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Time-to-collision estimates during congruent visuo-vestibular stimulations

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Everyday our senses cooperate and inform us about our orientation relative to different references. For instance, vision informs us about our orientation with respect to the ground, or more generally relative to parts of the world around us that are optically specified. Our vestibular system informs us about our orientation relative to the direction of balance. The illuminated environment, gravity, direction of balance (DOB), Earth, and more are independent referents that co-exist, and relative to which we control different aspects of our behavior (Stoffregen & Bardy, 2001). During flight, a pilot must control the orientation and position of the aircraft relative to the surface of the Earth (e.g., for navigation), while maintaining aircraft orientation relative to DOB (e.g., to maintain aerodynamic stability); an inability to simultaneously attend to these referents often results in misperception of movement direction, speed or acceleration, spatial disorientation (SD), and loss of control.

Here we initiate a research agenda on the perception and control of disorientation during flight, with the goals to (1) verify the existence of classical disorientation phenomena in simulated flying scenarios, (2) evaluate how multimodal combinations produce or suppress SD, in order to (3) design new ecological interfaces (e.g., Vicente & Rasmussen, 1992) reducing disorientation in airline and helicopter pilots.

In this chapter, we concentrate on the first goal. We propose to use a virtual reality (VR) based time-to-collision (TTC) judgement task to evaluate a specific category of SD, sometimes referred to as *somatogravic illusions* (e.g., Newman et al., 2007), classically interpreted as resulting from the conjunction of two factors: (i) optic flow is poor or limited (ii) the vestibular system is limited in differentiating between forward linear acceleration or deceleration and tilt (e.g., Berger, Schulte-Pelkum, & Bülthoff, 2007). We propose to investigate the range of motion perception, specifically velocity and acceleration, while tilting participants at various degrees with corresponding optical flow. The aim of this work is to replicate the results of the classic TTC task while further investigating

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the effects of acceleration using a unique motion simulator setup, such that visual and vestibular stimulation can be administered congruently and/or separately. Congruent stimulation is defined as the physical consequence, in terms of patterns of stimulation that reach our perceptual systems, of a real-life event.

Method

21 healthy volunteers with normal or corrected vision were exposed to the VR TTC estimation task (11 males and 4 females, 33±10 years old). Six participants were removed, either because the task was not understood or responses were not exploitable. All participants gave their verbal consent to participate in the experiment and to have their data used for scientific purposes.

Realistic motion was simulated using the six degrees of freedom iMose motion simulator (See Figure 1). iMose is composed of an industrial Kuka KR500-3 robotic arm with a cabin mounted at the end, for one occupant only. The control parameters consisted of: initial speed (10, 20, 60 and 70 meters/second (m/s)), visual acceleration (2, 3 and 4m/s²), tilted or not (pitch), occlusion time (time to closure:1,1.5 and 2s). During the pitch condition, the angle was calculated so that the longitudinal projection of gravity was consistent with the optic flow acceleration;

Participants performed 72 trials during 25 minutes. Each trial followed this sequence: 10 s viewing period starting from variable initial position + blinded task period + 5 s rest. The trials were randomly assigned per subject. During the viewing period, participants longitudinally flew towards an obstacle –a building- above a virtual city landscape. At time-to-closure, the visual scene was occluded. Participants had to press a button when they judged that they would collide with the obstacle. During the ‘rest period’, participants viewed the virtual scene at a variable starting distance from the obstacle, which ensured a constant viewing period given the visual initial velocity and acceleration.

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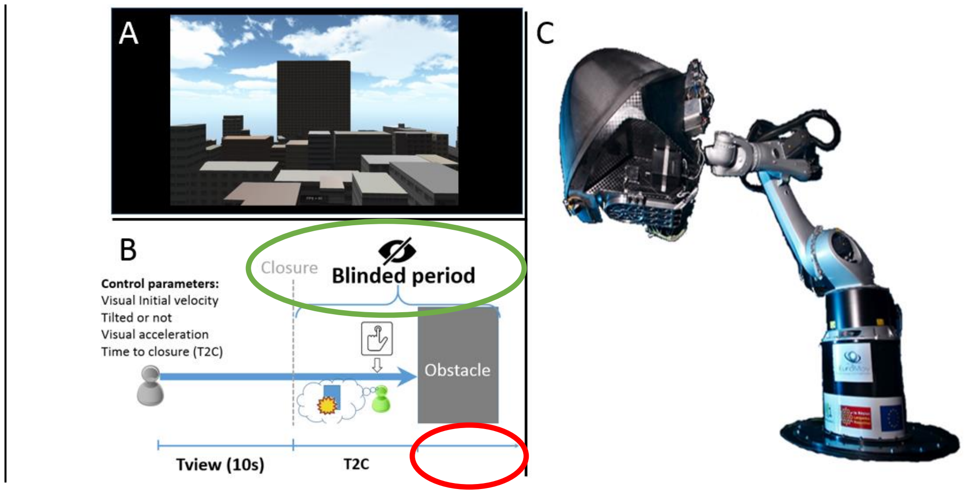

Figure 1. VR visual scene (A), timeline of task events (B), and the iMose motion simulator (C).

Motion perception was evaluated via the measured time between the button push and the actual collision.

Results and Discussion

Participant responses for initial velocity and time-to-closure conditions were similar to previously reported results (McLeod & Ross, 1983). For both pitched and non-pitched trials, higher velocities produced more accurate TTC estimations. Similarly, larger time-to-closure distances caused participants to anticipate more (respond earlier) in comparison to smaller time-to-closure distances, which imply that participants were influenced by distance-velocity cues (Schiff & Detwiler, 1979). In addition, typical of TTC estimations, participants' responses greatly varied, which may be due to the fact that they used absolute estimates more than relative estimates (Lugtigheid & Welchman, 2011). These results confirm that it is possible to use our simulator to replicate basic TTC results.

Our key result was a significant difference observed between pitched and non-pitched trials ($p < 0.05$). Non-pitched (non-congruent visuo-vestibular stimulation) trials had no physical vestibular stimulation, whereas pitched (congruent visuo-vestibular stimulation) trials had similarly deflected optic flow and physical orientation. Moreover, participants with congruent visuo-vestibular stimulation underestimated the time before collision more than with only visual stimulation. In this passive judgment task with no change in the

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vestibular stimulation, participants could not differentiate between motion and orientation; they could not differentiate between being tilted relative to gravity or accelerating relative to the visually depicted environment. Larger TTC values demonstrated that participants perceived themselves as accelerating rather than being titled. If participants had perceived being titled as opposed to accelerating TTC values would not have been affected.

Finally, it was of interest to investigate the visuo-vestibular interaction on TTC estimates with visual acceleration. Similar to previous reports, for non-pitched conditions, acceleration did not have a significant effect on TTC estimates (Kaiser & Hecht, 1995). However, it was observed that the greater the visual acceleration, the response difference during pitched and non-pitched conditions were larger; participants noticeably felt moving faster when they were pitched at the highest visual acceleration ($4 m/s^2$). This result suggests that the additional congruent vestibular stimulation, at high accelerations, caused participants to perceive the presence of acceleration. Again this demonstrates that orientation and acceleration were similarly perceived.

In summary, these results suggest that so-called somatogravic disorientation occurring during real flight situations (ambiguous motion perception due to limited stimulation) can be reproduced with our iMose simulator, and that TTC judgement tasks are appropriate to evaluate the severity of disorientation. Our next steps will include (i) testing the existence of disorientation during active control tasks with more natural congruencies between vision and vestibular stimulation, and (ii) the development of specific interfaces able to compensate ambiguous stimulation when present.

References

Stoffregen, T. A. & Bardy, B. G. (2001). On specification and the senses. *The Behavioral and Brain Sciences*, 24, 195–213.

Vicente, K. J. & Rasmussen, J. (1992). Ecological interface design: theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics*, 22, 589–606.

Newman, D. G. (2007). An overview of spatial disorientation as a factor in aviation accidents and incidents. *Australian Transport Safety Bureau*, Canberra City, ACT.

Berger, D. R., Schulte-Pelkum, J., & Bülthoff, H. H. (2007). Simulating believable forward accelerations on a Stewart motion platform. Technical Report No. 159, Max Planck Institute for Biological Cybernetics.

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McLeod, R. W. & Ross, H. E. (1983). Optic-flow and cognitive factors in time-to-collision estimates. *Perception*, 12, 417–423.

Schiff, W. & Detwiler, M. L. (1979). Information used in judging impending collision. *Perception*, 8, 647-658.

Lugtigheid, A. J. & Welchman, A. E. (2011). Evaluating methods to measure time-to-contact. *Vision Research*, 51, 2234-2241.

Kaiser, M. K. & Hecht, H. (1995). Time-to-passage judgments in nonconstant optical flow fields. *Perception & Psychophysics*, 57, 817-825.

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