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Extending mind, visuospatial integration, and the evolution of the parietal lobes in the human genus

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ABSTRACT

Current theories in extended mind suggest that cognition is the result of an integrative process involving brain, body, and environment. The relationships between inner and outer components strictly depend on the functional interface, which is represented by the body. Posture and locomotion influence the sensorial and behavioral relationships between the body and the environment which, in Primates, are strongly dependent on the eye-hand system, and coordinated by processes of visuospatial integration. The upper and medial parietal areas (like the precuneus and the intraparietal sulcus) are crucial for such functions. These areas are associated with specific human cortical features, and have undergone relevant morphological changes in *Homo sapiens*. Therefore, it can be hypothesized that the visuospatial functions and the role of the body as an interface have experienced important evolutionary changes in our species. Neandertals did not display similar changes in terms of brain morphology, and at the same time they showed a different manipulative behavior: they needed their teeth and mouth to properly handle tools much more than any modern human group does. This may suggest a different (and probably less specialized) way to integrate inner and outer components through the body interface. Archaeology is essential to evaluate possible functional changes in extinct human species, by considering other kinds of visuospatial behaviors that are evident from human ecology and material culture. We suggest that changes in the visuospatial integration functions and in the parietal areas may have represented an essential component for enhancing embodiment capacity. What remains to be established is the role of genetic, epigenetic, and environmental factors, in generating anatomical and functional differences among human species and between human and non-human primates. Visuospatial integration, within the perspective of extended cognition, may have had a major influence in establishing current human intellectual abilities and social patterns.

1. Beyond the braincase

René Descartes (1596–1650) was an influential supporter of the dichotomy between body and soul, introducing his dualistic philosophy based on a body component (*Res extensa*) and a soul component (*Res cogitans*). Following incomplete and incorrect neuroanatomical information integrated with some principles of symmetry and geometrical position within the body structure, he proposed the pineal gland as the point in which these two components interact (Berhouma, 2013). The symmetry issue was a little naïve: he stressed that the pineal gland was the only non-symmetrical element of the brain, and hence probably the point in which all the inputs must converge. The geometry issue was definitely structural: the pineal gland was at the center of the volume, namely the spatial core of the brain. Particularly, he proposed that the pineal gland was central in integrating eye movements and vision processes, with particular emphasis on the eye-hand system (Fig. 1).

For a long time, the brain was interpreted as a self-sufficient machine. Many current reductionist approaches seem to continue following this perspective. Recently, we recognized the importance of the environment, its influence in shaping the brain structure and functions, and the incredible plasticity and sensitivity of the cerebral system. Nonetheless, despite the relevance of such influence, the "mind" was still interpreted as a product of the brain alone, which was thought to be simply influenced by external stimuli. A

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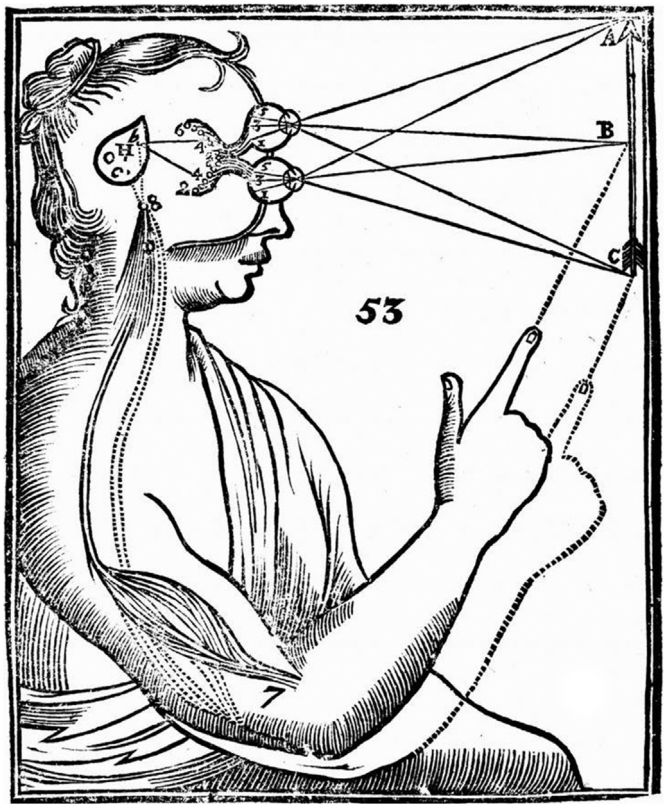

Fig. 1. Discussing the dichotomy between body and soul, Descartes gave much importance to the role of the eye-hand system in integrating the outer and inner environments, with the pineal gland being the pivotal structure able to coordinate the process (Meditations metaphysiques, 1641).

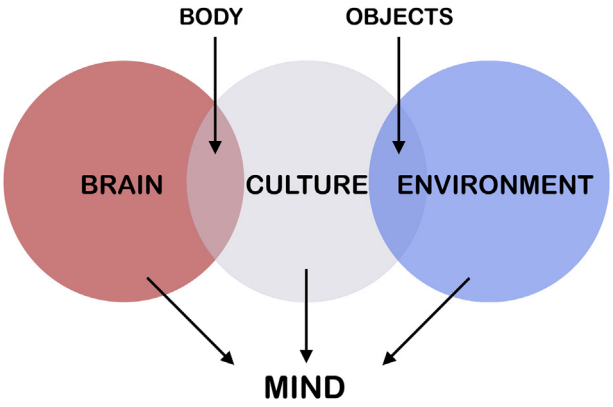

Fig. 2. The integration between brain, culture, and environment is a basic principle in human ecology. According to the theory of extended mind, these three systems are all necessary to generate our cognitive levels, these levels being grounded in the body experience and its interactions with the material component of culture.

further epistemological step has been currently put forward following the theories on *extended mind*, which suggest that cognition is the integrative result of the outer and inner environments, bridged by the interface of the body (Clark, 2007, 2008).

The inner environment is represented by the network of organic structures characterizing the organisms as individual entities, as delimited by the body, by the actual cellular range of the nervous system, and by the processes associated with the neural responses. The outer environment is represented by the physical and cultural system forming the matrix in which the organism acts and perceives, composed by objects and processes which alter the organism's structural and functional conditions, and integrating the organism's reactions and responses.

According to perspectives in cognitive extension, the cognitive process is strongly based on the body experience (*embodiment*) and dependent on activations and regulations exerted by the physical interaction between body and objects (*body-artefact interface*) (Malafouris, 2010a). We can say that the body and the objects are the interfaces between brain, culture, and environment (Fig. 2).

The body, intended as the structural and perceptual component of an organism, bridges the inner (neural) and outer (environmental) spaces. Objects, both natural and artificial, are intended as the material components of a culture, and represent a further (extra-corporal) interface, between the body and the environment. The interaction between the body and the objects is probably a dynamic process, which is part of the cognitive structure itself. The body is necessary to perform and decode the perceptive experience, while the material culture closes this loop to trigger and drive these neural processes. Objects can store information as external memories, support neural circuits through catalytic processes, and enhance our sensorial and computational capacities shaping our neural organization as active components of their functional networks. Objects, embedded as functional components of the environment, are incorporated within the neural and cognitive processes according to the principles of material engagement (Malafouris, 2008, 2010b). Our neural system is constantly trained and educated as to properly integrate the surrounding components, generating a network of dynamic relationships relying on organic and inorganic elements. Objects are formally implemented as the extended functional properties of the existing neural system, through processes which depends upon their physical distance from the body (Maravita and Iriki, 2004). Such a circuit is based on coordinated feedbacks and sensitive to reciprocal dynamics. These adaptive processes, represented as functional plasticity of the neural circuitry, are in addition shown to accompany structural modifications, not only at microscopic level (Hihara et al., 2006) but also at macroscopic level (Quallo et al., 2009). As a consequence, ecological, neural, and cognitive levels are part of an integrated system developed and evolved through mutual interactions (Iriki and Taoka, 2012).

There are several mechanical variables involved in this feedback, including the physical and spatial properties of the object, the way the hand touches the object, and the sensory input transmitted by the object when used to perceive or interact with the outer environment (see Turvey and Carello, 2011 for a detailed review). The body should be intended as a deformable interface receiving information from the external space, a perceptual system detecting information about internal and external inputs. It has properties typical of the tensional integrity (*tensegrity*) structures, namely mechanical systems which achieve a functional stability by continuous isometric tensions (Ingber, 2008). This condition generates a common tensile pre-stress condition able to synchronize mechanochemical transduction among its different components. This structural network can be hypothesized to act at organism, tissue, cellular, and subcellular level, and allows the perception of local forces on a global scale. Through the interface of body and objects, the brain and the environment shape each other (Malafouris, 2010b, 2013), giving the mind a historical perspective that goes beyond a strictly genetic and organic product. These external components could even supply “epigenetic” or extra-genomic information that can be inherited over generations, contributing to the shaping of postnatal developmental patterns both in terms of bodily structures and cognitive capacities of offspring (descendants), to match such environmental conditions.