Journal of Environmental Psychology 32 (2012) 89–96

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Gender differences in wayfinding in virtual environments with global or local landmarks

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ARTICLE INFO

Article history:
Available online 3 January 2012

Keywords:
Wayfinding
Spatial navigation
Global and local landmarks
Gender differences

ABSTRACT

This study assesses gender differences in wayfinding in environments with global or local landmarks by analyzing both overall and fine-grained measures of performance. Both female and male participants were required to locate targets in grid-like virtual environments with local or global landmarks. Interestingly, the results of the two overall measures did not converge: although females spent more time than males in locating targets, both genders were generally equivalent in terms of corrected travel path. Fine-grained measures account for different aspects of wayfinding behavior and provide additional information that explains the divergence in overall measures; females spent less time traveling away from the target location, a higher proportion of time not traversing, and made more rotations when stopping than males did. Rather than unequivocally supporting male superiority in wayfinding tasks, both the overall and fine-grained measures partially indicate that males and females are differentially superior when using global and local landmark information, respectively. To summarize, males moved faster than females but did not necessarily navigate the spatial surroundings more efficiently. Each gender showed different strengths related to wayfinding; these differences require the application of both overall and fine-grained measures for accurate assessment.

1. Introduction

Wayfinding refers to the purposive, directed, and motivated process of determining and following a route between an origin and a destination (Golledge, 1999; cf. Wiener, Buchner, & Holscher, 2009). Wayfinding requires intricate interactions among multisensory perceptions of environmental and self-motion cues, spatial computations, executive processes, and various types of online and offline spatial representations (Wolbers & Hegarty, 2010). Given the complex interactions among cues, representations, and computational processes, it is quite natural to observe differences in wayfinding between genders (Astur, Ortiz, & Sutherland, 1998; Chen, Chang, & Chang, 2009; Coluccia & Louse, 2004; Mueller, Jackson, & Skelton, 2008), age groups (Driscoll & Sutherland, 2005; Moffat, Elkins, & Resnick, 2006; Moffat & Resnick, 2002; Moffat, Zonderman, & Resnick, 2001), and levels of expertise (Maguire et al., 2003; Woollett & Maguire, 2010).

Among the factors that influence wayfinding abilities, gender has received the most attention from researchers because gender differences in wayfinding may be the most sizable of all differences in male and female cognitive abilities (Lawton & Morrin, 1999) and may have significant implications in pedagogy and environmental designs. Coluccia and Louse (2004) reviewed experimental studies conducted between 1983 and 2003 that compared male and female performance in spatial orientation tasks. They found that 61% of the wayfinding experiments showed that males performed better in wayfinding tasks, whereas the remaining experiments showed no gender difference. Coluccia and Louse (2004) attributed the better performance of males in wayfinding to the males' larger visual short-term working memory (VSWM). This hypothesis predicts that the emergence of gender differences in spatial orientation tasks depends on the difficulty, or load on VSWM, associated with different wayfinding tasks (note, however, that Chen et al., 2009; did not find an interaction between gender and task difficulty). The prediction can be restated more generally: the environmental context may interact with the gender differences in cognitive

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0272-4944/$ – see front matter
doi:10.1016/j.jenvp.2011.12.004

capacity and lead to differential performance in wayfinding. Thus, determining how fundamental contextual characteristics interact with subject variables is crucial to understanding wayfinding.

One particularly essential contextual characteristic of wayfinding is the type of available landmarks. Landmarks are salient objects or geometric features in the environment that are not necessarily visual. However, given that human wayfinding relies primarily on visual cues, we confine the discussion to visual landmarks hereafter. Studies on insects, animals, and humans (e.g., Begega et al., 2001; Jacobs, Laurance, & Thomas, 1997; Maguire, Frith, Burgess, Donnett, & O'Keefe, 1998; Moffat & Resnick, 2002) have revealed that landmarks serve as reference points for both survey and route knowledge and assist in wayfinding performance (Jacobs et al., 1997; Jansen-Osmann, 2002; Jansen-Osmann & Fuchs, 2006; Waller & Lippa, 2007). Based on visuospatial characteristics, landmarks can be divided into two major categories: geometric landmarks and object landmarks. Geometric landmarks are structural or surface features in the environment (Gallistel, 1990), such as T-junction intersections, crossroads, or boundaries of an area. Object landmarks, by contrast, are salient objects that can be easily distinguished from the background, such as the Eiffel Tower, a streetlamp, or a building with a peculiar exterior design. Regarding gender difference in processing landmarks, a previous study showed that whereas males could utilize both geometric and object landmarks, females relied primarily on object landmarks (Sandstrom, Kaufman, & Huettel, 1998) in a virtual Morris water maze (MWM). This suggests that males may utilize different types of environmental features to find their way more successfully.

Depending on the scale of visibility, landmarks can also be divided into two other categories: global and local (Gillner, Weiss, & Mallot, 2008; Hurlebaus, Basten, Mallot, & Wiener, 2008; Stankiewicz & Kalia, 2007; Steck & Mallot, 2000). Global landmarks are visible everywhere inside the environment and can serve as references of absolute direction. Environment-wide visibility allows global landmarks to provide a stable frame of reference, which is particularly useful when traversing between two locations in separate occasions and along different routes (Evans, Skorpanich, Gärling, Bryant, & Bresolin, 1984; Ruddle & Lessells, 2006). By contrast, local landmarks can be observed only at limited locations and from restricted perspectives. The positional information provided by local landmarks can reduce errors in making turning decisions when learning the shortest route between two locations (Jansen-Osmann & Fuchs, 2006). Given their distinct properties, global and local landmarks may facilitate the formulation of and access to cognitive maps in distinct ways.

Currently, only three studies have systematically analyzed the respective contributions of global and local landmarks to wayfinding, and none of these studies examined the interaction between landmark type and gender (Hurlebaus et al., 2008; Ruddle, Volkova, Mohler, & Bulthoff, 2011; Steck & Mallot, 2000). Steck and Mallot (2000) asked participants to learn the spatial relationships between several places in a virtual city that had both global and local landmarks. After the learning phase, the spatial representations of participants were tested. Participants were asked to choose a direction at road intersections while landmarks were transposed or strategically misplaced. The results showed sizable variations among individuals. Participants' performance improved when either the local or the global landmark was available, as compared with a control condition without landmarks; this improvement suggests idiosyncratic reliance on global or local landmarks. Furthermore, Steck and Mallot (2000) also showed that people could perform highly when forced to use landmarks they were unaccustomed to using. This finding implies that individual differences may arise at the retrieving rather than at the encoding stage of spatial memory.

Hurlebaus et al. (2008) asked participants to learn a path between two locations in a complex, cluttered, and unstructured virtual environment that contained both local and global landmark information. Participants were then asked to find their way in the same environment, with only global or local landmarks available. Some participants chose highly variable routes from trial to trial, whereas others were inclined to adopt fixed routes. The group exhibiting high variability in route choice showed dependence on global landmarks, whereas the group exhibiting fixed route choice relied on local landmarks. The differential dependence on global or local landmarks reflected the primary information each type of landmark carried: orientation information by global landmarks and positional information by local landmarks.

Ruddle et al. (2011) asked participants to perform "out-and-back" navigation along a fixed route between two locations in a grid-structured environment (from A to B and then return to A). Participants were divided into four groups, each of which performed the navigation in one of four different environments: without landmarks, with global landmarks, with local landmarks, or with both global and local landmarks. These authors found that only local, not global, landmarks helped reduce errors in following the route. These authors attributed the lack of beneficial effects of global landmarks to participants' uncertainty in deciding where to make turns in an environment with orthogonal structures when only the global landmarks were available.

Both Steck and Mallot (2000) and Hurlebaus et al. (2008) made both global and local landmarks available during the learning phases of their experiments; therefore, it was likely that participants constructed a cognitive map integrating both types of landmarks, which in turn allowed participants to rely on one type of landmark or the other as needed. Although global and local landmarks often coexist in daily life, presenting both simultaneously during the learning phase of an experiment makes evaluating their respective contributions to wayfinding difficult; how participants would behave differently in environments with only global or local landmarks remains to be investigated. Other gaps in our understanding of wayfinding are also apparent. Ruddle et al.'s (2011) findings that the presence of global landmarks produced no beneficial effect contradict previous findings and require clarification. Furthermore, after a review of the literature, we found no study that systematically compared gender differences in using global and local landmarks in online wayfinding. Given the lack of empirical investigation into how global or local landmarks independently contribute to wayfinding for each gender, experiments designed to explore this issue could advance the understanding of both the nature of gender differences and online wayfinding.

To this end, various studies have consistently indicated that males tend to pay more attention to global reference points and configurational aspects of the environment, whereas females focus on local features and procedural strategies such as how to get from one place to another (Galea & Kimura, 1993; Lawton, Charleston, & Zieles, 1996; Lawton & Morrin, 1999; O'Laughlin & Brubaker, 1998). Recently, Coluccia, Iosue, and Brandimonte (2007) tested male and female participants on map-drawing and a set of spatial orientation tasks to examine landmark, route, and survey knowledge. Consistent with earlier studies, Coluccia et al. (2007) found a strong relationship among various map-drawing skills and spatial orientation abilities, which were particularly more pronounced in males than in females. Because global landmarks could be easily used to determine environment-related orientation and local landmarks could be used as part of the detailed features inside the environment, it is reasonable to speculate that the gender difference revealed by the map-drawing study should be replicated in online wayfinding tasks involving global or local landmarks in a virtual environment (VE). Therefore, we hypothesize that the existence of a gender by landmark type interaction in the current study. In other words, males should perform higher than females in VEs with global rather than local landmarks, whereas females should perform as well as or better than males in VEs with only local landmarks.

The major aim of this study was to assess gender differences in online wayfinding in VEs with global *or* local landmarks. Specifically, global or local landmarks were placed on different blocks in the environments for the participants to use as references while they looked for targets. A variety of measurements were extracted from participants' travel paths to describe the metrics of task performance and physical behaviors (Ruddle & Lessells, 2006). Through the independent presentation of various types of landmarks and dependent measures that represent physical behaviors in the VE, this paper illustrates both quantitative and qualitative differences in cognitive processing between females and males engaged in wayfinding in different environmental contexts.

2. Materials and design

2.1. Participants

Fifteen males (22.3 ± 4.6 years) and fifteen females (20.5 ± 3.5 years) from National Chiao-Tung University, Taiwan, participated in the experiment after providing informed consent. The participants were college students, were not personally related to the authors, had normal or corrected-to-normal vision, and did not exhibit any neurological or psychological pathology. Twelve males and six females reported that they played video games frequently on a questionnaire asking for their demographic information (that is, "Do you play computer games frequently?"). Participants received monetary compensation of NT$200 (approximately US$6.50) for their time.

2.2. Apparatus and materials

The virtual maze environment was implemented with a custom software system that displayed 3D environments and allowed users to navigate using a first-person view. The field-of-view (FOV) of the VE was approximately 37 degrees. The participants used four arrow keys on a QWERTY keyboard to move forward, backward, left, and right inside the maze. The layout of the maze included a 5 × 5 grid of interweaving roads and cubic blocks surrounded by walls (Fig. 1a).

To examine whether global (Fig. 1b) and local (Fig. 1c) landmarks lead to differential performance, we constructed two types of mazes. In the environment with global landmarks, eleven enormous structures (for example, a tower, lighthouse, water tower, windmill, and other buildings), which participants could see from everywhere inside the maze, were placed outside the surrounding walls. In the environment with local landmarks, eleven different cartoon pictures (an axe, banana, bell, bird, bow, radish, deer, fish, desk lamp, scissors, and umbrella) were placed on the sides of the cubic blocks inside the maze. Each local landmark appeared on only one side of a given cube. Participants could see a particular local landmark only from a few restricted orientations at certain locations inside the maze. However, if a participant modified his/her view by rotating at any position, he/she would see at least one landmark. Either local or global landmarks were displayed in each trial.

Four targets (an airplane, bicycle, grape, and penguin under the global landmark condition; and a candle, duck, flag, and kettle under the local landmark condition) were placed at different locations under each type of landmark condition. Each target was displayed on one side of a block that formed the internal structure of the maze, or on one segment of the surrounding walls. An icon of the target picture (.1 width × .15 length of the screen) was shown at the bottom of the display before its location was found. Locations and the appearance of the targets differed between the global and local landmark conditions.

2.3. Procedure

All participants were tested in both global and local landmark mazes: half of the participants were first tested with global landmarks, whereas the other half were first tested with local landmarks. Before the formal experiment started, the participants were briefed about the procedure and stimulus configuration, and they practiced using the arrow keys for controlling movement in the VE for approximately 5 min. The formal experiment involved eight trials under each landmark condition. Each trial started with a learning period in which participants could search for the targets until all were found or until a 6-min period had elapsed. The learning period in each trial allowed participants to become familiar with the positions and spatial relationships among targets and landmarks. The testing period immediately followed the learning period, and the search time for each target location was limited to 20 s. Only one target was shown until it was found or until the 20-s time limit had elapsed. After finding a target, the participant's current view in the virtual environment was immediately transformed to another random location, and a new target picture appeared. During the testing period, each target appeared three times, giving a total of twelve target-searching periods. The testing period lasted until all targets were found or until the time limit (4 min) was reached. The order of the targets in the learning and testing periods was randomized in each trial.

2.4. Dependent measures

Six dependent variables were involved in the wayfinding task: 1) the ratio of the actual travel distance to the optimal travel distance (corrected path, P); 2) the travel time between the beginning and the

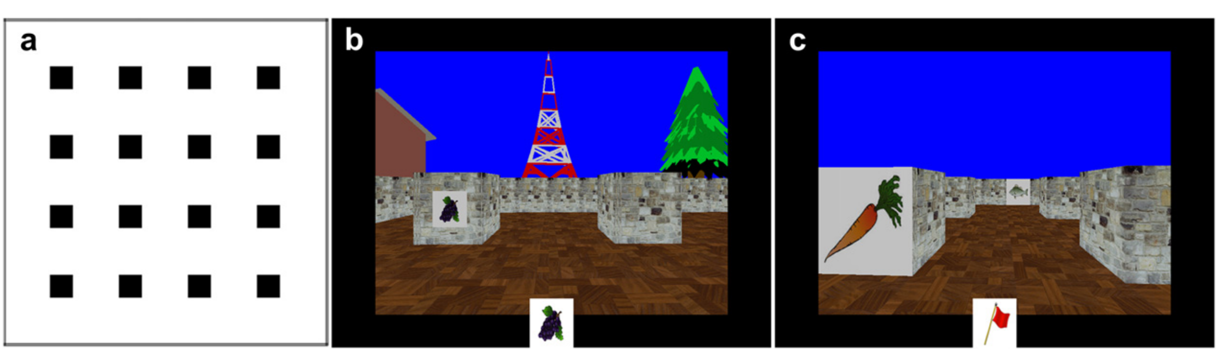

Fig. 1. (a) A bird's eye view of the simple maze structure adopted in the current study; (b) First-person view of the global-landmark condition; (c) First-person view of the local-landmark condition.

end of target searching (T); 3) the proportion of time when the participant was moving away from the target location (TR_{away}); 4) the proportion of time when the participant was not traversing ($TR_{no\text{-}translation}$); 5) accumulated angle of rotation when the participant was traversing ($ROT_{translation}$); and 6) accumulated angle of rotation when the participant was not moving ($ROT_{no\text{-}translation}$).

Although the corrected path and the overall travel time are regularly considered in wayfinding studies, the other dependent measures are rarely examined, and this paper further investigates these measures to facilitate our understanding of wayfinding. Both TR_{away} and $TR_{no\text{-}translation}$ were ratios of their defining durations to the total travel duration. The duration of TR_{away} was calculated when the Euclidean distance between the current location and the target location at a given frame was increasing, as compared with the preceding frame. The duration of $TR_{no\text{-}translation}$ was calculated when the participant was not traversing (but could still be rotating at the same location) in the environment. By definition, TR_{away} and $TR_{no\text{-}translation}$ should develop in opposite directions. In the scenario of a small TR_{away} and a large $TR_{no\text{-}translation}$ during wayfinding, the participant may often stay in the same location to compare visual scenes carefully with mental representations of the environment in order to plan the optimal path. By contrast, in the scenario of a large TR_{away} and a small $TR_{no\text{-}translation}$, the participant may either get lost frequently or adopt an exploratory strategy of continuing to move in hopes of finding a recognizable landmark. The latter scenario naturally results in a larger P than does the former. $ROT_{translation}$ and $ROT_{no\text{-}translation}$ were derived by tallying the absolute values of the difference in heading orientation between successive frames when the participant was moving or not moving, respectively. A large $ROT_{translation}$ may result from frequent instances of unnecessary detours, and a large $ROT_{no\text{-}translation}$ may imply difficulty in determining the direction of the next move.

In the framework for levels of measurement metrics in wayfinding by Ruddle and Lessells (2006), P and T were termed "performance measures", whereas TR_{away}, $TR_{no\text{-}translation}$, $ROT_{translation}$, and $ROT_{no\text{-}translation}$ were termed "physical behavior measures". Here, we refer to the former group as "overall measures" because they are indicative of the overall wayfinding performance, but they do not represent the minute (or "fine-grained") details of how participants find their way. We refer to the latter group of measures as "fine-grained measures" because each of these measures captures a structural aspect of wayfinding behavior, such as moving away from targets (TR_{away}), stopping ($TR_{no\text{-}translation}$), changing direction while moving ($ROT_{translation}$), and changing orientation while stopped ($ROT_{no\text{-}translation}$).

2.5. Data analyses

For each trial, twelve values, each representing one type of variable, were collected, and each participant completed eight trials in the global and local landmark conditions, respectively. The data from the first four trials and the data from the second four trials were averaged separately. All dependent variables from the thirty participants were subjected to a three-way mixed-design ANOVA, with gender as a between-subject factor and landmark type (global versus local) and trial blocks (the first and the second block) as within-subject factors. The significance level for all statistical comparisons was set at *p*-value $< .05$. Post hoc analysis was conducted with Tukey's HSD test.

3. Results

3.1. Corrected travel path (P)

The three-way ANOVA revealed significant main effects of landmark type ($F(1, 28) = 56.94$, $p < .0001$, $\eta_p^2 = .67$) and trial blocks ($F(1, 28) = 32.43$, $p < .0001$, $\eta_p^2 = .54$) but not gender ($F(1, 28) = .85$, $p = .36$, $\eta_p^2 = .03$). The main effect of landmark type resulted from a longer P under the local (1.72) than under the global landmark (1.41) condition. The main effect of trial blocks resulted from a shorter P in the later trials (1.48) than in the earlier trials (1.65). Significant interactions were found between landmark type and trial blocks ($F(1, 28) = 4.30$, $p < .05$, $\eta_p^2 = .13$), and between landmark type and gender ($F(1, 28) = 5.04$, $p < .05$, $\eta_p^2 = .15$). The landmark type by trial blocks interaction was due to the larger difference between trials (1.83 for the first half vs. 1.61 for the second half of trials; $p < .01$) for the local landmarks than for the global landmarks (1.46 for the first half vs. 1.35 for the second half of trials; $p = .034$). The landmark type by gender interaction was due to the larger difference between global and local landmarks for males (1.39 vs. 1.80; $p < .0001$) than for females (1.42 vs. 1.64; $p = .003$). In addition, the difference between females and males did not significantly vary between landmark types (both $ps > .05$). The trial blocks by gender interaction ($F(1, 28) = .22$, $p = .64$, $\eta_p^2 = .01$) and the three-way interaction (($F(1, 28) = 3.46$, $p = .07$, $\eta_p^2 = .11$) did not reach significance.

A trend of three-way interaction was present but did not reach significance ($F(1, 28) = 3.46$, $p = .07$, $\eta_p^2 = .11$). As can be seen in Fig. 2a, the difference in P between the first and second half of trials was larger for local than for global landmarks for males, but this difference did not occur for females. Consistent with this observation, we conducted two separate two-way ANOVAs with landmark type and trial blocks as the within-subject factors for each gender group and found a significant landmark type by trial blocks interaction in males ($F(1, 14) = 9.07$, $p < .001$, $\eta_p^2 = .39$) but not in females ($F(1, 14) = .02$, $p = .89$, $\eta_p^2 = .001$). The significant two-way interaction in males was due to the larger difference between the first half (1.93) and the second half of trials (1.67; $p < .001$) for the local landmarks than for the global landmarks (1.41 for the first half vs. 1.37 for the second half of trials; $p = .11$).

Because the starting position in each trial was randomly allocated, the average length of optimal paths may differ between conditions. If this is the case, it is likely that unequal lengths of corrected paths between groups or conditions were caused not only by experimental manipulations *per se* but also by the unequal lengths of optimal paths. To ensure that the results of corrected paths were not confounded by unequal lengths of optimal paths, the optimal path length was also subjected to the same ANOVA. Only the main effect of landmark type ($F(1, 28) = 83.65$, $p < .0001$, $\eta_p^2 = .75$) and the interaction between landmark types and gender ($F(1, 28) = 6.74$, $p < .05$, $\eta_p^2 = .19$) were significant. None of the other main effects (trial blocks: $F(1, 28) = .76$, $p > .39$, $\eta_p^2 = .02$; gender:

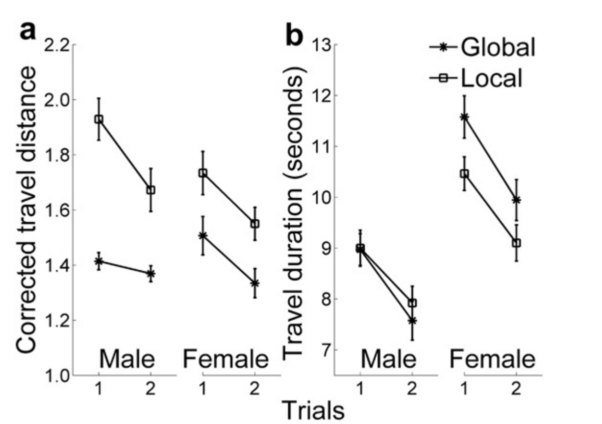

Fig. 2. The corrected travel distance (a) and total travel duration (b) As a function of trial block, landmark types, and gender. Squares and asterisks indicate local and global landmarks, respectively. Error bars indicate standard error. The trial blocks were averaged separately for the first four trials (#1) and the second four trials (#2).

$F(1, 28) = .38$, $p > .54$, $\eta_p^2 = .01$) or interactions (trial blocks by gender: $F(1, 28) = .44$, $p > .51$, $\eta_p^2 = .02$; landmark type by trial blocks: $F(1, 28) = .70$, $p > .41$, $\eta_p^2 = .03$; three-way interaction: $F(1, 28) = .11$, $p > .74$, $\eta_p^2 = .00$) reached significance. However, the pattern of results for optimal paths was quite distinct from those observed for corrected paths. First of all, the main effect showed that optimal path length under the global landmark condition (178) was longer than optimal path length under the local landmark condition (162). Moreover, *post hoc* comparisons of the two-way interactions showed that although the optimal paths for females and males differed under the global landmark condition (175 for females vs. 181 for males, $p < .05$), the optimal paths for both genders did not differ significantly under the local landmark condition (164 for females vs. 160 for males, $p = .26$). This is exactly the opposite of the pattern observed in the results for corrected path length. In other words, although the optimal path length was shorter for the environment with local landmarks than with global landmarks, the participants actually traveled a longer distance in the former than in the latter. Thus, the results for the corrected path cannot be due to the unequal lengths of the optimal path.

3.2. Travel duration (T)

The main effects of trial blocks ($F(1, 28) = 94.45$, $p < .0001$, $\eta_p^2 = .77$) and gender ($F(1, 28) = 19.13$, $p < .001$, $\eta_p^2 = .41$) were significant. As can be seen in Fig. 2b, earlier trials took longer (10.00 s) to complete than later trials (8.64 s), and females took longer (10.27 s) on average than males (8.27 s). There was also a significant interaction between landmark type and gender ($F(1, 28) = 6.79$, $p < .05$, $\eta_p^2 = .20$). A post hoc analysis on the landmark type by gender interaction revealed that male participants spent similar amounts of time in both landmark environments (8.27 vs. 8.46 s for global and local landmarks, respectively; $p > .05$), whereas female participants spent less time finishing a trial under the local (9.78 s) than under the global condition (10.76 s; $p < .05$). In addition, males spent less time than females under both landmark conditions, and the difference between genders was larger in the global (2.52 s; $p = .0001$) than in the local (1.32 s; $p = .047$) condition. None of the other main effects (landmark type: $F(1, 28) = 3.13$, $p = .09$, $\eta_p^2 = .10$) or interactions (trial blocks by gender: $F(1, 28) = .87$, $p = .36$, $\eta_p^2 = .03$; landmark type by trial blocks: $F(1, 28) = 1.06$, $p = .31$, $\eta_p^2 = .04$; three-way interaction: $F(1, 28) = .01$, $p = .93$, $\eta_p^2 = .00$) approached significance (see Fig. 2b).

3.3. Ratio of duration of moving away from the target location to the total duration (TR_{away})

The main effects of landmark type ($F(1, 28) = 43.27$, $p < .001$, $\eta_p^2 = .61$), trial blocks ($F(1, 28) = 19.25$, $p < .001$, $\eta_p^2 = .41$), and gender ($F(1, 28) = 6.28$, $p < .05$, $\eta_p^2 = .18$) were significant. Fig. 3a shows that in general, the proportion of time moving away from the target location was larger under the local (.057) than under the global (.033) landmark condition, larger in the earlier trials (.050) than in the later trials (.039), and larger for males (.052) than for females (.038).

Significant interactions were also found between landmark type and trial blocks ($F(1, 28) = 8.50$, $p < .01$, $\eta_p^2 = .23$). Post hoc analysis revealed that the difference in TR_{away} between the first and the second half of the trials was larger for the local landmarks (.07 vs. .05; $p < .05$) than for the global landmarks (.04 vs. .03; $p = .22$). The landmark type by gender interaction was marginally significant ($F(1, 28) = 3.71$, $p = .06$, $\eta_p^2 = .12$). A post hoc comparison revealed that the difference between females and males was not significant in the global landmark condition (.03 vs. .04; $p = .7$), but this difference was significant in the local landmark condition (.05 vs. .07; $p = .014$). In addition, the difference between global and local landmarks was larger in males (.04 vs. .07; $p < .001$) than in females (.03 vs. .05; $p = .013$). The trial blocks by gender interaction was not significant ($F(1, 28) = .18$, $p = .67$, $\eta_p^2 = .01$).

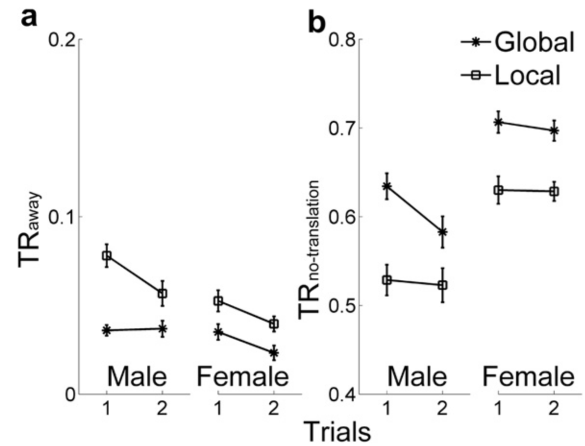

Fig. 3. TR_{away}(a) and $TR_{no\text{-}translation}$(b) as a function of trial block, landmark types, and gender. Squares and asterisks indicate local and global landmarks, respectively. Error bars indicate standard error. The trial blocks were averaged separately for the first four trials (#1) and the second four trials (#2).

The three-way interaction was also significant ($F(1, 28) = 6.83$, $p < .05$, $\eta_p^2 = .20$). As can be seen in Fig. 3a, the difference in TR_{away} between the first and second half of the trials was larger for the local than for the global landmarks for males, whereas there was no difference for females. In accordance with this observation, separate follow-up tests for each gender revealed a significant interaction between landmark types and trial blocks ($F(1, 14) = 15.19$, $p < .01$, $\eta_p^2 = .52$) for males but not for females ($F(1, 14) = .05$, $p = .83$, $\eta_p^2 = .00$).

3.4. Ratio of duration without translation to the total duration ($TR_{no\text{-}translation}$)

The main effects of landmark ($F(1, 28) = 48.48$, $p < .0001$, $\eta_p^2 = .63$), trial block ($F(1, 28) = 8.58$, $p < .01$, $\eta_p^2 = .24$) and gender ($F(1, 28) = 31.66$, $p < .0001$, $\eta_p^2 = .53$) were significant. Fig. 3b shows that in general, the proportion of time spent at the same location was longer under the global (.66) than under the local (.58) landmark condition, longer in the first half of trials (.63) than in the second half of trials (.61), and longer for females (.67) than for males (.57).

Significant interactions were also found between landmark types and trial blocks ($F(1, 28) = 7.03$, $p < .05$, $\eta_p^2 = .20$). Post hoc analysis revealed that the difference in $TR_{no\text{-}translation}$ between the first and the second half of trials was larger for the global landmarks (.67 vs. .64; $p = .12$) than for the local landmarks (.58 vs. .58; $p = .87$). The three-way interaction ($F(1, 28) = 3.44$, $p = .07$, $\eta_p^2 = .11$) and trial blocks by gender interaction ($F(1, 28) = 3.92$, $p = .06$, $\eta_p^2 = .12$) were marginally significant. As can be seen from Fig. 3b, the difference in $TR_{no\text{-}translation}$ between the first and second half of trials was larger for global than for local landmarks for males, whereas no difference was apparent for females. Consistent with this observation, separate follow-up tests for each gender revealed a significant interaction between landmark types and trial blocks ($F(1, 14) = 7.46$, $p < .05$, $\eta_p^2 = .35$) for males but not for females ($F(1, 14) = .50$, $p = .49$, $\eta_p^2 = .03$). The landmark type by gender interaction did not approach significance ($F(1, 28) = .21$, $p = .65$, $\eta_p^2 = .01$).

3.5. Rotation angle with translation ($ROT_{translation}$)

The main effects of landmark type ($F(1, 28) = 12.54$, $p < .01$, $\eta_p^2 = .31$) and gender ($F(1, 28) = 32.03$, $p < .0001$, $\eta_p^2 = .53$) were

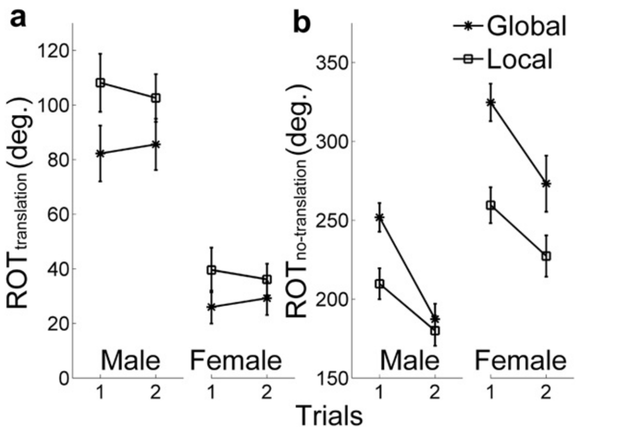

Fig. 4. $ROT_{translation}$(a) and $ROT_{no\text{-}translation}$(b) as a function of trial block, landmark types, and gender. Squares and asterisks indicate local and global landmarks, respectively. Error bars indicate standard error. The trial blocks were averaged separately for the first four trials (#1) and the second four trials (#2).

significant. The angle of rotation during translation was larger under the local (72°) than under the global (56°) landmark condition and larger for males (95°) than for females (33°) (Fig. 4a). None of the other main effects (trial blocks: $F(1, 28) = .11$, $p = .74$, $\eta_p^2 = .00$) or interactions (landmark type by gender: $F(1, 28) = 1.57$, $p = .22$, $\eta_p^2 = .05$; trial blocks by gender: $F(1, 28) = .08$, $p = .78$, $\eta_p^2 = .00$; landmark type by trial blocks: $F(1, 28) = 2.55$, $p = .12$, $\eta_p^2 = .08$; three-way interaction: $F(1, 28) = .05$, $p = .82$, $\eta_p^2 = .00$) reached significance.

3.6. Rotation angle without translation ($ROT_{no\text{-}translation}$)

The main effects of landmark *type* ($F(1, 28) = 22.32$, $p < .0001$, $\eta_p^2 = .44$), trial *order* ($F(1, 28) = 70.68$, $p < .0001$, $\eta_p^2 = .72$) and gender ($F(1, 28) = 23.57$, $p < .0001$, $\eta_p^2 = .46$) were significant. The angle at which participants rotated at the same location was larger under the global (259°) than under the local (219°) landmark condition, larger in the first half of trials (261°) than in the second half of trials (217°), and larger for females (271°) than for males (207°) (Fig. 4b).

The landmark type by gender interaction was marginally significant (landmark type by gender: $F(1, 28) = 3.29$, $p = .08$, $\eta_p^2 = .11$). Post hoc comparisons revealed that the difference between females and males was larger in the global landmark condition (299° vs. 210°, $p < .001$) than in the local landmark condition (244° vs. 195°, $p = .016$). In addition, the difference between global and local landmarks was larger in females ($p = .001$) than in males ($p = .19$).

There was also a significant interaction between landmark types and trial blocks ($F(1, 28) = 6.80$, $p < .05$, $\eta_p^2 = .20$). This interaction was due to the larger difference between the first and second half of trials for the global landmarks (288° vs. 230°; $p < .001$) than for the local landmarks (235° vs. 204°; $p = .02$). None of the other interactions approached significance (trial blocks by gender: $F(1, 28) = .25$, $p = .62$, $\eta_p^2 = .01$; three-way interaction: $F(1, 28) = .57$, $p = .46$, $\eta_p^2 = .02$).

4. Discussion

4.1. Summary of main findings

The current study adopted both overall and fine-grained measures to examine how gender differences in wayfinding are modulated by the type of landmark available in the virtual environment. Two major findings emerged from this investigation: First, the main effects of gender in both overall measures did not converge to reflect the typical superiority of male performance observed in wayfinding tasks. That is, while females spent more time than males in locating targets, both genders were generally equivalent in terms of corrected travel paths. The divergence between the conventional overall measures in the spatial and temporal domains contradicted the close correspondence between these two domains reported in previous studies (Canovas, Espinola, Iribarne, & Cimadevilla, 2008; Moffat, Hampson, & Hatzipantelis, 1998; Ross, Skelton, & Mueller, 2006). As already suggested by some researchers, the overall measures, though indicative of overall performance, present a coarse resolution and may miss fine-grained characteristics of wayfinding behavior (Ruddle & Lessells, 2006; Spiers & Maguire, 2008).

Second, the prediction that males would outperform females in the global condition and that females would outperform males in the local condition was only partially confirmed. For the overall measures, both the path and time measures showed landmark type by gender interactions, but the patterns of interaction were different. Regarding the corrected travel path, there was a tendency for males to travel longer distances than females in both landmark conditions, but the gender difference was not significant for either type of landmark. In terms of travel duration, males did spend less time than females in both landmark conditions, and the gender difference was larger in the global than in the local condition. Although these results are not entirely consistent with the original prediction, they do partially echo the idea that the superior performance of males is more obvious in the global than in the local landmark condition. Regarding the fine-grained measures, TR_{away} showed that females spent a smaller proportion of time than males in traveling away from the target location when local landmarks were available, but there was no gender difference when global landmarks were present. Assuming that less time moving away from the target location indicates better performance, this result is consistent with the prediction of female superiority in the local landmark condition, though not with the prediction of male superiority in the global landmark condition. $ROT_{no\text{-}translation}$ showed a tendency for females to rotate more angles than males when they made stops, and this gender difference was more prominent in the global than in the local condition. Assuming that less rotation indicates better performance, this result is consistent with the prediction of male superiority in the global landmark condition, though not with the prediction of female superiority in the local landmark condition.

In the following sections, three issues raised in the preceding summary will be discussed in turn: 1) Why did the overall spatial measure diverge from the temporal measure? 2) How do results from the overall and fine-grained measures conjointly form a complete picture of gender differences in wayfinding? 3) How does landmark type moderate gender differences in wayfinding?

4.2. Divergence between overall spatial and temporal measures

Two non-exclusive explanations of the divergent results from the overall spatial and temporal measures are provided here. The first explanation is not directly related to wayfinding ability *per se*. The discrepancy between spatial and temporal measures may simply result from the more advanced computer skills of male participants. Coluccia and Louse (2004) suggested that male advantage is dramatically enhanced (males outperforming females in 57 %–86 % of the experiments reviewed) in VEs when the participants had the opportunity to interact actively with the computerized environment during wayfinding. This is likely due to a higher familiarity with the virtual environment among males because statistically, males play more video games than do females (Barnett et al., 1997; cf. Sandstrom et al., 1998). We noted that all male participants were enrolled in departments related to engineering, whereas only seven female participants were from those departments. Furthermore, twelve males reported playing video games frequently, whereas only six females reported the same. Because males might already be quite familiar with the computer interface, they may not have much room for improvement in speed. Consistent with this account, a trend in our results (though not remarkable) seems to suggest that wayfinding time improves more from the first half of trials to the second half in females than in males (Fig. 2b). Thus, the males' advantage in time may reflect their superior skills in operating the computer interface, but their familiarity with the computer interface may be independent of their cognitive map, which was more directly reflected by the path measure.

The second explanation of the divergent results is that females and males adopted different strategies when performing the wayfinding task. Females may have adopted a less exploratory strategy than males did; they tended to stay in the same locations to look around rather than continuing to move, as evidenced by their higher $TR_{no\text{-}translation}$ and $ROT_{no\text{-}translation}$. By contrast, males preferred to cover a larger area in the virtual environment. A higher proportion of time on the move also led to more changes in orientation while moving (indicated by males' higher $ROT_{translation}$). Continuously moving did not make males more effective wayfinders. Based on TR_{away}, it seems that males spent a slightly higher proportion of time moving away from the target location than did females. However, given the fact that no dead end existed in the grid-like environment, this strategy increased the males' chances of finding the target within a shorter amount of time. By monitoring the gaze of participants in a virtual version of the Morris water maze experiment, Mueller et al. (2008) demonstrated that females showed initially longer fixation durations and increases in pupil diameter than males did when looking for the path to the hidden platform. Perhaps when finding their way, females require frequent stops to look around and compare the flow of visual scenes with their spatial representations of the environment.

4.3. Integrating overall and fine-grained measures of wayfinding performance

This latter interpretation of the gender difference integrates results from the fine-grained measures. Numerous studies on wayfinding have adopted overall travel duration (Hund & Nazarczuk, 2009; Maguire et al., 1998; Moffat et al., 1998; Sandstrom et al., 1998; Saucier et al., 2002), length of travel path (Newman et al., 2007), or both (Astur et al., 1998; Astur, Tropp, Sava, Constable, & Markus, 2004; Canovas et al., 2008; Mueller et al., 2008; Rizk-Jackson et al., 2006) as an indicator of performance. In this experiment, the overall travel duration indicated a clear male advantage (shorter travel time), similar to the findings of several previous studies in certain contexts of wayfinding (Moffat et al., 1998; Sandstrom et al., 1998; Saucier et al., 2002). The results of the corrected path measure were also similar to the results of some wayfinding studies (Astur et al., 2004) that demonstrated no gender difference. The divergence between spatial and temporal measures in the current study suggests that both should be analyzed. Although these measures usually concur, perfect correlation between them is not always guaranteed. The strength of consistency between these two types of measures may depend on the geometric or visual features of the environment or on the idiosyncratic wayfinding strategies adopted by the participants. Merely relying on one type of measure may lead to biased interpretations of the differences between groups or conditions. When the overall measures diverge, researchers must examine information regarding metrics at other levels for an accurate interpretation of participant performance (see Ruddle & Lessells, 2006; for comprehensive illustrations).

4.4. Influences of landmark types on gender differences

It is also worth noting how wayfinding performance differed between the global and local landmark conditions. As an overall trend, participants traveled longer paths in the local than in the global landmark environment. This was most likely due to the fact that global landmarks could be constantly seen in the mazes and used as visual anchors when computing orientation and heading. By contrast, participants had to move around to search for local landmarks, which made the travel distance longer in the local landmark condition than in the global landmark condition. Analyses of overall measures (Fig. 2) also indicated that males benefited more from the presence of global landmarks than did females. Furthermore, it seemed that global landmarks even slowed down female performance. These results are consistent with previous findings that females and males are sensitive to the local and global aspects of the environment, respectively (Coluccia et al., 2007; Galea & Kimura, 1993; Lawton et al., 1996; Lawton & Morrin, 1999; O'Laughlin & Brubaker, 1998).

Aside from the global/local landmark processing tendencies of each gender group, a different but not mutually exclusive interpretation based on gender-specific strategies of movement in the VE is also possible. Participants walked away from the target location (TR_{away}; Fig. 3a) and continued moving ($TR_{no\text{-}translation}$, Fig. 3b) for longer portions of time under the local than under the global landmark condition. These general differences between global and local landmarks were also mediated by gender and trial blocks. From the significant three-way interaction observed for corrected travel distance and TR_{away}, we found larger differences between the first and second halves of the trials for the local landmark condition only for males. Males had disproportionately larger travel distances and proportions of time of moving away from targets in the early phase of wayfinding in the environment with local landmarks. This can be attributed to the more exploratory wayfinding strategy that males use to reorient themselves in the VE (Coluccia et al., 2007), especially at the beginning of the local landmark condition. When navigating the environment with local landmarks, seeing a particular landmark is difficult because it is only visible from certain locations and perspectives. This characteristic may have bolstered the male tendency to continue moving, especially at the beginning of the experiment, when they were still not familiar with the environment.

4.5. Conclusion

To conclude, contextual features of the environment, such as the types of available landmarks, modulate gender differences in wayfinding behavior. This is particularly obvious at the early phase of learning to find the way in a novel virtual environment. Although not all dependent measures confirmed our initial hypothesis of the gender by landmark type interaction, the distinct patterns of results from different measures actually provided complementary information. Generally, males tended to engage in a more exploratory mode of wayfinding, which led to quicker moves but not necessarily to optimal routes. By contrast, females adopted a more conservative strategy by making more stops to change their viewing orientation, which led to slower moves but not fewer detours. These gender differences were most obvious for VEs with local landmarks, most likely due to the different strategies adopted during wayfinding; males learned the map from a configural perspective, whereas females focused on local features (Coluccia et al., 2007). Future wayfinding studies on gender or other variables of individual differences could benefit from analyzing both the overall and fine-grained measures of performance, which would reduce the risk of biased conclusions on wayfinding ability in different subject groups or environmental contexts.

Acknowledgments

The study was supported by the National Science Council of Taiwan under the following grants: NSC-97-2627-E-009-001 and NSC-99-3114-B-009-001 to Chin-Teng Lin, NSC-96-2413-H008-003-MY3 and NSC-99-2410-H008-065 to Erik C. Chang, and NSC-100-2911-I-009-101 to the UST-UCSD International Center of Excellence in Advanced Bio-engineering sponsored by I-RiCE Program.

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