



Editorial: Multisensory Integration: Brain, Body, and World

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The Editorial on the Research Topic

Multisensory Integration: Brain, Body, and World

The brain is safely sealed inside the cranium, with virtually no direct interaction with other parts of the body and the outside world. Nevertheless, it constantly processes the information conveyed by several sensory modalities in order to create representations of both body and outer world and to generate appropriate motor responses (Ehrsson et al., 2005; Farnè et al., 2005; Green and Angelaki, 2010). For example, vision can convey information about dangerous stimuli to trigger the generation of appropriate motor response (e.g., escape, avoidance, fight, etc.). Rather than processing sensory inputs in isolation, the brain *integrates* sensory information (Stein and Meredith, 1993; Fetsch et al., 2012) by forming reliable and robust representation of the external world and body. For example, when both visual and auditory input inform about the same danger, an appropriate motor response is more rapid and efficient (Serenio and Huang, 2006; Laing et al.).

Until a few decades ago, it was strongly believed that sensory (or multisensory) integration occurred only in high-level/associative areas or the cortex (Ghazanfar and Schroeder, 2006; Pavani and Galfano). Recently, several “new” multisensory areas have been discovered (Gobbelé et al., 2003; Pietrini et al., 2004), suggesting that a larger portion of the cortex is engaged in multisensory processing. Additional evidence suggests that multisensory integration also occurs in sub-cortical areas (Kuraoka and Nakamura, 2007; Amad et al., 2014). Finally, and perhaps surprisingly, some studies have demonstrated that multisensory processing occurs in primary sensory areas that were traditionally considered to be *uni-sensory* (Zangaladze et al., 1999; Murray et al., 2005).

Theories such as “neural reuse” (Anderson, 2010) and “metamodal” organization of the brain (Pascual-Leone and Hamilton, 2001) attempt to provide new paradigms for brain functioning taking into account widespread multisensory integration. The evolutionary advantage of multisensory integration might be the resulting availability of more reliable representations of the external world and body (Elliott et al., 2010; Grüneberg et al.) based on multiple sensory inputs and the resilience to brain injuries and sensory loss (Sarno et al., 2003; Pasqualotto and Proulx, 2012; Brown et al.; Finocchietti et al.). Indeed, multisensory integration has been reported in various experimental tasks including spatial representation (Pasqualotto et al., 2005), object recognition (Woods and Newell, 2004; Harris et al.; Höchenberger et al.; Laing et al.), movement perception (Grüneberg et al.; Imaizumi et al.; Uesaki and Ashida), body representation (Pasqualotto and Proulx, 2015; Pavani and Galfano; Tajadura-Jiménez et al.; Yiltiz and Chen), emotional processing (Miu et al.; Piwek et al.), attentional deployment (Spence, 2002; Depowski et al.), language

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(Gallese, 2008; Myachykov and Tomlin, 2008; Myachykov et al., 2012; Lam et al.; Shaw and Bortfeld), embodied reasoning (Dumitru, 2014), sensory awareness (Cox and Hong), numerical cognition (Dumitru and Joergensen), auditory perception (Brogaard and Gatzia), and time perception (Homma and Ashida).

The articles included in this special issue offer novel insights about recent developments within the field of multisensory integration, and we believe that they will help understanding the multisensory nature of brain functioning.

REFERENCES

- Amad, A., Cachia, A., Gorwood, P., Pins, D., Delmaire, C., Rolland, B., et al. (2014). The multimodal connectivity of the hippocampal complex in auditory and visual hallucinations. *Mol. Psychiatry* 19, 184–191. doi: 10.1038/mp.2012.181
- Anderson, M. L. (2010). Neural reuse: a fundamental organizational principle of the brain. *Behav. Brain Sci.* 33, 245–266. doi: 10.1017/S0140525X1000853
- Dumitru, M. L. (2014). Moving stimuli guide retrieval and (in)validation of coordination simulations. *Cogn. Process.* 15, 397–403. doi: 10.1007/s10339-014-0604-6
- Elliott, M. T., Wing, A. M., and Welchman, A. E. (2010). Multisensory cues improve sensorimotor synchronisation. *Eur. J. Neurosci.* 31, 1828–1835. doi: 10.1111/j.1460-9568.2010.07205.x
- Ehrsson, H. H., Holmes, N. P., and Passingham, R. E. (2005). Touching a rubber hand: feeling of body ownership is associated with activity in multisensory brain areas. *J. Neurosci.* 25, 10564–10573. doi: 10.1523/JNEUROSCI.0800-05.2005
- Farnè, A., Iriki, A., and Làdavas, E. (2005). Shaping multisensory action-space with tools: evidence from patients with cross-modal extinction. *Neuropsychologia* 43, 238–248. doi: 10.1016/j.neuropsychologia.2004.11.010
- Fetsch, C. R., Pouget, A., DeAngelis, G. C., and Angelaki, D. E. (2012). Neural correlates of reliability-based cue weighting during multisensory integration. *Nat. Neurosci.* 15, 146–154. doi: 10.1038/nn.2983
- Gallese, V. (2008). Mirror neurons and the social nature of language: the neural exploitation hypothesis. *Soc. Neurosci.* 3, 317–333. doi: 10.1080/17470910701563608
- Ghazanfar, A. A., and Schroeder, C. E. (2006). Is neocortex essentially multisensory? *Trends Cogn. Sci.* 10, 278–285. doi: 10.1016/j.tics.2006.04.008
- Gobbelé, R., Schürmann, M., Forss, N., Juottonen, K., Buchner, H., and Hari, R. (2003). Activation of the human posterior parietal and temporoparietal cortices during audiotactile interaction. *Neuroimage* 20, 503–511. doi: 10.1016/S1053-8119(03)00312-4
- Green, A. M., and Angelaki, D. E. (2010). Multisensory integration: resolving sensory ambiguities to build novel representations. *Curr. Opin. Neurobiol.* 20, 353–360. doi: 10.1016/j.conb.2010.04.009
- Kuraoka, K., and Nakamura, K. (2007). Responses of single neurons in monkey amygdala to facial and vocal emotions. *J. Neurophysiol.* 97, 1379–1387. doi: 10.1152/jn.00464.2006
- Murray, M. M., Molholm, S., Michel, C. M., Heslenfeld, D. J., Ritter, W., Javitt, D. C., et al. (2005). Grabbing your ear: Rapid auditory-somatosensory multisensory interactions in low-level sensory cortices are not constrained by stimulus alignment. *Cereb. Cortex* 15, 963–974. doi: 10.1093/cercor/bhh197
- Myachykov, A., and Tomlin, R. (2008). Perceptual priming and syntactic choice in Russian sentence production. *J. Cogn. Sci.* 9, 31–48. doi: 10.17791/jcs.2008.9.1.31
- Myachykov, A., Garrod, S., and Scheepers, C. (2012). Determinants of structural choice in visually-situated sentence production. *Acta Psychol.* 141, 304–315. doi: 10.1016/j.actpsy.2012.09.006
- Pascual-Leone, A., and Hamilton, R. (2001). The metamodal organization of the brain. *Prog. Brain Res.* 134, 427–445. doi: 10.1016/S0079-6123(01)34028-1
- Pasqualotto, A., Finucane, C. M., and Newell, F. N. (2005). Visual and haptic representations of scenes are updated with observer movement. *Exp. Brain Res.* 166, 481–488. doi: 10.1007/s00221-005-2388-5
- Pasqualotto, A., and Proulx, M. J. (2012). The role of visual experience for the neural basis of spatial cognition. *Neurosci. Biobehav. Rev.* 36, 1179–1187. doi: 10.1016/j.neubiorev.2012.01.008
- Pasqualotto, A., and Proulx, M. J. (2015). Two-dimensional rubber-hand illusion: the Dorian Gray hand illusion. *Multisens. Res.* 28, 101–110. doi: 10.1163/22134808-00002473
- Pietrini, P., Furey, M. L., Ricciardi, E., Gobbi, M. I., Wu, W. H. C., Cohen, L. G., et al. (2004). Beyond sensory images: object-based representation in the human ventral pathway. *Proc. Natl. Acad. Sci. U.S.A.* 101, 5658–5663. doi: 10.1073/pnas.0400707101
- Sarno, S., Erasmus, L. P., Lipp, B., and Schlaegel, W. (2003). Multisensory integration after traumatic brain injury: a reaction time study between pairings of vision, touch and audition. *Brain Inj.* 17, 413–426. doi: 10.1080/0269905031000070161
- Sereno, M. I., and Huang, R. S. (2006). A human parietal face area contains aligned head-centered visual and tactile maps. *Nat. Neurosci.* 9, 1337–1343. doi: 10.1038/nn1777
- Spence, C. (2002). Multisensory attention and tactile information-processing. *Behav. Brain Res.* 135, 57–64. doi: 10.1016/S0166-4328(02)00155-9
- Stein, B. E., and Meredith, M. A. (1993). *The Merging of the Senses*. Boston, MA: The MIT Press.
- Woods, A. T., and Newell, F. N. (2004). Visual, haptic and cross-modal recognition of objects and scenes. *J. Physiol.* 98, 147–159. doi: 10.1016/j.jphysparis.2004.03.006
- Zangaladze, A., Epstein, C. M., Grafton, S. T., and Sathian, K. (1999). Involvement of visual cortex in tactile discrimination of orientation. *Nature* 401, 587–590. doi: 10.1038/44139

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