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Beyond imagination: Perspective change problems revisited

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Traditional models of perspective change problems (i.e., judgment of egocentric target directions from an imagined perspective) assume that performance reflects one's ability to imagine the new perspective. Three experiments investigated whether advanced cuing of the imagination direction improves performance in an imagined self-rotation task. RT performance did not improve when extended time was given to complete the imagination process, or after participants reported the completion of the imagination. Moreover, when pointing to multiple targets after a single imagination, later responses did not show improvement. These results cast doubt on the traditional imagination hypothesis and suggest re-interpretation of the angular disparity effects in perspective changes tasks.

Perspective change problems require one to make inferences about spatial relationships after certain spatial transformations. For example, an imagined self-rotation task asks one to imagine herself turning to face a different orientation, and locate objects from the imagined perspective. Perspective change problems have received a great deal of attention in research on human spatial abilities, mechanisms of spatial processing, and the nature of spatial representations (e.g., Easton & Sholl, 1995; Farrell & Robertson, 1998; Franklin, & Tversky, 1990; Franklin, Tversky, & Coon, 1992; Huttenlocher & Presson, 1973, 1979; Newcombe & Huttenlocher, 1992; Piaget & Inhelder, 1956; Presson, 1980, 1982; Rieser, 1989; Rieser, Garing & Young, 1994; Sholl & Nolin, 1997; Wang, in press; Wraga, Creem, & Proffitt, 1999, 2000; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999). Furthermore, various research in related areas uses the perspective change paradigm to address issues on scene memory, reference frame using and navigation, using both real and virtual environments (Amorim & Stucchi,

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1997; Bryant, & Tversky, 1992; Bryant, Tversky, & Franklin, 1992; Christou & Bülthoff, 1999; Presson & Montello, 1994; Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Shelton & McNamara, 1997; 2001; Simons & Wang, 1998; Wang & Simons, 1999; Werner & Schmidt, 1999).

One of the most significant and reliable findings from the extensive research on perspective change problems in the past thirty years is the "angular disparity effect." For example, Rieser (1989; also see Easton & Sholl, 1995; Shelton & McNamara, 1997; Wraga et al, 2000) showed that when participants were asked to imagine themselves turn to face a different orientation and "point to object **X** as if you were facing object **Y**", both error and reaction time increased as the imagined heading deviated farther and farther away from their actual heading. Based on the angular disparity effect, it was suggested that imagined self-rotation is the same as the mental rotation process, i.e., performance reflects the "mental turning" of oneself and therefore the larger the rotation angle, the longer it takes. A similar conclusion was also suggested for imagined self-translation, i.e., the farther the distance, the longer it takes to mentally "translate" oneself to the new position (e.g., Easton & Sholl, 1995).

A number of studies have also compared different types of mental transformations of space. For example, Rieser (1989; also see Easton & Sholl, 1995; May, 1996; etc) showed that imagined self-rotation is difficult and slow, and performance decreases as the imagined rotation angle increases (angular disparity effect). In contrast, imagined self-translation is easy and fast, and performance remains relatively constant. Wraga et al. (2000; Huttenlocher & Presson, 1973, 1979; Presson, 1982, etc.) asked participants to either imagine themselves turning or imagine the targets rotating, and then name the target in a specified direction. They showed that the imagined self-rotation condition was easier than the imagined target-rotation condition, an effect they referred to as the "viewer advantage". A similar effect was shown in scene representations (Simons & Wang, 1998; Wang & Simons, 1999) and spatial language research (Tversky, Kim, & Cohen, 1999).

Based on these findings, important theories have been proposed on the nature of human spatial representations, the reference frames used to encode spatial locations, and how spatial representations are transformed. For example, Rieser (1989) argued that spatial representations of object arrays encode the object-to-object relationship instead of the self-to-object relationship. Huttenlocher & Presson (1979) proposed that children encode both the object locations and the location of themselves relative to the larger, permanent environment. Wraga et al (2000) suggested that transformations of the egocentric reference frame are easier than transformations of the object-centered reference frame, because self-turning is common in everyday life while object rotation is relatively rare.

These theories, however, rest on an implicit assumption that performance in the perspective change tasks reflects the "imagination" process. For example, the difference between imagined self-rotation and imagined object array-rotation is due to the relative difficulty to mentally "turn" oneself or "turn" the object array (Wraga et al., 2000). This assumption is consistent with the finding that performance degrades progressively as the angle of "turning" increases, for both imagined self-rotation and imagined object array-rotation. Moreover, the imagined object-rotation and the imagined self-rotation tasks differ only in instruction. Thus, it seems reasonable to assume that any difference in performance is a result of the participants' literal interpretation of the instructions – either mentally rotated themselves or the objects. As a result, interpretations of these findings have relied on this assumption, either explicitly or implicitly, despite the lack of direct testing of its validity.

Unlike studies in perspective change problems, this issue has been carefully addressed in classical mental rotation research. For example, it was shown that judgment of the handedness of a letter presented at a non-canonical orientation is progressively slower as the test letter rotates farther and farther away from the upright orientation (angular disparity effect) (e.g., Cooper & Shepard, 1973, 1975). Cooper & Shepard (1973) reasoned that if the judgment time reflects a "mental rotation" process, which rotates an upright letter in memory to align with the test letter so that a comparison/judgment can be made, this "mental rotation" process should be independent of the presentation of the test letter. That is, as long as one knows which letter to rotate and to which orientation it should be rotated, mental rotation should occur without the presentation of the test stimuli. Thus, they predicted that the angular disparity effect should disappear if the orientation of the test letter was provided in advance and sufficient time was given for the mental rotation process to complete. Their findings showed convincingly that extended imagination delay indeed eliminated the angular disparity effect and supported the mental rotation hypothesis.

The perspective change tasks differ from the classical mental rotation tasks in several important ways. For example, perspective change tasks often measure the judgment of relative spatial directions instead of using recognition tasks, involve the imagined movement of oneself as well as the objects, and use arrays of objects surrounding the observer. The imagination process in a perspective change task is against propioceptive and vestibular cues, while mental rotation of objects is not. Given the importance of the findings on perspective change tasks for theories of spatial representations and spatial processing, the same issue should be addressed in the perspective change paradigm. Thus, the current paper directly examined the prevalent hypothesis that performance in one of the perspective change tasks - imagined self-rotation task - reflects the "imagination" process[1]. Similar to the assumptions and logic described by Cooper & Shepard (1973), the imagination hypothesis predicts that imagined turning of oneself should be independent of the presentation of the responding target. Thus, as long as the participants know what to rotate (i.e., themselves) and how much to rotate (i.e.,

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[1] The imagination process may include many components, such as memory retrieval, imagined self-rotation, maintenance of the mental image, and so on. However, only the imagined self-rotation component can potentially produce the angular disparity effect.

the imagined heading), and sufficient time is allowed for this mental turning to complete, then the angular disparity effect should disappear.

EXPERIMENT 1

Experiment 1 followed the general logic used in Cooper & Shepard (1973) in studying mental rotation processes, by providing the imagined heading in advance and allowing an extended time for the imagination process to complete. The imagination target was announced first, followed by a delay (either 0s or 10s), before the pointing target was announced and RT timed. According to the imagination hypothesis, the angular disparity effect should be observed in the 0s-delay condition but should be eliminated, or substantially reduced, in the 10s-delay condition.

METHOD

Participants. Ten University of Illinois undergraduate students from an introduction to psychology class participated in the experiment and received course credit for their participation.

Apparatus. Participants were tested individually in a rectangular room (3.8m by 2.4m), as illustrated in Figure 1. Five targets, a closet, a door, a VCR, a poster, and a computer were placed around the participants. The overhead image of the room and the participants' responses were recorded with a VCR, which was connected to a small video camera mounted on the ceiling just above the swivel chair the participants sat. A Gateway PC4200 desktop computer randomized the order of the targets for each participant and controlled the timing for the imagination delay, as described below.

Design and Procedure. Participants first learned the target locations by sitting in the swivel chair in the middle of the room and turning freely, for as long as they desired. Then they were blindfolded and put on an earphone with white noise as a sound mask, and turned to a predetermined direction where they remained throughout the testing. In each trial, the participant was asked to "imagine that you were facing **X**". Then after either an extended delay (10s condition) or no delay (0s condition), they were asked "where's **Y**." [2]

In each condition, the participants imagined facing each object and pointed to each of the remaining objects, yielding a total of 20 trials (5

[2] The imagination delay (10s) was chosen according to the previous studies (typical reaction times for an imagined self-rotation task were about 5 s or less, e.g., Rieser, 1989) to allow sufficient time to complete the imagination process. Although the mean response time was typically about 5s or less, there are individual differences and variations across trials. In a pilot study we found that most participants have reaction times up to about 10s. Thus, we used 10s to ensure that the imagination process was completed.

imagination targets X 4 pointing targets) per condition. Thus, the angular disparity was systematically varied between 0° and 180°. The entire 40 trials were intermixed and presented in a random order. This procedure provided the exact match of the angular disparity (the angle between imagined heading and the actual heading) and equivalent response directions in the two delay conditions. Thus, any difference between the two imagination conditions should be due to the imagination delay.

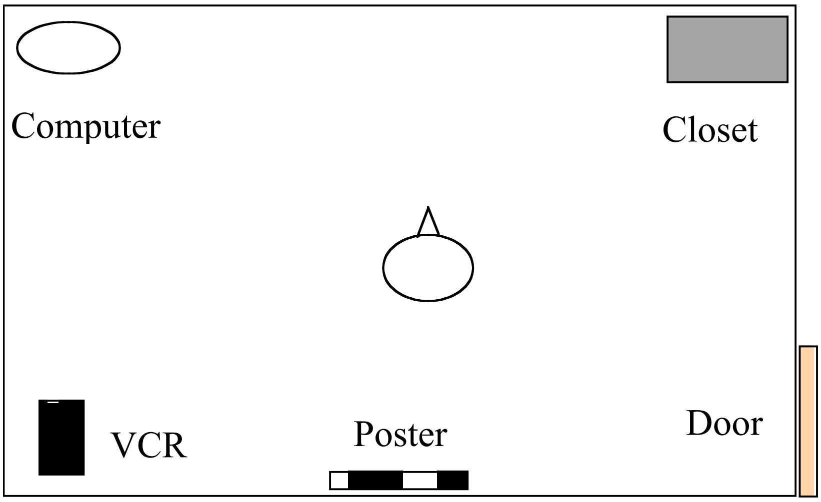

Figure 1. An overhead view of the rectangular room.

Data analysis. The directions of the targets and the pointing responses were measured from the TV monitor after the testing was completed, by superimposing a transparent radial grid on the monitor, which had 10° units. The response time was measured from the ending of the target name to the completion of the pointing response, indicated by the stabilization of the hand. The angular error for each response was calculated as the small angle (i.e., <180°, unsigned) between the correct direction and the actual pointing direction. Since the objects were 60 ± 4° away from their neighbors (123° between Computer & Closet), the angular disparities between the actual heading and the imagined headings were considered multiples of 60° (0°, 60°, 120°, and 180°) and combined in the analysis. [3] The primary measure is reaction time, although errors were also analyzed to test possible speed-accuracy trade-offs.

[3] The angular disparity of 180° was included in the analysis. However, some studies found that some people show advantage at 180° (e.g., Rieser, 1989).

RESULTS & DISCUSSION

The results were shown in Figure 2. Participants showed a significant effect of angular disparity (ANOVA $F(3, 68)=3.94$, $p<.01$), and it appeared that RT increased as the angular disparity increased, except for the special case of straight behind (180°). The same pattern was shown in angular error. This finding was consistent with many previous studies (e.g., Rieser, 1989). The important finding, however, was the absence of an effect of the imagination delay ($F(1, 68)=.02$, $p=.89$). Moreover, there was no interaction between delay condition and angular disparity ($F(3, 68)=.18$, $p=.91$), suggesting extended time for the imagination process did not affect performance either in terms of slop or intersection. Thus, these results failed to provide evidence for the imagination hypothesis, which predicts that the angular disparity effect should be significantly reduced in the 10s delay condition.

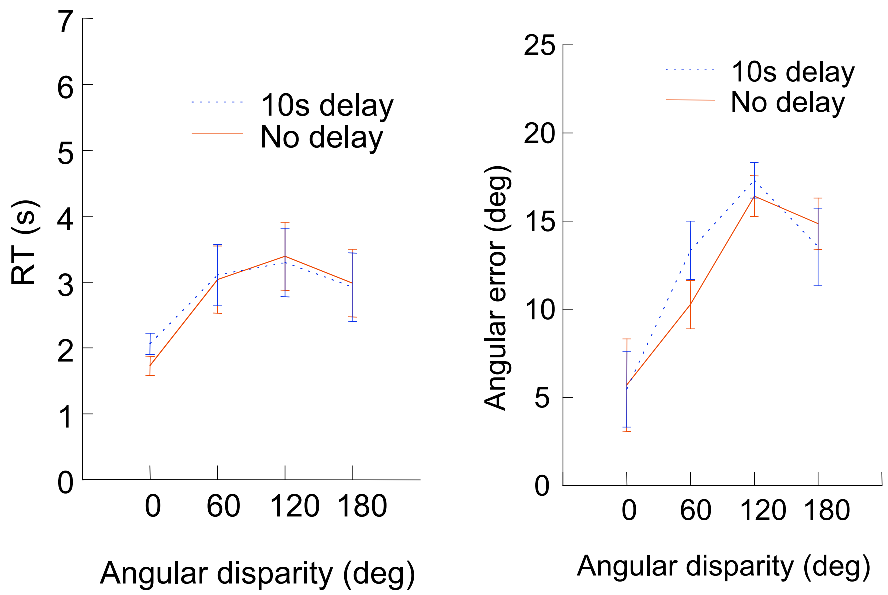

Figure 2. The response time (RT) and mean angular errors in Experiment 1, for the two delay conditions (0s vs. 10s) as a function of imagination angle (Angular disparity). The error bars are between-subject standard errors.

One possible explanation for the lack of effect of the imagination delay is that 10s imagination delay, which should be sufficient, was too long. As a result, participants might have lost the representation of the imagination process by the time the pointing target was announced. Furthermore, there was no independent evidence that participants followed the instruction to perform the imagination during the delay period. To address these possibilities, Experiment 2 replicated Experiment 1, except that participants themselves determined the duration of the imagination delay for each trial in the delay condition. This procedure should provide the appropriate imagination duration for each trial and also provide a subjective measure of the "imagination" process.

EXPERIMENT 2

METHOD

Experiment 2 replicated Experiment 1 with only one change. Instead of a constant 10s imagination delay, the participants determined the delay duration for each trial by verbally responding "ready" in the delay condition. Thus, each participant was tested in 20 trials with no delay (no-delay condition) and 20 trials with variable imagination delay (delay condition) in a random order. Moreover, in addition to measuring the response time and error as in Experiment 1, the imagination delay was also measured as the temporal interval between the announcement of the imagination direction and the completion of the participants' verbal response "ready". Totally there were ten participants.

RESULTS & DISCUSSION

As in Experiment 1, participants showed an angular disparity effect (significant for RT: $F(3, 68)=6.3$, $p<.001$; marginal for error: $F(3, 68)=2.6$, $p=.06$). However, again there was no significant effect of the imagination delay ($Fs(1, 68)<1$, $ps>.75$), nor was there an interaction between delay condition and angular disparity ($Fs(1, 68)<1$, $ps>.77$).

A careful examination of the self-determined imagination delay suggested that not all participants showed angular disparity effect in the imagination time. Thus, a further analysis was conducted using only those participants (5 participants) who showed clear angular disparity effect in their self-reported imagination time. Figure 3 showed their imagination delay and RT as a function of angular disparity. The self-reported imagination time increased as the angular disparity increased ($F(3, 15)=10.9$, $p<.01$), suggesting that these participants performed the imagination. However, their response latency and angular error again failed to show any evidence of improvement in the delay condition: although there was an angular disparity effect (significant for RT: $F(3, 30)=7.3$, $p<.01$; non-significant for error: $F(3, 30)<1$, $p=.81$), there was no significant difference between the delay and no-delay conditions ($Fs(1, 30)<1$, $ps>.80$), nor was there an interaction between delay condition and angular disparity ($Fs(3, 30)<1$, $ps>.80$). Thus, even when participants themselves determined the duration of the imagination delay and indicated they had completed the "imagination" – which was reflected in their imagination time – their performance was not affected in any way by the extra time to perform the "imagination" in advance.

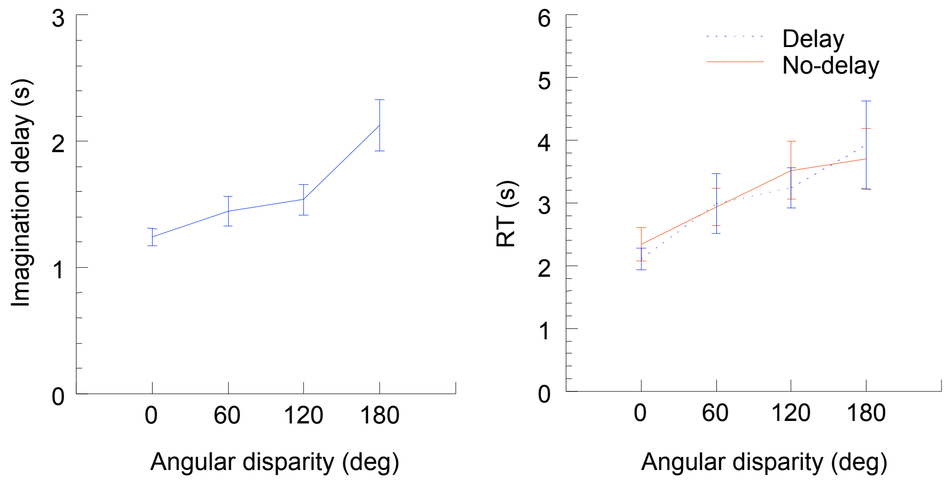

Figure 3. The self-reported imagination time and the response time (RT) in Experiment 2, for the two delay conditions (no-delay vs. delay) as a function of imagination angle (Angular disparity) for the selected participants who showed the angular disparity effect in their self-reported imagination time. The error bars are between-subject standard errors.

These results again failed to provide any evidence for the traditional imagination hypothesis. However, the fact that participants had to inform the experimenter with a "ready" response may have interfered in the stabilization of the new perspective. Moreover, one might still argue that performance is determined by the mental turning of oneself: although the participants' self-report showed some evidence that they did not simply ignore the instruction, they could not actually complete the imagination process – even though they thought they did – until they made their pointing response. That is, after the participants made the first response, the imagination process would have been completed. Thus, according to this modified imagination hypothesis, multiple responses after a single imagination should show a difference in angular disparity effect: although the first response should show strong angular disparity effect, because the imagination process cannot be performed until the response target is announced, the later responses should show little angular disparity effect because the imagination process was completed after the first response. Experiment 3 was conducted to test this hypothesis, i.e., whether performance in the later responses show a significant reduction in the angular disparity effect comparing to the first response when participants pointed to multiple targets after a single imagination.

EXPERIMENT 3

METHOD

Sixteen participants from the same population as in Experiments 1 & 2 were tested. Each participant was tested in two conditions, one with 0° angular disparity and one with 123° angular disparity. Half participants (8 participants) had the 0° condition first, and half had the 123° condition first. Within each half, half (4 participants) faced the computer and imagined facing the closet, and half faced the closet and imagined facing the computer. Thus the response directions were matched across participants for the two conditions, and the order of responses was randomized for each participant.

As in Experiments 1 & 2, participants first learned the target locations by looking around while sitting in the swivel chair. When they indicated that they were ready, they were blindfolded and turned to face the assigned direction. They were then given the instruction for the specific condition. If they were in the 123° condition, they were instructed to "imagine that you were facing X". After 10s, the target names were announced one by one in a random order by the experimenter and the participants pointed as quickly and accurately as possible. In the 0° condition, they were instructed to point to the actual location of the targets as the experimenter announced their names in a random order. In each condition, four targets were tested, not including the one they were physically facing (0° condition) or imagining facing (123° condition).

RESULTS & DISCUSSION

Overall, both response time and angular error showed significant angular disparity effect ($Fs(1, 120)>29.2$, $ps<.01$), replicating Experiments 1 & 2 (see Figure 4). However, there was no significant effect of response order ($Fs(3, 120)<1$, $ps>.41$), nor was there interactions between angular disparity and response order ($Fs(3, 120)<1$, $ps>.79$). These results provided evidence against the hypothesis that imagination is completed after, and only after the first response, and once the imagination is completed the angular disparity effect should be eliminated.

GENERAL DISCUSSION

Traditional models of perspective change tasks assume that performance in imagined self-rotation, self-translation, or object-array-rotation tasks is primarily due to difficulty of the "imagination" process, e.g., mentally turning oneself or rotating objects. According to findings of the mental rotation process (Cooper & Shepard, 1973), imagined rotation can occur independent of the test item as long as participants know what to rotate and by how much. Thus, the imagination hypothesis for the perspective change problems should predict that advanced cuing of the imagined heading should eliminate the angular disparity effect and improve performance substantially. Results in three experiments failed to provide any support to the imagination hypothesis. Although there was a clear angular disparity effect as shown in previous research, advanced cuing of the imagination heading had little effect on their performance, whether the imagination delay was extensive or was determined by the participants in each trial. Moreover, even after the participants made one response, which commanded the "imagination" process to be completed, responses still showed no reduction in the angular disparity effect. These results failed to support the assumption that the angular disparity effect in an imagined self-rotation task is due to the imagination process, and thus cast doubt on the imagination hypothesis.

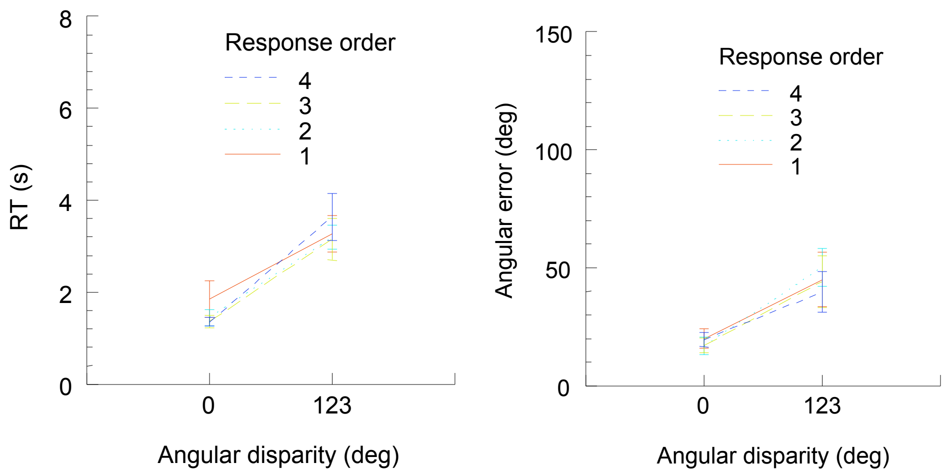

Figure 4. The response time (RT) and angular errors in Experiment 3 as a function of the angular disparity (0º vs. 123º), for the four responses under a single imagination. The error bars are between-subject standard errors.

These results were quite different from the classical studies on mental rotation (e.g., Cooper & Shepard, 1973). Although there was a strong angular disparity effect in the imagined self-rotation task, as shown in previous research, this effect was unaffected by the advanced time for imagination, either in terms of slope or intersection. Thus, unlike previously believed, the angular disparity effect in an imagined self-rotation task has a very different interpretation than the one in a mental rotation task: although RT in the mental rotation task increases with angular disparity because of the time needed to mentally "rotate" the object to the test orientation, RT in an imagined self-rotation task does not seem to result from the process of mentally "rotating" oneself.

Nonetheless, one possible amendment for the imagination hypothesis to account for these findings is that the angular disparity effect, and performance in general, was still due to an imagination process. However, the imagined self-rotation process cannot begin until the response target is given, therefore extensive imagination delay would not affect performance. The assumption that imagined self-rotation is dependent on response target is possible but logically weak – why does the pointing target have anything to do with imagining oneself turning? Moreover, this assumption does not explain Exp. 3 by itself. To explain Exp. 3, one needs to assume that the representation generated by the imagined self-rotation process is short-lived and is lost immediately after the response is made. Thus multiple responses after a single imagination will require the imagined self-rotation process be repeated anew for each individual response target. The claim that imagination is transient is also possible. However, we found no support from other literature that imagination is unsustainable, and studies on mental imagery suggest just the opposite. Moreover, participants in our experiments typically report having no trouble imagining themselves turn to face a different direction (with their eyes closed) and maintaining that imagination for the trial; however, that imagination did not help their response.

The current findings and the subjective reports are more consistent with the interference hypothesis suggested by May (1996, 2004; also see Brockmole & Wang, 2003; Huttenlocher & Presson, 1979; Presson, 1982). According to the interference hypothesis, difficulty in perspective change tasks reflects the conflict between reality and imagination. Huttenlocher & Presson (1973, 1979; Piaget & Inhelder, 1956) found that children often made "egocentric" errors, pointing to the target's actual location instead of the "imagined" location, suggesting the representation of a target's actual location interfered with their representation of its "imagined" location. May (1996) showed that disorientation reduced the angular disparity effect and argued that disorientation improved performance because there was less interference from one's representation of the targets' actual positions. The interference during responding hypothesis is also supported by recent findings that the angular disparity effect depends on the type of responses used in a perspective change task. Consistent with studies on dissociate representations and processes for perceptual and action tasks (Bridgeman, Peery, & Anand, 1997; Creem & Proffitt, 1998; Goodale & Milner, 1992; Loomis, Da Silva, Philbeck, & Fukusima, 1996; etc.), Wang (in press) showed strong angular disparity effect using a pointing task, but not when using a verbal task, even though both tasks required participants to report the egocentric direction of targets from imagined perspectives. Thus, it is reasonable to assume that the conflict between a target’s actual and imagined positions may be resolved only after the target is named, and this process had to be performed on an individual basis, as shown in the current data.

The current results cast doubt on several theories of spatial representations and reference frames, which were based on findings of perspective change tasks and assumed that the angular disparity effect was primarily due to the imagination process (e.g., Huttenlocher & Presson, 1973, 1979; Rieser, 1989; Wraga, et al, 2000). For example, Rieser (1989) demonstrated nicely that RT in an imagined self-rotation task increased with angular disparity, while imagined self-translation was relatively constant. However, the proposed theory based on this finding – that human spatial representations encode object-to-object relationship instead of self-to-object relationship – assumed that the increase of RT was due to the imagination process. Similarly, Huttenlocher & Presson (1973, 1979) showed a nice contrast between self-rotation and item/array rotation, but the conclusion on an environment-centered representation is called into question if performance in the imagined self-rotation task does not reflect how difficult one can mentally rotate herself and generate a representation of the new perspective. Instead, these angular disparity effects may result from difference in interference during the responding stage (May, 1996, 2004; Wang, in press). Further reinvestigation of these findings by specifying exactly which processes determine performance is needed to either confirm or reject these important theories of human spatial representations.

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