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COMMENTARY

Does the vestibular system exert specific or general influences on cognitive processes?

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Vestibular cognition is a newly emerging field with exciting and unexpected implications for our understanding of how the brain works and our ability to provide therapies when neural processes are disrupted. Up until recently, the vestibular system, when considered at all, has tended to be thought of as a rather mechanical system picking up accelerations of the head and contributing to the reflex control of posture and eye movements – not really the realm of cognition. As a perceptual system, it contributes to guidance and knowledge of self-motion and orientation but even those functions were not acknowledged as being of vestibular origin until early in the twentieth century when Robert Bárány (1876–1936) proved that vestibular stimulation alone could evoke such perceptions (Lopez & Blanke, 2014). For this discovery, Bárány was awarded the Nobel Prize in 1914. But even now, the vestibular system's contributions to perception have largely been ignored and, with some notable exceptions (e.g., Wolfe et al., 2017), the system hardly even figures in undergraduate textbooks on Sensation and Perception or Cognition, and still less in Neuropsychology textbooks.

Physicians have been dimly aware of the vestibular system's cognitive roles even back in the nineteenth century when centrifuging mental patients was found to have a calming effect (Harsch, 2006; Wade, 2005), a phenomenon known to baby-rocking mothers and roundabout-riding children since time immemorial. The realization that the vestibular system contributes to many aspects of cognition beyond moving and knowing the direction of "down", has gradually been dawning in a more formal way in the twenty-first century (Ferrè & Harris, 2017). Scattered studies have now shown that vestibular activity plays a role in such varied cognitive functions as spatial perception, mental imagery, memory, body awareness and ownership, and even decision making, emotional control and personality (Smith & Darlington, 2013). However, these studies are indeed scattered, with no studies comparing the vestibular system's influence on multiple functions and possible correlations among them, and with no systematic approach to understanding how the vestibular system exerts its influence as a whole. Elisa Ferrè and Patrick Haggard's contribution (Ferrè & Haggard, 2020) is a first pass at providing a structure for understanding how the vestibular system might exert its influence. Noting the extensive vestibular projections over large parts of the cortex, they divide vestibular contributions into three domains: autonomic, sensorimotor, and cognitive. They then challenge researchers to design experiments to address a critical, central, but largely ignored point: does vestibular input enable all these domains equally, in a manner similar to arousal? Or are individual functions independently and discretely affected according to the demands of the moment? Not only do they throw down this gauntlet, but they provide a detailed pipeline about how to accept the challenge and to better characterize the system.

Their brief review of the cortical pathways likely to be involved in cognitive functions assigns cognitive function mainly to the frontal areas, assigning the parieto-insular-vestibular cortex which includes the enigmatic temporo-parietal junction (TPJ) (Frank & Greenlee, 2018) to the sensorimotor domain. The TPJ

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has been implicated in multiple high-level cognitive functions including theory of mind, beliefs and the representation of self (Arzy et al., 2006) and so this might be something of an oversimplification. The cerebellum, a direct recipient of vestibular projections (Barmack, 2003), is here relegated to the autonomic domain despite many studies revealing it to have its own role in higher level cognitive functioning (Koziol et al., 2014; Schmahmann, 2019). However, these oversimplifications are largely beside the point. This paper does not aim to comprehensively review vestibular projections; instead it encourages others to follow a suggested pipeline to identify pathways, activate vestibular inputs, and assess the effect size of vestibular influences on cognitive functioning. An important novel suggestion here is recognising the need to assess whether simultaneous vestibular influences on multiple systems are independent. For example, vestibular stimulation is known to influence the sense of body-ownership: the sense that a particular body part or even your whole body, belongs to you (Hoover & Harris, 2015; Lenggenhager & Lopez, 2015; Lopez, 2015). Might the magnitude of this vestibular influence correlate with the effect of the very same stimulation on, for example, somatosensory perception or pain processing? The hope here is to give direction to the generation of a database that can be more effectively used and exploited by neuropsychologists working with a wide range of cognitive impairments.

The proposed pipeline recommends using artificial ways to stimulate the vestibular system, especially caloric and galvanic stimulation. This might seem a little odd, like suggesting that visual research should concentrate on electrically stimulating the optic nerve rather than using visual stimuli. But a problem with natural vestibular stimuli (i.e., physical acceleration) is that on earth at least, it is impossible to provide such stimulation without also activating other sensory systems – in particular the somatosensory system which responds to the force that the body's mass exerts on the support surface. This includes the feet while standing, the back while lying supine, and the backside and back when in a chair, whether moving or stationary. This was why Robert Bárány needed to use caloric stimulation for his pioneering work. It is possible to partially overcome concurrent somatosensory stimulation using local anaesthetic but this procedure introduces other complications (Gandevia & Phegan, 1999). Neutral buoyancy (Jarchow & Mast, 1999), parabolic flight and space are not easily available alternatives although the consequences of an understanding of the cognitive effects of changes in vestibular activity in such environments would be an important outcome of the proposed pipeline.

There is no doubt that research in vestibular cognition needs structure. The broad-strokes classifications and research pipeline that Ferrè and Haggard provide in this paper represent a stimulating starting point.

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References

Arzy, S., Thut, G., Mohr, C., Michel, C. M., & Blanke, O. (2006). Neural basis of embodiment: Distinct contributions of temporoparietal junction and extrastriate body area. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *26*(31), 8074–8081. https://doi.org/10.1523/JNEUROSCI.0745-06.2006

Barmack, N. H. (2003). Central vestibular system: Vestibular nuclei and posterior cerebellum. *Brain Research Bulletin*, *60* (5–6), 511–541. https://doi.org/10.1016/S0361-9230(03)00055-8

Ferrè, E. R., & Haggard, P. (2020). Vestibular cognition: State-of-the-art and future directions. *Cognitive Neuropsychology*. in press. https://doi.org/10.1080/02643294.2020.1736018

Ferrè, E. R., & Harris, L. R. (2017). *Vestibular cognition*. E. R. Ferrè & L. R. Harris (Eds.). Brill.

Frank, S. M., & Greenlee, M. W. (2018). The parieto-insular vestibular cortex in humans: More than a single area? *Journal of Neurophysiology*, *120*(3), 1438–1450. https://doi.org/10.1152/jn.00907.2017

Gandevia, S., & Phegan, C. (1999). Perceptual distortions of the human body image produced by local anaesthesia, pain and cutaneous stimulation. *The Journal of Physiology*, *514*(2), 609–616. https://doi.org/10.1111/j.1469-7793.1999.609ae.x

Harsch, V. (2006). Centrifuge "therapy" for psychiatric patients in Germany in the early 1800s. *Aviation, Space, and Environmental Medicine*, *77*(2), 157–160. PMID: 16491585.

Hoover, A. E. N., & Harris, L. R. (2015). Disrupting vestibular activity Disrupts body ownership. *Multisensory Research*, *28* (5-6), 581–590. https://doi.org/10.1163/22134808-00002472

Jarchow, T., & Mast, F. W. (1999). The effect of water immersion on postural and visual orientation. *Aviation, Space and Environmental Medicine*, *70*(9), 879–886. PMID: 10503753.

Koziol, L. F., Budding, D., Andreasen, N., D'Arrigo, S., Bulgheroni, S., Imamizu, H., Ito, M., Manto, M., Marvel, C., Parker, K., Pezzulo, G., Ramnani, N., Riva, D., Schmahmann, J.,

Vandervert, L., & Yamazaki, T. (2014). Consensus paper: The cerebellum's role in movement and cognition. *The Cerebellum*, *13*(1), 151–177. https://doi.org/10.1007/s12311-013-0511-x

Lenggenhager, B., & Lopez, C. (2015). *Vestibular contributions to the sense of body, self, and others*. *Open mind* (Vol. 23). https://doi.org/10.15502/9783958570023

Lopez, C. (2015). Making sense of the body: The role of vestibular Signals. *Multisensory Research*, *28*(5-6), 525–557. https://doi.org/10.1163/22134808-00002490

Lopez, C., & Blanke, O. (2014). Nobel Prize centenary: Robert bárány and the vestibular system. *Current Biology*, *24*(21), R1026–R1028. https://doi.org/10.1016/j.cub.2014.09.067

Schmahmann, J. D. (2019). The cerebellum and cognition. *Neuroscience Letters*, *688*(2018), 62–75. https://doi.org/10.1016/j.neulet.2018.07.005

Smith, P. F., & Darlington, C. L. (2013). Personality changes in patients with vestibular dysfunction. *Frontiers in Human Neuroscience*, *7*(October), 1–7. https://doi.org/10.3389/fnhum.2013.00678

Wade, N. J. (2005). The original spin doctors - the meeting of perception and insanity. *Perception*, *34*(3), 253–260. https://doi.org/10.1068/p3403ed

Wolfe, J. M., Kluender, K. R., Levi, D. M., Bartoshuk, L. M., Herz, R. S., Klatsky, R. L., & Merfeld, D. M. (2017). *Sensation and perception*. Sinauer Associates, Oxford University Press.