Stable Self-to-Object Spatial Relations Acquired from Sequential Spatial Learning

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Abstract

Self-to-object spatial relations are generally considered to be transient and supported primarily by perceptual processes. The present study investigates whether people can acquire stable self-to-object spatial relations that are not disrupted by disorientation. Participants either simultaneously or sequentially viewed the object locations from a learning position amidst a geometrically irregular array. Next they were blindfolded and pointed to the objects under three conditions: before turning (baseline), after rotating 240° (updating), and after disorientation (disorientation). Finally, all participants were taken to another room to perform judgments of relative direction (JRDs) among remembered object locations. The internal consistency of pointing among objects was disrupted by disorientation following simultaneous viewing but not sequential viewing. However, participants' memories of object-to-object relations were equivalent in the two viewing conditions. Together, these results suggest that people construct stable self-to-object spatial relations when they sequentially view each object of the irregular layout.

Keywords: self-to-objection spatial relations; sequential learning; disorientation

Introduction

In everyday life, people use self-to-object (egocentric) and object-to-object (allocentric) spatial relations to encode the location of objects or landmarks in the environment, navigate effectively to significant places, and reorient themselves when getting lost. In a self-to-object reference system, locations are represented with respect to the particular perspective of a perceiver, whereas in an object-to-object reference system, locations are represented within a framework external to the holder of the representation and independent of his or her position e.g., Easton & Sholl, 1995; Klatzky, 1998).

Generally, it is believed that self-to-object spatial relations are transient and supported primarily by the perceptual processes, and that object-to-object spatial relations are stable and can be preserved in the memory system (e.g., Burgess, 2006; Holmes & Sholl, 2005; Mou, McNamara, Valiquette, & Rump, 2004). When moving around the environment, if people navigate by means of the self-to-object spatial relations, one has to add a common vector to each individual target vector to compute the new egocentric coordinates of the target locations. If this updating process is disrupted through procedures that induce a state of disorientation, the coherence of relative locations among different targets is reduced. Therefore, a disoriented participant's pointing response will show an inconsistency among different targets (disorientation effect). To the contrary, if people navigate by means of the object-to-object spatial relations, which remains the same regardless of people's movements, the state of disorientation cannot reduce the coherence of relative locations among different targets. Therefore, the consistency of the pointing response among different targets will be equal between oriented and disoriented participants (absence of disorientation effect). By measuring the standard deviation across target objects of the mean signed pointing errors (configuration error), the accuracy of the localization of each target in relation to the others can be assessed. Following this logic, recent research has indicated that people can navigate by means of either the transient self-to-object or stable object-to-object spatial representations (Holmes & Sholl, 2005; Mou, McNamara, Rump, & Xiao, 2006; Sargent, Dopkins, Philbeck, & Modarres, 2008; Waller & Hodgson, 2006; Wang & Spelke, 2000). In most situations, people acquire both self-to-object and object-to-object spatial representations, and can navigate by means of one of them according to the layout geometry or instruction (Xiao, Mou, & McNamara, 2009).

However, in all the previous research, which indicated that people were able to navigate by means of transient self-to-object spatial representations, the pointing responses of disoriented participants still had a relatively high consistency among different targets. The configuration errors in the disorientation condition were no more than 30°, which were much less than the expected configuration error of randomly pointing (approaching 104°). It is possible that disorientation does not totally disrupt the self-to-object spatial representations, and that the disoriented participants can still locate objects based on the impaired self-to-object spatial representations that persist in their memory. One of our recent experiments provided circumstantial evidence for this hypothesis (Xiao, et al., 2009). After visually learning object locations amidst, or at the periphery of an irregular array (see Figure 1), blindfolded participants pointed to the objects before turning (baseline), after rotating 240° (updating), and after disorientation (disorientation). In both learning conditions, the configuration error significantly increased after disorientation, indicating that the participants located objects by means of the self-to-object spatial relations. When explicitly instructed to use the object-to-object spatial relations (e.g., "Please keep track of all of the locations of the objects relative to other objects while you are turning to face the ball."), after the baseline pointing test and before rotation, the participants who learned at the periphery of the irregular array could follow the instruction to prevent the disorientation effect, while the participants who learned amidst the irregular array could not follow the instruction to prevent the disorientation effect. These results suggest that after visually learning object locations at the periphery of the irregular array, the participants established both self-to-object and object-to-object spatial relations, but updated self-to-object spatial relations during rotation by default. They could also update object-to-object spatial relations when required. However, after visually learning the object locations amidst an irregular array, the participants can only establish the self-to-object spatial relations. They may only represent minimally, if at all, object-to-object spatial relations, which cannot be used during rotation. Therefore, there is little possibility that the participants used the object-to-object spatial relations after disorientation. The disoriented participants can only locate objects by means of the self-to-object rather than the object-to-object spatial relations, suggesting that the self-to-object spatial relations are preserved, to some extent, over disorientation in memory.

In the object-to-object spatial relations, object locations are represented with respect to another object or set of objects, while in the self-to-object spatial relations object locations are represented with respect to the perceiver (e.g., Easton & Sholl, 1995; Klatzky, 1998; Mou, Xiao, & McNamara, 2008). If the perceiver takes him or herself as a stable object, and refers every other object location relative to him or herself, a special kind of object-to-object spatial representation is built, and can be well preserved in memory as another kind of object-to-object spatial representation. In other words, the perceiver establishes a stable self-to-object spatial representation. After disorientation, the perceiver can recover object locations by retrieving the remembered self-to-object spatial information. In Xiao et al. (2009), the participants visually learned object locations amidst the irregular array, where they could not perceive the whole layout from a single viewpoint. However, participants could directly view inter-object spatial relations between objects separated by small angular distances, and thus fragmentary object-to-object spatial representations might be acquired (Sargent, Dopkins, Philbeck, & Chichka, 2010). Attending to and memorizing neighboring object-to-object spatial relations might interfere with the acquisition of self-to-object spatial relations. Therefore, participants might develop unstable self-to-object spatial representations after they visually learned amidst the irregular array. There is a high possibility that participants will construct more stable self-to-object spatial representations through the new learning methods, by which they can only directly perceive the self-to-object spatial relations but not the inter-object ones, such as through sequential learning. Previous research has demonstrated that participants can learn spatial locations by viewing one object at a time (e.g., Yamamoto & Shelton, 2007, 2009). Compared with visually learning object locations amidst the array, sequentially viewing each object prevents participants from directly perceiving any inter-object relations, but compels them to focus on each object's location relative to themselves. Therefore, the acquisition of object-to-object spatial representations is maximally reduced and the salience of self-to-object spatial relations is enhanced, and the participants may develop stable self-to-object spatial representations and minimal object-to-object spatial relations.

In the present study, participants either sequentially or simultaneously viewed object locations from a learning position amidst the same irregular layout as in Xiao et al. (2009). After learning, all participants were blindfolded and pointed to object locations in baseline, updating, and disorientation conditions. Before rotating to a new heading in the updating condition, half of the participants were explicitly instructed to use object-to-object spatial relations during locomotion as in Xiao et al. (2009). At last, all participants were taken to another room to perform judgments of relative direction (JRDs), which have been commonly used to assess the memory of the object-to-object relations in an environment (e.g., Mou, et al., 2004; Shelton & McNamara, 2001; Waller & Hodgson, 2006). Because we hypothesized that participants would use self-to-object spatial relations to locate objects before and after disorientation when learning amidst the irregular layout, and that the participants would establish more stable self-to-object spatial relations following sequential viewing than by following simultaneous viewing, we expected that the configuration error in sequential viewing condition would be smaller than that in the simultaneous viewing condition, and that the disorientation effect would be absent in the sequential viewing condition but present in the simultaneous viewing condition. Meanwhile, since we hypothesized that the participants would establish minimal object-to-object spatial relations in both the simultaneous and sequential viewing condition, we expected that the participants could not use the object-to-object spatial relations during locomotion and after disorientation. As in Xiao et al. (2009), the participants could not follow the object-to-object instruction to prevent the disorientation effect after simultaneous learning of the layout. Because we predicted that the participants would use the stable self-to-object spatial relations after sequentially learning the layout, we expected that there will be no disorientation effect in both the object-to-object instruction and the non-instruction group. Because the participants established minimal object-to-object spatial relations, a floor effect might be present, and the performance on JRDs in the sequential learning group might be equivalent or inferior to that in the simultaneous learning group.

Method

Participants

Thirty-two university students (16 men and 16 women) participated in this experiment in return for monetary compensation.

Materials

The irregular layout of Xiao et al. (2009) was used in this experiment. As illustrated in Figure 1, nine objects were presented on the floor in a cylinder that was located in an experiment room. The cylinder was 3.0 m in diameter, made by black fabric and reinforced cloth. Objects were chosen with the restrictions that they were visually distinct, fit with approximately 0.3 m on each side, were familiar to people, and shared no obvious semantic association. The scissors, the hat, and the brush were placed in a line. Participants were standing 1 meter away from the brush, facing the scissors. The floor was covered with gray carpet. Four lights were placed on the ceiling near the side of the cylinder to illuminate the area. They were placed at equal intervals and at equal distance from the center of the cylinder to minimize directional illumination cues.

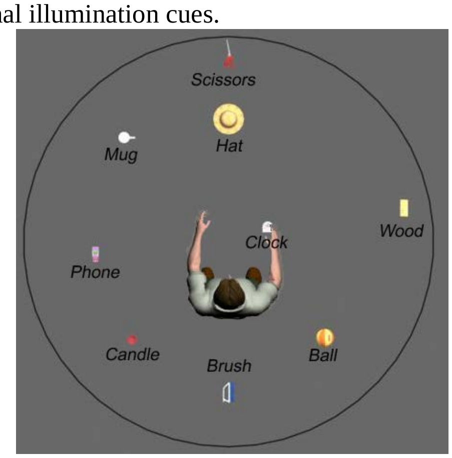

Figure 1: Layout of objects used in the study.

Test trials were presented by a computer via wireless earphone. A joystick was used as the pointing apparatus.

Procedures and Design

Before entering the study room, each participant was instructed to learn the location of objects for a spatial memory test and trained in how to use a joystick. After that, the objects that would be encountered in the experiment layout were presented individually to all participants and the name of each object was given. Then, the blindfolded participants were escorted to the study room and led to the learning position by the experimenter. The participant was then asked to remove the blindfold.

Simultaneous Viewing All nine objects were presented on the floor. Half of the participants viewed the layout for 30 s and then closed their eyes and named and pointed to each object with one of their fingers. Throughout the learning phase, the participants were stationary at the learning position. They were allowed to turn their heads to review the layout but were required to maintain their body orientation.

Sequential Viewing The other half of the participants viewed each object presented alone for 3 s in a spatially random sequence. To control the viewing time, the participant was asked to close his/her eyes while the experimenter replaced the just-viewed object on the floor with a new object in a new location. After viewing the last object, the participant was asked to close his/her eyes and to name and point to each object with one of their fingers. The learning sequence of the objects was randomized.

In both learning conditions, the learning-pointing session was repeated until participants could fluently name and point to the correct object locations twice in a row. (Fluency and accuracy were determined by the experimenter's visual inspection of the pointing performance.) The number of repetitions needed to achieve the learning criterion was recorded. During training and learning, the participants were not aware of what particular tasks they would perform in the testing stage.

Egocentric Pointing Tasks After learning the layout, all of the participants put on the wireless earphone, and held the joystick against their front waist. All of the participants were blindfolded and tested in the order of the baseline, updating, and disorientation conditions. In the baseline condition, participants maintained their heading to the scissors. In the updating condition, participants rotated 240° by themselves (e.g., "Please turn right until you are facing the candle"). Half of the participants turned right to face the candle, and half turned left to face the ball. Within each group, immediately before rotation, half of the participants were explicitly instructed to use object-to-object spatial relations during rotation (e.g., "Please keep track of all of the locations of the objects relative to other objects while you are turning to face the candle"). The other half were not given this instruction. In the disorientation condition, the participants rotated in place for 1 minute. Then they pointed to the location of an object named by the experimenter (e.g., "Please point to the ball"). This rotation and pointing procedure was repeated until the absolute pointing error was larger than 90°. Then the participants were instructed to turn to face the ball (or candle) if they faced the candle (or ball) in the updating condition ("Please turn right until you believe you are facing the ball"). They were allowed to adjust their position by themselves if they thought they had drifted off the testing location while rotating. A recovery period was given before the final pointing test.

In each rotation condition, four blocks of trials were included, and each block involved pointing to all nine objects once in a random order. After hearing the warning indication ("Start"), the participants pulled the joystick trigger, and the target object was immediately announced (e.g., "Please point to the candle"). Then the participants used the joystick to point to the direction of the target object.

The *configuration error* was measured as in Xiao et al. (see Table 1), which defined as the standard deviation of the means per target object of the signed pointing errors, which indicated the internal consistency of pointing response among different targets. As pointing data is inherently circular data, circular statistics (e.g., Jammalamadaka & SenGupta, 2001) were used.

Table 1: Definitional Formulas for Dependent Variables

Variable	Formula
Signed pointing error for object i on trial j	e_{ij} = judged direction – actual direction
Mean signed pointing error for object *i*	$\bar{e}_{i.} = \frac{\sum_j e_{ij}}{T}$
Configuration error	$\sqrt{\frac{\sum_i \left(\bar{e}_{i.} - \frac{\sum_i \bar{e}_{i.}}{N}\right)^2}{N-1}}$

Note: T = number of pointing trials per object;
N = number of target objects.

JRDs Task After finishing the egocentric pointing tasks, the blindfolded participants were escorted to another room to perform JRDs. They were allowed to remove the blindfold and take a short break before proceeding to the JRDs. The participants first initiated each trial by pressing a button of the joystick. Trials began with the imagined standing location and facing object given aurally (e.g., "Imagine you are at the mug facing the ball"). After having a clear mental image of where he or she was standing and what he or she was facing, participants pulled the joystick trigger, and the target object was immediately presented (e.g., "Please point to the scissors."). Then the participants used the joystick to point to where the target would be if he or she occupied the standing location and facing the direction as presented. The participants were instructed to hold the joystick exactly in the front of his or her waist and to keep the joystick forward when he or she pointed.

The JRDs test included 8 imagined headings. To facilitate exposition, we arbitrarily labeled headings counterclockwise from 0° to 315° in 45° steps. The learning direction was defined as 0°. Because the geometry of the layout was irregular, there were little pairs of objects established the imagined heading parallel to above 8 directions. Therefore, the imagined heading established by any pair of objects varied within ± 15° (that is, 0° ± 15°, 45° ± 15°, 90° ± 15°, 135° ± 15°, 180° ± 15°, 225° ± 15°, 270° ± 15°, and 315° ± 15°) was included in the 8 imagined headings (e.g., at the candle facing the mug established the imagined heading 1.56°, and were taken as the imagined heading 0°). The participants were given a total of 48 trials, six trials at each of eight imagined headings. The dependent measures were the angular error of the pointing response, measured as the absolute angular difference between the judged pointing direction and the actual direction of the target.

In both egocentric pointing and JRDs tasks, pointing accuracy but not speedy response was emphasized.

Results

Egocentric pointing

Configuration error on egocentric pointing were subjected to mixed-model analyses of variance (ANOVAs), with the rotation condition (baseline, updating, and disorientation) as the within subject variable, the viewing type (sequential, simultaneous) and object-to-object instruction (yes, no) as the between subjects variables. The results revealed no main effect or interactions of the object-to-object instruction. Data were therefore collapsed across this factor for subsequent analyses.

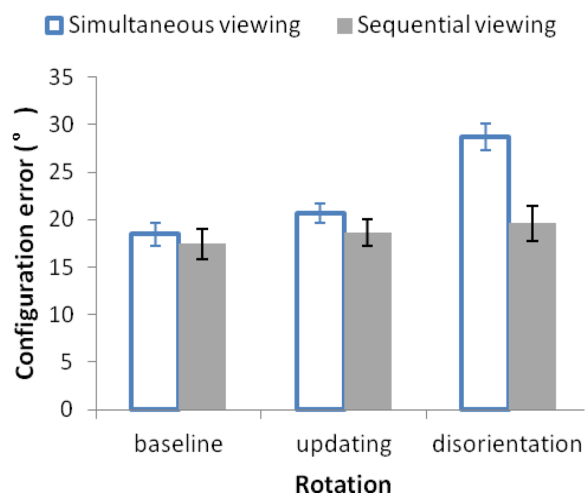

Figure 2: Configuration errors in egocentric pointing as a function of rotation condition and viewing type. Error bars are confidence intervals corresponding to ± 1 SEM.

The main effect of the rotation condition was significant, F (2, 60) = 13.13, p < .001, MSE = 24.92, the main effect of the viewing type was significant, F (1, 30) = 7.83, p < .01, MSE = 16.88, and the interaction of the rotation and the viewing type was significant, F (2, 60) = 6.09, p < .005, MSE = 24.92. As shown in Figure 2, three major findings were revealed. First, as in Xiao et al. (2009), the configuration error increased after disorientation when participants simultaneously viewed the layout, which indicated that participants had used the transient self-to-object spatial relations during rotation. This observation was supported statistically by a planned contrast comparing the participants' configuration errors in the updating condition with that in the disorientation condition following simultaneously viewing, F (1, 30) =17.18, p < .001, MSE =

59.05. Second, the configuration errors were equivalent before and after disorientation when participants sequentially viewed the layout, which indicated that participants used a kind of stable spatial relations before and after disorientation. This observation was supported statistically by a planned contrast comparing participants' configuration error for the updating condition with that for the disorientation condition following sequential viewing, $F(1, 30) < 1$. Third, the configuration errors were indistinguishable for simultaneous and sequential viewing in the baseline and updating conditions, but significantly higher for simultaneous viewing than for sequential viewing in the disorientation condition. These observations were supported statistically by planned contrast comparing participants' configuration errors for simultaneous viewing with those for sequential viewing at each rotation condition. There were no differences in the baseline and updating conditions, $Fs(1, 30) \leqslant 1.39$, $ps \geqslant .24$, but there was a significant difference in the disorientation condition, $F(1, 30) = 15.01$, $p < .001$, $MSE = 43.69$.

JRDs

Performance data on JRDs were subjected to mixed-model analyses of variance (ANOVAs), with the imagined heading (0° to 315° in 45° steps) as the within subject variable, viewing type (sequential, simultaneous) and object-to-object instruction (yes, no) as the between subjects variables.

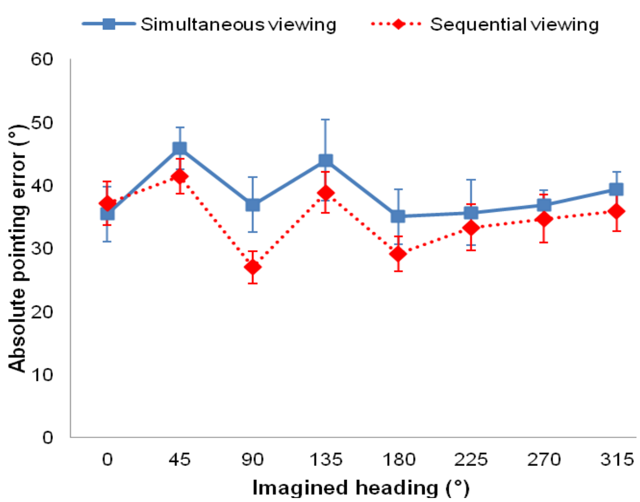

Figure 3: Mean absolute angular errors in JRDs as a function of imagined heading and viewing type. Error bars are confidence intervals corresponding to ±1 SEM.

Three major findings were revealed. First, as shown in Figure 3, the participants' performance on JRDs was indistinguishable for simultaneous viewing and sequential viewing, which indicated that participants had constructed object-to-object spatial representations of equivalent fidelity through simultaneous viewing and sequential viewing. This observation was supported statistically by no main effect or interactions of the viewing type, $Fs \leqslant 1.36$, $ps \geqslant .25$. Second, the participants' performance on JRDs was sensitive to the imagined headings, as supported statistically by the significant main effect of the imagined heading, $F(7, 210) = 3.75$, $p < .001$, $MSE = 147.10$. Third, the instruction before the updating condition affected the participants' performance on JRDs. The performances on JRDs were more accurate for the participants following object-to-object updating instruction than those following no instruction. This observation was supported statistically by the main effect of instruction, $F(1, 28) = 5.30$, $p < .05$, $MSE = 727.92$. The interaction between the imagined heading and instruction was marginally significant, $F(7, 196) = 1.93$, $p = .067$, $MSE = 147.10$. The simple effect of instruction was significant within the headings of 135°, 180°, and 225°, $Fs(1, 28) > 4.93$, $ps < .05$, but not significant within the headings of 0°, 45°, 90°, 270°, 315°, $Fs(1, 28) < 2.21$, $ps > .14$.

Discussion

The absence of the disorientation effect has been interpreted as evidence that object-to-object spatial relations have been used during rotation (Holmes & Sholl, 2005; Mou, et al., 2006; Sargent, et al., 2008; Xiao, et al., 2009). However, in the present study, the absence of the disorientation effect following sequential viewing can unlikely be explained by using the object-to-object spatial relations. The participants' performance on JRDs was equivalent across sequential and simultaneous viewing, suggesting that the participants established equivalent object-to-object spatial relations among each viewing group. If the object-to-object spatial relations could be used in one viewing group, there is little possible that the object-to-object spatial relations could not be used in another group. If the participants in the sequential viewing condition used the object-to-object spatial relations to prevent the disorientation effect, the participants in the simultaneous viewing condition should also be able to use them to prevent the disorientation effect. However, in the simultaneous viewing condition, the disorientation effect consistently appeared, even when the participants were explicitly required to use the object-to-object relations during rotation. This result is consistent with Xiao et al. (2009), indicating that the participants could not have used the object-to-object but rather used self-to-object spatial relations to perform egocentric pointing during rotation and after disorientation. Therefore, it is unlikely that the participants could have used the object-to-object spatial relations to perform egocentric pointing in the disorientation condition following sequential viewing. The absence of the disorientation effect following sequential viewing can only be explained by using the stable self-to-object spatial relations.

As the transient self-to-object spatial representation, the stable self-to-object spatial representation may make use of a special polar coordinate system in which the origin is at the participant and the reference direction is participant's front. Object locations are specified by egocentric distance and egocentric bearing. During locomotion, the sensory-perceptual input enables the participant to update multiple self-to-object spatial relations. Although the procedures that induce a state of disorientation will disrupt this updating process, and the coherence of relative locations among different targets will plummet if the participant still relies on the sensory-perceptual system; the participant could recover object locations by retrieving the remembered angular and distance information from the learning view. If the test heading misaligned with the learning view, a mental rotation process would be involved to align the remembered self-to-object spatial representation with respect to the test heading. This retrieving process is similar to retrieving object-to-object spatial representations (Mou, Fan, McNamara, & Owen, 2008; Mou, Xiao, et al., 2008). At this point, the differences between object-to-object and stable self-to-object spatial representations become less dramatic, because both representations could be preserved in memory and be retrieved from a novel heading after disorientation. However, unlike the object-to-object spatial relations, it is difficult to use the stable self-to-object spatial relations to judge inter-object spatial relations. Because every single object is represented with respect to the self, the participants have to compute an inter-object spatial relation, and this computation process will introduce error (Klatzky, 1998). Therefore, in present study, the participants in the sequential learning condition could use the stable self-to-object spatial relations to avoid disorientation effect, but could not use them to improve their JRDs performance. Their performance on JRDs was not superior to the simultaneous viewing condition.

In summary, the present research indicates that by sequentially viewing every object location from a learning position, the participants constructed stable self-to-object spatial relations which could be preserved over disorientation. These results suggest that self-to-object spatial relations are not only transient and supported primarily by perceptual systems, but can also be stable and preserved in memory.

Acknowledgements

Preparation of this article and the research reported in it were supported by a grant from the National Natural Science Foundation of China Grant 31000457 to Chengli Xiao. Correspondence concerning this article should be addressed to Chengli Xiao, Department of Psychology, Nanjing University, 22 Hankou Road, Nanjing 210093, China. E-mail: xiaocl@nju.edu.cn

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