Visual-Vestibular Sensor Integration

Follows a Max-Rule:

Results from Psychophysical Experiments in Virtual Reality

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**Introduction**

How are visual and vestibular information integrated for turning behavior?

Perception of ego turns is crucial for navigation and self-localization. Yet in most Virtual Reality (VR) applications turns are misperceived which leads to disorientation. In following experiments subjects learned and memorized turns and were able to reproduce them even with different gain factors for the vestibular and visual feedback. We focused on two cues providing no absolute spatial reference: optic flow and vestibular cues.

We asked whether:

- (a) both visual and vestibular information are stored and can be reproduced later;
- (b) those modalities are integrated into one coherent percept or if the memory is modality specific; and
- (c) absolute visual information alters performance or strategies.

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**Independent Variables**

- **Is active learning important?**

  - Active/passive: In one condition (ACTIVE) subjects continuously adjusted the roll axis of the platform to level position (see Fig. 1&2 for detailed task description). Subjects controlled their heading with a joystick and thereby maintained an upright position. In all other conditions subjects were passively guided through the sequence of heading turns without any roll signal.

- **Which information / modality is memorized?**

  - Visual/vesibular gain: During the reproduction phase the gain between the joystick control (steered angle) and the resulting visual and vestibular turns were independently varied by a factor of 1/sqrt(2), 1 or sqrt(2). In one additional block of the PASSIVE condition the gain of one modality was set to zero, resulting in no vestibular turn or straight optic flow (ZERO). The provided visual information was either a textured ground plane (ACTIVE, PASSIVE, ZERO) or a complex town environment with salient landmarks (Fig. 3). In the town environment subjects either started in the SAME ORIENTATION during learning and reproduction phase or in RANDOM ORIENTATION.

- **How is optic flow and landmark information used?**

  - Textured plane/complex scene: The textile ground plane (grass) provides visual information whereas the complex scene provides additional landmark information and absolute size cues (SAME ORIENTATION & RANDOM ORIENTATION).

- **Models & Predictions**

  Different strategies can be used to integrate the visual and vestibular information. The simplest models predict qualitatively different results as plotted below. Each graph depicts the steering angle (integral of joystick movements), plotted over the different visual gain factors. The vestibular gain factors are color coded. In order to see (or feel) the same amount of turn, one has to steer more for smaller gain factors and steer less for bigger gain factors.

- **Models for single modalities and multi-modal cue integration.**

  - Motor learning: ignore both visual and vestibular feedback
  - Visual effect: ignore vestibular cues and use only visual feedback
  - vestibular effect: ignore visual cues and use only vestibular feedback
  - additive effect: combine visual and vestibular information linearly
  - multiplicative effect: visual and vestibular information enhance each other

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**Results**

The actual data does not match any of the above models perfectly, but does allow to reject certain ideas: The subjects did not use motor-learning or pure vestibular strategies.

**Visual-Vestibular Effects**

- **ACTIVE/PASSIVE:** Overall, for the large vestibular gain factor, the steered angle is (almost) independent of the visual gain factor (compare with vestibular model). Likewise, for the large visual gain factor, the steered angle is independent of the vestibular gain factor (compare with visual model). While the active group generally turned too far, this might be an artifact of the movement paradigm which included additional roll rotation.

- **ZERO:** Setting one gain factor to zero results in a huge overshoot of the turn, extending the data pattern of the PASSIVE condition.

- **SAME ORIENTATION/RANDOM ORIENTATION:** As expected, the reliable landmarks yield a purely visual strategy. Accordingly, subjects reported that they used only landmarks to guide their turns. In the intermediate condition (RANDOM ORIENTATION) between solely optic flow and reliable landmark information we observed an intermediate data pattern, as one might expect.

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**Conclusions**

- **Subjects stored both visual and vestibular information.**

- **Cue integration can qualitatively be described by a “max-rule”.**

- **Landmark information dominates over vestibular turns.**

- **Large visual or vestibular gain factors have a dominant impact when integrating optic flow and vestibular turns.**

- **Subjects in all conditions learned and memorized curves of the vestibularly defined virtual path and were able to reproduce the amplitudes of the turns. The ACTIVE, PASSIVE, and ZERO conditions demonstrated the relevance of the vestibular signals for spatial orientation in Virtual Reality.**

- **The modality with the bigger gain factor had a dominant effect on the reproduced turns for the ACTIVE and PASSIVE groups. This integration of visual and vestibular information seems to follow a “max rule”, in which the larger signal is responsible for the perceived and memorized heading change.**