

Introduction to Vestibular Cognition Special Issue: Progress in Vestibular Cognition

Elisa R. Ferrè^{1,*} and Laurence R. Harris^{2,*}

¹ Institute of Cognitive Neuroscience, University College London, 17 Queen Square,
London, WC1N 3AR, UK

² Centre for Vision Research, York University, 4700 Keele St, Toronto (ON), M3J 1P3, Canada

“*How many senses do you have?*” Most of us would probably respond with the traditional five senses we were taught in school: sight, hearing, smell, taste and touch. However, there is an additional sensory modality that is essential in almost all our behaviours. The vestibular system is a sophisticated set of organs located in the inner ear. It comprises the semicircular canals, which detect rotational movements of the head in three-dimensional space, and the otolith organs, which code translational acceleration, including the orientation of the head relative to the gravitational vertical.

Most scientists consider the vestibular system as an organ specialized for balance, orientation and control of eye movements. However, vestibular inputs are *always on* and turn out to be involved in almost all our interactions with the external world in ways that go far beyond these fundamental reflexes. Vestibular signals have extensive projections throughout the cerebral cortex, and can potentially influence any behaviours that involve relating to external space. Over the last decade, emerging studies have demonstrated that sensory information provided by the vestibular system is deeply involved in several cognitive processes. This special issue, which contains both reviews and original articles, focuses on vestibular effects on higher cortical function and seeks to provide a comprehensive overview of the key findings on *vestibular cognition*.

In our special issue, we distinguish specific cognitive sub-functions and highlight how basic vestibular input contributes to each. The broad range of

* To whom correspondence should be addressed. E-mail: e.ferre@ucl.ac.uk; harris@yorku.ca

these functions is consistent with the broad spread of vestibular projections throughout the cortex. Under normal circumstances, the vestibular system supplies a signal that has been shown to play a fundamental role in spatial cognition. Combining vestibular signals about the head's orientation relative to gravity with other proprioceptive information about head position relative to the body provides sufficient information to map body position onto the ground surface. This could explain how gravity influences our spatial orientation as summarized by Lacquaniti, Bosco, Gravano, Indovina, La Scaleia, Maffei and Zago (this issue). Accordingly, Barnett-Cowan, Snow and Culham (this issue) demonstrate that the recognition of faces and letters is influenced by both gravity and body orientation. Mast and Ellis (this issue) suggest a systematic computational approach to providing a coherent framework for investigating such vestibular contribution to spatial transformations. Evidence of the effect of bilateral vestibular deafferentation on spatial memory is reviewed by Smith, Darlington and Zheng (this issue), highlighting the vestibular contribution to neural-cognitive maps of environmental navigational space, possibly located in the hippocampus and parietal regions, confirming the vestibular contribution to the brain's *Global Positioning System*.

Vestibular signals are also fundamental to higher sensorimotor control. As reviewed by Blouin, Bresciani, Guillaud and Simoneau (this issue), moving an arm during body motion requires compensatory movements that rely on efficient vestibulo-motor transformations. Critically, such transformations cannot be considered as reflexes, rather they appear to be influenced by vestibular-based predictive mechanisms to counteract the disruptive effect that body motion would otherwise introduce. Seemungal (this issue) further shows how motion perception is decoupled from the more reflex aspects of vestibular functioning.

The vestibular system also contributes to high-level bodily perception, such as the sense of body ownership, the sense of being located within the body, and the anchoring of perspective to the body, as reviewed by Lopez (this issue). Ferrè and Haggard (this issue) focus on the interaction between vestibular and bodily somatosensations. They propose that the target of such interactions is a form of self-representation, which is important to link the spatial description of one's own body to the spatial description of the outside world. Original results by Hoover and Harris (this issue) show that disruptive artificial vestibular stimulation affects the sense of body ownership, altering the boundaries between self and others.

Clinical observations in brain-damaged patients confirm the essential role of vestibular signals in maintaining a coherent self-representation. Bottini and Gandola (this issue) summarize the effects of artificial vestibular stimulation on impaired bodily awareness. Even more dramatically, vestibular dysfunction contributes to autoscopic phenomena, such as the impression of seeing

one's own body in extrapersonal space. Out-of-body experiences, in which patients localise the self outside their own body and experience seeing their body from this disembodied location, were attributed to failures in integrating multisensory bodily information due to conflicting visual and vestibular information. Kaliuzhna, Vibert and Blanke (this issue) analyse the behaviour of a patient with vestibular damage when presented with out-of-body experiences. They describe abnormalities in visuo-vestibular and visuo-tactile integration that have previously been shown to induce out-of-body illusions. Additionally, vestibular damage can produce psychiatric-like symptoms of depersonalisation, defined as '*subjective experience of unreality and detachment from the self*', and derealisation, '*the experience of the external world appearing strange or unreal*'. Jauregui-Renaud (this issue) proposes that depersonalization/derealisation are a consequence of a sensory mismatch between disordered vestibular input and other sensory signals that provide orientation information.

It has been recently suggested that artificial vestibular stimulation may be adopted as rehabilitation technique. Critically, Grabherr, Macauda and Lenggenhager (this issue) review the literature on the use of vestibular stimulation as a therapy for a range of psychiatric, neurological and neurodevelopmental conditions and give examples of its successes and drawbacks.

These studies and reviews confirm that the vestibular system plays a fundamental and hitherto largely unsuspected role in almost all aspects of cognition. We hope that this collection will provoke the same enthusiasm in you it did in us.

Papers in the Special Issue

- Barnett-Cowan, M., Snow, J. C. and Culham, J. C. (2015). Contribution of bodily and gravitational orientation cues to face and letter recognition. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002481.
- Blouin, J., Bresciani, J., Guillaud, E. and Simoneau, M. (2015). Prediction in the vestibular control of arm movements. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002501.
- Bottini, G. and Gandola, M. (2015). Beyond the non-specific attentional effect of caloric vestibular stimulation: evidence from healthy subjects and patients. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002504.
- Ferrè, E. R. and Haggard, P. (2015). Vestibular–somatosensory interactions: a mechanism in search of a function? *Multisens. Res.* **28**, DOI:10.1163/22134808-00002487.
- Grabherr, L., Macauda, G. and Lenggenhager, B. (2015). The moving history of vestibular stimulation as a therapeutic intervention. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002495.
- Hoover, A. E. and Harris, L. R. (2015). Disrupting vestibular activity disrupts body ownership. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002472.
- Jauregui-Renaud, K. (2015). Vestibular function and depersonalization/derealization symptoms. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002480.

- Kaliuzhna, M., Vibert, D. and Blanke, O. (2015). Out-of-body experiences and other complex dissociation experiences in a patient with unilateral peripheral vestibular damage and deficient multisensory integration. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002506.
- Lacquaniti, F., Bosco, G., Gravano, S., Indovina, I., La Scaleia, B., Maffei, V. and Zago, M. (2015). Gravity in the brain as a reference for space and time perception. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002471.
- Lopez, C. (2015). Making sense of the body: the role of vestibular signals. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002490.
- Mast, F. and Ellis, A. (2015). Internal models, vestibular cognition, and mental imagery: conceptual considerations. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002503.
- Seemungal, B. (2015). The components of vestibular cognition — motion *versus* spatial perception — a practical discourse. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002507.
- Smith, P. F., Darlington, C. L. and Zheng, Y. (2015). The effects of complete vestibular deaf-ferentation on spatial memory and the hippocampus in the rat: the Dunedin experience. *Multisens. Res.* **28**, DOI:10.1163/22134808-00002469.