; Nakagawa & Schielzeth, 2013). In addition, individual model parameters were tested for significance using an F test with Satterthwaite-approximated degrees of freedom (Kuznetsova, Brockhoff, & Christensen, 2015).

Each alternative model was a significantly better fit than the previous one, as indicated by the likelihood ratio test (see Table 2). Each subsequent model improved the proportion of variance explained by the previous one by about .01, suggesting that both types of variables (reference frames and others) contributed to participants' confidence judgments.

The fixed-effects parameters generated by the model suggest that both alignment and direction contribute to participants' confidence judgments, consistent with our hypothesis (see Table 3). The estimated parameter for alignment is -3.45 , meaning that aligned viewpoints lead to confidence intervals that are 3.45 degrees narrower on average. Similarly, the estimate for direction is -2.01 , meaning that confidence intervals were 2.01 degrees narrower when pointing to front targets. Response time does not appear to be a significant predictor of confidence.

Discussion

The results of Experiment 1 suggest that people are sensitive to the effects of alignment and direction on performance. However, this sensitivity is imperfect, as participants do not sufficiently widen their confidence intervals to account for the lower performance. Moreover, perspective does not appear to affect confidence. Finally, facing a target appears to help people better discriminate between well-known and lesser-known targets.

Previous studies show that there is typically a main effect of both alignment and direction on pointing error (Mou et al., 2004; Werner & Schmidt, 1999). Instead, we observed an interaction, such that people performed worse when misaligned, but only for back targets. It is possible that the overall difficulty of the task removed the advantages typically afforded by aligned viewpoints and frontward pointing. For each judgment, participants needed to retrieve the locations of three landmarks with very little external support for their heading. This experimental feature may have obscured the typical effects of alignment and target direction on performance. By contrast, participant confidence judgments

Table 2
Model-Fit Statistics and Tests for Experiment 1

Model	Df	AIC	BIC	logLik	χ^2	χ^2 Df	$R^2_{GLMM(c)}$
Null model	4	28747	28771	-14369			.36
Model 1	6	28494	28530	-14241	256.828***	2	.37
Model 2	13	28448	28528	-14211	59.633***	7	.38

Note. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion Df = Degrees of freedom.

*** Significant at $p < .001$.

Table 3
Fixed-Effects Parameter Estimates and Significance Tests

Factor	Estimate (SE)	SS	NumDF	DenomDF	F
Gender (male)	−5.33 (3.38)	667.8	1	50.9	2.483
Response time	−.02 (.04)	98.4	1	3317.8	.366
Target difficulty	.46 (.06)	14742.1	1	3287.1	54.809***
Alignment (aligned)	−3.45 (1.10)	6630.5	1	3287.2	24.651***
Direction (front)	−2.01 (1.10)	8678.8	1	3287	32.266***
Perspective (allocentric)	−.85 (3.53)	11.3	1	50.9	.042
Align:Direction	−2.47 (1.55)	486.4	1	3287	1.808
Align:Perspective	.29 (1.61)	314.1	1	3287.1	1.168
Direction:Perspective	−.92 (1.60)	.1	1	3287	0
Align:Direction:Group	1.89 (2.27)	185.2	1	3287	.689

Note. DenomDF = Denominator degrees of freedom; Df = Degrees of freedom; NumDF = Numerator degrees of freedom; SE = Standard Error; SS = Sum of Squares.

*** Significant at $p < .001$.

showed clear main effects of both alignment and direction (in both the ANCOVA and regression analyses) frontward and aligned trials felt easier for participants, even though they were not actually easier. This suggests that both alignment and target direction are used as confidence cues.

Our hypothesis that people would be more confident and more overconfident when using egocentric perspectives was not supported by the data. Participants in both perspective groups gave confidence intervals of the same size on average, but within-range percentages were lower for those in the allocentric group. Directional judgments, like those in the JRD task, are often believed to be mediated by the egocentric reference frame (Mou et al., 2004). It is possible that attempting to use an allocentric reference frame introduced a conflict that occupied mental resources and reduced the precision of the spatial representation.

Overall, participants were overconfident in their spatial judgments, and this overconfidence is exacerbated by conditions that make spatial judgments more difficult. The participants' confidence intervals contained the true direction about 50% of the time, which is consistent with results reported in other domains (Block & Harper, 1991). Misaligned viewpoints, backward pointing, and using an allocentric perspective all reduced this percentage. This suggests that these conditions all produced conflict or interference that impaired participants' ability to monitor performance.

The regression analysis suggests that both target familiarity and reference frame effects affect spatial confidence judgments. People appear to be sensitive to both types of information when monitoring the precision of their spatial memories.

The correlation between accuracy and confidence was influenced by direction, but not by alignment. This is most likely because one's egocentric direction makes some targets more accessible than others for a given trial (Kelly & McNamara, 2009). By contrast, alignment affects all of the targets in the environment equally. The conflict created by a misaligned viewpoint thus may not impair access to information that is needed for monitoring processes to discriminate between particular targets.

The perspective manipulation did not affect confidence, but it did affect absolute accuracy. It is not clear if people simply do not take perspective into account or if they ignored it because it had a weak effect on performance. We sought to rectify this in Experiment 2 by using both instructions and visual stimuli to help participants shift perspectives.

Experiment 2

In Experiment 2, we used photographs and maps, as well as instructions, to manipulate the perspectives participants adopted. We expected that this would result in a stronger manipulation of perspective because it would make it easier to visualize the egocentric and allocentric perspectives. Previous researchers have successfully manipulated perspective using instructions (Bryant & Tversky, 1999; Gramann et al., 2005), but it is also possible to manipulate perspective by using different types of stimuli. Bryant and Tversky (1999) induced an egocentric perspective by using three-dimensional (3D) models and diagrams with depth cues. Similarly, they induced an allocentric perspective using maps and flat diagrams. These two approaches appear to be equally effective for simple recall judgments, but it is possible that manipulating visual stimuli may be better suited to a JRD task. These materials also allowed us to establish headings more directly, without reference to a heading location about which participants might be uncertain. This change should reduce pointing error, and perhaps allow better monitoring.

As in Experiment 1, we expected that confidence would fail to fully track the effects of the independent variables on performance. We hypothesized that the egocentric perspective would result in better calibration than the allocentric perspective. Further, aligned viewpoints and forward pointing should result in better calibration than misaligned viewpoints and backward pointing respectively. Finally, based on the results of Experiment 1 we expected that participant confidence would be more strongly predicted by confidence in building location than by alignment and direction.

Method

Participants. Seventy-seven undergraduate students (37 males) were recruited from Penn State's psychology subject pool. All participants received a small amount of course credit for participating. Twenty-one females and 20 males were assigned to the egocentric condition and 19 females and 17 males were assigned to the allocentric condition.

Design. Experiment 2 used a 2 (perspective) $\times$ 2 (alignment) $\times$ 2 (direction) mixed design. Once again, perspective was a between-subjects variable and alignment and direction varied within subjects.

In this experiment, participants received the same instructions concerning egocentric and allocentric perspectives as did participants in Experiment 1. In addition, they viewed visual displays to strengthen the manipulation. The egocentric group was shown photographs of their given viewpoints. The allocentric group was shown a small section of the map of campus centered on the origin building.

Stimuli. Two origin buildings and six target buildings were selected for this experiment. At each origin, participants were asked to assume one of eight different headings (four aligned and four misaligned). This yielded a total of 96 trials. The order in which the origin buildings were presented was counterbalanced.

Depending on perspective condition, either photographs (egocentric) or maps (allocentric) were used to orient participants to each heading. The photographs were taken from a fixed spot outside the main entrance of each building. Eight different orientations were used in this experiment, spaced 45° apart. The first orientation faced campus east and was designated as the 0 degree direction (see the campus map in Figure 1). One photograph was taken facing campus east, and then the viewpoint was rotated 45° for each subsequent photograph. Figure 8 illustrates the headings for the HUB. The map stimuli consisted of circular portions of an unlabeled campus map. There were two maps, each one centered on one of the origin buildings. Each viewpoint was created by rotating the maps in 45-degree increments. The size of the map was carefully adjusted to be just large enough so that all of the landmarks that would be visible in the egocentric condition would also be visible in the allocentric condition. Figures 9 and 10 display example headings from the egocentric and allocentric conditions, respectively.

Procedure. Participants were randomly assigned to either the egocentric or allocentric perspective and then the appropriate perspective induction instructions were read. Participants completed eight practice trials with feedback to make sure they understood the task. Participants then completed all of the trials associated with one of the two origin buildings (the order was counterbalanced). First, participants were told the name of the origin building. Then they were shown all viewpoints associated with that building. They first saw the viewpoint directly facing the building entrance (for Thomas this was the 0-degree viewpoint and for the HUB this was the 90-degree viewpoint). After seeing the viewpoint for 5 s, they were asked how confident they were that they

Figure 8. An illustration of the viewpoint types in Experiment 2. The heading facing campus east was selected as the 0° heading.

Figure 9. An example heading photograph from the egocentric condition of Experiment 2. This is the 270° heading. See the online article for the color version of this figure.

could point to the targets from that viewpoint (on a 0% to 100% scale). After entering their confidence judgment, they were told that they would see the next viewpoint, which was rotated 45° to the right of the previous one.

After participants were familiarized with the viewpoints for the origin building, one of the eight viewpoints was randomly selected and once again displayed to the participants for 5 s. The black circle was then displayed on the screen with the name of one of the target buildings at the top. Participants pointed to all six target landmarks in a random order, entering the usual confidence judgments after each one. Once all six judgments were made, another

Figure 10. An example heading map from the allocentric condition of Experiment 2. This heading is the 270° heading.

viewpoint from the same origin was randomly selected and displayed to the participant. After all eight viewpoints for the first origin building were complete, the familiarization and test procedures were completed for the second origin building. When the experimental trials were completed, participants completed the same questionnaire as they did in Experiment 1.

Results

The analysis for this experiment followed the same logic as that of the first experiment. First, the questionnaire results and perspective use data were analyzed to check for group equivalence. Next, performance and confidence variables were analyzed. Finally, metacognitive quality measures were analyzed. Once again, a regression analysis was conducted to determine the relative contribution of the independent variables and landmark knowledge on confidence judgments.

Unlike Experiment 1, perspective had no detectable effect on performance (apart from a few subtle interactions). However, performance, confidence, and metacognitive quality were once again higher for the aligned and egocentric-front conditions than for the misaligned and egocentric-back conditions respectively. Finally, the regression results were consistent with those of Experiment 1.

Questionnaire results. Independent samples *t* tests revealed no significant differences between the perspective groups on any of the demographic survey measures collected. However, there was a marginal difference in terms of self-reported navigational ability, $t(68) = 1.884, p = .063$. People in the allocentric group ($M = 62\%$) reported a slightly lower confidence in their ability to navigate than people in the egocentric group ($M = 73\%$). Descriptive statistics can be found in Table 4.

Performance.

Pointing error. Pointing error was lower in Experiment 2 ($M = 24^\circ$) than in Experiment 1 ($M = 38^\circ$), as expected, given that uncertainty about a heading location was no longer involved in establishing heading. The effects of the independent variables on pointing error were consistent with the spatial memory literature. Both alignment and direction had significant main effects on error. Participants were significantly more accurate when aligned than when misaligned, $F(1, 74) = 109, p < .0005, \eta_p^2 = .596$. They were also significantly more accurate for front targets than for back targets, $F(1, 74) = 47, p < .0005, \eta_p^2 = .388$. These main effects were qualified by an Alignment $\times$ Direction interaction, $F(1, 74) = 4.3, p = .042, \eta_p^2 = .055$. This interaction shows that the direction effect was stronger when participants were misaligned. For an illustration of these effects, see Figure 11. Once again, perspective had no effect on performance (egocentric =

Figure 11. Pointing error in Experiment 2.

24.1° , allocentric = $24.9^\circ; p = .8$). Consistent with Experiment 1, males made smaller pointing errors than females (males = $20^\circ, SE = 2^\circ$; females = $29^\circ, SE = 2^\circ$), $F(1, 74) = 10.9, p = .002, \eta_p^2 = .128$.

Response time. Because participants all viewed the heading images for 5 s, there was no measure of orientation time. The ANCOVA on response time revealed significant effects of both alignment and direction. Response times were slower when participants were misaligned ($M = 5.9$ s, $SE = .3$ s) than when they were aligned ($M = 5.3$ s, $SE = .3$ s), $F(1, 74) = 20.645, p < .0005, \eta_p^2 = .218$. And response times were slower when participants were pointing backward ($M = 5.9$ s, $SE = .3$ s) than when they were pointing forward ($M = 5.2$ s, $SE = .3$ s), $F(1, 74) = 30.989, p < .0005, \eta_p^2 = .295$.

Confidence.

Confidence intervals. As in Experiment 1, participants were more confident when aligned and when pointing ahead. The main effects of alignment, $F(1, 74) = 44.287, p < .0005, \eta_p^2 = .374$; and direction, $F(1, 74) = 13.835, p < .0005, \eta_p^2 = .158$, were significant. Perspective had no effect on confidence. These results are illustrated in Figure 12. Unlike Experiment 1, females were less confident than males overall (females = $34^\circ, SE = 2^\circ$; males = $25^\circ, SE = 2^\circ$), $F(1, 74) = 11.541, p = .001, \eta_p^2 = .135$.

Metacognitive quality—absolute.

Within-range percentage. Participants had better within-range percentages when aligned ($M = 70.5\%, SE = 2\%$) than misaligned ($M = 55.9\%, SE = 2\%$), $F(1, 74) = 69.554, p < .0005, \eta_p^2 = .485$. Further, participants had better percentages for front targets ($M = 65.1\%, SE = 2\%$) than back targets ($M = 61.2\%$,

Table 4
Questionnaire Averages for Participants in Experiment 2

Group	Campus map use	GPS use	General map use	Spatial ability	Semesters on campus	Year in school	Years exp. in navigation
Egocentric	1.41	2.27	1.81	72.78[†]	1.95	1.41	2.11
Allocentric	1.64	2.73	1.97	62.33	2.33	1.58	1.52

Note. GPS = Global Positioning System. Numbers in bold represent means that differ significantly.

[†] Marginally significant at $p < .1$. ** Significant at $p < .01$.

Figure 12. Average confidence intervals in Experiment 2.

$SE = 2\%$, $F(1, 74) = 10.238$, $p = .002$, $\eta_p^2 = .122$. The effect of perspective was not significant.

Over/underconfidence. Participants were far less overconfident than in Experiment 1. The ANOVA on these scores revealed main effects of alignment, $F(1, 74) = 39.729$, $p < .0005$, $\eta_p^2 = .349$; and direction, $F(1, 74) = 6.290$, $p = .014$, $\eta_p^2 = .078$. Participants were overconfident in the misaligned and back conditions. The effect of direction on over/underconfidence was stronger for misaligned trials than for aligned trials, $F(1, 74) = 5.829$, $p = .018$, $\eta_p^2 = .073$ (see Figure 13).

Metacognitive quality—relative. Correlations between confidence and performance were lower than in Experiment 1 ($r = .11$) but they were still significantly different from zero, $t(75) = 4.99$, $p < .0005$. Thus, participants were still able to predict their performance at a level better than chance. Once again, participants had better relative accuracy when pointing forward ($M = .14$, $SE = .03$) than when pointing backward ($M = .07$, $SE = .03$), $F(1, 72) = 6.018$, $p = .017$, $\eta_p^2 = .077$. The effect of alignment was not significant. In addition, male confidence was more predictive of

Figure 13. Over/underconfidence scores in Experiment 2.

performance ($M = .17$, $SE = .03$) than female confidence was ($M = .06$, $SE = .03$), $F(1, 72) = 5.762$, $p = .019$, $\eta_p^2 = .074$.

Regression

Our regression analysis for Experiment 2 followed the same logic as that of Experiment 1. First we fit a null model with subject and gender variables. Then we fit a model containing fluency and target identity. The final model included the independent variables and their interactions. The only difference was that, because we had two origins in this experiment (the HUB and the Thomas building) we added a variable specifying origin as a random effect into Models 1 and 2.

As before we began by confirming that the landmarks (origins and targets) involved in the judgments influenced their difficulty. The LME model and likelihood ratio test indicated that both origins, $\chi^2(1) = 12.9$, $p < .001$, $\Delta R^2 = .005$, and targets, $\chi^2(1) = 25.9$, $p < .001$, $\Delta R^2 = .003$, significantly predicted participant error, albeit accounting for less variance than the target variability in Experiment 1. To account for item and origin variability in the model, we entered the rank order difficulty of the targets and the identity of the origin location as predictors in Models 1 and 2.

Both steps resulted in a small but significant increase in explanatory power over the null model ($\Delta R^2_{\text{Model 1}} = .02$, $\Delta R^2_{\text{Model 2}} = .01$). Consistent with Experiment 1, the full model (Model 2) was the best fit to the data, suggesting that the effect of reference frame factors on confidence cannot be explained away by fluency or target confidence. Moreover, the variables in each of these levels explain unique variance (i.e., they do not overlap with the other variables; see Table 5 for the model fit statistics).

Examining the parameters of the full model reveals that reference frame factors (alignment and direction), response fluency, and target difficulty all influence participants' confidence judgments (see Table 6). Regarding the effects of reference frame factors (alignment and direction) the results of Experiment 2 confirm those of Experiment 1. For alignment, we obtain an estimate of -3.6 , meaning that people were on average 3.6° more confident when their viewpoints were aligned. This is very similar to the estimate we obtained in Experiment 1 (-3.45°). Our estimate for direction (-4.07°) is also similar to that of Experiment 1 (-2.01°). Additionally, participants appear to have accounted for target difficulty in their confidence judgments.

Unlike Experiment 1, response time was a significant predictor of confidence here. The fixed-effect estimate given by the model is positive, meaning that participants increased their confidence intervals (i.e., became less confident) as the judgment time increased. This raises the question of why this was not observed in

Table 5
Model-Fit Statistics and Tests for Experiment 2

Model	Df	AIC	BIC	logLik	χ^2	χ^2 Df	$R^2_{\text{GLMM(c)}}$
Null model	4	58614	58642	-29303			.49
Model 1	7	58332	58380	-29159	288.58***	3	.51
Model 2	14	58096	58193	-29034	249.55***	7	.52

Note. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; DF = Degrees of freedom.

*** Significant at $p < .001$.

Table 6
Fixed-Effects Parameter Estimates and Significance Tests for Experiment 2

Factor	Estimate (SE)	SS	NumDF	DenomDF	F
Gender (male)	−9.91 (2.7)	2159.6	1	74	13.716***
Response time	.15 (.03)	5115.4	1	7269.5	32.488***
Target difficulty	.79 (.09)	13232.9	1	7225.3	84.043***
Alignment (aligned)	−3.65 (.57)	24906.3	1	7225.6	158.181***
Direction (front)	−4.07 (.57)	11188.3	1	7225.7	71.058***
Perspective (allocentric)	−3.07 (2.7)	112.9	1	74	.717
Align:Direction	.92 (.81)	258.9	1	7225.1	1.645
Align:Perspective	−.63 (.83)	291.7	1	7225.1	1.853
Direction:Perspective	2.41 (.83)	2279	1	7225.3	14.474***
Align:Direction:Group	−.33 (1.18)	12.6	1	7225.1	.08

Note. DenomDF = Denominator degrees of freedom; Df = Degrees of freedom; NumDF = Numerator degrees of freedom; SE = Standard Error; SS = Sum of Squares.

*** Significant at $p < .001$.

Experiment 1. In Experiment 1 participants took longer to make their judgments ($M = 9.9$ s) than they did in Experiment 2 ($M = 6.7$ s). Research in time estimation shows that time intervals become harder to estimate as they increase in length (Rakitin et al., 1998). Therefore, it is possible that participants in Experiment 1 simply had more difficulty keeping track of the time they spent on each problem.

The regression analyses of Experiments 1 and 2 show that participants' sensitivity to reference frame factors cannot be explained by judgment fluency or target difficulty. People use multiple sources of information to evaluate confidence in spatial judgments. This includes information related to the landmarks involved in the problem (item difficulty, origin identity), and the actual experience of making the judgment (judgment fluency, reference frame effects).

Discussion

The results of Experiment 2 replicate and extend those of Experiment 1. Once again, participant confidence judgments were sensitive, albeit imperfectly, to reference frame characteristics. Experiment 2 also provides further evidence that participant confidence judgments are a function of both target confidence and reference frame factors. Finally, the regression analysis of Experiment 2 is consistent with that of Experiment 1. Both suggest that participants use both reference frame factors and target knowledge to predict their performance.

In this experiment, both alignment and direction affected pointing error. Participant confidence judgments were sensitive to this fact, and showed the same overall pattern. However, as in Experiment 1, participants underestimated the effects of these variables on performance, leading to worse absolute accuracy in the misaligned and back trials. Within-range percentage suffered and participants became more overconfident in the misaligned and back conditions. This could mean that people are making these judgments based on general metacognitive beliefs, without regard to trial-by-trial performance. However, it could also mean that people have more difficulty accessing metacognitive cues in the harder conditions.

Unlike Experiment 1, perspective had no overall effect on the ability to monitor performance. Within-range percentage and over/underconfidence were similar for both perspectives. It is possible

that participants in Experiment 1 had difficulty imagining the allocentric perspective and the increased visual support in Experiment 2 alleviated this difficulty. Thus, the reduced performance in the allocentric group in Experiment 1 might not be due to difficulty with the allocentric perspective per se, but rather due to increased working memory load resulting from attempting to visualize the allocentric perspective. Regardless, participants' confidence is not affected by the perspective they adopt.

General Discussion

These experiments produced several major results. First, participants' judgments of relative direction were affected by reference frame variables—the egocentric direction of the target, and alignment of the heading with major axes of the space—in a manner consistent with the existing literature. Judgments were less accurate for targets in the rear hemi-field, and when headings were misaligned. These effects were clearer in Experiment 2, in which more support was provided for establishing headings. Second, participants were generally overconfident, reporting confidence intervals narrower than their accuracy warranted. Overconfidence was greater in Experiment 1 than in Experiment 2, where retrieval of three locations rather than two was required to perform the task. Third, although reported confidence significantly predicted accuracy, relative metacognitive accuracy was modest. Fourth, reported confidence reflected the effects of the reference-frame variables, but confidence was not adjusted sufficiently to account for the effects of these variables on accuracy. As a result, when viewpoints are misaligned with the environment, the absolute accuracy of metacognition suffers. When the target is behind the observer, both absolute and relative accuracy are impaired. Finally, our efforts to manipulate the perspectives adopted to make judgments had only small and inconsistent effects on performance and confidence.

These results provide clear support for the hypotheses that confidence ratings would be sensitive to allocentric alignment and egocentric direction, but they do not support the hypothesis that they would be sensitive to perspective. Our primary goal was to test these hypotheses, which were based empirically on prior research on the effects of these reference frame factors on the accuracy of spatial judgments. In the remainder of this discussion, we consider each factor in turn, speculating on explanations for the

effects on metacognition on the basis of prior metacognitive research and on the differences between Experiments 1 and 2.

Confidence was lower in both experiments for misaligned viewpoints. One possible explanation for this is that the retrieval of spatial information was more difficult or less self-consistent (Koriat, 2012) with misaligned viewpoints. However, the difference in reported confidence intervals between aligned and misaligned conditions was smaller in Experiment 1, which required retrieval of three locations, than in Experiment 2, in which more information about the origin was provided for participants. Another possibility is that awareness of the additional inference process required to determine object locations from a misaligned viewpoint (Mou & McNamara, 2002) served as a metacognitive cue. Participants' experience of this inference process may also reflect the conflict between reference frames. It thus seems likely that experience of the inference process contributes to lower confidence with misaligned viewpoints (Brewer & Sampaio, 2012). Either of these possibilities—effects on retrieval, or experience of the inference process—seems more likely to us than the possibility that participants had preexisting metacognitive beliefs about the effects of allocentric alignment. In either case, although participants adjusted their confidence in an appropriate direction when making judgments from misaligned viewpoints, this adjustment was smaller than the effect of alignment on performance, resulting in greater overconfidence for misaligned viewpoints.

Confidence was also sensitive to the effects of egocentric direction on performance. People are consistently more confident when the target is in the front half of space, even when this does not actually provide a benefit (as in the aligned trials in Experiment 1). Again, this might reflect retrieval processes, perhaps because it is easier to focus on targets in the front half of space due to the asymmetry of the egocentric reference frame, as discussed by Kelly and McNamara (2009). Orienting toward a target could result in spatial priming for the target, making it easier to retrieve information about it from memory (Hintzman, O'Dell, & Arndt, 1981). This same facilitation of the front half of space might also affect inferential processes. Finally, it seems more likely in this case that individuals have a general metacognitive belief that directional judgments for the front half of space are easier than those for the back half. In any case, people do appear to underestimate the effect of egocentric direction and do not adjust their confidence intervals enough to compensate for the effect of egocentric direction on performance.

Given the inconsistent results between Experiments 1 and 2, the effect of perspective on performance and metacognition in this task remains unclear. It appears perspective may have a very weak effect on performance. In Experiment 1, the within-range percentage scores suggest that pointing error was slightly higher for the allocentric group, but confidence judgments did not detect the increase in difficulty. This finding was not replicated in Experiment 2. Thus, our hypothesis that confidence would be higher when using the egocentric perspective was not supported. Strong individual preferences for perspectives do exist (Lawton, 1994), and it is possible that the manipulations were not strong enough to overcome these preferences. It is also possible that perspective is not a factor people use to monitor spatial memory precision.

These results fit nicely with a recent study by Galati and Avraamides (2014) showing that people use reference frame cues when communicating spatial information to others. In this study,

participants described the layout of a space to a partner. Participants organized their descriptions allocentrically when they knew their partner's viewpoint was aligned with the environment, but they organized them egocentrically when they did not know their partner's viewpoint. This study further reinforces the notion that people are sensitive to the effects of reference frames on spatial memory accuracy, and can use this knowledge to adapt their behavior to better suit the task.

An interesting open question is whether people's confidence judgments would still incorporate reference frame factors if their confidence judgments were made before completing the task. In other words, would people know, without attempting the task that back targets are more difficult than front targets and misaligned viewpoints are harder than aligned? The present experiments were not designed to answer this question, but we speculate that reference frame effects would be less apparent (and perhaps nonexistent) in such prospective confidence judgments because participants would not experience the subjective difficulty of making the pointing judgment. We believe that it is the subjective experience of realigning one's viewpoint that makes people less confident.

There are two ways in which the precision of judgments can be uncertain, external and internal. External uncertainty refers to environmental sources of uncertainty (e.g., moving targets, noise in movement trajectories) whereas internal uncertainty refers to the precision of a person's memory or judgment (Pfuhl et al., 2013; Teigen & Jørgensen, 2005). Our focus here was on internal uncertainty, but it is an interesting question whether similar cognitive processes are used to monitor external uncertainty. Alignment with environmental axes, for instance, is likely to be a powerful cue that one's heading has remained straight while traveling. Future research should examine this possibility.

Conclusion

In navigation, it is very important to be able to update the locations of landmarks as one's reference frame changes within an environment. The spatial memory literature has revealed that different reference frames have strong, reliable effects on performance. The present study sought to determine whether reference frames could also affect the experienced difficulty of a spatial judgment. And if so, do they affect experienced difficulty in the same way they affect actual difficulty? The answer to the first question is definitely yes. Both viewpoint alignment and target direction affect peoples' confidence in their pointing judgments, indicating they believe that misaligned viewpoints and back targets are more difficult. The answer to the second question is a qualified yes. The reference frames people identify as harder actually are harder. But participant confidence judgments underestimate the difference between these conditions.

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