

*Editorial*

# On the Nature of the Interplay of Perception, Action, and Cognition

Giovanni Anobile<sup>1,†</sup>, Roberto Arrighi<sup>1,\*,†</sup>

<sup>1</sup>Department of Neuroscience, Psychology, Pharmacology and Child Health, University of Florence, 50135 Florence, Italy

\*Correspondence: [roberto.arrighi@unifi.it](mailto:roberto.arrighi@unifi.it) (Roberto Arrighi)

†These authors contributed equally.

Academic Editor: Silvio Ionta

Submitted: 7 July 2022 Accepted: 14 July 2022 Published: 19 September 2022

One of the fundamental searches in cognitive neuroscience is for the role of the perceptual and cognitive systems. Much evidence suggests that a critical function is to allow actions. The idea of a link between sensorimotor development and cognition has a long history. Piaget, in 1955 [1], proposed that basic sensorimotor functions are the foundation for the development of higher-level cognitive functions. According to this perspective, knowledge of the environment is built through active exploration. Actions are planned and organized in light of the collected sensory information and cognitive inputs (e.g., expectations). These, in turn, yield modifications to the environment that provide new information to the sensory systems, which are again combined with cognitive processes to create memories, strategies, and, eventually, new actions, in a never-ending loop.

Since Piaget, much has been done to investigate the relationship between perception, action, and cognition, but there is much still to be done. Notably, the lack of comprehension of the interplay between sensorimotor and cognitive functions is one of the most salient limitations to a holistic comprehension of human brain function and development. This special issue aims to tackle this problem, directly, by reporting innovative studies investigating the relationship between perceptual, motor, and cognitive functions, from low-level to high-order domains, via a wide range of multidisciplinary approaches, across the entire lifespan.

## 1. Perception, Action, and Cognition: A Complex Interaction

Perception has been classically considered to arise from an active combination of sensory signals, but numerous reports support the idea of an intimate combination of both sensory and motor inputs. For example, Arrighi and co-workers [2] showed that patients with a complete locomotor impairment, due to spinal injury, show a reduction in visual sensitivity for biological motion patterns of the routines they were no longer able to perform. If motor deprivation impairs sensory processing, the opposite also holds true; a brief period of motor stimulation yields robust perceptual distortions. Performance in several visual and auditory tasks has been measured psychophysically after a period of “motor adaptation” consisting of a short phase (few

seconds) of motor activity (fast or slow finger tapping). Perception of space [3] (separation between two points), time [4] (duration of a visual stimulus), and numerosity [5,6] (number of visual objects scattered in a given space or of flashes/sounds in a sequence) were all strongly distorted soon after the motor phase, compared to performance after no motor activity, suggesting a sensorimotor system for magnitude encoding. Similar motor-induced visual distortions of space, time, and numerosity have also been reported during saccadic eye movement [7]. Finally, time perception is even altered during walking [8] or running [9], generalizing the sensorimotor interactions to many different motor effectors as well as to different motor routines. In brief, the internal representation of the external world can be considered an active combination of perceptual and motor information.

As for low-level perception, there is also much evidence indicating that actions can shape high-level cognitive functions. For example, a paradigmatic high-level human cognitive ability is language-based mathematical reasoning. Individuals with developmental dyscalculia (a specific deficit limiting mathematical learning) are also more likely to show motor impairments than are age-matched neurotypical peers [10]. Similarly, individuals with motor coordination disorder [11] and individuals with hemiplegia [12] and diplegia show, along with motor difficulties, impaired mathematical skills. Even within the neurotypical population, a covariation between mathematical achievements and sensorimotor abilities (e.g., hitting moving targets) has been reported in children and adolescents [13]. Mental-calculation accuracy in adults shows systematic biases during saccadic eye movement [14]. Moreover, individuals suffering from motor impairments (coordination disorder and hemiplegia or diplegia) also show combined impairment of visual numerosity perception and cognitive mathematical abilities [11,12]. Widening the horizon beyond numerical cognition, the involvement of motor circuits in cognitive functions has also been well demonstrated by the mirror-neuron system [15] (encoding abstract representations) and by the involvement of motor cortex in language processing [16] and comprehension [17], as well as in speech perception [18].



## 2. An Action-Oriented Perspective for Cognitive Neuroscience

These and many other studies clearly indicate that inputs conveyed to our sense organs are actively combined with self-produced motor signals, and that cognitive abilities are also inextricably intertwined with actions. This complex interaction has been well summarized by the concept of “embodied mind” [19]. As sketched above, the development of human numerical cognition is just one of the many potential paradigmatic examples of how significant and pervasive the relationship is between sensorimotor skills (e.g., grasping a moving ball), perception (visual numerical quantities), and cognition (e.g., mental calculation abilities). Broadening the perspective, Engel and co-workers have nicely illustrated the current need for what they termed a “pragmatic turn in cognitive science”, where cognition should be considered a form of practice [20].

A deep comprehension of how action, perception, and cognition interact has the potential to increase knowledge about how the human brain evolves and operates in circumstances in which action, perception, and cognition seldom, if ever, operate in isolation. Moreover, as we are constantly interfacing with devices requiring the integration of action, perception, and cognition, this collection of articles has high potential to subserve a significant technological development. Finally, understanding the interplay between sensorimotor systems and cognitive capacities might also provide invaluable information to clinicians and school operators about the development of effective training protocols.

### Author Contributions

Both authors contributed equally to the manuscript.

### Ethics Approval and Consent to Participate

Not applicable.

### Acknowledgment

Not applicable.

### Funding

This research was funded by the Italian Ministry of Education, University, and Research under the PRIN2017 program (grant no. 2017XBJN4F—“EnvironMag”).

### Conflict of Interest

The authors declare no conflict of interest. GA and RA are serving as the Guest editors of this journal. We declare that GA and RA had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to SI.

## References

- [1] Piaget J. The child's construction of reality. Routledge & Kegan Paul: London. 1955.
- [2] Arrighi R, Cartocci G, Burr D. Reduced perceptual sensitivity for biological motion in paraplegia patients. *Current Biology*. 2011; 21: R910–R911.
- [3] Petrizzo I, Anobile G, Arrighi R. Motor adaptation distorts visual space. *Vision Research*. 2020; 171: 31–35.
- [4] Anobile G, Domenici N, Togoli I, Burr D, Arrighi R. Distortions of visual time induced by motor adaptation. *Journal of Experimental Psychology*. 2020; 149: 1333–1343.
- [5] Anobile G, Arrighi R, Togoli I, Burr DC. A shared numerical representation for action and perception. *eLife*. 2016; 5: e16161.
- [6] Togoli I, Crollen V, Arrighi R, Collignon O. The shared numerical representation for action and perception develops independently from vision. *Cortex*. 2020; 129: 436–445.
- [7] Burr DC, Ross J, Binda P, Morrone MC. Saccades compress space, time and number. *Trends in Cognitive Sciences*. 2010; 14: 528–533.
- [8] Castellotti S, D'Agostino O, Biondi A, Pignatiello L, Del Viva MM. Influence of Motor and Cognitive Tasks on Time Estimation. *Brain Sciences*. 2022; 12: 404.
- [9] Petrizzo I, Anobile G, Chelli E, Arrighi R, Burr DC. Visual Duration but Not Numerosity Is Distorted While Running. *Brain Sciences*. 2022; 12: 81.
- [10] Westendorp M, Hartman E, Houwen S, Smith J, Visscher C. The relationship between gross motor skills and academic achievement in children with learning disabilities. *Research in Developmental Disabilities*. 2011; 32: 2773–2779.
- [11] Gomez A, Piazza M, Jobert A, Dehaene-Lambertz G, Dehaene S, Huron C. Mathematical difficulties in developmental coordination disorder: Symbolic and nonsymbolic number processing. *Research in Developmental Disabilities*. 2015; 43-44: 167–178.
- [12] de Freitas Feldberg SC, da Silva Gusmão Cardoso T, Santos FH, Muszkat M, Bueno OFA, Berlim de Mello C. Numerical cognition in children with cerebral palsy. *Research in Developmental Disabilities*. 2021; 119: 104086.
- [13] Pickavance JP, Giles OT, Morehead JR, Mushtaq F, Wilkie RM, Mon-Williams M. Sensorimotor ability and inhibitory control independently predict attainment in mathematics in children and adolescents. *Journal of Neurophysiology*. 2022; 127: 1026–1039.
- [14] Binda P, Morrone MC, Bremmer F. Saccadic compression of symbolic numerical magnitude. *PLoS ONE*. 2012; 7: e49587.
- [15] Rizzolatti G, Craighero L. The MIRROR-NEURON SYSTEM. *Annual Review of Neuroscience*. 2004; 27: 169–192.
- [16] Giacobbe C, Raimo S, Cropano M, Santangelo G. Neural correlates of embodied action language processing: a systematic review and meta-analytic study. *Brain Imaging and Behavior*. 2022; 1–22.
- [17] Pulvermüller F, Fadiga L. Active perception: sensorimotor circuits as a cortical basis for language. *Nature Reviews Neuroscience*. 2010; 11: 351–360.
- [18] Scott SK, McGettigan C, Eisner F. A little more conversation, a little less action-candidate roles for the motor cortex in speech perception. *Nature Reviews Neuroscience*. 2009; 10: 295–302.
- [19] Varela FJ, Rosch E, Thompson E. The Embodied Mind: Cognitive Science and Human Experience. *Psychological Medicine*. 1991. 23: 308–532.
- [20] Engel AK, Maye A, Kurthen M, König P. Where's the action? The pragmatic turn in cognitive science. *Trends in Cognitive Sciences*. 2013; 17: 202–209.