THEORETICAL AND GENETIC CORRELATIONS BETWEEN LANGUAGE AND MOVEMENT

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ABSTRACT

The work presented aims to highlight the correlation existing between movement and language, integrating it with all the connections and brain functions involved in the two competences. Numerous studies highlight the relationship between language and movement and how they affect linguistic and sensorimotor cognitive maturation. Motor action is a complex coordination of planning, organization and monitoring; there appears to be an intuitive connection with executive functions (FE), although the exact definition is widely disputed.

The idea that there is a relationship between movement and higher cognitive functions, such as FE and language, also derives in part from theoretical perspectives such as the theory of embedded cognition. From the neurobiological point of view, this notion implies that the understanding of language is based, at least in part, on the neural systems of perception and action. FOXP2 is presumed to have played a role in evolution, due to its peculiarities of shaping the craniofacial bones, bone cartilages and participation in brain structure, having importance on the evolutionary changes of the cartilages and bones involved in the production of language and movement, promoting their evolution and reinforcing them.

It is hoped that, based on the various considerations and question marks that have arisen, a study can be carried out that investigates the role of the Foxp2 gene in subjects with speech disorders and premature at birth, aiming to identify the predictive factors and the language disorder: that of movement, trying to clarify the dark points of their correlation.

INTRODUCTION

The work presented aims to highlight the correlation existing between movement and language, integrating it with all the connections and brain functions involved in the two competences.

Several studies highlight the relationship between language and movement and how they affect linguistic and sensorimotor cognitive maturation. During the development, children become increasingly skillful at controlling their motor actions (Hamilton, Southgate, & Hill, 2016). Motor action is a complex coordination of planning, organization and monitoring; there appears to be an intuitive connection with executive functions (FE), although the exact definition is widely disputed. Many researchers would agree that FE are responsible for a series of higher-order cognitive processes, such as inhibition and working memory, tools that support motor and language control (Carlson, Faja, and Beck, 2016). The ability to communicate through language is a developmental skill to be taken into account when exploring the relationship between motor action and FE. In fact, the language supports the control of the action, i.e. it describes the action and evaluate the action performed, arranging for the planning of future actions (Kray, Eenshuistra, Kerstner, Weidema, and Hommel 2006). During early childhood, children acquire fundamental movement skills, which the most complex motor skills necessary for daily life actions are formed upon (Gabbard, 2008; Piek, Le Mani e Licari 2012).

A further study concerns the dynamics between movement-language-environment to highlight how the relationships between them are interconnected in the human body. Some authors believe that children's

ability to move has important implications to their cognitive and social development (Diamante, 2007). The maturation of motor control provides children with new opportunities to get to know the surrounding environment, both for the objects and for the individuals around him (Adolph & Joh, 2007; Von Hofsten 2009). Being able to act in the surrounding environment allows children to acquire new knowledge that will influence and trigger the changes of the various perceptual and motor systems (Von Hofsten, 2009).

MATERIALS AND METHODS

The idea that there is a relationship between movement and higher cognitive functions, such as FE and language, also derives in part from theoretical perspectives such as the theory of embedded cognition. This theory does not represent a compact theoretical front, but it rather consists of multiple approaches, sometimes even very different from each other. This makes it difficult to identify unique defining characteristics, leaving blurred boundaries between the various proposals that pertain to the theory of embedded cognition and those that instead refer to the classical cognitive paradigm. It is possible to identify at least two general assumptions which the theories of embedded cognition seem to converge to. With regard to the role of corporeality in cognition, there are at least two different approaches: the epistemic approach and the constitutive approach.

• epistemic approach

The epistemic thesis can be summarized as follows: it is impossible to outline a science of cognitive processes without understanding the structures of the body in which these processes are carried out [Row-

Fig. 1 - Brain areas and executive functions

lands, 2010, Shapiro, 2011]. According to the epistemic approach, any attempt to understand the information involved in cognitive processing must take into consideration the causal role of the morphological and dynamic properties of the body. The epistemic thesis merely focuses on the functional role of body properties in defining sensitive inputs, thereby denying the possibility of describing the cognition on the basis of merely arbitrary symbolic processing forms. This does not mean questioning the computational and representative nature of cognitive processes, but rather prefiguring an indissoluble correlation with the characteristics of the body in which the processes are carried out. The mere adoption of an epistemic approach does not seem to be able to generate a concrete break to the assumptions of classical cognitivism, it is rather limited by focusing on bodily constraints to defining the information available to the system. It is actually necessary to adopt a constitutive approach to achieve a more radical divergence.

- **constitutive approach**

According to the constitutive thesis, the cognitive processes are not limited to the operations instantiated within the cognitive system, but they include wider body structures and processes of interaction with the environment [Lakoff & Johnson, 1999; Noë, 2004; Clark, 2008; Chemero, 2009]. Ultimately the main difference between epistemic and constitutive approaches concerns the boundaries of what we refer to as cognition. (ZipoliCaianiSilvano.APhEx 8, 2013. ed. Vera Tripodi)

In literature, there are several evidences that underline the relationship between language and sensor-motor processing in the so-called embedded cognition. This approach argues that simulation and sensor-motor playing during language processing are necessary for a proper understanding. By the neurobiological point of view, this notion implies that the understand-

ing of language is based, at least partially, upon the neural systems of perception and action (Barsalou, 2008; Fischer & Zwaan, 2008; Glenberg & Gallese, 2012; Pulvermüller, 2005; de Vega, Glenberg, and Graesser 2008) [Fig.1]. Such point of view is proved by studies where by motor activity associated with language, describing an action, is investigated. In an article, Glenberg and Kaschak (2002) reported that the processing time of the sentences, which contain actions, is modulated by the preparation or an internal simulation of a movement corresponding, or not, to the action described in the sentence. Aravena et coll. (2010) found out that, through the evoked potentials, the incompatibility between a hand movement and the action depicted in a sentence increases significantly the cerebral response, in the central-parietal area (Kutas & Federmeier 2011).

A similar model was also found in studies looking for the effects of compatibility between movement and understanding of language. This study highlighted an increase of the evoked potentials when participants were reading sentences which contained two simultaneous manual actions, which could not be performed at one time (Santana & de Vega 2013). This type of data allows us to assume the existence of some common functional active substrates, both for semantic language processing and for motor control. To supporting what has been said, neuroimaging studies have reported the activation of brain regions triggered both by movement and by the use of words containing movement actions. Other studies have highlighted the activation of the fronto-parietal area between the motor and premotor cortex [Fig. 2], as a function of the verbs that contained action, compared to nouns that referred to objects (Pulvermüller 1996, 2005). Furthermore, the verbs representing actions, allowed the processing associated to different parts of the

body and the activation of the cortical somatotopic regions, which partially overlapped to those specifically involved in the execution of these actions (Hauk & Pulvermüller, 2004; Pulvermüller, Hauk, Nikulin, and Ilmoniemi 2005). The somatotopia is evident in response to the phrases that describe actions and a strong activation of the fronto-parietal network has instead been reported with regards to sentences of abstract contents (Aziz-Zadeh, Wilson, Rizzolatti, and Iacoboni, 2006; de Vega et al. 2014; Tettamanti et al., 2005).

In this perspective, it is also possible to represent the importance of another property of language: syntax, which studies the rules establishing the place occupied by each word within a sentence. Syntax assumes motion control and its main function is to combine linguistic components to produce a communicative goal, therefore the syntax uses motion action control to produce word control (Glenberg and Gallese 2012). Actually, it is well known that Broca's area is functionally involved in both syntax and sensor-motor systems (Clerget, Winderickx, Fadiga, & Olivier, 2009; Friederici, Bahlmann, Friedrich, and Makuuchi, 2011; Moro, 2014; Pulvermüller & Fadiga 2010). Up to date, the empirical research on embedded language has focused mainly on the semantic domain, i.e. how the processing of the meaning of words, concerning actions (nouns and verbs), both presented on their own and included in sentences, was recruited by our sensorimotor systems.

Neuroimaging studies have shown that the activity of the listener's motor system is shaped by the verbal description of actions and in the absence of any performed or imagined action (Boulenger, Hauk, & Pulvermüller, 2009; Buccino et al., 2005; Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson 2006; Hauk, Johnsrude, and Pulvermüller, 2004; Hauk, Shtyrov, & Pulvermüller, 2008; Pulvermüller, Shtyrov, & Ilmoniemi, 2005; Tettamanti et al., 2005).

Brain areas associated with FE, such as: the dorsolat-

eral prefrontal cortex and the brain areas necessary for the design and execution of movements, are co-activated during the execution of specific actions (Diamante, 2000). Furthermore, it has been shown that the areas of the brain involved in linguistic functions (for example, Broca's) are also activated during FE activities (Gerton et al., 2004) and the performance of motor tasks, such as, for example, action planning, action observation, understanding of actions, imitation; (Nishitani, Schürmann, Amunts, and Hari 2005) and activation of motor areas was observed during tongue articulation activities (e.g., Casado et al., 2018; Pulvermüller 2005; Willems & Hagoort 2007). [Figure 3] Nonetheless, behavioral studies observing direct links between development domains have not delivered definitive results. Furthermore, although studies have reported that children with motor coordination difficulties, including children diagnosed with Generalized Coordination Development Disorder (DCD), have clear difficulties in FE (Leonard & Hill, 2015; Wilson, Ruddock, Smits -Engelsman, Polatajko, and Blank, 2013), research has also shown that the commonly assumed link between motor coordination difficulties and FE dysfunction is not always present (Molitor, Michel, and Schneider 2015). Likewise, the latest studies have shown growing empirical evidence, which has highlighted a link between the performance of movement and speech, in children with standard development during the first 3 years of life (Walle, and Campos 2015; Libertus & Violi 2016; Walle & Campos 2014), whose relationship seems to weaken or disappear according to the age (Libertus & Hauf 2017; Oudgenoeg-Paz et al., 2016). Although it has been proven that in children with developmental disorders there is a relatively high correlation rate between motor difficulties and language problems, it is also true that not all children with motor difficulties have language problems. Regarding the relationship between verbal ability and FE, some studies have shown that children with standard devel-

Fig. 2 - Where are the executive functions ?

Fig. 3 - Illustration of human brain functions.

opment have verbal skills in relation to FE and that children with speech disorder have low scores on FE performance (Fuhs & Day 2011; Gooch, Thompson, Nash, Snowling, and Hulme, 2016; Kaushanskaya, Parco, Gangopadhyay, Davidson, and Weismer 2017; see Müller, Jacques, Brocki & Zelazo 2009). Overall, the studies are inconclusive about the exact extent of relationships between development domains, probably due to both the differences between children and the different measures used to evaluate children movements, FE and verbal skills (Leonard & Hill, 2015; Libertus & Hauf 2017).

Several studies have correlated fundamental human traits, namely language and movement, which are as-

sociated with each other by a series of craniofacial adaptations and skeletal muscle remodeling. However, it is not clear how these morphological features arose during the evolution of men. [Figure 4]

A factor that could have played a fundamental role in the birth of language and movement is the FOXP2 gene. FOXP2 is presumed to have played a role in evolution, due to its peculiarities of shaping the craniofacial bones, bone cartilages and participation in brain structure, having importance on the evolutionary changes of the cartilages and bones involved in the production of language and movement, promoting their evolution and reinforcing them. Changes in the morphology of the vocal tract may have played a role in the birth of the human voice.

Fig. 4 - The evolution of the human brain.

This gene is implicated in a rare disease involving apraxia and speech difficulties. In a study, by the analysis of the skeleton of a mice, the FOXP2 genes in the skull, in the skeletal area and in the geometry of the vocal-tract were identified, including the sphenoid and the laryngeal cartilage and it is deduced that Foxp2 could help establish the anatomical substrates utilized for voice communication. The results indicate that Foxp2 performs a pleiotropic influence and helps regulate the strength, length of the hind limbs, helps supporting the articular cartilage of the knees and the intervertebral discs. [Figure 5] Studies in people with FOXP2 variation have reported difficulty feeding and coughing, this could plausibly relate to changes in the laryngeal cartilage due to the variation of the gene. In light of the known roles of Foxp2 in brain circuits, the studies suggest that this gene could contribute to the coevolution of neural and anatomical adaptations related to language and motor activity. The emergence of human language has caused not only neural, but also anatomical changes in the vocal tract, including the configuration of the vocal cords, the trachea and the oral cavity. However, this new discovery of the FOXP2 gene could give further answers to all scholars seeking correlations between movement and language.

Fig. 5 - Comparative images: deletion of the FOXP2 gene with consequent morphological changes of the structures concerned.

CONCLUSIONS

Based on the emerged results, the correlations between movement and language are increasingly evident, thanks also to the discovery of the FOXP2 gene and the probable interconnections that it creates between verbal and motor skills. This discovery highlighted the importance of the gene in the formation of fundamental structures for human evolution and how

it regulates movement and language, which are the cornerstones of human development. It is hoped that, based on the various considerations and question marks that have arisen, a study can be carried out that investigates the role of the Foxp2 gene in subjects with speech disorders and premature birth, aiming to identify the predictive factors both of the language and movement disorders, trying to clarify the dark points of their correlation.

Fig. 5a - Photos of the different sizes of the skull structure of mice.

Fig. 5b - Photos of the different sizes of vocal tract and hind limbs of mice.

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