

Cognitive and higher-level contributions to illusory self-motion
perception (“vection”) —Does the possibility
of actual motion affect vection?—

Bernhard E. RIECKE*

*School of Interactive Arts & Technology (SIAT), Simon Fraser University**

基礎心理学研究 第28卷 第1号 別刷

平成21年9月

Cognitive and higher-level contributions to illusory self-motion perception (“vection”) —Does the possibility of actual motion affect vection?—

Bernhard E. RIECKE*

*School of Interactive Arts & Technology (SIAT), Simon Fraser University**

Large-field moving visual stimuli have long been known to be capable of inducing compelling illusions of self-motion (“vection”) in stationary observers. Traditionally, the origin of such visually induced self-motion illusions has been attributed to low-level, bottom-up perceptual processes without much cognitive/higher-level contribution. In the last years, however, this view has been challenged, and an increasing number of studies has investigated potential higher-level/cognitive contributions. This paper aims at providing a concise review and discussion of one of these aspects: Does the cognitive framework of whether or not actual movement is possible affect illusory self-motion? Despite a variety of different approaches, there is growing evidence that both cognitive and perceptual information indicating movability can facilitate self-motion perception, especially when combined. This has important implications for our understanding of cognitive/perceptual contributions to self-motion perception as well as the growing field of self-motion simulations and virtual reality, where the need for physical motion of the observer could be reduced by intelligent usage of cognitive/perceptual frameworks of movability.

Key words: self-motion perception, vection, higher-level influences

Introduction

There is a long tradition of investigating how large-field moving visual stimuli can induce illusory self-motions. For example, when standing on a bridge looking down on a fast-moving river, the initial percept that the river is moving and one is stationary can eventually (after a so-called vection onset latency) switch to a compelling perception of illusory self-motion in the direction opposite of the moving visual stimulus. The earliest accounts of vection go back more than a century ago, when Mach (1875) and Helmholtz (1896) first described the phenomenon. Since then, vection has been extensively studied, and comprehensive reviews can be found in (Dichgans & Brandt, 1978; Howard, 1986; Warren & Wertheim, 1990). More recently, vection has also been discussed in the context of self-motion simulation

and virtual reality, where the illusory sensation of self-motion might be able to contribute to more believable, naturalistic, and effective simulations at reduced cost and effort (Hettinger, 2002; Riecke, Schulte-Pelkum, Caniard, & Bühlhoff, 2005; Riecke, Västfjäll, Larsson, & Schulte-Pelkum, 2005; Schulte-Pelkum, 2008).

Much of the previous research focused on the influence of various physical stimulus parameters like the visual field of view and spatial frequency of the stimulus and how these contribute to vection via low-level, bottom-up perceptual processes (e.g., Dichgans & Brandt, 1978). During the last decades, however, the prevailing notion that vection is primarily driven by low-level perceptual processes has been put into question, and an increasing number of studies have proposed or investigated potential contributions of various higher level, cognitive processes (Andersen & Braunstein, 1985; Lepecq, Giannopulu, & Baudonniere, 1995; Mergner & Becker, 1990; Riecke et al., 2005). In this paper, I will focus on the question whether illusory self-motion can be facilitated if cog-

* School of Interactive Arts & Technology (SIAT), Simon Fraser University, 250–13450 102nd Avenue, Surrey, BC V3T 0A3, Canada
E-mail: ber1@sfu.ca

nitive and/or perceptual information indicates that actual motion is, in fact, possible.

Does the possibility of actual self-motion enhance vection?

One of the first indications of potential cognitive contributions to vection stems from Andersen and Braunstein (1985), who remarked that "several subjects in pilot studies and other observers had previously reported that the experience of self-motion was inhibited by the observation that they were in an environment in which they could not be physically moved" (p. 124). This led the authors to seat participants in a moveable booth and demonstrate the possibility of motion prior to the actual experiment. Similar procedures have been used in earlier studies for translations using a moveable cart (e.g., Berthoz, Pavard, & Young, 1975; Pavard & Berthoz, 1977) and rotations using a rotating chair (e.g., Lackner, 1977), although none of these or earlier studies had explicitly demonstrated that knowledge about the potential or plausibility of actual self-motion does indeed affect vection. The earliest study that explicitly addressed this conjecture was to the best of our knowledge the seminal study by Lepecq et al. (1995), in which stationary observers (children aged 7 and 11 years) were seated either on a room-fixed chair or a moveable chair with rollers. Before the actual experiments, half of the participants were shown and experienced themselves that the chair was attached to the experimental apparatus and thus could not be moved ("movement impossible" condition). The other half of the participants were shown and experienced themselves that the chair could be moved ("movement possible" condition). When subsequently exposed to backward linear vection stimuli, participants in the movement possible condition experienced vection earlier, although not more frequently. These results suggest that cognitive factors (the knowledge and prior experience that actual motion is (im)possible) can affect the onset latency of vection but not the occurrence of vection, at least in children. As I will discuss below, there is mixed evidence whether similar cognitive contributions to vection occur in adults.

Wright, DiZio, and Lackner (2006) demonstrated a cognitive contribution to the compellingness of vection in adults: Participants were presented with a movie of a vertical oscillation (at 0.2 Hz with 1.7 m amplitude) displayed via a head-mounted display subtending a field of view of $48^\circ \times 36^\circ$. In the movement possible condition, participants were seated in the vertical oscillator that was used to create the movie and were given, prior to the actual experiment, a demonstration of the oscillatory motion that was used to create the stimulus movie. In the movement impossible condition, participants were seated on a desk chair in a separate room. Although there was never any actual motion throughout the vection testing, participants in the movement possible condition reported more compelling sensations of up-down ("elevator") vection than in the movement impossible condition. Vection amplitudes and onset latencies were unaffected by the cognitive manipulation, though. The authors proposed two dissociable mechanisms for vection: One the one hand, a process primarily driven by the visual cues that determines the vection onset latency and extent of the illusory self-motion. One the other hand, a process susceptible to cognitive factors that determines the compellingness of vection. Note that these results differ from Lepecq et al.'s study where the cognitive manipulation affected vection onset times.

A circular vection study that also used photorealistic stimuli failed to find any cognitive contributions to vection in adults, though (Schulte-Pelkum, Riecke, & Bühlhoff, 2004, see also Schulte-Pelkum, 2008, exp. 3): Participants were presented with circular vection stimuli of a real-world scene (the Tübingen market place, which was familiar to all participants) displayed on an immersive video projection subtending a field of view of $86^\circ \times 63^\circ$. The whole setup was mounted on a 6 degree-of-freedom Stewart motion platform, and vision of the outside lab was excluded through heavy curtains. In the movement possible condition, participants were shown prior to this block how the platform could move. At the beginning of this block participants mounted the motion platform, put on the safety belt, and the platform was moved up (30 cm) to the default position, with no

further physical motion. In the movement impossible condition, participants were told that the platform would not move, the platform remained switched off, and participants did not wear safety belts. Although 67% of participants were fooled into believing that they physically moved in at least some of the movement possible trials, neither vection onset time nor the intensity or convincingness of vection were affected by the cognitive manipulation. This lack of any cognitive influence on any of the vection responses might be related to a possible ceiling effect, as vection in all conditions was quite strong and compelling. Furthermore, several differences in the experimental procedure between the current study and (Wright, DiZio, & Lackner, 2006) might account for the different results, including difference in the vection type (circular vection vs. oscillatory linear (elevator) vection), display device (projection screen vs. head-mounted display), direct prior exposure to the physical motion (seen from the outside in Schulte-Pelkum et al., (2004) vs. experienced from sitting on the moving platform in Wright, DiZio, & Lackner (2006)) and differences in the match between the visually presented scene and the actual surroundings: While Schulte-Pelkum et al. (2004) presented a remote scene in both conditions, Wright, DiZio, and Lackner (2006) presented participants in the motion possible condition with a movie of the actual surrounding scene. Pilot studies conducted by J. Schulte-Pelkum and myself suggest that this last issue might indeed be critically affecting the strength of vection: In a pilot study (unpublished), we used high-quality panoramic images of the actual test room as the vection-inducing stimulus, such that the rotating visual stimulus depicted on the projection screen displayed what participants would have seen if the projection screen was a window onto the real lab. While this stimulus resulted in strong circular vection, it also resulted in unexpectedly high levels of dizziness and discomfort, which lasted for several hours for one lab member. The unusually strong vection and the fact that it was the first time that vection stimuli in our lab resulted in serious motion sickness suggests possible higher-level/cognitive contributions to vection, in the sense that

depicting a rotating naturalistic view of the actual surrounding lab has different effects on observers than displaying a similarly naturalistic view of a remote location. We are planning further studies to further investigate the influence of consistency between simulated and actual scene, although careful experimentation is needed due to the high potential for adverse effects like dizziness.

Young and colleagues investigated if tactile cues could affect visually induced roll illusions in weightlessness (Young, Crites, & Oman, 1983; Young & Shelhamer, 1990). In a "free floating" condition, participants' position in weightlessness was only fixed by a bite bar. In a "tactile" condition, participants were additionally restrained by a shoulder harness that held them on the floor via elastic bands. This additional restraint in the tactile condition reduced the strength of roll vection and increased the vection drop-out rate, and in some participants even increased vection onset times. Note that the restraint might have affected vection via both cognitive/higher-level factors (e.g., knowledge that actual motion was clearly impossible) and perceptual/lower-level factors (e.g., sensation that one is tied to the stationary floor).

Another study in which both cognitive and perceptual factors might have contributed investigated auditory circular vection (Riecke, Feureissen, & Rieser, 2008, 2009).

Prior to the vection experiment, auditory vection-inducing stimuli were created by seating participants on a hammock chair mounted above a circular treadmill and passively rotating them in the lab where two easily localizable sound sources were positioned. Participants wore in-ear microphones that enabled individualized binaural recordings of what it sounded like to physically rotate in the lab. During the vection testing, participants were blindfolded and seated on the same hammock chair while noise-cancelling headphones displayed the rotating sound-field. In a "movement possible" condition, participants put their feet on a foot-rest attached to the hammock chair. In a "movement impossible" condition, participants put their feet on the stationary ground. When participants' feet did not touch solid

ground in the “movement possible condition”, vection intensity was increased, and there was a marginally significant ($p < .1$) trend towards reduced vection onset times and higher rates of vection occurrence as well as increased realism of actually rotating in the lab. While participants in auditory vection studies are often seated on moveable chairs (e.g., Lackner, 1977; Våljamäe, 2007), this seems to be the first study that actually demonstrates that this procedure does, in fact, facilitate vection. Similar to the studies by Young et al., both cognitive and perceptual processes might have contributed to the vection-facilitating effect: Having one’s feet touch the stationary floor provides us on the one hand with higher-level, cognitive “knowledge” that actual motion is impossible. On the other hand, it provides us with sensory information (e.g., biomechanical, tactile, and deep pressure cues) indicating the lack of physical self-motion. Further, careful experimentation is needed to disambiguate the potential influence from cognitive and perceptual cues, though.

Conclusions

In conclusion, there is clear evidence that perceptual and cognitive cues indicating the potential for actual self-motion can enhance vection. This is consistent with the often observed practice of seating participants in vection studies on moveable chairs or platforms (e.g., Berthoz et al., 1975; Lackner, 1977; Pavard & Berthoz, 1977; Andersen & Braunstein, 1985; Våljamäe, 2007). When only cognitive, but no direct perceptual information indicates the potential of actual self-motion, only some of the studies report a clear vection-facilitating effect: Lepecq et al. (1995) observed reduced vection onset times for backward linear vection in 7 and 11 year old children when they knew and had experienced beforehand that actual motion was indeed possible. Wright et al. (2006) showed a similar vection-facilitating effect for vertical oscillatory vection in adults. While these results are promising, further investigations are necessary for a deeper understanding of why, how, and under what conditions prior knowledge about the possibility of actual motion can affect self-motion perception. Such deeper understanding how our knowl-

edge, expectations, and prior assumptions can affect our self-motion perception would not only be theoretically interesting, but could also be of considerable applied interest: For example, in motion simulator-based joy rides, users are often intentionally immersed into the context of the ride theme and primed to believe that actual motion might be possible. Moreover, they are hardly allowed to see the mechanics and actual motion restrictions of the simulators. While research and development results in such commercial applications are typically not published and openly accessible, there seems reason to believe that such measures might not only affect the users’ enjoyment and pleasure, but also contribute to an improved naturalism, convincingness, and effectiveness of the simulated self-motions. I posit that only a research approach that encompassed both a perceptual/lower-level perspective and a cognitive/higher level perspective will ultimately enable use to more deeply understand and employ the fascinating phenomenon of self-motion illusions.

References

- Andersen, G. J., & Braunstein, M. L. (1985). Induced self-motion in central vision. *Journal of Experimental Psychology—Human Perception and Performance*, 11(2), 122–132.
- Berthoz, A., Pavard, B., & Young, L. R. (1975). Perception of linear horizontal self-motion induced by peripheral vision (linearvection)—Basic characteristics and visual-vestibular interactions. *Experimental Brain Research*, 23(5), 471–489.
- Dichgans, J., & Brandt, T. (1978). Visual-vestibular interaction: Effects on self-motion perception and postural control. In *Perception, Handbook of sensory physiology* (pp. 756–804). Springer.
- Helmholtz, H. V. (1896). *Handbuch der physiologischen Optik*. Hamburg-Leipzig: L. Voss.
- Hettinger, L. J. (2002). Illusory self-motion in virtual environments. In K. M. Stanney (Ed.), *Handbook of Virtual Environments* (pp. 471–492). Lawrence Erlbaum.
- Howard, I. P. (1986). The perception of posture, self motion, and the visual vertical. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Sensory processes and perception, Handbook of human perception and performance* (Vol. 1, pp. 18.1–18.62). New York: Wiley.
- Lackner, J. R. (1977). Induction of illusory self-rotation and nystagmus by a rotating sound-field.

- Aviation Space and Environmental Medicine*, 48(2), 129-131.
- Lepecq, J. C., Giannopulu, I., & Baudonniere, P. M. (1995). Cognitive effects on visually induced body motion in children. *Perception*, 24(4), 435-449.
- Mach, E. (1875). *Grundlinien der Lehre von der Bewegungsempfindung*. Leipzig, Germany: Engelmann.
- Mergner, T., & Becker, W. (1990). Perception of horizontal self-rotation: Multisensory and cognitive aspects. In R. Warren, & A. H. Wertheim (Eds.), *Perception & control of self-motion* (pp. 219-263). New Jersey, London: Erlbaum.
- Pavard, B., & Berthoz, A. (1977). Linear acceleration modifies perceived velocity of a moving visual scene. *Perception*, 6(5), 529-540.
- Riecke, B., Feuereissen, D., & Rieser, J. J. (2008). Auditory self-motion illusions ("circular vection") can be facilitated by vibrations and the potential for actual motion. In *ACM SIGGRAPH Symposium on applied perception in graphics and visualization (APGV)* (pp. 147-154). doi: <http://doi.acm.org/10.1145/1394281.1394309>.
- Riecke, B. E., Feuereissen, D., & Rieser, J. J. (2009). Auditory self-motion simulation is facilitated by haptic and vibrational cues suggesting the possibility of actual motion. *ACM Trans. Appl. Percept.* 6.
- Riecke, B., Schulte-Pelkum, J., Caniard, F., & Bülthoff, H. H. (2005). Towards lean and elegant self-motion simulation in virtual reality. In *Proceedings of IEEE Virtual Reality 2005* (pp. 131-138). Bonn, Germany.
- Riecke, B., Västfjäll, D., Larsson, P., & Schulte-Pelkum, J. (2005). Top-down and multi-Modal influences on self-motion perception in virtual reality. In *Proceedings of HCI International 2005* (pp. 1-10). Las Vegas, NV, USA.
- Schulte-Pelkum, J. (2008). *Perception of self-motion: Vection experiments in multi-sensory virtual environments*. PhD thesis Ruhr-Universität Bochum.
- Schulte-Pelkum, J., Riecke, B., & Bülthoff, H. H. (2004). Vibrational cues enhance believability of ego-motion simulation. In *International Multisensory Research Forum (IMRF)*.
- Väljamäe, A. (2007). *Sound for multisensory motion simulators*. PhD thesis, Chalmers University of Technology.
- Warren, R., & Wertheim, A. H. (1990). *Perception & Control of Self-motion*. New Jersey, London: Erlbaum.
- Wright, W. G., DiZio, P., & Lackner, J. R. (2006). Perceived self-motion in two visual contexts: dissociable mechanisms underlie perception. *Journal of Vestib. Research*, 16(1-2), 23-28.
- Young, L., Crites, T., & Oman, C. (1983). Brief weightlessness and tactile cues influence visually induced roll. *Advances in Oto-Rhino-Laryngology*, 30, 230-234.
- Young, L., & Shelhamer, M. (1990). Weightlessness enhances the relative contribution of visually-induced self-motion. In R. Warren, & A. H. Wertheim (Eds.), *Perception & control of self-motion: Resources for ecological psychology*. Erlbaum, Hillsdale, NJ.