2014

Where is uphill? Exploring sex differences when reorienting on a sloped environment presented through 2-D images

Daniele Nardi
Eastern Illinois University, dnardi@eiu.edu

Roberta Miloni

Marco Orlandi

Marta Olivetti-Belardinelli

Recommended Citation

Nardi, Daniele; Miloni, Roberta; Orlandi, Marco; and Olivetti-Belardinelli, Marta, "Where is uphill? Exploring sex differences when reorienting on a sloped environment presented through 2-D images" (2014). *Faculty Research and Creative Activity*. 15.
http://thekeep.eiu.edu/psych_fac/15

Perception, 2014, volume 43, pages 249 – 264

doi:10.1068/p7622

Where is uphill? Exploring sex differences when reorienting on a sloped environment presented through 2-D images

Daniele Nardi[1], Roberta Meloni[1], Marco Orlandi[2], Marta Olivetti-Belardinelli[1]
[1] Sapienza University of Rome, Psychology Department, and ECONA, Via dei Marsi 78, Rome 00185, Italy; [2] Research Center on Vision, Via di Acqua Bullicante 435, Rome 00177, Italy; e-mail: d.nardi@uniroma1.it
Received 7 October 2013, in revised form 3 March 2014

Abstract. One of the spatial abilities that has recently revealed a remarkable variability in performance is that of using terrain slope to reorient. Previous studies have shown a very large disadvantage for females when the slope of the floor is the only information useful for encoding a goal location. However, the source of this sex difference is still unclear. The slope of the environment provides a directional source of information that is perceived through dissociable visual and kinesthetic sensory modalities. Here we focused on the visual information, and examined whether there are sex differences in the perception of a slope presented through 2-D images with a desktop computer connected to an eye-tracking device. Participants had to identify and point to the uphill direction by looking at different orientations of two virtual, slanted environments (one indoor and one outdoor). Men were quicker and more accurate than women, indicating that the female difficulty with slope emerges at an early, unisensory, perceptual level. However, the eye-tracking data revealed no sex differences in the slope cues used, providing no support to the hypothesis of sex-specific, visual-processing strategies. Interestingly, performance correlated with a test of mental rotation, and we speculate that the disadvantage in mental rotation ability might be an important factor responsible for females' difficulty using slope.

Keywords: spatial abilities, sex differences, slope or slant, eye-tracking, reorientation

1 Introduction

Regaining a sense of orientation after having lost track of which direction one is facing—a process called reorientation—is a crucial skill for successful navigation. Even though the literature has been focused on the role of landmarks and of the geometric shape of the environment (for a recent review see Cheng, Huttenlocher, & Newcombe, 2013), many other types of spatial information can be potentially used to reorient. One cue that has only recently received attention is the slope of the terrain. When walking on a homogeneously tilted floor, the slant provides a directional frame of reference which can be used like a compass to reorient and to encode a goal location (eg "in order to find the car, I have to walk 45° clockwise relative to the uphill direction"). Studies on pigeons have shown not only that terrain slope can be used for reorientation but also that it is a very salient type of information (Nardi & Bingman, 2009; Nardi, Nitsch, & Bingman, 2010), possibly because it is associated with effort when moving on it (Nardi, Mauch, Klimas, & Bingman, 2012). Studies on humans, nonetheless, have revealed very large individual differences, the most apparent source of which seems to be sex. Males consistently outperform females when the floor slant is the only cue available for reorientation—even if this is explicitly pointed out by the experimenter. This female disadvantage has been shown in both adults (Nardi, Newcombe, & Shipley, 2011) and children (Holmes, Nardi, Newcombe, & Weisberg, under review), and the magnitude of the effect size (*d* = 1.4, in Nardi et al., 2011) has warranted further investigation.

Evidence gathered to date indicates that, when directional cues (including, but not limited to, slope) and positional cues (including landmarks) are available, men tend to rely more on a directional strategy than women (Chai & Jacobs, 2009, 2010; Jacobs & Schenk, 2003); this, however, has been shown in virtual environments (VEs) only, and may not generalize to a real-world environment (Nardi, Newcombe, & Shipley, 2013). When only the slope gradient is available for reorientation, the female disadvantage seems to be related to a decreased likelihood of noticing the floor tilt that, however, is not due to the footwear worn during the experiment or to footwear habits (Holmes et al., under review; Nardi et al., 2011, 2013). Interestingly, sex differences with slope in richer and larger environments, where other cues are available, have not been found (Restat, Steck, Mochnatzki, & Mallot, 2004; Weisberg & Newcombe, in press), suggesting that environment complexity may play a modulatory role.

Sex differences in spatial cognition abound. Males and females differ in terms of both performance and strategy preference in a variety of spatial abilities, including spatial perception, mental rotation, reorientation and navigation using a number of cues (eg D. M. Kelly & Bischof, 2005; Lawton, Charleston, & Zieles, 1996; Linn & Petersen, 1985; Moffat, Hampson, & Hatzipantelis, 1998; Saucier et al., 2002; Voyer, Voyer, & Bryden, 1995). Compared with other types of spatial information, the unique property of terrain slope is multimodality. A homogeneously tilted floor can be perceived by a navigator moving on it through two dissociable sensory modalities—each one sufficient for determining directional information. The slope gradient is sensed through a class of kinesthetic cues, including the angles of the joints, the weight on the feet, and the differential effort when walking upward, downward, or sideways. Furthermore, the slope can be perceived by a class of visual cues—for example, the ground appears to be closer to the eyes when facing uphill than downhill, the optic slant with the ground surface changes depending on the orientation, the main terrain lines appear tilted when facing the side of a hill (the horizon appears tilted), the angles subtended by the floor and vertical objects (eg trees or walls) are different between the uphill and downhill side (acute on one side and obtuse on the other), and objects that are uphill appear higher than the same objects downhill (gaze declination). The role of these two sensory modalities for slope perception and reorientation is unclear. It is possible that males' advantage with slope stems from a better integration of visual and kinesthetic modalities (Barnett-Cowan, Dyde, Thompson, & Harris, 2010; Berthoz & Viaud-Delmon, 1999) or from better use of at least one of them.

The goal of the present study was to focus specifically on visual information, and examine whether sex differences are supported by this sensory modality. To date, only one study (Weisberg, Nardi, Newcombe, & Shipley, 2014) has systematically isolated the contribution of different sensory modalities for slope encoding, and it has found a general faster reaction time (RT) for men when retrieving information, but no significant differences among a visual-only, a kinesthetic-only, and a combined kinesthetic-plus-visual encoding condition. That task involved spatial memory and reference frame selection. Here we used a visuoperceptual task, which simply involved identifying the uphill direction of a sloped environment presented on a computer screen. In this way we could assess whether there is a female difficulty solely with extracting slope information from visual stimuli. We chose uphill as the goal direction because studies on nonhuman (Nardi & Bingman, 2009) and human animals (J. Y. Kelly, 2011; Nardi et al., 2011) indicate the vertical axis of the slope as the most salient reference direction.

Participants viewed images of two different sloped environments—one indoor and one outdoor (see figures 1 and 2)—on a desktop computer screen equipped with eye-tracking device. The indoor environment was a bare room, similar to the (real-world) enclosure used in Nardi et al. (2011), but with benches and painting; the outdoor environment was a yard surrounded by a hedge, with trees and benches. In both cases the environment was square, with objects placed identically on all sides. Therefore, the only property that polarized an otherwise fourfold rotationally ambiguous environment was the slant of the ground. The presented images were taken from the center of the environment with four different orientations:

facing the uphill side (hereafter also called north, N), the downhill side (south, S), and sideways (east, E; and west, W). Participants had to point to the uphill direction imagining that they were in the center of the environment, in the same orientation purported in the image. If the female difficulty with slope is related to the kinesthetic component only (having less access to kinesthetic cues), or to a kinesthetic–visual integration, there should be no differences in performance in this visual slope task. If, instead, the difficulty is related to the visual component of slope encoding, the disadvantage should be present. In this case we expect more errors and/or longer RTs for women.

There is evidence suggesting a different pattern of visual attention between sexes in spatial tasks. Women are commonly reported to rely more on landmark, pinpoint cues, and to have better object memory, whereas men are often reported to use more global, environmental and geometric cues (Andersen, Dahmani, Konishi, & Bohbot, 2012; Barkley & Gabriel, 2007; D. M. Kelly & Bischof, 2005; Levy, Astur, & Frick, 2005; Saucier et al., 2002). Using the eye-tracking data, we examined for the first time whether sex differences with slope are supported by different visual-processing strategies, as measured by attending different visual areas that indicate the slope direction. Specifically, we considered the cues that are locally informative: any cue that covers a relatively small portion of the visual field and that by itself (in isolation) reveals the direction of uphill. On the basis of this definition, as shown in figures 1 and 2, in each environment we chose the following slope cues as areas of interest (AOIs):

- Main terrain lines of the environment: the lines parallel to the terrain appear tilted when facing the sides of the hill (in E and W), and they appear flat (horizontal) when facing both N and S. Therefore, these AOIs can be used locally to distinguish between E and W, but not between N and S.
- Angles between main terrain lines and vertical elements: the angles subtended between main terrain lines and vertical elements (eg the angle between walls and floor in the indoor environment, and the angle between trees and ground in the outdoor environment) vary based on the facing direction. When facing the E and W orientations, they are acute on one side and obtuse on the other. Conversely, when facing N and S, the angles are 90° on both sides. Therefore, these angles can be used locally to distinguish between E and W, but not between N and S.
- Floor: floor texture gradient can be used alone to determine the slope direction in every orientation. Indeed, note that it can be used locally also to distinguish N from S: the floor appears closer and it has larger texture when facing uphill compared with downhill.
- Objects: by looking at the bases of the objects (benches), one can determine the slope direction in every orientation. Indeed, note that benches can be used locally also to distinguish N from S (the base of the bench forms a wedge that is oriented differently).
- Top of the image: the ceiling (indoor) or sky (outdoor) of the environment was analyzed because it covered a large area of the image surface. However, it was not locally informative of the slope direction.(1)
- Center of the image: a portion of the image, not part of the abovementioned AOIs, was analyzed because it covered the center (in the indoor environment only). However, this area was not locally informative of the slope direction.

---

(1) Note that the uphill direction may be identified—at least in some orientations—by using other sources of information from the image. For example, the sky (or ceiling) covers a greater portion of the image in S than in N. Therefore, this AOI could be regarded as informative for solving the task, even though not at a local level, because you would need to consider the size of the whole portion of sky—a relatively large chunk of the visual field. In comparison, think of the floor: a small area of this is sufficient to infer the uphill direction because it has texture gradient.

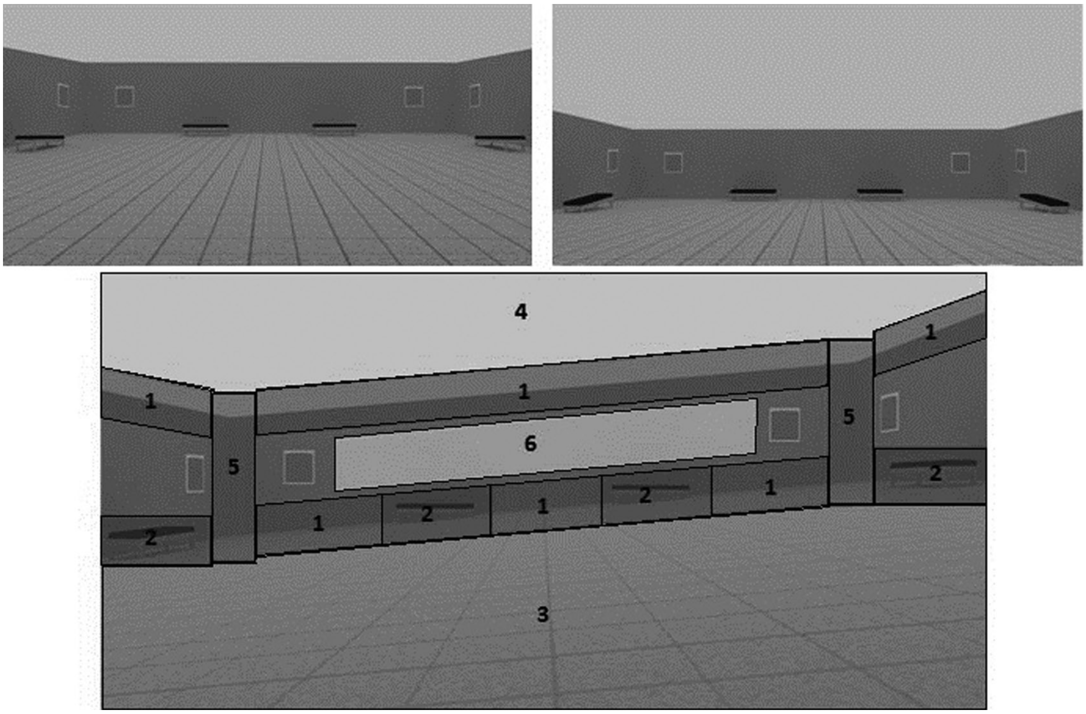

Figure 1. Sample of 3 (of the 4) image stimuli presented for the indoor environment: N orientation in the top-left corner, S in the top-right corner, and W in the bottom. The size of the image in the bottom is enlarged to show the areas of interest selected. They are labeled in the following way: (1) main terrain lines, (2) objects (benches), (3) floor, (4) ceiling, (5) angles (between walls and floor), (6) center. A preliminary analysis revealed that the paintings were fixated for only 0.6% of the overall fixation time. Note that the stimuli used were color images.

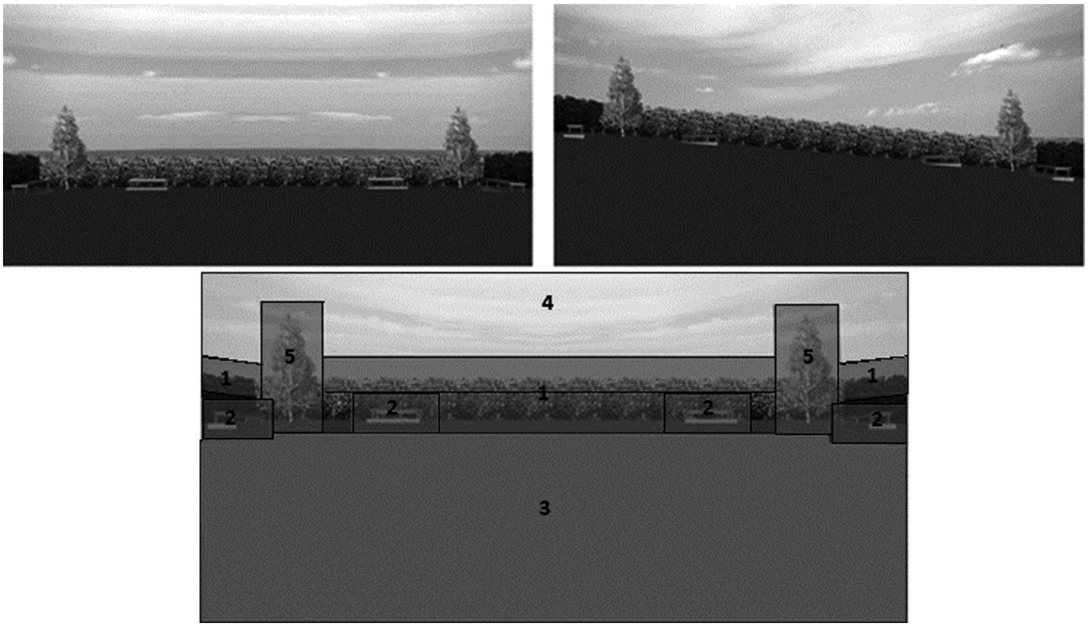

Figure 2. Sample of 3 (of the 4) image stimuli presented for the outdoor environment: S orientation in the top-left corner, E in the top-right corner, and N in the bottom. The size of the image in the bottom is enlarged to show the areas of interest selected. They are labeled in the following way: (1) main terrain lines, (2) objects (benches), (3) floor, (4) sky, and (5) angles (between trees and ground). Note that the stimuli used were color images.

If there are different visual strategies, a straightforward hypothesis based on the above-mentioned literature would predict women to fixate more the distinct objects and men more the global features of the environment, such as the main terrain lines and the floor. Alternatively, if there are no sex-specific visual strategies with slope cue use, we expect men and women to attend similar AOIs. In this case, we predict more fixations to be directed to the more informative slope cues—that is, those that can be used to identify uphill in all orientations (floor and objects). Finally, because all the slope cues can be used to distinguish between the E and W orientations (4 AOIs: lines, angles, floor, and objects), but only two slope cues can be used to distinguish between N and S (floor and objects), we expect that solving the task will be easier in E and W compared with N and S. This should be measured in longer latency and/or reduced accuracy in N and S compared with E and W.

2 Methods

2.1 *Apparatus*

First we constructed two square, symmetric, tilted, computerized 3-D VEs using a 3-D modeling software (Google SketchUp™). Then bidimensional images (1366 × 674 pixels) were extracted from a point of view of 1.70 m (eye height), and presented on a 22 inch LCD computer monitor (see figure 3). Participants sat approximately 70 cm in front of the monitor (1680 × 1050 pixels). Horizontal field of view was approximately 31 deg.

Eye movements were recorded with a remote eye-tracker (RED 500, SensoMotoric Instruments), with a frequency of sampling of 500 Hz and an accuracy of 0.4 deg. A 9-point calibration was performed before starting the experiment, followed by validation.

2.2 *Virtual environments*

The environments represented an indoor and an outdoor scene (see figures 1 and 2). In both cases the environments were square, with a 5° inclination. Presented images reproduced four different perspectives in each environment, facing each side of the square. The perspectives are called, for practicality, N, S, E, and W, on the basis of considering the uphill direction as north. In each environment all sides had the same objects, and they were arranged symmetrically on each side. Therefore, the environments were fourfold ambiguous, except for the presence of the slant. The indoor environment consisted of a square room containing, on each side, two benches and two paintings symmetrically placed. The outdoor environment consisted of a square yard surrounded by a hedge, which contained, on each side, two benches and two trees.

2.3 *Areas of interest*

As shown in figures 1 and 2, within each environment we chose the following general AOIs: floor/ground, objects (benches), main terrain lines, and angles (between vertical elements and ground). We also included the following areas, even though they were not locally informative: top of the image (ceiling for indoor, and sky for outdoor environment), and center of the image (for indoor environment only). In the indoor environment, another AOI was also included—the paintings (see figure 1). However, a preliminary analysis of the data revealed that, overall, the paintings were fixated for only 0.6% of the total fixation time. Because of its trivial role, and in order to increase variance homogeneity, this AOI was not included in the following analyses.

2.4 *Participants*

Participants were twenty male and twenty female undergraduate students from the Sapienza University of Rome, between 20 and 32 years old. The average ages were 25.7 years for males (SD = 4.1 years) and 25.3 years for females (SD = 3.3 years). All subjects participated on a voluntary basis and had normal or corrected-to-normal vision.

2.5 *Preliminary questions and assessment of visual functions*

Initially, participants indicated their age, height, and weight. Height and weight were collected to examine whether measures of body structure (like height of center of body mass) correlated with sensitivity to slope, as measured by RT and accuracy in the reorientation task. Furthermore, in order to examine a possible relationship with performance in the reorientation task, a battery of tests of visual functions was administered. The tests evaluated: visual acuity, the ability of accommodation, and stereo acuity (assessed by the Stereo Fly test, Stereo Optical Co, Inc). Overall, this phase took approximately 10 min. Then the reorientation task began.

2.6 *Experimental procedure*

Participants were instructed that, in each trial, they were going to be presented with an image of an environment and had to indicate the uphill side, imagining that they were in the center of that environment with the orientation purported in the image. The experimenter ensured that the subjects understood the task before starting. They were told to be as accurate as possible, but that they would also be timed. The task consisted of two blocks of training trials followed by one block of test trials. This sequence was completed for both environments, in counterbalanced order within each sex (half of the male and female sample started with the indoor environment, and the other half with the outdoor environment). Each block was composed of 4 trials; in each trial an image of one of the 4 orientations (N, S, E, W) was presented in random order. A summary of the procedure is shown in figure 3.

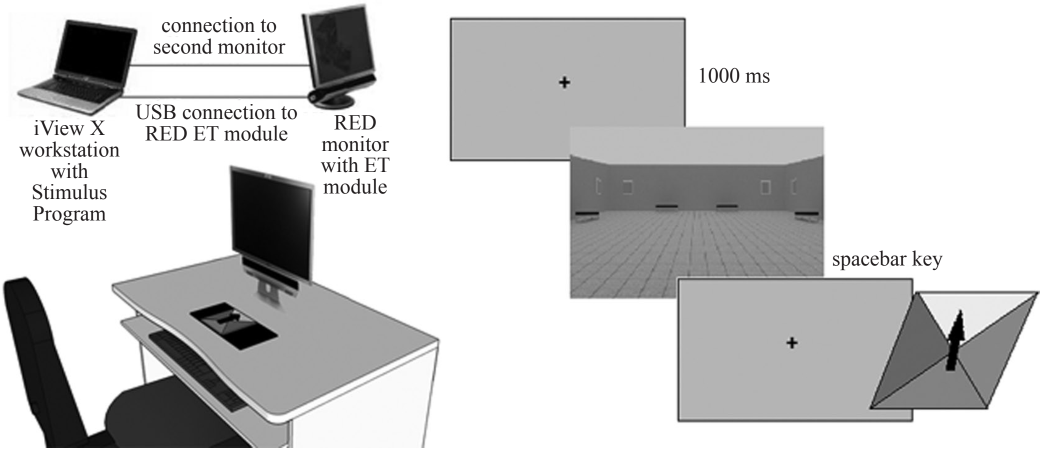

Figure 3. Schematic representation of the experimental set-up and of the stimuli presentation. Participants viewed the image as long as they wanted. When ready, they had to press spacebar, at which point the image disappeared and they had 5 s to indicate the uphill direction with the pointer, imagining that they were in the center of the environment in the same orientation purported in the image. Eye movements were recorded with a remote eye-tracker (RED 500, SensoMotoric Instruments).

In each trial, after 1 s presentation of a white screen with central fixation point, the image appeared; and, when the participant was ready to answer, he or she had to press the spacebar on a keyboard placed near at hand. (Subjects were instructed not to lower their eyes before pressing the spacebar, in order to keep recording their gaze for the whole image presentation.) At this point the image disappeared and a white screen with central fixation point appeared. The subject had 5 s to indicate his or her answer using a pointer, which consisted of a square piece of cardboard (15 cm × 15 cm) with an arrow that could be rotated in 4 quadrants: forward, backward, left, or right (see figure 3). Participants were told if they were correct; and, if incorrect, the correct answer was given. In the test block the procedure was the same as for training, except that no feedback was given, and that the image stimuli presented were slightly more zoomed in compared with those used during training.

2.7 *Psychometric tests*

After the task, each participant took two psychometric tests. These tests assessed different spatial abilities and were administered in order to examine a possible relationship with the slope task. These were the water level test (WLT) (Piaget & Inhelder, 1956; we used the test devised by Liben, 1995), which assesses the use of the gravity reference frame for inferring the level of a liquid in a tilted bottle, and the mental rotation test (MRT) (Vandenberg & Kuse, 1978; adapted by Peters et al., 1995), which requires the ability to change the orientation of a mental representation of an object. These psychometric tests were placed and completed on a flat desk.

2.8 *Analyses*

RT was calculated as the time elapsed between the onset of the image and the spacebar key press. Only statistically significant effects according to an α-level of 0.05 are reported. Following significant main effects in the omnibus ANOVAs, a posteriori tests were carried out using Sidak's correction for multiple comparisons.

3 Results

3.1 *Performance*

statistically significant ($r_{38} = 0.215$, $p = 0.182$), suggesting t The correlation between RT and number of errors committed during the task was not hat there was not a significant speed–accuracy trade-off in the task.

3.1.1 *Accuracy.* Considering the cumulative number of errors that each subject committed in the experiment (total of 24 trials: 2 environments × 3 blocks × 4 trials), the sample as a whole pointed to the correct direction significantly above chance (25% correct) ($t_{39} = 64.42$, $p < 0.001$). When breaking down the sample by sex, both men ($t_{19} = 48.68$, $p < 0.001$) and women ($t_{19} = 51.27$, $p < 0.001$) performed significantly above chance. However, the error rate for women ($M = 10.2\%$, SD = 5.7) was significantly higher than for men ($M = 4.6\%$, SD = 6.5; $t_{38} = 2.93$, $p = 0.006$, $d = 0.95$).

The overall number of errors committed in the N and S orientation was significantly higher than in E and W (65 vs 6, respectively), even when considering separately males (nineteen vs three, respectively) and females (forty six vs three, respectively) (binomial tests, ps < 0.001). Participants did not commit a significantly different number of errors between the N and S orientation (37 vs 28, respectively), even when considering separately men (twelve vs seven, respectively) and women (twenty five vs twenty one, respectively) (binomial tests, ps > 0.32). The most common type of error was a 180° error (eg pointing backward when the correct answer is forward), which was committed significantly more frequently than a 90° error (58 vs 13, respectively), even when considering separately males (seventeen vs five, respectively) and females (forty one vs eight, respectively) (binomial tests, ps < 0.05). In sum, participants erred most frequently by mistaking N for S and S for N. The number of errors did not differ significantly between the indoor and outdoor environment (34 vs 37, respectively), even when considering separately males (nine vs thirteen, respectively) and females (twenty five vs twenty four, respectively) (binomial tests, ps > 0.52).

Figure 4 represents the average error rate separately for the N + S and the E + W orientations during the blocks in both environments, in the order they were chronologically experienced by the participants (ie training 1, training 2, test for the first experienced environment, and then training 1, training 2, test for the second experienced environment, whichever it was). When the error rate was analyzed with a 2 (sex) × 2 (first vs second experienced environment) × 2 (N + S vs E + W) mixed ANOVA, the following main effects were found to be statistically significant. Error rates—again—were higher for women than for men ($F_{1,38} = 8.58$, $p = 0.006$, $\eta_p^2 = 0.18$). Furthermore, errors declined from the first to the second experienced environment ($F_{1,38} = 9.68$, $p = 0.004$, $\eta_p^2 = 0.20$), and more errors were committed in the

N + S orientations than in the E + W orientations ($F_{1,38} = 46.09$, $p < 0.001$, $\eta_p^2 = 0.55$). The only significant interaction was sex by orientation ($F_{1,38} = 9.65$, $p = 0.004$, $\eta_p^2 = 0.20$), qualified by the fact that, while both sexes committed significantly more errors in the N and S orientation than in E and W (Sidak, *p*s < 0.05), women committed significantly more errors than men only in the N and S orientation (Sidak, $p < 0.01$).

3.1.2 *Reaction time.* Reaction time was analyzed using a mixed ANOVA with sex as between-subject factor and environment (indoor, outdoor), block (training 1, training 2, and test), and orientation (N, S, E, W) as within-subject factors. There was a significant main effect of block ($F_{2,76} = 34.50$, $p < 0.001$, $\eta_p^2 = 0.47$); a posteriori tests revealed that RT in training 1 was significantly longer than in training 2 and in test (Sidak, $p < 0.001$). There was also a significant main effect of orientation ($F_{3,114} = 40.29$, $p < 0.001$, $\eta_p^2 = 0.52$); RTs were significantly higher in N and S compared with E and W (Sidak, *p*s < 0.001). Furthermore, there was a significant main effect of sex ($F_{1,38} = 4.35$, $p = 0.044$, $\eta_p^2 = 0.10$), with men ($M = 2752$ ms, SD = 1328) quicker than women ($M = 3591$ ms, SD = 2007; $d = 0.66$). The main effect of environment was not significant ($F_{1,38} = 0.06$, $p = 0.806$, $\eta_p^2 = 0.002$).

There was a significant sex-by-orientation interaction ($F_{3,114} = 2.98$, $p = 0.044$, $\eta_p^2 = 0.07$); a posteriori *t*-tests revealed that men responded quicker than women in the N and S orientation (*p*s < 0.035), but not in E and W (*p*s > 0.210).

There was also a significant three-way interaction among environment, block, and orientation ($F_{6,228} = 3.39$, $p = 0.017$, $\eta_p^2 = 0.08$). This was qualified by the fact that, in the outdoor environment training block 1, the simple effect of orientation was different from the prevailing main effect described above: only in this block RTs in N and S were significantly longer than W (but not E) (Sidak, $p < 0.05$). All other interactions were not significant.

Figure 4 represents the average RT separately for the N + S and the E + W orientations during the blocks in both environments, in the order they were chronologically experienced by the participants (ie training 1, training 2, test for the first experienced environment, and then training 1, training 2, test for the second experienced environment, whichever it was). When RT was analyzed with a 2 (sex) × 2 (first vs second experienced environment) × 2 (N + S vs E + W) mixed ANOVA, the following main effects were found to be statistically significant. Again, women were slower in responding compared with men ($F_{1,38} = 4.35$, $p = 0.044$, $\eta_p^2 = 0.10$). Furthermore, RT declined from the first to the second experienced environment ($F_{1,38} = 52.21$, $p < 0.001$, $\eta_p^2 = 0.58$), and RT was higher in the N + S orientations than in the E + W orientations ($F_{1,38} = 125.29$, $p < 0.001$, $\eta_p^2 = 0.77$). There was also a significant sex-by-orientation interaction ($F_{1,38} = 9.57$, $p = 0.004$, $\eta_p^2 = 0.20$), qualified by the fact that, while both sexes were significantly slower in responding in the N and S orientation compared with E and W (Sidak, *p*s < 0.001), women were significantly slower than men only in N and S (Sidak, $p < 0.05$).

3.2 *Eye-tracking data*

Both fixation time and number of fixations were analyzed, but because the two dependent variables showed identical patterns, for brevity we report results of only fixation time.

3.2.1 *Indoor environment.* The AOIs considered were the following: floor, objects (benches), main terrain lines, angles (between walls and floor), center, and top of the image (ceiling). Fixations were analyzed using a mixed ANOVA with sex as between-subjects factor and block (training 1, training 2, test), orientations (N, S, E, W), and AOIs as within-subject factors. There was a significant main effect of AOI ($F_{5,190} = 20.462$, $p < 0.001$, $\eta_p^2 = 0.35$); the floor, the lines, and objects were fixated significantly longer compared with ceiling, angles, and center (Sidak, *p*s < 0.05); furthermore, the center was fixated more than the ceiling

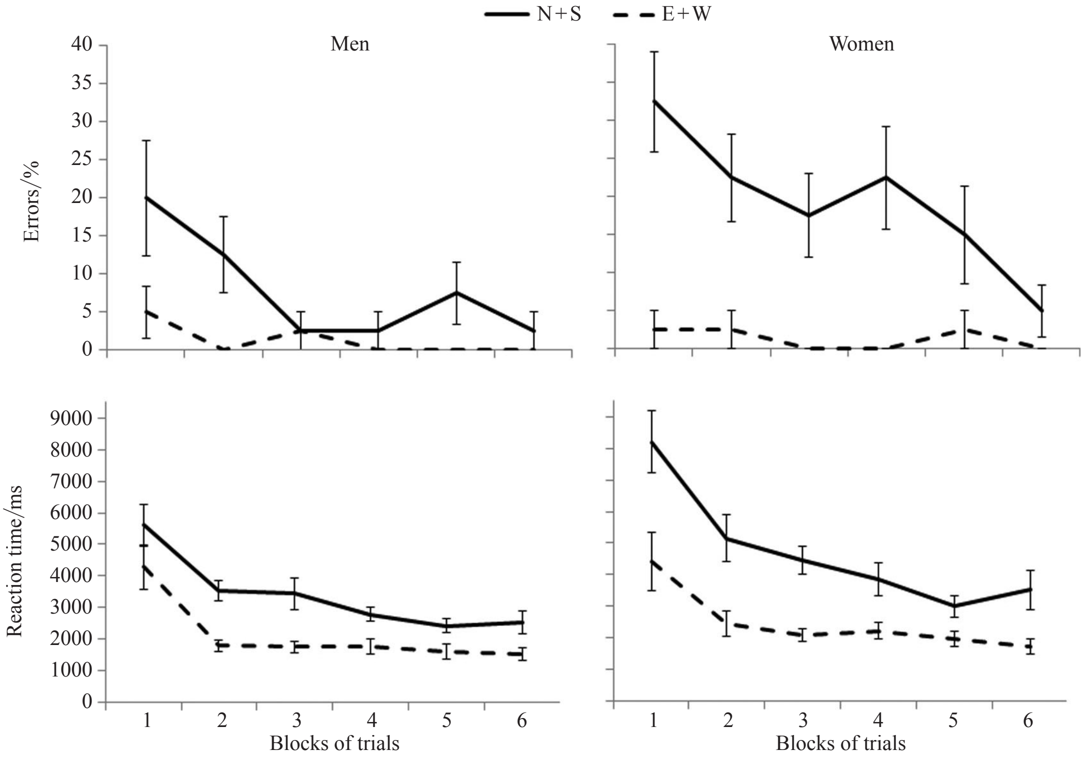

Figure 4. Graphs representing task performance (average error rates at the top, and average RT at the bottom) during the blocks of trials in the indoor and outdoor environment, in the order they were chronologically experienced by the participants. Blocks 1–3 represent the first environment (training 1, training 2, test), and blocks 4–6 represent the second experienced environment, whichever it was. Error rates and RT were significantly higher in the N and S orientations than in E and W, and they declined significantly from the first to the second experienced environment. Women committed significantly more errors and were significantly slower than men only in the N and S orientations. Error bars of the graphs represent SEM.

(Sidak, $p < 0.05$). The main effect of orientation was statistically significant ($F_{3,114} = 20.952$, $p < 0.001$, $\eta_p^2 = 0.36$), with fixation times significantly longer in N and S compared with E and W (Sidak, ps < 0.05). Furthermore, there was a significant main effect of block ($F_{2,76} = 8.720$, $p = 0.002$, $\eta_p^2 = 0.19$); fixation times decreased monotonically during the task, and they were significantly longer in training 1 compared with training 2 and test.

There was a significant orientation-by-AOI interaction ($F_{15,570} = 7.618$, $p < 0.001$, $\eta_p^2 = 0.17$). The floor was fixated significantly longer in N compared with E and W, and in S compared with E; the lines were fixated significantly more in S compared with E; landmarks were fixated significantly longer in N and S compared with E and W; the center was fixated significantly longer in W compared with N and S; and the ceiling was fixated significantly more in S compared with all other orientations (Sidak, ps < 0.05); fixation time at the angles did not change significantly among orientations (Sidak, $p > 0.05$). Putting the interaction a different way, the floor, lines, and landmarks were fixated longer than angles and ceiling in every orientation (Sidak, ps < 0.05); in N and S these more-attended AOIs (floor, lines, and landmarks) were also fixated longer than the center, but in E only landmarks were fixated longer than the center, and in W the center was not fixated differently from floor, lines, and landmarks (Sidak, ps < 0.05).

There was also a significant block-by-AOI interaction ($F_{10,380} = 2.870$, $p = 0.029$, $\eta_p^2 = 0.07$); this was qualified by a significant reduction of fixation time for floor (training 1 compared to training 2), and lines (training 1 compared with test); for all other AOIs the change of fixation time throughout the task was not significant (Sidak, *p*s > 0.05), probably because of a floor effect. All other interactions were not significant.

To summarize, the main results were: (1) the floor, lines, and objects were fixated significantly longer compared with ceiling, angles, and center; (2) fixation times were significantly longer in N and S compared with E and W; (3) fixations were significantly longer in training 1 block compared with the training 2 and test blocks; (4) no significant main effect of sex and no significant interactions involving sex were found.

3.2.2 *Outdoor environment.* The AOIs considered were the following: floor, objects (benches), main terrain lines, angles (between trees and ground), and top of the image (sky). Fixations were analyzed using a mixed ANOVA with sex as between-subjects factor and block (training 1, training 2, test), orientations (N, S, E, W), and AOIs as within-subject factors. There was a significant main effect of AOI ($F_{4,152} = 17.404$, $p < 0.001$, $\eta_\mathrm{p}^2 = 0.31$); the floor, lines, and objects were fixated significantly longer than the angles and sky (Sidak, *p*s < 0.05). The main effect of orientation was significant ($F_{3,114} = 17.378$, $p < 0.001$, $\eta_\mathrm{p}^2 = 0.31$), with N significantly more fixated than W, and S more fixated than E and W (Sidak, *p*s < 0.05). Furthermore, there was a significant main effect of block ($F_{2,76} = 19.158$, $p < 0.001$, $\eta_\mathrm{p}^2 = 0.34$); fixation time was significantly longer in training 1 compared with training 2 and test (Sidak, *p*s < 0.05).

There was a significant orientation-by-AOI interaction ($F_{12,456} = 7.136$, $p < 0.001$, $\eta_\mathrm{p}^2 = 0.16$). The floor was fixated significantly more in N compared with E and W; the lines were fixed more in S than any other orientation; the objects were fixated more in N, S, and E compared with W, and more in S compared with E; the sky was fixated significantly more in S than any other orientation, and less in N than any other orientation (Sidak, *p*s < 0.05); fixation time to the angles did not change depending on the orientation (Sidak, *p*s > 0.05). Putting the interaction a different way, the lines and objects were fixated significantly longer than sky and angles in every orientation (Sidak, *p*s < 0.05). In addition, in N and W the floor was significantly more fixated than sky and angles; in S the floor was more fixated than angles only, and in E the floor was fixated more than sky only; furthermore, in W the lines were fixated significantly more than objects (Sidak, $p < 0.05$).

There was also a significant block-by-AOI interaction ($F_{8,304} = 4.948$, $p = 0.002$, $\eta_\mathrm{p}^2 = 0.12$); this was qualified by a significant reduction of fixation time for floor, lines, and objects from training 1 compared with training 2 and test (Sidak, *p*s < 0.05); for all other AOIs the change of fixation time throughout the task was not significant (Sidak, *p*s > 0.05), probably because of a floor effect.

Finally, there was a significant block-by-orientation-by-AOI interaction ($F_{24,912} = 2.369$, $p = 0.020$, $\eta_\mathrm{p}^2 = 0.06$). This three-way interaction was driven by the fact that—while the orientation-by-AOI interaction did not change during the blocks for objects, sky, and angles (described above)—the pattern of fixations for the floor and lines changed during the blocks: fixations to floor did not change depending on the orientation in training 1, but in training 2 the floor was fixated more in N than E, and in test the floor was fixated more in N and S than E (Sidak, *p*s > 0.05); furthermore, fixations to lines were significantly longer in S than any other orientation in training 1, but did not change among orientations in training 2 and test (Sidak, *p*s > 0.05). All other interactions were not significant.

To summarize, the main results were: (1) the floor, lines, and objects were fixated significantly longer than the angles and sky; (2) fixation times in N were significantly longer than in W, and fixation times in S were significantly longer than in E and W; (3) fixations were significantly longer in training 1 block compared with training 2 and test blocks; (4) no significant main effect of sex and significant interactions involving sex were found.

3.2.3 *Further analyses.* We examined whether participants who committed more errors were attending different AOIs compared with better performers. In order to address this, we considered only N and S orientations, which were the orientations where the overwhelming majority of errors were committed. An aggregate fixation time to AOIs (floor, objects, main terrain lines, angles, and top of the image) was calculated for each participant averaging across all blocks and both environments. We divided the sample into two performance groups: those who committed 0 or 1 error (better performers = twenty-one subjects; sixteen men and five women) and those who committed 2 or more errors (poor performers = nineteen subjects; four men and fifteen women). A mixed ANOVA (type-III sum of squares) was used, with aggregate fixation time as dependent variable, performance group (better and poor performers) and sex as between-subjects factor, and AOI as within-subject factor. A significant main effect of AOI was found ($F_{4,144} = 15.199$, $p < 0.001$, $\eta_p^2 = 0.30$); but, crucially, the pattern of fixations to AOIs was not significantly different between better and poor performers (group-by-AOI interaction) ($F_{4,144} = 0.770$, $p = 0.547$, $\eta_p^2 = 0.02$), and—again—between men and women (sex-by-AOI interaction) ($F_{4,144} = 1.312$, $p = 0.268$, $\eta_p^2 = 0.04$). Furthermore, poor performers did not exhibit longer overall fixations than better performers (main effect of group) ($F_{1,36} = 0.000$, $p = 0.998$, $\eta_p^2 = 0.00$), but women exhibited significantly longer overall fixations than men (main effect of sex) ($F_{1,36} = 5.730$, $p = 0.022$, $\eta_p^2 = 0.14$). Other interactions were not significant (*p*s > 0.05).

3.3 *Psychometric and visual tests*

There were no significant differences between men and women in the WLT ($t_{38} = 0.582$, $p = 0.564$, $d = 0.18$) or in the MRT ($t_{38} = 1.857$, $p = 0.071$, $d = 0.59$). Considering the battery of visual tests, there were no significant differences between sexes (*t*-test, *p*s > 0.216).

We were interested in the visual and psychometric correlates of performance in the slope task, and they are reported in table 1. Noteworthy, we found a significant negative correlation between MRT scores and number of errors committed, and a negative correlation between visual acuity and RT (see table 1); these correlations were significant even when controlling for sex ($r_{37} = -0.380$, $p = 0.017$, and $r_{37} = -0.399$, $p = 0.012$, respectively). Even though outside the scope of our study, there was a significant correlation between height of the participants and MRT scores ($r_{38} = 0.336$, $p = 0.034$); furthermore, stereoacuity correlated with WLT ($r_{38} = 0.340$, $p = 0.032$) and with participant's weight–height ratio ($r_{38} = -0.375$, $p = 0.017$).

Table 1. Correlations between performance in the reorientation task [reaction time (RT) and accuracy] and psychometric and visual tests (*p*-values in parentheses).

Variable	WLT	MRT	Weight	Height	W/H	Stereopsis	Acuity	Accom.
RT	–0.306	–0.169	–0.257	–0.159	–0.242	0.035	–0.405*	–0.091
	(0.055)	(0.296)	(0.109)	(0.327)	(0.132)	(0.830)	(0.010)	(.575)
Number of errors	–0.271	–0.452**	–0.096	–0.100	–0.086	0.104	–0.056	0.194
	(0.090)	(0.003)	(0.554)	(0.538)	(0.598)	(0.521)	(0.731)	(.231)

* $p < 0.05$, ** $p < 0.01$.

Notes. WLT = water level test; MRT = mental rotation test; W/H = participants' weight–height ratio; Accom. = accommodation.

4 Discussion

Our experiment tested for the first time the ability to infer the uphill direction of a sloped environment from 2-D images, while assessing the visual cues used with an eye-tracking device. We provided images of different perspectives taken from two VEs—one indoor and one outdoor. The main results are in agreement between the two environments, and support the following conclusions. Overall, the most attended slope cues were the floor, the objects, and the main terrain lines. Even though fixations to AOIs changed depending on the orientation, these cues were fixated significantly longer throughout the whole task, suggesting that participants were mainly using these cues to solve the task. The floor and objects were probably fixated longer because they can be used alone to determine uphill in all orientations. As such, they are more informative and reliable slope cues. Regarding the main terrain lines, even though they cannot be used locally to distinguish between N and S (they are horizontal in both orientations), they were probably fixated longer because very salient; when looking at the sides of a hill (orientation E and W), the main terrain lines appear tilted relative to the gravity-defined horizontal—a macroscopic sign of geographical slant (Proffitt, Creem, & Zosh, 2001). Furthermore, our data indicate that reorientation was not equally demanding in all orientations. Fixations were generally longer in N and S compared with E and W. This result is matched by the performance data, which showed longer latencies and more errors in N and S. It can be concluded that identifying uphill on a slant is easier when looking sideways, and more difficult when directly facing the top or the bottom of the hill. Many factors could be responsible for this. One could be the general richness of slope cues that can be used to distinguish between E and W (4 AOIs), compared with the fewer slope cues that can be used to distinguish between N and S (only 2 AOIs). Another factor could be that one of the three most attended slope cues—the main terrain lines—is not informative of the distinction between N and S, rendering judgments in these orientations more difficult. Furthermore, E and W might be ecologically more salient because, when standing on a slope facing sideways, there is a large body weight asymmetry on the feet. Of course, it is important to emphasize that we used a moderate inclination (5°), and results might be different with steeper slopes.

The main purpose of our study was to examine sex differences in the ability to solve the task and in the visual-processing strategies employed. We found consistent evidence in support of a female disadvantage in performance. When having to identify the uphill direction of two sloped, VEs presented through images on a computer screen, women took longer time and committed more errors than men. This was true, specifically, for the N and S orientations—where the uphill direction is more difficult to infer. Even though participants improved considerably with training and learned to better distinguish N and S, women were generally more likely to confuse these two orientations than men. This result adds to the literature showing a male advantage in visuospatial tasks (D. M. Kelly & Bischof, 2005; Lawton & Morrin, 1999; Linn & Petersen, 1985; Moffat et al., 1998; Sandstrom et al., 1998). More importantly, it suggests that the female difficulty reorienting with slope (Nardi et al., 2011) emerges at a lower, perceptual level of processing—identifying the slope direction—and it is not just present when spatial memory or strategy selection are involved. In order to use terrain slope to encode a target location or to navigate, two preliminary steps are required: one must detect the presence of ground tilt and must identify a direction of reference. Although this may theoretically be any direction extracted from the slope gradient, perceptual salience dictates a privileged status for the vertical axis (uphill–downhill), as it is the direction of steepest ascent and descent, and is associated with most effort (J. Kelly, 2011; Nardi et al., 2011). Evidence gathered to date suggests that females have difficulty in both of these steps: Holmes et al. (under review) found that females (children in this case) are significantly less likely to notice the presence of underfoot slope; and the present study revealed that, when the environment is known to be sloped, females have also a disadvantage in identifying the direction of reference. Our result confirms and extends a previous finding of female difficulty inferring the uphill direction using a real-world, walkable slope (Nardi et al., 2011); in that case, however, women exhibited only longer latencies, and accuracy was not significantly lower with respect to men. Importantly, the similarity of the results using different stimuli presentation (real environment vs VE) suggests that the female underperformance in the present study was not due to a general poor understanding of the 2-D images, but to a specific difficulty identifying uphill. This difficulty, together with that of detecting slope, might underlie the female disadvantage found in more complex tasks that deal with slope and involve spatial memory (Holmes et al., under review; Nardi et al., 2011), reference frame selection (Weisberg et al., 2014), and strategy choice (Chai & Jacobs, 2009, 2010).

Furthermore, the findings of the present study suggest that, in order to explain the female difficulty with slope, a less efficient integration of vision and kinesthesia does not have to be invoked (Barnett-Cowan et al., 2010; Berthoz & Viaud-Delmon, 1999). It is sufficient to hypothesize that women's visual contribution to slope reorientation is less efficient, and that this impairs their performance even when all sensory inputs are available. To the best of our knowledge, only one study has addressed the issue of modality input for slope representation (Weisberg et al., 2014), and this has provided no evidence in support of poorer multisensory integration for women; a female difficulty (longer RT) was found, but not significantly different among a visual-only, a kinesthetic-only, and a visual-plus-kinesthetic condition. This result suggests that females might have also a difficulty with kinesthetic cues alone—a result not found in other types of kinesthetic tasks (eg Alvis, Ward, & Dodson, 1989; Livesey & Intili, 1996). Further research on the contribution of kinesthetic cues for slope reorientation is necessary; but according to data gathered to date, the female disadvantage may be determined by a difficulty in unisensory processing of slope—at least with visual cues.

Considering the eye-tracking data, there were no significant differences based on sex. In particular, we found no significant differences between men and women with respect to which slope cues were most fixated. Both sexes relied mostly on the floor, the main terrain lines, and the objects in the environment. Therefore, our study does not support the hypothesis of sex-specific visual-processing strategies; as such, it also does not lend support to the hypothesis that females are outperformed because they rely on different, less effective visual strategies compared with men. Sex differences in gaze behavior have been reported, and they tend to show that females have longer average fixations to salient, task-relevant cues (Campagne, Pebayle, & Muzet, 2005; Miyahira, Morita, Yamaguchi, Morita, & Maeda, 2000; Mueller, Jackson, & Skelton, 2008), and greater reliance on landmarks for visual navigation (Andersen et al., 2012). More relevant to this study, in some cases men have been shown to rely more on directional cues (including slope) and women more on positional cues (including landmarks) presented visually (Barkley & Gabriel, 2007; Chai & Jacobs, 2009, 2010). The present study is more in line with Nardi et al. (2013), which also did not find evidence of sex-specific strategy preference for slope. All the available visual cues in the present experiment were slope related, in the sense that they provided no spatial information other than regarding the direction of the slope gradient. In particular, there were no beacons, landmarks or geometric cues because the environment was fourfold rotationally ambiguous (all the cues were symmetrically placed on each side). It is thus possible that sex-specific preferences apply only between heterogeneous types of information (eg between directional and positional cues), but considering slope information alone, men and women rely on similar visual cues.

If women do not use less efficient slope cues, then why are they outperformed? Better performers did not rely on different slope cues compared with poor performers. Furthermore, there was no correlation between performance and measures of body structure, such as height, weight, and their ratio. To the best of our knowledge, this was the first study to consider whether people with a higher center of body mass (less stable balance) are more sensitive to slope, but the lack of significant relationship may be due to the experimental set-up (purely visual stimuli presented with the participant sitting on a chair). Of course, this question would be addressed better if subjects had to identify the slope by moving on it.

We were also interested in testing if measures of visual functions and psychometric tests of spatial ability correlated with performance in the task. Regarding the visual functions, we found only that participants with higher visual acuity displayed shorter RTs. This makes intuitive sense in a visual task where subjects are timed: if you can see more clearly, you can also identify the uphill direction more quickly. More interesting were the results regarding the tests of spatial abilities: we discovered a significant correlation between accuracy in the slope task and score in the MRT (but not in the WLT). This might reflect a role of general spatial intelligence. Alternatively, it could be related to a spatial memory comparison factor that is not present in the WLT. Participants' most frequent error was to confuse N with S, and the fact that errors declined with training suggests that participants learned to distinguish more effectively the two orientations, perhaps by mentally comparing how N and S look. Another possibility could be that performing accurately in the reorientation task involves an important component of mental rotation ability. Perhaps this mental transformation was required to infer the goal direction (uphill) from the presented view. Women are known to have a disadvantage in mental rotation (Linn & Petersen, 1985; Voyer et al., 1995); and, even in our sample, their score in the MRT was numerically, but not significantly, lower than men. Therefore, it can be proposed that women performed worse because of an associated difficulty with mentally rotating the representation of the environment from the given view to the uphill direction. We speculate that this factor might also play a role in real-world, navigable environments: females' disadvantage reorienting with slope might be related to a difficulty updating their orientation relative to the vertical axis. There is abundant evidence indicating that women are outperformed in tasks that involve spatial updating ability (eg J. W. Kelly, McNamara, Bodenheimer, Carr, & Rieser, 2009; Lawton & Morrin, 1999; Lawton et al., 1996; Sholl, Acacio, Makar, & Leon, 2000), and it has also been suggested that spatial strategies that require being oriented relative to the environment (as opposed to following a route strategy) might be less preferred by women (Dabbs, Chang, Strong, & Milun, 1998; Lawton, 1994; Saucier et al., 2002). Therefore, even though spatial updating is improved when self-motion is added to visual input (Chance, Gaunet, Beall, & Loomis, 1998; Klatzky, Loomis, Beall, Chance, & Golledge, 1998), it is possible that the difficulty with updating may also impair performance in real-world, walkable slopes (Holmes et al., under review; Nardi et al., 2011). In this regard, it is worth noting that previous studies (eg Nardi et al., 2011, 2013) have not administered tests of mental rotation to participants.

In conclusion, this is the first report of a sex difference in the ability to identify uphill when the slope is presented visually, and it raises the possibility that poor mental rotation ability may be responsible for the female difficulty. Further research is necessary to examine this relationship, and especially whether this generalizes to real, navigable environments, so that the characterization of a major female disadvantage in spatial cognition will become clearer.

Acknowledgments. This research was supported by a Marie Curie International Reintegration Grant within the 7th European Community Framework Programme.

References

Alvis, G. R., Ward, J. R., & Dodson, D. L. (1989). Equivalence of male and female performance on a tactuo-spatial maze. *Bulletin of the Psychonomic Society*, **27**, 29–30.

Andersen, N. E., Dahmani, L., Konishi, K., & Bohbot, V. D. (2012). Eye tracking, strategies, and sex differences in virtual navigation. *Neurobiology of Learning and Memory*, **97**, 81–89.

Barkley, C. L., & Gabriel, K. I. (2007). Sex differences in cue perception in a visual scene: Investigation of cue type. *Behavioral Neuroscience*, **121**, 291–300.

Barnett-Cowan, M., Dyde, R. T., Thompson, C., & Harris, L. R. (2010). Multisensory determinants of orientation perception: Task-specific sex differences. *European Journal of Neuroscience*, **31**, 1899–1907.

Berthoz, A., & Viaud-Delmon, I. (1999). Multisensory integration in spatial orientation. *Current Opinion in Neurobiology*, **9**, 708–712.

Campagne, A., Pebayle, T., & Muzet, A. (2005). Oculomotor changes due to road events during prolonged monotonous simulated driving. *Biological Psychology*, **68**, 353–368.

Chai, X. J., & Jacobs, L. F. (2009). Sex differences in directional cue use in a virtual landscape. *Behavioral Neuroscience*, **123**, 276–283.

Chai, X. J., & Jacobs, L. F. (2010). Effects of cue types on sex differences in human spatial memory. *Behavioural Brain Research*, **208**, 336–342.

Chance, S. S., Gaunet, F., Beall, A. C., & Loomis, J. M. (1998). Locomotion mode affects the updating of objects encountered during travel: The contribution of vestibular and proprioceptive inputs to path integration. *Presence*, **7**, 168–178.

Cheng, K., Huttenlocher, J., & Newcombe, N. S. (2013). 25 years of research on the use of geometry in spatial reorientation: A current theoretical perspective. *Psychonomic Bulletin & Review*, **20**, 1033–1054.

Dabbs, J. M. Jr., Chang, E. L., Strong, R. A., & Milun, R. (1998). Spatial ability, navigation strategy, and geographic knowledge among men and women. *Evolution & Human Behavior*, **19**, 89–98.

Holmes, C. A., Nardi, D., Newcombe, N. S., & Weisberg, S. M. (under review). Hitting the slopes: Gradient cues in child navigation.

Jacobs, L. F., & Schenk, F. (2003). Unpacking the cognitive map: The parallel map theory of hippocampal function. *Psychological Review*, **110**, 285–315.

Kelly, D. M., & Bischof, W. F. (2005). Reorienting in images of a three-dimensional environment. *Journal of Experimental Psychology: Human Perception and Performance*, **31**, 1391–1403.

Kelly, J. (2011). Head for the hills: The influence of environmental slant on spatial memory organization. *Psychonomic Bulletin & Review*, **18**, 774–780.

Kelly, J. W., McNamara, T. P., Bodenheimer, B., Carr, T. H., & Rieser, J. J. (2009). Individual differences in using geometric and featural cues to maintain spatial orientation: Cue quantity and cue ambiguity are more important than cue type. *Psychonomic Bulletin & Review*, **16**, 176–181.

Klatzky, R. L., Loomis, J. M., Beall, A. C., Chance, S. S., & Golledge, R. G. (1998). Spatial updating of self-position and orientation during real, imagined, and virtual locomotion. *Psychological Science*, **9**, 293–298.

Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles*, **30**, 765–779.

Lawton, C. A., Charleston, S. I., & Zieles, A. S. (1996). Individual- and gender-related differences in indoor wayfinding. *Environment and Behavior*, **28**, 204–219.

Lawton, C. A., & Morrin, K. A. (1999). Gender differences in pointing accuracy in computer-simulated 3D mazes. *Sex Roles*, **40**, 73–92.

Levy, L. J., Astur, R. S., & Frick, K. M. (2005). Men and women differ in object memory but not performance of a virtual radial maze. *Behavioral Neuroscience*, **119**, 853–862.

Liben, L. S. (1995). Educational applications of geographic information systems: A developmental psychologist's perspective. In D. Barstow (Ed.), *First national conference on the educational applications of geographic information systems* (pp. 44–49). Cambridge, MA: TERC.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, **56**, 1479–1498.

Livesey, D. J., & Intili, D. (1996). A gender difference in visuo-spatial ability in 4-year-old children: Effects on performance of a kinesthetic acuity task. *Journal of Experimental Child Psychology*, **63**, 436–446.

Miyahira, A., Morita, K., Yamaguchi, H., Morita, Y., & Maeda, H. (2000). Gender differences and reproducibility in exploratory eye movements of normal subjects. *Psychiatry and Clinical Neurosciences*, **54**, 31–36.

Moffat, S. D., Hampson, E., & Hatzipantelis, M. (1998). Navigation in a "virtual" maze: Sex differences and correlation with psychometric measures of spatial ability in humans. *Evolution & Human Behavior*, **19**, 73–87.

Mueller, S. C., Jackson, C. P., & Skelton, R. W. (2008). Sex differences in a virtual water maze: An eye tracking and pupillometry study. *Behavioural Brain Research*, **193**, 209–215.

Nardi, D., & Bingman, V. P. (2009). Pigeon (*Columba livia*) encoding of a goal location: The relative importance of shape geometry and slope information. *Journal of Comparative Psychology*, **123**, 204–216.

Nardi, D., Mauch, R. J., Klimas, D. B., & Bingman, V. P. (2012). Use of slope and feature cues in pigeon (*Columba livia*) goal-searching behavior. *Journal of Comparative Psychology*, **126**, 288–293.

Nardi, D., Newcombe, N. S., & Shipley, T. F. (2011). The world is not flat: Can people reorient using slope? *Journal of Experimental Psychology: Learning, Memory and Cognition*, **37**, 354–367.

Nardi, D., Newcombe, N. S., & Shipley, T. F. (2013). Reorienting with terrain slope and landmarks. *Memory & Cognition*, **41**, 214–228.

Nardi, D., Nitsch, K. P., & Bingman, V. P. (2010). Slope-driven goal location behavior in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, **36**, 430–442.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse mental rotations test: Different versions and factors that affect performance. *Brain and Cognition*, **28**, 39–58.

Piaget, J., & Inhelder, B. (1956) *The child's conception of space.* London: Routledge.

Proffitt, D. R., Creem, S. H., & Zosh, W. D. (2001). Seeing mountains in mole hills: Geographical-slant perception. *Psychological Science*, **12**, 418–423.

Restat, J. D., Steck, S. D., Mochnatzki, H. F., & Mallot, H. A. (2004). Geographical slant facilitates navigation and orientation in virtual environments. *Perception*, **33**, 667–687.

Sandstrom, N. J., Kaufman, J., & Huettel, S. A. (1998). Males and females use different distal cues in a virtual environment navigation task. *Cognitive Brain Research*, **6**, 351–360.

Saucier, D. M., Green, S. M., Leason, J., MacFadden, A., Bell, S., & Elias, L. J. (2002). Are sex differences in navigation caused by sexually dimorphic strategies or by sex differences in the ability to use strategies? *Behavioral Neuroscience*, **116**, 403–410.

Sholl, J. M., Acacio, J. C., Makar, R. O., & Leon, C. (2000). The relation of sex and sense of direction to spatial orientation in an unfamiliar environment. *Journal of Environmental Psychology*, **20**, 17–28.

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual & Motor Skills*, **47**, 599–604.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, **117**, 250–270.

Weisberg, S. M., Nardi, D., Newcombe, N. S., & Shipley, T. F. (2014). Up by upwest: Is slope like north? *The Quarterly Journal of Experimental Psychology*. doi:10.1080/17470218.2014.880122

Weisberg, S. M., & Newcombe, N. S. (in press). A slippery directional slope: Individual differences in using slope as a directional cue. *Memory & Cognition.* doi:10.3758/s13421-013-0387-5