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A dissociation between mental rotation and perspective-taking spatial abilities

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Abstract

Recent psychometric results [Mem. Cogn. 29 (2001) 745] have supported a distinction between mental abilities that require a spatial transformation of a perceived object (e.g., mental rotation) and those that involve imagining how a scene looks like from different viewpoints (e.g., perspective taking). Two experiments provide further evidence for and generalize this dissociation. Experiment 1 shows that the separability of mental rotation and perspective taking is not dependent on the method by which people are tested. Experiment 2 generalizes the distinction to account for perspective taking within perceived small-scale and imagined large-scale environments. Although dissociable, measures of perspective taking and mental rotation are quite highly correlated. The research suggests some reasons why psychometric studies have not found strong evidence for the separability of the spatial visualization and spatial orientation factors, although a strong dissociation between tasks that are dependent on mental rotation and perspective-taking processes has been found in the experimental cognitive literature.

Keywords: Dissociation; Mental rotation; Perspective taking

1. Introduction

Psychometric studies of spatial ability (e.g., Carroll, 1993; Eliot & Smith, 1983; Lohman, 1979, 1988; McGee, 1979) have identified several different spatial abilities factors. One of these factors, spatial visualization, involves the ability to imagine the movements of objects and spatial forms.

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Typical markers for these factors involve tests of mental rotation,[1] form board tests, and surface development tests (which, for example, test the ability to image the folding and unfolding of pieces of paper). A second spatial factor, spatial orientation, is proposed to measure an ability to imagine the appearance of objects from different orientations (perspectives) of the observer (McGee, 1979). The most commonly used marker for this ability is the Guilford and Zimmerman (1948) Spatial Orientation Test, in which observers are shown two different views of a landscape from the prow of a boat, and have to determine how the boat has changed position from the first to the second view (see Ackerman & Kanfer, 1993; Egan, 1981; Eliot & Smith, 1983 for examples of other, less studied, spatial orientation tests).

As they are conceptualized, tests of spatial visualization and tests of spatial orientation involve different types of mental spatial transformations. These transformations require the viewer to update relations between three different spatial frames of reference; the intrinsic reference frames of objects, the egocentric reference frame (centered on one's body), and the reference frame of the environment (Zacks, Mires, Tversky, & Hazeltine, 2000). The spatial visualization factor has been conceptualized as the ability to make object-based spatial transformations in which the positions of objects are moved with respect to an environmental frame of reference, but one's egocentric reference frame does not change. In contrast, the spatial orientation factor has been interpreted as the ability to make egocentric spatial transformations in which one's egocentric reference frame changes with respect to the environment, but the relation between object-based and environmental frames of reference does not change (Thurstone, 1950).

Although several investigators have supported the existence of a spatial orientation factor that is separable from spatial visualization (Guilford & Zimmerman, 1948; McGee, 1979; Thurstone, 1950), many studies have questioned this distinction. Markers for the two factors are often highly correlated, and sometimes approach the reliabilities of the tests themselves (Borich & Bauman, 1972; Goldberg & Meredith, 1975, Price & Eliot, 1975; Roff, 1952; Vincent & Allmandinger, 1971). In a major meta-analysis of the factor-analytic research, Carroll (1993) failed to find evidence for the separability of spatial orientation from spatial visualization. Although he generally supported the distinction of spatial orientation from spatial visualization, Lohman (1979) also concluded that the Guilford–Zimmerman Spatial Orientation Test and Spatial Visualization Tests do not measure different factors.

In contrast to the psychometric literature, a strong dissociation has been found in the experimental cognitive literature between tasks that depend on object-based spatial transformations and those that depend on egocentric spatial transformations (Amorim & Stucchi, 1997; Huttenlocher & Presson, 1973, 1979; Presson, 1982; Simons & Wang, 1998; Wang & Simons, 1999; Wraga, Creem, & Profitt, 2000; Zacks et al., 2000). In a typical study, observers are shown an array of objects and are asked questions about the positions of the objects after imagining either a rotation of the array or a rotation of themselves around (or within) the array. Although the outcomes of object rotations and self-rotations are equivalent (e.g., a rotation of an array of objects by 90° clockwise produces the same result as a rotation of oneself around the array by 90° counterclockwise), these two tasks are not equivalent in difficulty. The relative difficulty of object rotation tasks and self-rotation tasks depends on factors such as how the question is asked (Huttenlocher & Presson, 1973, 1979; Presson, 1982), whether a single object or an array of objects is rotated (Wraga et al., 2000), and whether or not people physically move themselves or the

[1] Speeded tests of mental rotation in two dimensions sometimes define a factor known as "spatial relations" or "speeded rotation" that is somewhat separable from spatial visualization (Carroll, 1993; Eliot & Smith, 1983; Lohman, 1988).

object/array while mentally imagining the spatial transformation (Simons & Wang, 1998; Wang & Simons, 1999). Furthermore, tasks requiring object rotations and self-rotations sometimes produce different response time profiles. Object rotations show a linear increase in response time as a function of angle of rotation (cf. Shepard & Metzler, 1971), whereas self-rotations do not always show this pattern (Wraga et al., 2000; Zacks et al., 2000). Finally, preliminary evidence suggests that object rotations and self-rotations depend on different neural structures (Creem et al., 2001; Kosslyn, DiGirolamo, William, & Alpert, 1998; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999).

Given the strong dissociations between object-based transformations and egocentric transformations in the cognitive literature, it is somewhat puzzling that a stronger dissociation has not been found in the individual differences literature between tests of spatial visualization and tests of spatial orientation. The dissociations found in the experimental literature do not necessarily imply that there will be a dissociation in individual differences, because two tasks may differ in difficulty but still be highly correlated. However, another possible reason for this lack of dissociation is that so-called tests of spatial orientation are not always solved by a perspective-transformation strategy. For example, Barratt (1953) interviewed 84 male students about their strategies in solving the Guilford–Zimmerman test of spatial orientation, often thought to be a strong marker for spatial orientation. The majority of these students (58) reported solving the items by mentally imagining the movement of the boat or response items (i.e., object-based transformations) but not by imagining themselves moving (i.e., egocentric transformations). More recently, Schultz (1991) found that mental rotation and spatial orientation tests are solved by a variety of strategies including an object-based mental rotation strategy, a perspective-taking strategy, and an analytic strategy (see also Just & Carpenter, 1985; Kyllonen, Lohman, & Woltz, 1984; Lohman, 1988 for studies of strategy variation on spatial tests). No test was a "pure" measure of either object rotation ability or perspective-taking ability (i.e., there was no test for which all participants used the same strategy) and strategy accounted for a significant proportion of the variance in test performance. It is thus possible that tests that invite multiple strategies have obscured the difference between spatial visualization and spatial orientation.

Kozhevnikov and Hegarty (2001) recently developed new tests of spatial orientation that were modeled after the types of stimuli used in experimental studies of perspective taking (Hintzman, O'Dell, & Arndt, 1981; Shelton & McNamara, 1997; Simons & Wang, 1998). In their study, participants were shown a two-dimensional array of objects or a schematic map of a town, and were asked to imagine themselves facing a particular direction within the array or map. They then indicated the direction to a target object in the array (or landmark in the map) from the imagined perspective. A sample item is shown in Fig. 1. Verbal reports from the participants indicated that the dominant strategy used to solve the test items was to imagine themselves reoriented with respect to the display (in a protocol study, only 1 out of 8 participants reported rotating the array), suggesting that the tests are true tests of spatial orientation ability (i.e., depend on egocentric rather than object-based spatial transformations). This conclusion was also supported by systematic errors in which participants confused left/right as well as front/back pointing directions, suggesting that they encoded the locations of the objects with respect to body coordinates. A confirmatory factor analysis (CFA) indicated that these new measures of spatial orientation ability are dissociable from measures of spatial visualization ability. In contrast, the Guilford–Zimmerman Spatial Orientation Test (Guilford & Zimmerman, 1948) was not dissociated from spatial visualization.

Although promising, there were some limitations of Kozhevnikov and Hegarty's (2001) study. First, they found that predominant use of a perspective-taking strategy occurred only on trials in which people were asked to take a perspective that was more than 90° different from their current view of the array. As

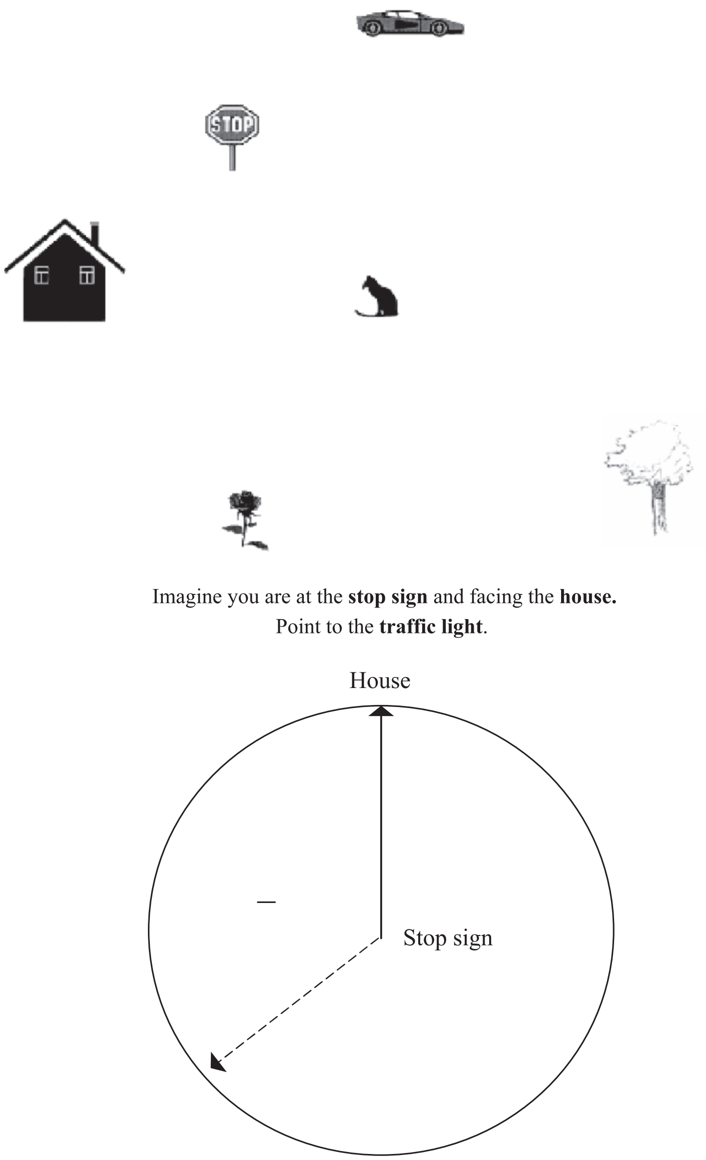

Fig. 1. Example of an item in the Object Perspective Taking Test. The dashed arrow indicates a participant's response to the item (direction to the traffic light).

a result, the spatial orientation scales used in that study were based on the small number of items for which the perspective change was greater than 90° (five for the test that showed an array of objects and seven for the test that showed a schematic map). Second, the spatial orientation factor in their study was defined by two very similar tests, the Object Perspective Test and the Map Perspective Test, which used the same method of responding (see Fig. 1) and differed only in the spatial array viewed. It is possible therefore that the new factor identified in that study was very specific and defined by the method of responding rather than spatial orientation ability in general. In contrast, the spatial visualization factor from which it was dissociated was quite broad, including a complex spatial visualization test (the Paper Folding Test, Ekstrom, French, & Harman, 1976) that involves imagining a sequence of spatial transformations, as well as simpler tests (e.g., the Card Rotation Test, Ekstrom et al., 1976) that require one to imagine a single transformation (rotation) of a two-dimensional figure. Finally, Kozhevnikov and Hegarty provided only weak evidence linking perspective-taking ability to real-world spatial cognition. A self-report scale, the Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), in which participants rate their own abilities on navigation and wayfinding tasks, had a small but significant loading on the perspective-taking factor in a CFA. Self-reported sense of direction is correlated with performance measures of large-scale spatial tasks, such imagining oneself reoriented in a known environment and learning spatial layout (Hegarty et al., 2002; Sholl, 1988), but this provides only indirect evidence of the relation of the perspective-taking tests to real-world spatial cognition.

The present study aimed to address some of the limitations of previous studies. One goal of the study was to develop a revised Object Perspective Test with more items and more difficult items, and to establish the reliability of that test. A second goal was to ensure that the ability measured by this perspective-taking test is independent of the method of responding. Therefore, in Experiment 1, we examined its relation to two other tests of perspective taking, the Money Standardized Test of Direction Sense (Money, Alexander, & Walker, 1965), which is solved primarily by an egocentric spatial transformation strategy (Schultz, 1991), and a new perspective-taking test that was developed in the context of this research. The third goal was to establish that perspective-taking tests are separable from tests of mental rotation specifically (rather than more diverse spatial visualization tests). Therefore, in this study, the tests of spatial visualization were all mental rotation tests that had been found in previous studies to be solved predominantly by an object-based transformation strategy (Just & Carpenter, 1985; Schultz, 1991). Finally, in Experiment 2, we examined the relation of the new perspective-taking test to two measures of a real-world task that involved imagining different perspectives in memorized environments.

We analyzed performance on tests of perspective-taking and mental rotation abilities using CFA. CFA differs from more commonly used exploratory factor analysis in that it allows researchers to impose a particular model on the data and examine how well the model fits, rather than determining in a post hoc way the one underlying factor model that best fits the data. It therefore allows researchers to test hypotheses more directly (Kline, 1998). If perspective-taking and mental rotation abilities are distinct, then a model assuming that tests of perspective taking and mental rotation load on a single spatial factor should not provide as good a fit to the data as a two-factor model that assumes their separability. The correlation between the two factors then provides an estimation of the degree to which the two abilities are related. If, however, perspective-taking and mental rotation abilities tap the same underlying construct, then a model with a single spatial factor should provide a good fit to the data.

2. Experiment 1

2.1. Method

2.1.1. Participants

The participants were 67 undergraduate students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. Four participants were omitted from the data analysis because they did not follow some of the task instructions correctly and one was omitted because her performance on one of the tests was significantly lower than chance, suggesting that she misunderstood the instructions. Therefore, the analyses were based on data from 62 participants.

2.1.2. Materials

The materials consisted of six paper-and-pencil tests of spatial abilities. Mental rotation ability was assessed using the Card Rotation Test (Ekstrom et al., 1976), the Flags Test (Thurstone & Thurstone, 1941), and the Vandenberg Mental Rotations Test (Vandenberg & Kuse, 1978). The Card Rotation Test requires participants to view a random polygon and judge which of the five alternative test figures are planar rotations of the target figure (as opposed to its mirror image) as quickly and as accurately as possible. The Flags Test requires participants to view a picture of a flag and judge which of the six alternative test figures are planar rotations of the flag. In the Vandenberg Mental Rotation Test, participants view a depiction of a three-dimensional target figure and four test figures. Their task is to determine which of the test figures are rotations of the target figure as quickly and accuracy as possible. For each of the mental rotation tests, the score was the number of items answered correctly minus the number of items answered incorrectly.

Perspective-taking ability was measured by a revised version of the Object Perspective Test (Kozhevnikov & Hegarty, 2001), a version of the Money Standardized Test of Direction Sense (Money et al., 1965, modified by Zacks et al., 2000) and a new test developed in the context of this study called the Pictures Test. In the revised Object Perspective Test, a configuration of seven objects was drawn on the top half of an 8.5×11 in. sheet of paper (see Fig. 1). On each item, the participant was asked imagine being at the position of one object in the display (the station point) facing another object (defining their imagined heading or perspective within the array) and was asked to indicate the direction to a third (target) object. The bottom half of the page showed a picture of a circle, in which the imagined station point (e.g., the stop sign) was drawn in the center of the circle, and the imagined heading (e.g., direction to the house) was drawn as an arrow pointing vertically up. The task was to draw another arrow from the center of the circle indicating the direction to the target object (e.g., the traffic light). Fig. 1 shows an example of a test item, with the dotted line indicating the correct response for this item. Participants were prevented from physically rotating the test booklet (which would provide them with a view of the array from another perspective).

All items involved an imagined perspective change of at least 90°. The direction of the target object relative to the heading was varied systematically by dividing the circle into four quadrants, 0° to 90°, 90° to 180°, and so on. There were 12 items in the test, and the answers of three of the items fell in each of the four quadrants. The score for each item was the absolute deviation in degrees between the participant's response and the correct direction to the target (absolute directional error). A participant's total score was the average deviation across all attempted items. The proportion of unattempted items was 4.95%.

We also used a modified version of the Money Test of Directional Sense (Money et al., 1965, modified by Zacks et al., 2000). In this test, participants are shown an overhead view of a meandering route through an environment that has 32 turns. Their task is to state whether each turn in the route corresponds to either a right or left turn from the perspective of the navigator. Participants responded by writing the letter R or L next to each turn. Schultz (1991) found that 80% of participants reported using a perspective-taking strategy on this task, and that use of this strategy was associated with higher scores on the test. Participants were allowed 30 s to do this task. A participant's score was the number of corners labeled correctly.

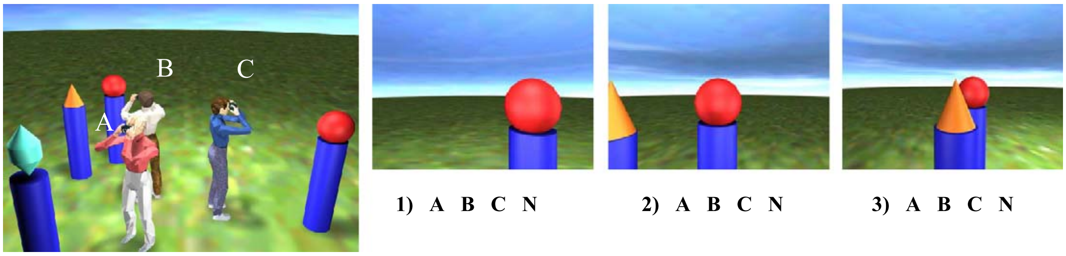

Fig. 2. Example of an item from the Pictures test. In the experiment, the pictures were presented in color, so the objects were more distinctive than they appear in this black-and-white reproduction.

Finally, the Pictures Test consisted of 30 multiple-choice items, grouped in 10 sets of 3. For each set of three items, a large figure illustrated an elevated view of three photographers (labeled A, B, and C) taking pictures of a complex layout of objects (see Fig. 2). Each test item then presented a small ground-level scene that either represented a picture that one of the photographers had taken or else represented another viewpoint of the layout. For each item, participants were asked to determine which of the three photographers (or none) took the picture. The test was scored as the number correct minus one-third of the number wrong (to correct for guessing). The proportion of unattempted items on this test was 15.94%.

2.1.3. Procedure

Participants were tested in groups of up to 10 students per session. They completed the Pictures Test, Vandenberg Mental Rotations Test, Money Road Map Test, Flags Test, Object Perspective Test, and Card Rotations Test in that order. Each of the tests was administered according to its standard instructions, including time limits.

3. Results and discussion

Descriptive statistics are given in Table 1. To reduce the effects of outliers in the data, values of any variable that were greater or less than 3 standard deviations from the mean were set to be equal to 3 standard deviations above or below the mean. This resulted in changing the values for one participant on the Pictures Test, one participant on the Card Rotation Test, and three participants on the Object Perspective Test. Values of skewness and kurtosis for the Object Perspective Test indicated that the

Table 1
Descriptive statistics for each test in Experiment 1

Test	Mean	S.D.	Range	Skewness	Kurtosis
Card Rotation	124.34	26.23	46–160	– 0.84	0.53
Flags	76.56	25.52	3–126	– 0.48	– 0.11
Vandenberg MRT	32.26	17.88	2–69	0.41	– 0.69
Object Perspective	24.53	14.29	5–68	1.51	2.32
Money Road Map	9.34	4.59	0–22	0.11	– 0.22
Pictures	13.35	5.13	3–25	0.19	– 0.47

distribution of items on this test departed from normality. To examine whether this affected the results, all subsequent analyses were conducted twice, once using the raw data for this variable and once using a log transformation of this variable, which did not differ significantly from normality (skewness = – 0.08, kurtosis = 0.42). Since the results of these analyses did not differ appreciably, the analyses based on raw data are presented here.

Reliabilities for the Object Perspective and Pictures Tests, based on this administration of the tests were .79 and .73, respectively (Cronbach's alpha statistic). Only 24 participants completed the Pictures Test in the time allotted, and alpha is based on these participants' data. Reliabilities for the Card Rotation, Flags, and Vandenberg Mental Rotation Tests, reported in the test manuals for these tests are .8 or above. (There is no measure of reliability for the Road Map Test, as there is only one trial in this test.)

Table 2 shows the correlations between the different spatial ability tests. Note that because the object perspective measure is an error score (a higher value indicates less ability), scores on this variable were linearly transformed (by subtracting the average error score from 180°) so that higher scores corresponded to better performance. This transformed variable was used in all analyses reported below.

We first tested a model assuming that the six spatial abilities tests load on a single spatial abilities factor. CFAs were carried out using the AMOS program (Arbuckle, 1999), which uses maximum-likelihood estimation to derive the specified parameters based on the covariance matrix. The estimated one-factor model, complete with factor loadings, is illustrated in Fig. 3. Numbers next to the straight, single-headed arrows are standardized factor loadings; numbers next to the curved, double-headed arrows are estimated correlations between the two factors (latent variables). All these numbers can be interpreted as standardized regression coefficients.

Values of fit indices for the one-factor model are reported in Table 3. We use several indices to evaluate the fit of the models, as recommended by Hu and Bentler (1998). The most common fit index is the χ^2 statistic, with a significant χ^2 indicating a poor fit to the data. However, the χ^2 statistic is correlated with sample size and is consequently significant with large samples even when differences between the model and data are small (Kline, 1998). For this reason, many researchers have advocated the χ^2/df statistic, with a value less than 2.0 indicating a good fit. Another index of fit is the Standardized Root Mean Squared Error Approximation (RMSEA); a value of .08 or below indicates a fair fit, and a value no higher than .05 indicates a good fit (Hu & Bentler, 1998). Finally, the Comparative Fit Index (CFI) measures the extent to which the examined model fits better than a baseline model, with a CFI of at least .9 indicating a fair fit and a value of at least .95 indicating a good fit to the data.

Table 2
Correlations among the measures in Experiment 1

Task	Road Map	Pictures	Card Rotation	Flags	Vandenberg MRT
Object Perspective	.49**	.26*	.40**	.42**	.33**
Road Map	–	.40**	.49**	.55**	.49**
Pictures		–	.23	.35**	.44**
Card Rotations				.73**	.52**
Flags			–		.43**

* $P < .05$.
** $P < .01$.

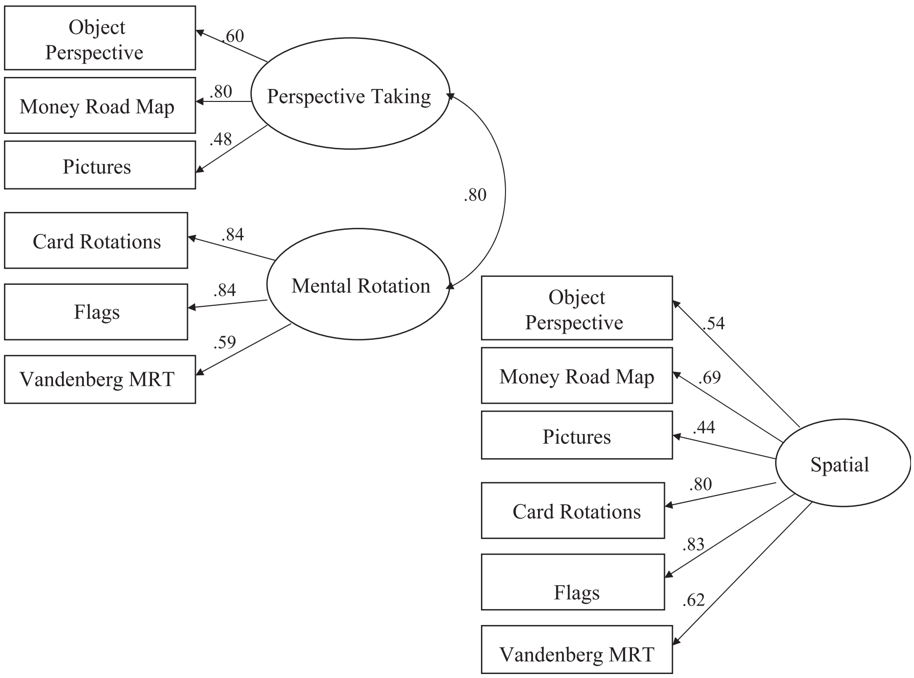

Fig. 3. Results of the CFAs for Experiment 1.

The overall χ^2 for the one-factor model was significant, $\chi^2(9) = 17.37$, $P < .05$, indicating that the model significantly deviated from the data. In addition, the value of RMSEA (0.12) was considerably higher than the criterion for a good fit. We therefore tested an alternative model assuming that there are two separable spatial factors: mental rotation ability and perspective-taking ability. In this model, we assumed that Card Rotation, Flags, and the Vandenberg Mental Rotations Tests would load on the mental rotation factor and that the Object Perspective Test, the Money Road Map Test, and the Pictures Test would load on the perspective-taking factor.

Three of the four indices suggest that the two-factor model fit the data well. This model produced a nonsignificant χ^2 [$\chi^2(8) = 12.57$], indicating that the model did not significantly deviate from the data. In addition, the Bentler CFI was .96, above the commonly used criterion of .95 for a good fit. The Standardized RMSEA was .10, which is greater than, but close to, the criterion value of .08. Moreover, a

Table 3
Fit indices for the single-factor and two-factor models in Experiments 1 and 2

Model	χ^2	*df*	χ^2/df	CFI	RMSEA
Experiment 1					
Single-factor	17.37	9	1.93	.93	.12
Two-factor	12.51	8	1.56	.96	.10
Experiment 2					
Single-factor	12.13	9	1.35	.98	.08
Two-factor	5.72	8	0.72	1.00	.00

χ^2 difference test comparing the fit of the two models indicated that the overall fit of the two-factor model was significantly better than that of the single-factor model [$\chi^2(1)=4.87$, $P<.05$].

In summary, Experiment 1 established that the revised version of the Object Perspective Test (Kozhevnikov & Hegarty, 2001) is reliable. This experiment also provides evidence for its validity as a test of spatial orientation ability, i.e., ability to make egocentric spatial transformations. The new Object Perspective Test loaded on the same factor as the Money Road Map Test, which is solved primarily by a perspective-taking strategy (Schultz, 1991) and a new test in which participants were explicitly instructed to assume the perspectives of different people in a scene. This provides evidence for the convergent validity of the Object Perspective Test. Furthermore, the Object Perspective Test was found to be dissociable from mental rotation, providing evidence for discriminant validity, i.e., that it measures something different from tests of mental rotation.

This experiment suggests that the ability to make egocentric spatial transformations and the ability to make object-based spatial transformations are somewhat dissociable. A model assuming that these are separable abilities provided a better fit to the data than a model that assumes they measure a single ability. However, it should also be noted that the two spatial factors are highly correlated (r=.80), indicating that they have considerable shared variance.

4. Experiment 2

In the Object Perspective Test (Kozhevnikov & Hegarty, 2001), the spatial display is visible at all times, so that participants do not have to memorize this display. In real-world spatial cognition involving large environments, however, perspective taking is more typically performed on the contents of *memorized* spatial layouts. This is because large-scale spaces are typically not completely available perceptually. For example, in giving verbal navigation instructions or deciding which route to take in order to travel to a particular destination, one typically has to imagine different perspectives in a memorized spatial representation of an environment. In Experiment 2, we examined the relation of the perspective-taking test to tasks that involve imagining different perspectives in memorized environments. In this experiment, we also tested participants on three tests of mental rotation, to replicate the dissociation of perspective-taking ability from mental rotation ability (found in Experiment 1 and by Kozhevnikov & Hegarty, 2001).

4.1. Method

4.1.1. Participants

The participants were 74 undergraduate students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. Ten participants were omitted from the data analysis because they did not follow some of the task instructions and three were omitted because their performance on one of the tests was significantly lower than chance, suggesting that they misunderstood the task instructions. Therefore, analyses were based on the data from 61 participants.

4.1.2. Materials

The materials consisted of six paper-and-pencil tests of spatial abilities. Mental rotation ability was assessed using the Vandenberg Mental Rotations Test (Vandenberg & Kuse, 1978), the Card Rotation

Test (Ekstrom et al., 1976), and the Cube Comparisons Tests (Ekstrom et al., 1976). The Vandenberg Mental Rotation and Card Rotations Tests are described above. In the Cube Comparisons task, each item presents two drawings of cubes, with letters and numbers printed on their sides. Participants must judge whether the two drawings could show the same cube (i.e., whether the cube on the right could be the one on the left rotated to a different orientation). The score is the number of items answered correctly minus the number of items answered incorrectly.

Perspective-taking ability was measured by the same version of the Object Perspective Test as in Experiment 1 and two tests, in which participants were asked to imagine a perspective in a known environment and to judge the direction to other landmarks in the same environment. These tests differed in the scale of the environment that participants were asked to imagine. In the *Campus Building Perspective Task* (Hegarty et al., 2002), items required participants to indicate directions between pairs of buildings on the UCSB campus. In the *City Perspective Task* (Hegarty et al., 2002), participants were asked to indicate directions between pairs of cities in the United States. All participants answered 20 questions at each scale. At both scales, questions were of the form: "Pretend you are at ___, facing ___. Draw an arrow pointing toward ___." (For campus building questions, participants were instructed to imagine themselves at the center of the building named). Participants drew direction arrows on "arrow circles," as in the object perspective task shown in Fig. 1. They were instructed to guess the directions if they were not sure of the location of one of the places and to check a box at the bottom of the page if they did not know the location one of the places. They were allowed 8 min to answer the 20 items at each scale. The proportion of unattempted items was 16.1% for the campus questions and 6.0% for the city questions. In most of these cases, answers were not attempted because participants did not know the locations of one of the places mentioned. The score for each task was the average deviation in degrees between the participant's response and the correct response, averaged across all attempted items.[2]

4.1.3. Procedure

Participants were tested in groups of up to six students per session. They completed the Card Rotations Test, Object Perspective Test, Vandenberg Mental Rotations Test, City Perspective Test, Campus Perspective Test, and the Cube Comparisons Test in that order. Each of the tests was administered according to its standard instructions, including time limits.

5. Results and discussion

One participant had a score that was more than 3 standard deviations above the mean on the Campus Perspective task. To reduce the effect of this outlier, this participant's score was set to be equal to 3 standard deviations above the mean. Descriptive statistics and measures of internal reliability are given in Table 4. As in Experiment 1, the measures of perspective taking departed somewhat from normality. To ensure that this did not affect the results, all analyses were conducted using both the raw values and log-transformed values for these measures and there were no appreciable differences in the results. Therefore, we report the analyses for the raw data.

[2] An alternative scoring procedure in which participants were assigned an error of 90° (i.e., chance performance) for uncompleted trials did not have any appreciable effect on any of the results presented here.

Table 4
Descriptive statistics for tests in Experiment 2

Test	Mean	S.D.	Skewness	Kurtosis
Card Rotation	101.84	26.54	− 0.48	0.15
Cube Comparisons	17.13	9.74	− 0.25	− 0.37
Vandenberg MRT	28.49	15.30	0.35	0.32
Object Perspective	38.01	28.08	1.24	0.33
Campus Perspective	45.17	19.10	1.34	1.58
City Perspective	47.87	20.06	0.58	− 0.75

The reliabilities for the Object Perspective Test, Campus Perspective Test, and City Perspective Test were .85, .84, and .85, respectively, based on this administration of the tests. The reliabilities for the mental rotation tests, reported in their test manuals, are all .8 or above.

Table 5 shows the correlations between the different spatial ability tests. Note that because the perspective measures are error scores (a higher value indicates less ability), we transformed these variables (by subtracting the average error score for each participant from 180°) before using these variables in the correlational and factor analyses.

We first tested a one-factor model in which all measures were assumed to load on a single spatial abilities factor. The model is illustrated in Fig. 1 and fit indices for this model are shown in Table 3. These indices indicate that the one-factor model is a good fit to the data. However, because previous research (Kozhevnikov & Hegarty, 2001) and Experiment 1 suggested that perspective taking and mental rotation are somewhat separable, we also thought it was important to examine whether a two-factor model would fit the data better than this one-factor model. Therefore, we tested an alternative model assuming that the Card Rotation, Cube Comparisons, and Vandenberg Mental Rotations Tests load on a mental rotation factor and that the Object Perspective Test, the Money Road Map Test, and the Pictures Test load on a perspective-taking factor.

The estimated two-factor model, complete with factor loadings, is illustrated in Fig. 4. Values of fit indices for the two-factor model are reported in Table 3. All indices suggest that the two-factor model fits the data extremely well. This model produced a nonsignificant $\chi^2(8) = 5.72$, P=.68, indicating that the model did not significantly deviate from the data. In addition, the Bentler CFI is 1.00; and the RMSEA is .00. Moreover, a χ^2 difference test comparing the fit of the two models indicated that the

Table 5
Correlations among the measures in Experiment 2

Task	Campus Perspective	City Perspective	Card Rotation	Cube Comparison	Vandenberg MRT
Object Perspective	.68**	.56**	.49**	.51**	.34*
Campus Perspective		.65**	.43*	.45**	.38*
City Perspective			.43*	.48**	.35*
Card Rotations				.53**	.47**
Cube Comparisons					.38*

* $P < .01$.
** $P < .001$.

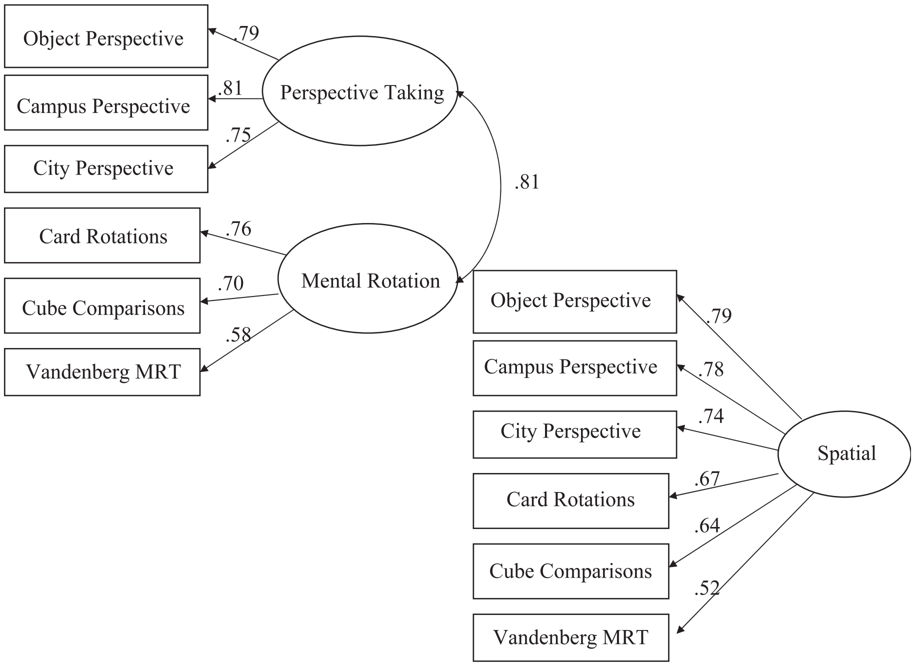

Fig. 4. Results of the CFAs for Experiment 2.

overall fit of the two-factor model is significantly greater than that of the single-factor model [$\chi^2(1) = 6.41$, $P < .025$].

6. General discussion

The goals of this study were to develop new tests of spatial orientation ability and to examine whether the ability measured by tests of spatial orientation is dissociable from the ability measured by tests of mental rotation. We developed two new tests of spatial orientation. One was a revised version of the Object Perspective Test (Kozhevnikov & Hegarty, 2001) that was more difficult because all items required the observer to imagine taking a perspective that was at least 90° different from the orientation of the array. The second was a new test in which people were explicitly instructed to take the perspectives of different people in an array. Both tests proved to be reliable. In Experiment 1 they loaded on the same factor as the Money Test of Road Map sense, which is solved primarily by imagining egocentric spatial transformations. In Experiment 2, the Object Perspective Test loaded on the same factor as two measures of perspective taking from memory of a familiar environment. In both experiments, a two-factor model, assuming that perspective-taking tests and mental rotation tests measure separable abilities, was a significantly better fit to the data than a one-factor model assuming that they measure the same ability. This provides evidence for the dissociation of abilities involved with spatial orientation from those involved with spatial visualization, specifically mental rotation.

We suggest that the dissociation between tests of perspective taking and mental rotation reflects a distinction between ability to make egocentric spatial transformations (i.e., to imagine the results of changing one's egocentric frame of reference with respect to the environment) and ability to make object-based transformations (i.e., to imagine the results of changing the positions of objects in the environment, while maintaining one's current orientation in the environment). In support of this view, a previous study (Kozhevnikov & Hegarty, 2001) found that the dominant strategy used in solving items from the perspective-taking test (particularly items that involve a perspective change of more than 90°) was to imagine oneself reoriented with respect to the display. This was also the dominant strategy identified in solving the Money Standardized Test of Direction Sense (Schultz, 1991). An informal protocol study of the Pictures Test also revealed that most participants solved the items by imagining taking the perspective of the different people shown in the displays. In contrast, previous protocol studies of the mental rotation tests used in this research found that the majority of participants report imagining the rotations of the objects, and not themselves, in performing these tests (Just & Carpenter, 1985; Schultz, 1991).

Although they were dissociated, the perspective-taking and mental rotation factors were highly correlated in both studies (see Figs. 3 and 4), suggesting that they have considerable shared variance. This may explain why they have not been found to be dissociated in the factor analysis literature, especially given that many factor-analytic studies use orthogonal methods of factor extraction and rotation. How can we account for the shared variance between perspective taking and mental rotation? First, although they depend on different types of spatial transformation (egocentric vs. object-based), perspective taking and mental rotation also rely on many common processes, such as the ability to encode spatial images and ability to maintain these representations in memory (Kosslyn, 1994). Thus, the shared variance may reflect individual differences in these common processes. Second, although each test has been shown to have a dominant strategy, as documented above, there is some variability in the strategies used to solve all spatial tests of this type, and no test is solved using the same strategy by all individuals (Schultz, 1991). Therefore, it is possible that some participants in our study used the same strategy to solve the perspective-taking and mental rotation tests. Third, even if egocentric and object-based spatial transformations depend on different cognitive operations, this does not necessarily imply that there will be no correlation between ability to perform the two types of operations. That is, similar factors (either innate or environmental) might determine one's ability to make the two types of spatial transformations.

Our research also indicates that performance in our pencil-and-paper perspective-taking tests is related to perspective taking in a large-scale space. Large-scale spatial cognition tasks, such as route planning and giving verbal navigational directions, often require one to imagine oneself at a particular place and orientation in a known environment and to determine the direction of travel to another place in that environment. Experiment 2 showed that performance in the perspective-taking task was highly related to measures of perspective taking in a memorized environment. Therefore, it appears to measure a general ability to imagine different headings or perspectives in a configuration, regardless of whether the configuration is viewed or imagined. Furthermore, both our perspective-taking task and the measures of perspective taking in memorized environments are correlated with people's self-reports of their "sense of direction," which has considerable predictive validity as a measure of large-scale spatial cognition (Hegarty et al., 2002; Sholl, 1988). This is an important finding because direct links between the abilities required for successful performance on small-scale "paper-and-pencil tests" and those required for large-scale environmental tasks have been difficult to find (Allen, Kirasic, Dobson, Long, & Beck, 1996; Hegarty & Waller, in press).

In addition to revising the Kozhevnikov and Hegarty (2001) perspective-taking test, in this study, we also developed an initial version of a new perspective-taking test, the Pictures Test. In Experiment 1, this test loaded on the perspective-taking factor, but its loading was relatively low. There are a couple of reasons why this test may not have loaded highly on the perspective-taking factor. First, it may have been too difficult. Note that only 24 participants completed the test in the allotted time. Second, it may have a reasoning component in addition to measuring spatial orientation ability. For each set of three items on this test, participants must choose which picture matches the view of each of the photographers, or some other view of the array (see Fig. 2). Therefore, if a participant determines, for example, that the first picture shown is that of photographer B, he or she can eliminate photographer B as a possible choice for the other two pictures in that set. An informal protocol study of this test indicated that participants were reasoning in this way, in addition to imagining the perspectives of the different photographers. Therefore, it seems that the Pictures Test has good potential as a test of perspective taking, but that it probably needs to be revised in order to better measure this ability. A revision of this test should probably include simplifying the items somewhat and presenting one item at a time, in which the solver is asked to take the perspective of a single photographer and verify whether a single picture of the array does or does not match the view of that photographer.

These experiments may begin to reveal why the psychometric literature has failed to find a dissociation between spatial orientation ability and spatial visualization ability. First, failure to find this distinction might be attributed to the fact that some so-called tests of perspective-taking tests are not valid measures of this ability i.e., they are not usually solved by a strategy of imagining a change in one's egocentric perspective. We have shown in two experiments that tests of perspective taking, which are solved predominantly by imagining egocentric spatial transformations, can be dissociated from tests of mental rotation, which are solved predominantly by imagining object-based spatial transformations (see also Kozhevnikov & Hegarty, 2001). A second reason for the failure to show this dissociation is that although dissociated, tests of egocentric spatial transformations and object-based spatial transformations share considerable variance. Therefore, it may be necessary to include several measures of each type of test in a study in order to observe this dissociation.

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