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Perspective-Taking vs. Mental Rotation Transformations and How They Predict Spatial Navigation Performance

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SUMMARY

In Experiment 1, participants completed one of two versions of a computerized pointing direction task that used the same stimuli but different spatial transformation instructions. In the perspective-taking version, participants were to imagine standing at one location facing a second location and then to imagine pointing to a third location. In the array-rotation version, participants saw a vector pointing to one location, were to imagine the second vector with the same base as the first pointing to a second location, to mentally rotate the two vectors, and finally to indicate the direction of the imagined vector after the rotation. In Experiment 2, participants completed the perspective-taking, mental rotation, and four large-scale navigational tasks. The results showed that the perspective-taking task required unique spatial transformation ability from the array rotation task, and the perspective-taking task predicted unique variance over the mental rotation task in navigational tasks that required updating self-to-object representations. Copyright © 2006 John Wiley & Sons, Ltd.

Research (e.g. Bryant & Tversky, 1999; Easton & Sholl, 1995; Rieser, 1989; Wraga, Creem, & Proffitt, 2000; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999) on spatial ability has suggested a distinction between two classes of spatial transformations: (1) object-based transformations—the imagined movement of an object (or set of objects) about an axis or axes intrinsic to the object, and (2) egocentric perspective transformations—the imagined movement of one's point of view in relation to other object (or set of objects). For instance, one could imagine standing near the northern side of a map lying on a table and then imagine the map rotating on the table 180° until the southern side is closest to the oneself, or one could imagine oneself moving 180° around the table to view the map from the southern side. Although this distinction between object-based and egocentric perspective transformations has been noted in the literature and various studies have been conducted to investigate the relation between object-based spatial ability and performance on navigation tasks (Bryant, 1982; Goldin & Thorndyke, 1982; Hegarty, Richardson, Montello, Lovelace, & Subbaih, 2002; Juan-Espinosa, Abad, Colom, & Fernandez-Truchaud, 2000; Kirasic, 2000; Lorenz & Neisser, 1986; Malinowki, 2001; Waller, 2000; see Hegarty & Waller, 2005), very little

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attention has been paid to the relationship between the ability to perform egocentric perspective-taking transformations and navigation abilities. Therefore, the current research was designed to further examine distinctions between object-based and egocentric spatial transformation abilities and to examine the relationships between these abilities and performance on a variety of navigational tasks.

Neuroscience and experimental studies have provided evidence suggesting that object-based and egocentric spatial transformations rely on different processing systems. For instance, Zacks et al. (1999) found that instructions to engage in egocentric spatial transformations (e.g. judging whether an object is to the left or right of a figure from the figure's perspective) led to activation in the left parietal-temporal-occipital junction, but instructions to engage in object-based transformations (e.g. mental rotation of an inverted figure) led to bilateral activation in inferior and posterior parietal areas that was greater in the right than in the left hemisphere (see also Zacks, Vettel, & Michelon, 2003). Furthermore, various experimental studies have found different response time and accuracy patterns for egocentric and object-based transformation tasks (e.g. Huttenlocher & Presson, 1979; Presson, 1982; Wraga et al., 2000; Zacks, Mires, Tversky, & Hazletine, 2002).

Although several studies have found response time to be faster and accuracy to be higher for egocentric transformations than for object-based transformations (e.g. Wraga et al., 2000; Zacks et al., 2002), such response time and accuracy patterns have not always occurred (Huttenlocher & Presson, 1979; Parsons, 1987a; Presson, 1982; Reiser, 1989), and it appears that the relative ease of performing egocentric versus object-based transformations is due more to task specific demands than to general processing differences. For instance, Huttenlocher and Presson (1979; Presson, 1982) found that the relative difficulty of perspective taking versus rotation transformations for their stimuli depended on the formulation of the task questions, with a perspective-taking strategy being easier for 'item questions' (e.g. 'what will be on your left?') and a rotation strategy being easier for 'position questions' (e.g. 'where will the object be?') and for 'appearance questions' (e.g. 'how will the array look?'). Additionally, for the majority of the studies showing an egocentric advantage, participants were given arrays to memorize that consisted of diamond-shaped configurations of four objects and imagined headings (i.e., the angular deviation of the imagined perspective from the original orientation of the array) that were only canonical angles (i.e., 90°, 180°, 270°). Yet, evidence suggests that participants are able to represent the object layouts along two intrinsic axes (i.e. 0°–180° and 90°–270°) significantly better than along other non-canonical axes (Mou & McNamara, 2002), and Kozhevnikov and Hegarty (2001) found that participants rarely used egocentric perspective transformations for imagined headings less than 100° or more than 260° and almost never used egocentric perspective transformations for imagined headings of 180°.

In Study 1, we further examined the relationship between response time and accuracy profiles for egocentric perspective-taking and object-based spatial transformations. For this purpose, we created two formally equivalent computerized object-based (array-rotation) and egocentric (perspective-taking) transformation tasks with similar stimuli and task parameters. Both tasks presented participants with a complex configuration of objects and a variety of non-canonical imagined heading changes, thus preventing the participants from using verbal-analytical strategies.

In Study 2, we then examined the relationships between egocentric perspective-taking ability (as measured by our computerized perspective-taking task) and performance on a variety of navigational tasks, and we contrasted these relationships with relationships between object-based spatial ability and performance on the same navigational tasks. Many studies have investigated the relationship between object-based spatial ability (e.g. mental rotation, spatial visualization) and way-finding performance (see Hegarty & Waller, 2005). These studies, however, have produced mixed results. Some studies have reported finding no relationship, others have reported finding weak and sometimes moderate relationships between small scale-spatial ability and performance on large-scale navigation tasks (e.g. Bryant, 1982; Malinowski, 2001; Kirasic, 2000; Rovine & Weisman, 1989; Waller, 2000; and see Hegarty & Waller, 2005). Others have reported that spatial ability tests and navigation tasks loaded on separate but weakly to moderately related factors (Hegarty et al., 2002; Juan-Espinosa et al., 2000; Lorenz & Neisser, 1986; Pearson & Ialongo, 1986) or separate factors that were only related through mediating variables (Allen, Kirasic, Dobson, Long, & Beck, 1996; Kirasic, 2000). For instance, Lorenz and Neisser (1986) administered to participants a number of spatial ability tests along with a variety of wayfinding and orientation tasks. Lorenz and Neisser found that 'small-scale' spatial tests were psychometrically distinct from the measures of environmental knowledge. Hegarty et al. (2002) also found that small-scale spatial abilities and environmental spatial abilities were psychometrically distinct abilities. In the above studies, however, small-scale spatial abilities were assessed by the tests that required object-based spatial transformations (e.g. mental rotation).

To our knowledge, only a few studies have examined the relationship between performance on perspective-taking tasks and performance on navigation tasks. Kozhevnikov and Hegarty (2001) found that paper-and-pencil perspective taking scores loaded on a separate factor from mental rotation scores and that self-reported sense of direction loaded on the same factor as perspective taking. The fact that sense of direction loaded on the perspective-taking factor and that sense of direction has been shown to be a reliable predictor of navigational performance (e.g. Hegarty et al., 2002) suggests that performance on perspective taking might be related to navigational performance in a large-scale space. However, this evidence is only preliminary because the self-report sense of direction questionnaire was not a direct measure of spatial navigation performance. In another study, Allen et al. (1996) suggested that perspective-taking laboratory tasks could be a mediator between small-scale spatial abilities and environmental learning. To assess perspective-taking ability, Allen et al. presented participants with a model town and asked participants whether a slide projected on the screen corresponded to a view of the town. The results from the two studies conducted by Allen et al., however, were inconsistent. In their first study, they found that perspective-taking latency mediated the relationship between psychometric measures of spatial ability and Euclidian direction knowledge of the environment (i.e. participants' abilities to point correctly to different target locations along the route), whereas in their second study, Allen et al. failed to replicate the relationship between perspective-taking latency and Euclidian direction knowledge.

Based on previous evidence showing that it is the self-to-object representational system that provides the base for successful navigation of a mobile organism in space (e.g. Easton & Sholl, 1995; Sholl, 1987; Wang & Spelke, 2000), and that during locomotion, observers need to continually keep track of their changing positions relative to other objects in the environment, we hypothesized that small-scale egocentric perspective-taking ability should predict navigation performance in a large-scale space more reliably than object-based spatial ability. Additionally, several researchers have argued that different environmental representations, particularly object-based versus self-based representations, influence various aspects of navigation (e.g. Mou, McNamara, Valiquette, & Rump, 2004; Wang & Spelke, 2000). Object-based representations code for the spatial relations of objects with respect to other objects, although often still having an orientation consistent with either the viewer's encoding perspective or along a salient scene axis (Mou & McNamara, 2002; Shelton & McNamara, 2001). Self-based representations, on the other hand, code for the spatial relations of objects with respect to one's own body axes (e.g. left-right, front-back, up-down). Thus, at least to the degree that self-based representations are part of performance on egocentric perspective transformation tasks, performance on such tasks should predict performance on navigational tasks also requiring self-based representations.

EXPERIMENT 1

Participants

Seventy-six undergraduate students from Rutgers University and the New Jersey Institute of Technology participated in the study. They received either course credit or monetary compensation.

Apparatus and materials

Each participant completed one of the two versions of our *Pointing Direction Task*. The pointing direction task was a modified, computerized adaptation of the paper-and-pencil perspective-taking test developed by Kozhevnikov and Hegarty (2001). Two different computerized versions of the pointing direction task were created for the purpose of this experiment: the perspective-taking and the array-rotation versions. Each version consisted of 36 test trails. On each trial, the participants viewed on the computer screen a picture representing a layout of different locations. The layout consisted of a starting location (a picture of a character's head or an arrow) and five other locations (e.g. university, airport, etc.). All of the locations were represented as black points with the name of the location and a small pictogram near each point. Instructions appeared on the bottom of the computer screen on each trial, and the programme recorded accuracy and response time.

In the *perspective-taking version* of the pointing direction task, a small figure representing a character's head indicated the starting location, where participants were to imagine themselves standing (see Figure 1). The character's eyes were looking towards one of the five locations that represented the to-be-imagined facing location (imagined orientation). Participants were to indicate the direction to a third (target) location from the imagined orientation by pressing a corresponding key on the computer keyboard. Instructions appeared at the bottom of the screen, for example (see Figure 1), 'Imagine you are the figure. You are facing the University. Point to the Airport'. Thus, participants were to imagine transforming their actual perspective (i.e. an aerial perspective of the character and the town) to that of the character's perspective, and then the participants were to imagine pointing to the target from the character's perspective.

In the *array-rotation version* of the pointing direction task, a green arrow with a green circle as a base pointed to one of the five locations (see Figure 2). Participants were to imagine a second arrow emanating from the green circle and pointing to a specific target location among the five other locations (e.g. 'Imagine a second arrow to the Airport'). Then participants were to imagine rotating the angle composed from these two arrows

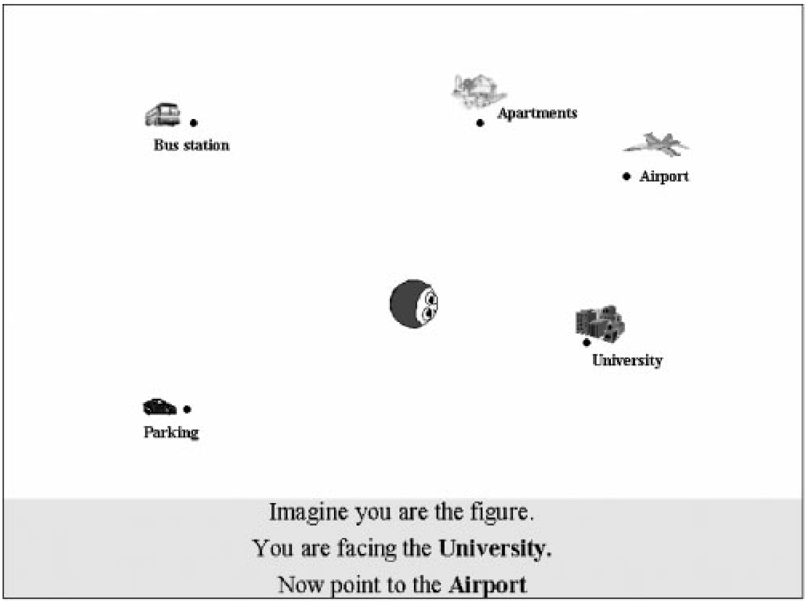

Figure 1. Example of a test trial from the perspective-taking version of the pointing direction task

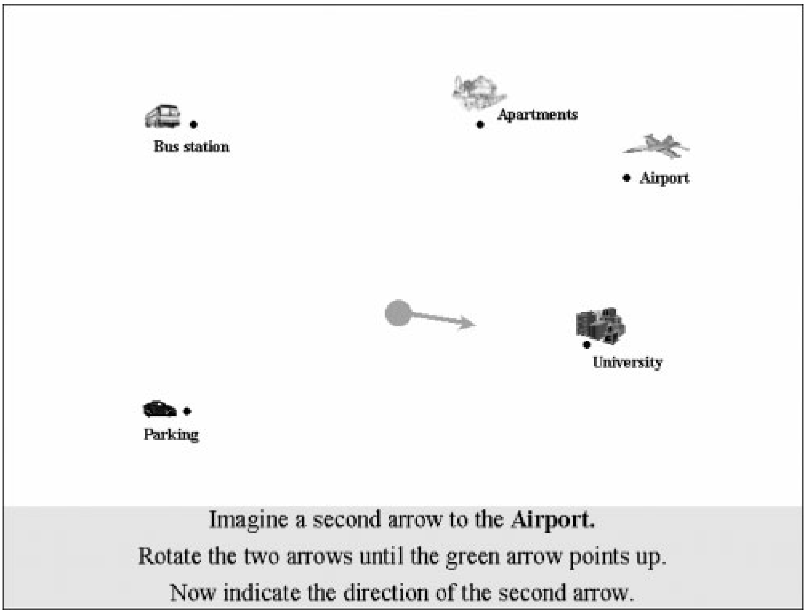

Figure 2. Example of a test trial from the array-rotation version of the pointing direction task

until the first arrow pointed vertically up (i.e. was aligned with a vertical axis of the computer screen). After mentally rotating the arrows, the participants were to indicate the direction that the second imagined arrow would point by pressing a correspondingly labelled key on the numeric keypad.

The imagined orientations in the perspective-taking version varied from 100° to 260° (relative to upright direction) in increments of 20°. We did not use angles less than 100° and more than 260° for imagined headings because previous research (Kozhevnikov & Hegarty, 2001) has shown that observers usually used strategies other than perspective-taking strategies for those angles (e.g. analytical strategies or tilting the head to 'see' the angle). The same angles (from 100° to 260°) were used for representing angles between the direction of the green arrow and the vertical axis of the computer screen in the array-rotation version of the pointing direction task.

In both of the above versions of the pointing direction task, four pointing directions were used (9 times each): Right-Front (RF; 45° to the right of the imagined orientation), Right-Back (RB; 135° to the right of the imagined orientation), Left-Back (LB; 135° to the left of the imagined orientation), and Left-Front (LF; 45° to the left of the imagined orientation).[1] To indicate the pointing direction, participants were to press an appropriate key on the keyboard. Arrows representing these directions were glued to the numeric keypad keys on a standard computer keyboard (keys 9, 3, 1 and 7, respectively). The arrows were positioned in a way to preserve the spatial configuration (e.g. the arrow representing Left-Front direction was placed to the left and above the arrow representing Right-Back direction). In addition to the arrows representing RF, RB, LB and LF directions, four other arrows were glued on the keypad keys representing Front (F), Back (B), Left (L) and Right (R) directions (keys 8, 2, 4 and 6, respectively). Although all of the correct responses were either RF, RB, LB or LF responses, the participants were allowed to choose their responses from the 8 possible keys (RF, R, RB, B, LB, L, LF and F), and they were not informed that some of the directions were not used. All participants used their right index finger to respond. All of the locations, except for the starting, facing, and target locations, were randomly placed on each trial to prevent the memorization of the layout and the verbal coding of objects' locations. The set of pictures representing different layouts and the method for responding were the same for both versions of the task.

Procedure

The participants were randomly assigned to one of the above versions of the task. All of the participants read and signed a consent form at the beginning of the study, and they filled out a questionnaire including general questions about their age, handedness, etc. Before beginning the pointing direction task, participants received training using printed pictures of different layouts and verbal instructions. During the training, participants were shown a printed picture with either perspective-taking or array-rotation instructions, and they were asked to indicate the correct directional response to the target. To make sure that they understood the instructions and used the appropriate strategy, they also were asked to explain how they solved the task. Five participants who reported they were unable to use the appropriate strategy according to the instructions were excluded from the study (3 participants were unable to use rotation strategy and 2 were unable to use perspective-taking strategy). After the experiment, the participants were debriefed and received their compensation.

[1]In the original version of the pointing direction task, we also used tasks with F, R, L and B pointing directions. However, because participants reported that they sometimes applied verbal strategies for these particular pointing directions, we did not include these directions in the final version of the pointing direction task.

Table 1. Descriptive statistics for two versions of the pointing direction task

Test	*n*	Mean accuracy	*SD*	Mean RT (s)	*SD*
Perspective taking instructions	40	0.69	0.24	13.63	6.94
Array-rotation instructions	36	0.68	0.18	15.50	9.03

Results and discussion

Descriptive statistics

Descriptive statistics for the two versions of pointing direction task (perspective-taking and array-rotation) are given in Table 1. Data for imagined headings of 180° were excluded from all further analyses because participants in the debriefing stage of the pointing direction task reported that they used strategies other than perspective taking for this particular imagined heading (e.g. they just 'mirrored' the facing direction of 0°). This is consistent with previous findings that participants typically use more verbal-analytical strategies for this particular facing direction (Hintzman, O'Dell, & Arndt, 1981; Kozhevnikov & Hegarty, 2001).

Pointing accuracy and latency as functions of the imagined heading

A change of perspective is a process that can be divided into two steps: (1) imagining the new facing direction (i.e. mentally reorienting oneself) and (2) pointing to the target from that newly imagined facing direction. In this section, we examined how pointing accuracy and latency varied as functions of the imagined heading and the version of the pointing direction task. Figure 3 shows pointing accuracy (the proportion of correct answers) as a function of the imagined heading (i.e. the imagined heading in the perspective taking

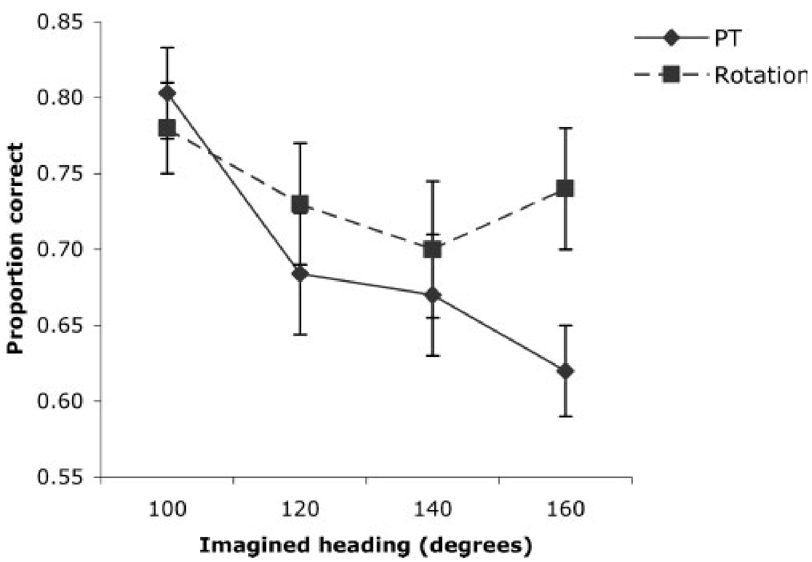

Figure 3. Pointing accuracy as a function of imagined orientation change for perspective-taking and array-rotation groups. Errors bars are standard mean errors. Note that the y-axis does not begin at the origin

version and the angle of rotation in the rotation version). The data were collapsed across equivalent, clockwise and counterclockwise imagined headings (e.g. 100° and 260°, 120° and 240°, etc.) due to the bilateral symmetry in the response profiles (i.e. the participants performed spatial transformations along the shortest path in angular distance, as has been reported in other studies, see Diwadkar & McNamara, 1997).

The data were analysed using a 4×2 mixed-model ANOVA with the imagined heading as a within-subjects variable and the pointing direction task (perspective-taking vs. array-rotation versions) as a between-groups variable. There was a significant main effect of imagined heading on accuracy, $F(3, 222) = 11.39$, $p < 0.001$. Overall, it was easier to solve the task for imagined headings of 100° than for larger imagined headings. This finding is consistent with the findings from previous perspective-taking studies that showed that errors and response times increased with the angular deviation of the imagined perspective or rotation from the orientation of the array (e.g. Hintzman et al., 1981; Rieser, 1989; Shelton & McNamara, 1997). In fact, the proportion of correct answers for the imagined heading of 100° degrees was significantly higher than the proportions of correct answers averaged across all of the other imagined headings (79% vs. 70.7%, 68.6% and 68.4%, respectively, $p < 0.001$).

Although the main effect of pointing direction task was not significant ($p = 0.41$), there was a significant Imagined Heading × Pointing Direction Task interaction, $F(3, 222) = 4.16$, $p < 0.01$. The effect of imagined heading on pointing accuracy was significantly different between participants that received the perspective-taking version versus participants that received the rotation version of the pointing direction task. As shown in Figure 3, the decrease in accuracy with larger imagined headings was greater for the perspective-taking group than for the array-rotation group. The difference between the two groups was significant at the 160° angle, $t(74) = 2.33$, $p < 0.05$.

Similarly, the latency data were analysed using a 4×2 mixed-model ANOVA with imagined heading as a within-subjects variable and the pointing direction task (perspective taking versus array-rotation versions) as a between groups variable. There was a significant main effect of imagined heading, $F(3, 222) = 3.26$, $p < 0.05$. RT for the imagined heading of 100° was significantly faster than RT averaged across all of the other imagined headings ($p = 0.01$). There was not a significant main effect of pointing direction task ($p = 0.15$), and there was not a significant Imagined Heading × Pointing Direction Task interaction, (for the perspective taking group, the means (in seconds) were $M_{100^\circ} = 11.79$, $M_{120^\circ} = 13.03$, $M_{140^\circ} = 13.93$, $M_{160^\circ} = 13.06$, and for the array rotation group, $M_{100^\circ} = 12.79$, $M_{120^\circ} = 16.23$, $M_{140^\circ} = 14.56$, $M_{160^\circ} = 14.85$; $p = 0.58$).

Thus, in contrast to those previous studies (Wraga et al., 2000; Zacks et al., 2000) that reported an advantage of egocentric perspective over object-based transformations, we did not find a significant main effect of the array-rotation versus perspective-taking task. The only significant difference between the perspective-taking and array-rotation groups was a significant Imagined Heading × Pointing Direction Task interaction due to the steeper slope of the accuracy profile for the perspective-taking group. To further examine the meaning of the differences in the slopes, we analysed the different types of errors made by the participants who completed the different versions of the pointing direction task.

Comparisons of the types of errors

There is evidence that egocentric spatial transformations and rotation transformations lead to different types of errors (Huttenlocher & Presson, 1973, 1979; Kozhevnikov & Hegarty, 2001; Presson, 1982). Egocentric spatial transformations should lead to systematic errors that reflect the symmetry of the coordinate system of the body (i.e. difficulties in specifying right-left and back-front directions to the target). In particular, front responses have been found to be significantly more accurate than back responses, and right-front and left-front responses have been found to be significantly more accurate than right-back and left-back responses, respectively (Kozhevnikov & Hegarty, 2001; Hintzman et al., 1981). Mental rotation transformations, on the other hand, do not lead to such errors, but rather lead to errors that reflect the under-rotation or over-rotation of a target object. Thus, we conducted two sets of analyses to examine these hypotheses.

First, we categorized the actual direction to the target from the imagined heading for all of the responses as LF, RF, LB or RB. We then analysed these data with a $2 \times 2 \times 2$ mixed-model ANOVA with Front versus Back and Left versus Right pointing directions as a within-subjects variables and pointing direction task (perspective-taking versus array-rotation versions) as a between-groups variable (see Figure 4). The analysis only revealed a marginally significant, two-way, Front-Back by pointing direction task interaction, $F(1, 74) = 3.97$, $p = 0.05$, and a significant, three-way, Front-Back by Left-Right by pointing direction task interaction, $F(1, 74) = 6.30$, $p < 0.05$. None of the other effects were significant, all $F\text{s} < 1$. For the perspective-taking group, follow-up interaction analyses revealed a significant main effect of Front-Back, $F(1, 38) = 6.48$, $p < 0.05$ and a marginally significant Front-Back by Left-Right interaction, $F(1, 38) = 3.29$, $p = 0.08$. For the array-rotation group, however, neither the Front-Back, Left-Right nor the interaction effects were significant, all $F\text{s} < 1$. As shown in Figure 4, the perspective-taking group made more errors when the pointing direction was backward than when it

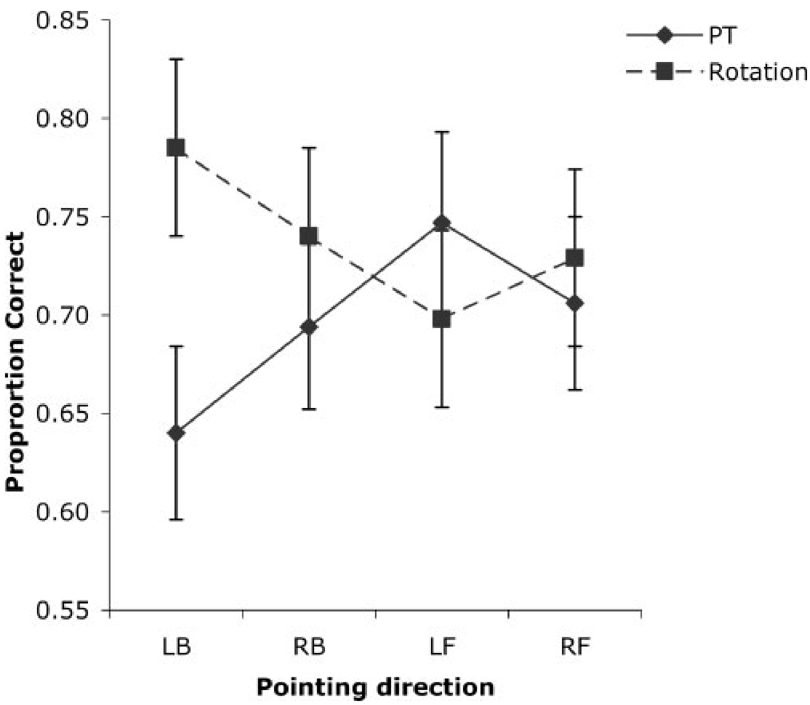

Figure 4. Pointing accuracy as a function of pointing direction for perspective-taking and array-rotation groups. Errors bars are standard mean errors. Note that the y-axis does not begin at the origin

was forward, and this was more pronounced for the LB direction. For the array-rotation group, on the other hand, errors did not systematically vary with the pointing direction of the imagined vector. Thus, the perspective-taking group was more accurate at making imagined LF and RF responses than at making imagined LB and RB responses. These results are very similar to the response profiles observed by Hintzman et al. (1981) for a similar pointing task and by Kozhevnikov & Hegarty (2001) and suggest that the participants used egocentric perspective transformations to perform the perspective-taking task. In contrast, the errors made by the array-rotation group did now show such an asymmetry and the different patterns of errors for the two groups suggest that the two groups used different strategies.

Next, to further examine the types of errors made by the two groups as evidence of the types of strategies used, the errors were categorized as reflection and adjacent errors. Adjacent errors were defined as the incorrect responses that deviated from the correct response by 45°, suggesting the over- or under-rotation of the imagined self or vector. Errors that reflected symmetry of the coordinate system of the physical body were considered reflection errors, and reflection errors were defined as errors that deviated from the correct response by 90° or more. The errors that deviated from the correct response by 90° suggested confusion between either left and right direction or front and back direction, whereas the errors that deviated from the correct response by 180° suggested confusion between both left/right and front/back directions. Finally, errors that deviated from the correct response by 135° suggested confusion between either left and right or front and back directions, in addition to the over- or under-rotation of the imagined self (see Figure 5).

For each participant, difference scores were calculated such that the number of adjacent errors made for a given heading was subtracted from the number of reflection errors made for that same heading. We expected that the perspective-taking group would perform egocentric spatial transformations and therefore make more reflection errors than adjacent errors but that the array-rotation group would perform allocentric spatial transformations and therefore make more adjacent than reflection errors. Figure 6 shows the mean reflection-adjacent error differences as a function of the imagined heading and the pointing direction task. A 4×2 mixed-model ANOVA revealed marginally significant effects of imagined heading, $F(3, 222) = 2.60$, $p = 0.05$, and pointing direction task, $F(1, 74) = 3.50$, $p = 0.065$, and a significant interaction, $F(3, 222) = 6.05$, $p = 0.001$. As shown in Figure 6, the difference scores for the array-rotation group ($M = -0.42$) were generally lower than those of the perspective-taking group ($M = 0.22$). In fact, the difference scores for the array-rotation group were significantly lower than those of the perspective-taking group at 100°, 120° and 140° imagined headings, all ts$(74) > 2.00$, $p < 0.05$. Furthermore, the mean for the array-rotation group was significantly less than zero, $t(35) = 2.44$, $p < 0.05$, and the means for all of the imagined headings for the array rotation group were significantly, or marginally, less than zero (for 100°, $t(35) = 1.82$, $p = 0.08$; for 120°, $t(35) = 3.04$, $p = 0.004$, and for 140°, $t(35) = 2.08$, $p = 0.045$), except for 160° changes, $t(35) < 1$. In contrast, the mean for the perspective-taking group was not significantly different from zero, $t(39) < 1$, except for the mean for the 100° imagined heading, which was significantly greater than zero, $t(39) = 2.15$, $p = 0.038$; for all of the others, $t(39) \leq 1$. Thus, the array-rotation group generally tended to make adjacent rather than reflection errors, which suggests that their errors tended to be mostly due to under- or over-rotation of the vectors. No such pattern was found for perspective-taking group, and at least for the 100° imagined heading, perspective-taking group tended to make reflection

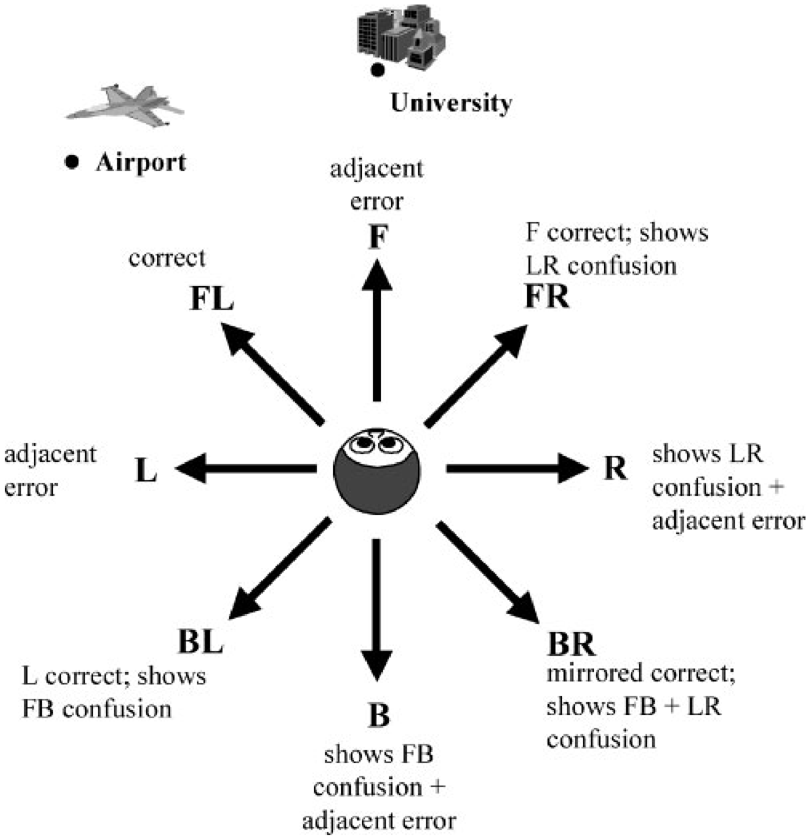

Figure 5. Examples of the classification of pointing errors. Errors that were $+/-45°$ from the correct response were classified as *adjacent* errors. Errors that were $+/-90°$ from the correct response were classified as *reflection* errors: 90° errors showed LR or FB confusion, 135° errors showed FB or LB confusion plus adjacent error, and 180° errors showed both FB and LR confusion

rather than adjacent errors, suggesting that their errors at this heading tended to be due to confusion regarding the location of the target relative to the body axes (FB and LR) following an imagined egocentric orientation change.

In summary, the results from Experiment 1 provide evidence that there are some differences in the response profiles for the perspective-taking and array-rotation tasks; however, these differences did not exclusively favour the perspective-taking task. First, larger imagined heading changes were more difficult for the perspective-taking group than for the array-rotation group, as revealed by the significant Imagined Heading $\times$ Task interaction. Second, the Pointing Direction $\times$ Task interaction also was significant, revealing an asymmetry in the difficulty for LB/RB and LF/RF responses for the perspective-taking group but not for the array-rotation group. Third, the analyses of the types of errors made by the perspective-taking and array-rotation groups showed that the participants made different types of errors while performing the respective tasks, and the patterns of error differences were consistent with the use of object-based spatial transformations by the array-rotation group and consistent with the use of egocentric spatial transformations by the perspective-taking group. Thus, the results of Experiment 1

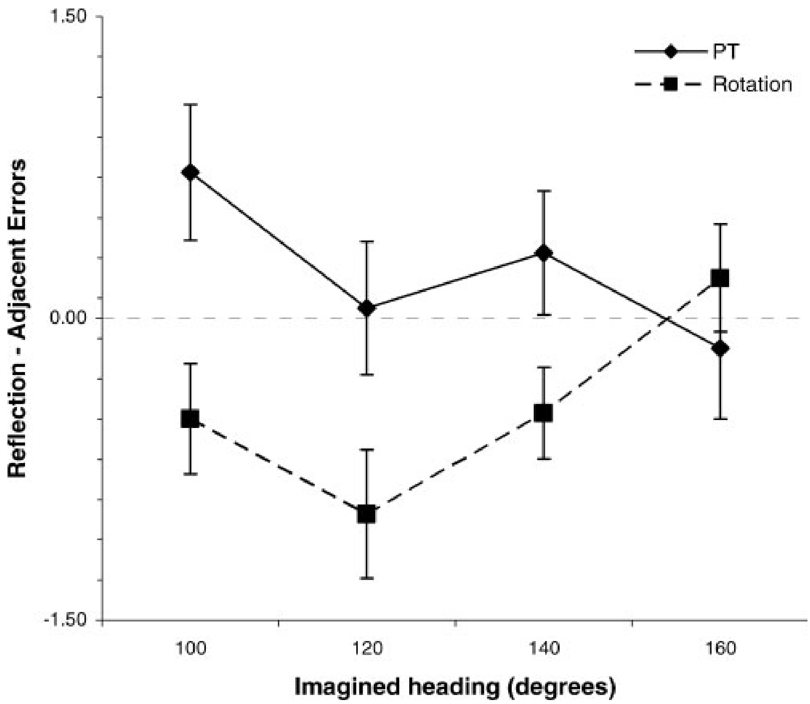

Figure 6. The mean differences in reflection and adjacent errors as a function of the imagined orientation change for the perspective-taking and array-rotation groups. Errors bars are standard mean errors

suggest that participants relied on the object-to-object representational system and allocentric rotations to solve array-rotation task but that participants relied on self-to-object representational system and egocentric perspective transformations to solve perspective-taking task.

EXPERIMENT 2

As noted in the Introduction, previous studies have investigated the relationship between object-based, small-scale, spatial ability (e.g. mental rotation, spatial visualization) and performance on navigation tasks (Bryant, 1982; Goldin & Thorndyke, 1982; Hegarty et al., 2002; Juan-Espinosa et al., 2000; Kirasic, 2000; Lorenz & Neisser, 1986; Malinowski, 2000; Waller, 2000; see Hegarty & Waller, 2005), but very little attention has been paid to the relationship between perspective-taking ability and navigation. Thus, the goal of Experiment 2 was examine differences between mental rotation and perspective-taking ability in predicting performance on a variety of navigational tasks, particularly to examine whether perspective-taking ability was a reliable and unique predictor of navigational performance. To assess different aspects of navigational performance, we administered to participants a number of navigational tasks: route retracing, finding a shortcut, drawing the route on a floor plan and large scale pointing direction (i.e. pointing to the non-visible locations on the route) tasks.

Method

Participants and stimuli

Fifty-four undergraduate students from Rutgers University and New Jersey Institute of Technology who reported not being familiar with the building where the experiment took place participated in Experiment 2. Among the students who participated in Experiment 2, 22 participated in the perspective-taking condition in Experiment 1 (all of the other participants from Experiment 1 reported being familiar with the building where the navigational tests were conducted). The 32 participants who did not participate in Experiment 1 were administered the perspective-taking version of the pointing direction task following the same procedure as described in Experiment 1. All of the participants in Experiment 2 were administered the Shepard and Metzler (1971) mental rotation task. Ideally, we would have liked for the participants in Experiment 2 to have completed both the array-rotation and perspective-taking tasks; however, our pilot data showed that participants often reported being unable to use a required strategy to solve the pointing direction task after being exposed to the alternative strategy.[2] Finally, all of the all of the participants in Experiment 2 were administered the navigational tasks described below.

The Shepard and Metzler Mental rotation task

In the computerized Shepard and Metzler (1971) mental rotation task, participants were shown pairs of two-dimensional pictures of three-dimensional geometric forms. The forms were rotated from 20° to 180°, either in the picture plane or in depth. On half of the trials, the second figure was a rotated version of the original stimulus, whereas on the other half of the trails, the figure was a rotated, mirror-reversed version of the original stimulus. Participants were to decide whether the two figures were the same or different. They received eight training trials with feedback before starting the task and completed 54 test trials, consisting of one 'same' and one 'different' trial for the different degrees of rotation (from 20° to 180° in increments of 20°) and for the different planes of rotation (along the x-, y-, and z-axes). Both accuracy and response times were recorded.

Navigational tasks

All of the participants followed the experimenter on a route that covered two floors of the science building at Rutgers University, Newark (see Figure 7). The route was approximately 376 feet long, and it took about 2.5 minutes to traverse. The route started at one of the psychology laboratories, went through several doors down to the basement, through part of the basement, and back upstairs to a location close to the starting point. The starting point was not visible from the ending point because of closed doors located between the two points.

At the ending point of the route, participants completed a large-scale pointing direction task in which they were to indicate the direction from their current position to two salient landmarks that they had encountered along the route (the building entrance and the staircase) and to two buildings on the campus. For each location, participants were given a sheet of paper with a smaller, filled circle centred within a larger circle and a line drawn from the centre of the filled circle to the larger circle. Participants were told that the filled

[2]For example several participants who completed the perspective-taking task first reported being unable to avoid using the perspective-taking strategy for the array-rotation task; for instance, one student reported that as soon as the scene with the arrow appeared he could not avoid imagining himself at the base of the arrow facing the direction that the arrow was pointing.

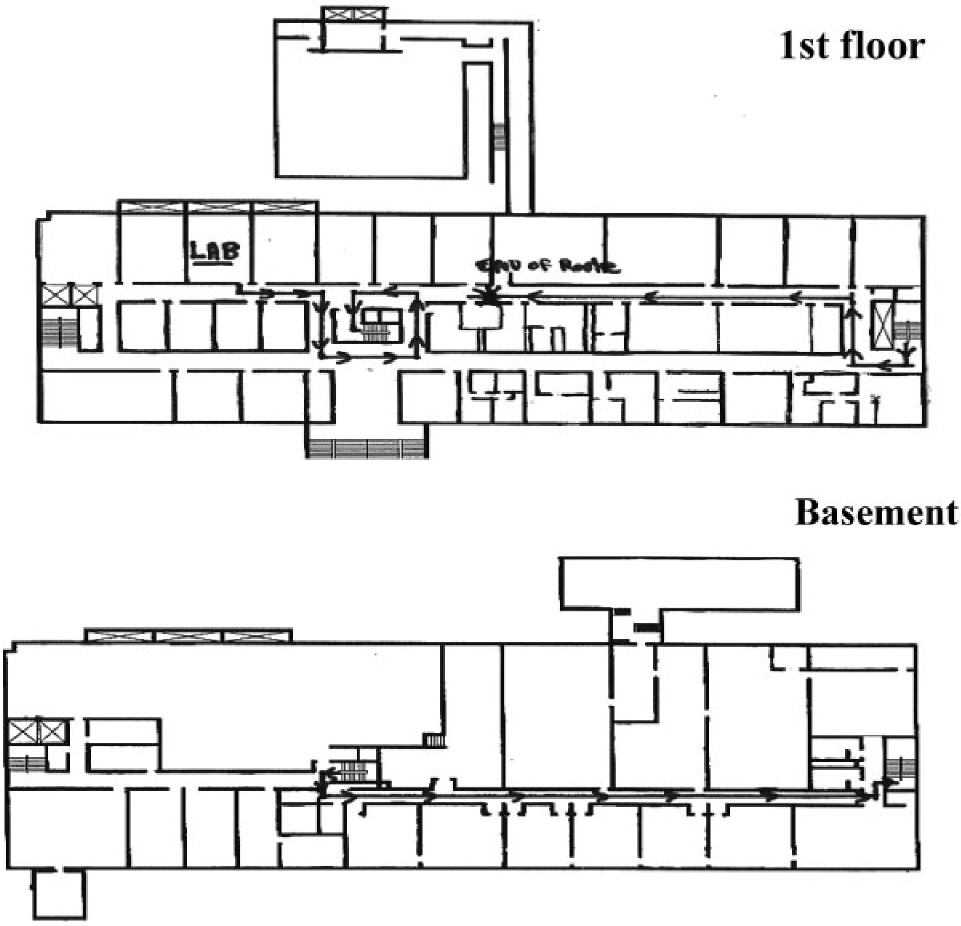

Figure 7. The route participants followed in a navigational task

circle represented their current position and the line represented their current heading. They were asked to indicate the direction to a target location by drawing a straight line from the filled circle to the outer circle. For each target location, pointing accuracy was calculated as the absolute value of the deviations in degrees (from 0° to 180°) between the participants' responses and the correct directions to the targets, and the participants' total score was calculated as the average deviation across all targets.

After completing the large-scale pointing direction task, the participants were to find a shortcut from the ending point to the starting point of the route. During the shortcut task, the experimenter followed behind the participants and recorded their movements. Performance on this task was scored in terms of the number of segments of the route participants walked before they reached the lab, where a segment of the route was defined as a part of the route between two intersections.

After returning to the starting point, participants were to retrace the route from beginning to end. Performance on the retracing task was scored as the number of correct turns divided by the total number of turns. Finally, after completing the retracing task, participants were given floor plans for the two floors and were to trace the route on the floor plans. Performance on this task was scored as the number of correct turns divided by the total number of turns traced.

Results and discussion

Correlations among the navigational tasks, the perspective-taking version of the pointing direction task, and the Shepard and Metzler mental rotation task are shown in Table 2. Accuracy on the Shepard and Metzler mental rotation task positively correlated with accuracy on the perspective-taking task ($r = 0.69$, $p < 0.001$), which shows that performance on the two tasks required the use of some shared spatial resources. The differences in the correlations between the mental rotation and perspective-taking tasks and the navigational tasks, however, showed that the mental rotation and perspective-taking tasks each also required the use of unique spatial resources. Although accuracy on both tasks significantly correlated with accuracy in drawing the route on the building floor plans ($p < 0.05$) and accuracy on neither task significantly correlated with accuracy at retracing the route, accuracy on the perspective-taking task was significantly correlated both with finding the shortcut ($p < 0.05$) and with performance on the large-scale pointing direction task ($p < 0.05$), whereas accuracy on the Shepard and Metzler mental rotation task was not significantly correlated with either of these tasks.

To further investigate this pattern of correlations, we first conducted a principle components analysis to determine whether the navigational tasks (i.e. retracing the route, finding the shortcut, tracing the route on the floor plan and pointing to locations) were measuring similar or different constructs. The principle components analysis with a Varimax rotation revealed two factors. Retracing the route and tracing the route on the floor plan loaded on one factor, where $r_{\text{retracing}} = 0.75$ and $r_{\text{tracing}} = 0.79$ (Eigenvalue = 1.58, Percentage of variance accounted for = 39.55%), and performance in finding the shortcut and in the large-scale pointing direction task loaded on a separate factor, where $r_{\text{shortcut}} = 0.55$ and $r_{\text{pointing}} = 0.78$ (Eigenvalue = 1.16, Percentage of variance accounted for = 28.87%).

The fact that these measures of environmental knowledge loaded on different factors is consistent with previous findings. Allen et al. (1996), for example, found that large-scale pointing direction error did not load on a topographical knowledge factor that included errors in retracing a route in reverse. In fact, large-scale pointing direction tasks are 'egocentric orientation' tasks in that they assess the navigators' knowledge of the spatial relations between themselves and landmarks that were not perceptually available during the task (Mou et al., 2004; Rieser, 1989; Wang & Spelke, 2000). Thus, accurate performance on these tasks is most likely based on accurate encoding of self-to-object relations. Furthermore, researchers have argued that accurate encoding of self-to-object relations results from accurate path integration processes that rely on an egocentric representational system. Path integration is the process of navigation by which the navigator's translations and rotations are integrated to provide a current estimate of position and orientation within a larger spatial framework (see Loomis et al., 1993), and path integration occurs via the acquisition and use of sensory information (e.g. vision or proprioception) about self-motion relative to a starting position or landmark to establish the representation of egocentric vectors to such targets and then update the vectors via vector summation when moving (Wang & Spelke, 2000; see Wang, 2003, for a review). Particularly relevant to the results from the principle components analysis, studies of humans and other animals have shown that accurate performance on shortcut tasks, like triangle-completion and return-to-origin tasks, also results from accurate encoding of self-to-object relations via path integration (Loomis, Klatzky, Golledge, & Philbeck, 1999). Thus, the shortcut/pointing factor overall appears to be a measure of self-to-object environmental representations.

As for the route-tracing and retracing factor, neither task necessarily requires accurate self-to-object environmental representations or path integration processes. Although path integration processes could lead to accurate configural representations that would facilitate performance on both tasks, both route-tracing and retracing tasks could be solved by relying on accurate procedural (e.g. motor imagery) or accurate verbal (e.g. a verbal a list of directions) representations of the route. Indeed, relying on accurate memory, even if it is sequential memory, for actions taken at decision points would lead to accurate performance on both tasks. Thus, the route tracing/retracing factor overall appears to be a measure of route knowledge (see also Allen et al., 1996).

The following correlations were performed using the factor scores for these two factors. As shown in Table 2, the correlation between perspective-taking and the route knowledge factor was significant ($p = 0.04$), the correlation between mental rotation and the route knowledge factor was only marginally significant ($p = 0.06$), and the difference between the correlation coefficients was not significant, $t(53) = 0.18$, $p = \text{ns}$. Furthermore, to examine whether perspective taking transformation ability predicted unique variance in the route knowledge measure over mental rotation transformation ability, we calculated semipartial correlations, as shown in Table 2 (also shown are the semipartial correlations for the individual navigation tasks). After partialling out the shared variance between perspective-taking and mental rotation accuracy, neither the semipartial correlation between perspective-taking accuracy and the route knowledge factor scores nor the semipartial correlation between mental rotation accuracy and the route knowledge factor scores were significant ($p = 0.32$, and $p = 0.51$, respectively), and the differences between the semipartial correlation coefficients was not significant, $t(53) < 1$. Thus, some common spatial abilities required to solve both the mental rotation and the perspective taking tasks appeared to have affected performance on this route knowledge factor.

As for the correlations between two versions of the pointing direction task and the self-to-object environmental representations factor, the correlation between perspective-taking

Table 2. Correlations between perspective-taking and mental rotation accuracy and navigational task performance and semipartial correlations between perspective-taking accuracy minus the shared variance with mental rotation accuracy (Residual: PT-MR) and mental rotation accuracy minus the shared variance with perspective-taking accuracy (Residual: MR-PT) and navigational task performance

	Retracing (proportion correct)	Floor plans (proportion correct)	Shortcut (number of segments)	Pointing (absolute error)	Factor1: tracing/ retracing	Factor 2: shortcut/ pointing
Perspective-taking (proportion correct)	0.09	0.43**	−0.30*	−0.29*	0.27*	−0.36**
mental rotation (proportion correct)	0.18	0.31*	−0.11	−0.25	0.26	−0.22
Residual: PT-MR	−0.05	0.29*	−0.31*	−0.16	0.13	−0.29*
Residual: MR-PT	0.17	0.03	0.13	−0.06	0.09	0.05

$n = 56$.
*$p < 0.05$.
**$p < 0.01$.

and the self-to-object environmental representations factor was significant ($p < 0.01$), the correlation between mental rotation and the self-to-object environmental representations factor was not significant ($p = 0.11$), and the difference between the correlation coefficients was marginally significant, $t(53) = 1.44$, $p = 0.08$. After partialling out the shared variance between perspective-taking and mental rotation accuracy, the semipartial correlation between perspective-taking and the self-to-object environmental representations factor was still significant ($p < 0.05$), the semipartial correlation between mental rotation and the self-to-object environmental representations factor was not significant ($p = 0.74$), and the difference between the semipartial correlation coefficients was marginally significant, $t(53) = 1.37$, $p = 0.09$. Thus, processing resources unique to perspective-taking ability appeared to have affected performance on this self-to-object environmental representations factor.

In summary, perspective-taking and mental rotation ability both predicted accuracy at tracing the route on the floor plan and the route knowledge factor scores. After partialling out the shared variance between the perspective-taking and mental rotation performance, however, neither predicted the route knowledge factor scores, although perspective-taking still predicted accuracy at tracing the route on the floor plan. Thus, performance on route knowledge tasks seems to require spatial abilities common to both the perspective-taking and mental rotation tasks. Perspective-taking ability, however, was the only reliable predictor of performance on the shortcut task, accuracy at pointing to landmarks encountered along the route, and the self-to-object environmental representations factor scores. Furthermore, perspective-taking was a reliable predictor of the self-to-object factor scores even after removing the shared variance between perspective-taking and mental rotation scores.

These latter findings also provide further evidence for the distinction between perspective-taking and mental rotation processes. Although the two tasks appear to require the use of some common processing resources based on the high correlation between scores on the two tests, the finding that perspective-taking scores reliably predicted the self-to-object environmental representations factor scores after removing the shared variance with mental rotation ability demonstrates that perspective-taking requires the use of some unique processing resources. Furthermore, this correlation provides evidence suggesting that participants indeed used the self-to-object representational system when solving the perspective-taking problems.

DISCUSSION

In Experiment 1, we developed computerized object-based (array-rotation) and egocentric (perspective-taking) versions of a pointing direction task that used equivalent stimuli and task parameters. Our analyses revealed different patterns and types of errors for the perspective-taking and array-rotation tasks. The slopes for the accuracy profiles as functions of imagined heading for the tasks differed between the tasks. Performance on the perspective-taking task decreased to a greater degree with larger imagined orientation changes than performance on the array-rotation task.

Thus, in contrast to some of the previous studies that found an advantage of egocentric over object-based transformations (e.g. Wraga et al., 2000), our results showed that using the egocentric strategy was not necessarily more beneficial and further suggest that task specific demands affect the relative ease of performing egocentric versus object-based transformations, for example, the particular type of judgement required (Huttenlocher & Presson, 1979; Presson, 1982) and the degree and axis of an imagined rotation (Parsons, 1987a, 1987b). Although our two tasks were equal in many ways, our object-based, array-rotation task required participants to imagine transformations in one plane, that is, rotating the vectors on the screen, whereas our egocentric, perspective-taking task required participants to imagine transformations in two planes, that is, a rotation from an aerial perspective and a rotation within the map. Thus, one of the limitations of our study is that this additional egocentric task demand might have contributed to the differences in accuracy profiles across the tasks (however, such differences in task demands should have also led to slower RTs for the perspective-taking group, which was not the case in our study).

The poorer performance when using egocentric as opposed to object-based transformations for larger imagined headings raises questions as to why people use egocentric spatial transformations and as to whether this strategy could be advantageous for other types of tasks. Although using egocentric perspective transformations might not be the most advantageous strategy when solving small-scale pointing direction tasks like ours, such transformations are often essential for navigation in large-scale environments, for example, when navigational tasks require updating one's position on the route with respect to other targets (see Loomis et al., 1999). Again, our findings showed that the perspective-taking task, even after partialling out the shared variance with mental rotation, reliably predicted performance on navigational tasks that required accurate self-to-object representations (i.e. finding a shortcut and pointing to non-visible targets). In contrast, performance on the mental rotation test did not reliably predict performance on such navigational tasks. Performance on the mental rotation test did predict the acquisition and use of route knowledge, but this appeared to be due to the use of spatial resources common to both object-based and egocentric transformations.

The above navigational findings support the notion that navigational tasks should not be treated as assessing an undifferentiated construct (Allen et al., 1996; Bryant, 1984). Furthermore, the patterns of correlations found in Experiment 2 with the spatial ability tests suggest that examinations of the cognitive processes underlying navigational skills might lead to better taxonomic classifications of such skills and to more precise theories of individual differences in navigation. Thus, future research should investigate the contributions of other spatial abilities (e.g. spatial relations, spatial visualization and spatial orientation), and other perceptual, cognitive and psychomotor abilities, to performance on particular types of navigational tasks. Diagnosing the particular psychological skills needed for large-scale navigational tasks should not only advance navigation theory but also should be useful for personnel selection and training. In fact, our data show that our computerized perspective-taking task is useful for such purposes when the large-scale navigation task involves representing, updating, and using self-to-object representations (e.g. for finding shortcuts between routes and keeping track of locations after detouring from a route when wayfinding; for sports or other fields where players or workers must perceive the spatial relations between themselves and field boundaries; and for work tasks where workers monitor and operate tools oriented differently from their own perceived headings).

Future research should also examine factors affecting one's ability to use and switch between using perspective-taking versus mental rotation strategies. Our informal interviews with participants conducted after the training phase of the pointing direction task suggest that for some the use of perspective-taking versus mental rotation strategies might be determined by resource availability rather than volition. Despite the instructions to use a rotation strategy, some participants consistently used the perspective-taking strategy. These participants reported that they were unable to perform object-based transformations (array-rotation), but they were able to successfully perform egocentric (perspective-taking) transformations. In addition to finding some participants who could not use a rotation strategy for the array-rotation task, we found some participants who consistently used a rotation strategy for the perspective-taking task and explained that they were unable to solve this task in any other way. A particularly interesting aspect of research on performance impediments would be to develop techniques to overcome the impediments and then examine whether the improved small-scale abilities transfer to real-world tasks (e.g. would improving small-scale perspective-taking ability improve performance at finding shortcuts).

Additionally, one of the limitations of our perspective-taking task was that it used two-dimensional arrays of symbolized objects, rather than three-dimensional arrays of objects (e.g. Huttenlocher & Presson, 1973; 1979; Presson, 1982; Wraga et al., 2000). Although the results from our current studies provided evidence that the two-dimensional perspective-taking task, in fact, elicits the use of a body-based frame of reference and can be considered a reliable instrument to measure perspective-taking skills, it is possible that creating three-dimensional perspective-taking tests (e.g. by using real arrays of objects or three-dimensional computerized tests) will 'suppress' the use of rotation strategies and encourage participants to use body-based frames of reference to a greater degree than the current two-dimensional version.

In summary, our results showed that perspective-taking required unique spatial transformation ability from mental rotation, and perspective-taking and mental rotation strategies produced different error profiles. Moreover, perspective-taking ability uniquely predicted performance on navigational tasks that have been reported to require updating self-to-object representations. This latter finding suggests that researchers and practitioners should not treat navigational tasks as if they are measuring an undifferentiated construct but should consider the spatial (and other psychological) resource requirements underlying the tasks. Furthermore, the latter finding also demonstrates that our perspective-taking test can be used successfully for predicting navigational performance on tasks that involve the use of the self-to-object representational system, an important application of our study.

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