The effect of terrain on eye movements while walking in the real world

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Introduction

Under natural conditions, humans continuously allocate their gaze according to task demands and environmental constraints. Despite a near century of eye-movement research in laboratory conditions, gaze control during truly real-world behavior is far from understood. With the recent advent of mobile eye-tracking systems measuring eye movements during free behavior is now feasible. Early studies in this realm focused either on very specific tasks in restricted environments (sports, food preparation, etc.) or on the environment's effect with little to no control of the task ("free exploration"). Here we investigate natural gaze control in an everyday situation - ascending and descending a hill in an urban environment.

Environment & task

Rather than varying the instruction, we have participants (n = 8) adapt their task set implicitly by varying terrain difficulty - a road of constant slope as compared to the adjacent irregularly spaced sidewalk steps. Participants were instructed to walk up and down both the road and steps "as they normally would". Eye-movements as well as head- and gaze-centered videos were recorded during the four short walks (fig 1).

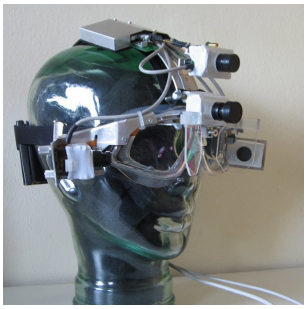

Figure 1. A: detailed view of the eye-tracker ("EyeSeeCam"). B: Local street (Hirschberg) with a participant wearing the eye-tracker.

Individual eye-in-head distributi ons

In the vertical and horizontal distributions of eye-position, some participants show a clearly bi-modal distribution in some conditions and not in others (fig 2). However, in averaged, centered gaze distributions, this effect disappears.

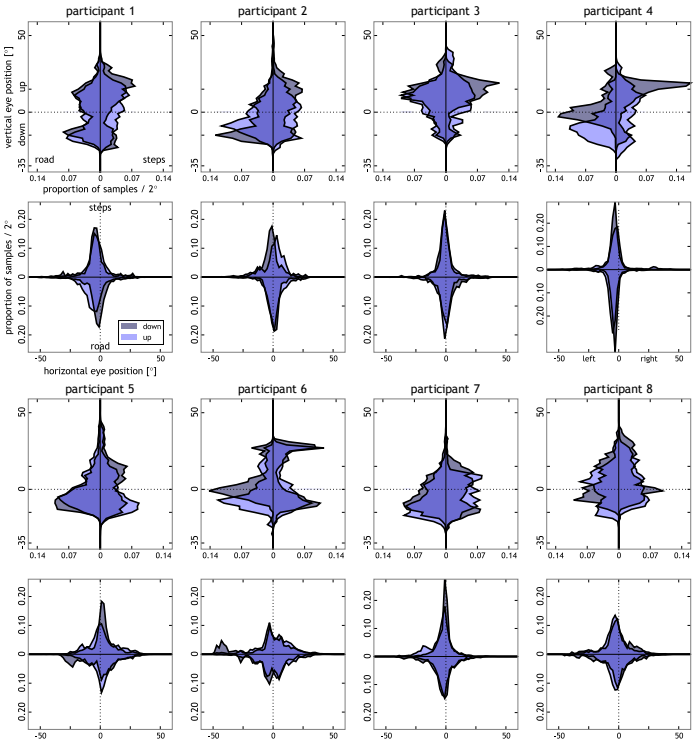

Figure 2. Vertical and horizontal gaze distributions for all subjects.

Eye-position distribution width

ANOVA's on the standard deviations in horizontal and vertical eye-position, using terrain (road, steps) and walking direction (up, down) as factors, showed only a significant main effect of terrain on vertical eye-position ($p < 0.01$). There were no other main effects and no interaction effects (all $p > 0.51$). In the steps condition, participants made eye-movements in a larger part of the visual field than in the road condition (fig 3,4).

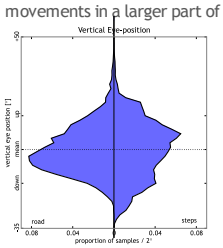

Figure 3. Centered vertical eye-position histograms.

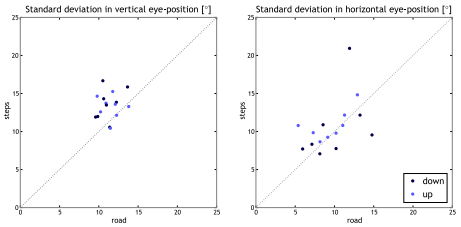

Figure 4. Standard deviations of all subjects' vertical and horizontal eye-position distributions.

Eye-movement directions

Eye-movement direction and length were calculated using a spherical model. On both terrains there is preference for vertical eye-movements, induced by the environment. This becomes clear in comparison with data from two open environments (fig 5).

Eye-movement length in the steps condition is slightly larger than in the road condition and this is even more so in eye-movements succeeding eye-movements in the upward and downward bins (fig 6).

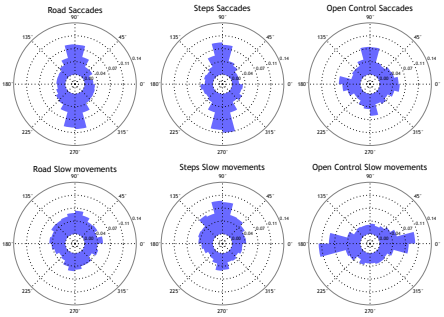

Figure 5. Eye movement direction histogram. "Open" control environments (beach and field) as a contrast.

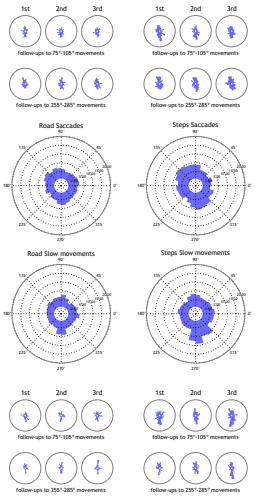

Figure 6. Eye-movement length by direction distribution. Subsequent movements in steps show an effect of direction on length.

Head-in-world movements

The location of a visual horizon in the head-centered video streams served as an approximation of vertical head-in-world movements. In contrast to vertical eye-position, the mean of this signal did not change with terrain (fig 7).

An ANOVA of the standard deviation of vertical horizon position using terrain (road, steps) and walking direction (up, down) as factors, shows no effect of terrain ($p = .65$), walking direction ($p = .09$) and no interaction ($p = .40$).

This indicates that head-in-world movements keep the horizon at constant height, while eye-in-world movements compensate for terrain demands.

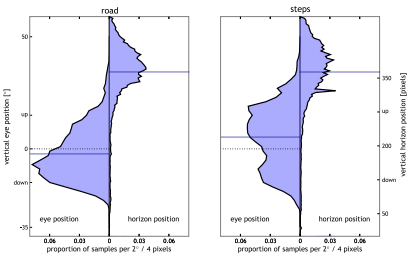

Figure 7. Horizon and vertical eye-position distribution. In uncentered data there is a change of the mean in vertical eye-position. The horizon distribution does not change between conditions.

Conclusions

- When walking in natural environments, the terrain modifies the endogenous task set, thereby affecting gaze behavior.
- On slopes, head-in-world movements stabilize the horizon at about constant height.
- Eye-in-head rather than head-in world movements subserve the bulk of terrain-dependent gaze-shifts.

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