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Variability in functional brain networks predicts expertise during action observation

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Observing an action performed by another individual activates, in the observer, similar circuits as those involved in the actual execution of that action. This activation is modulated by prior experience; indeed, sustained training in a particular motor domain leads to structural and functional changes in critical brain areas. Here, we capitalized on a novel graph-theory approach to electroencephalographic data (Fraiman et al., 2016) to test whether variability in functional brain networks implicated in Tango observation can discriminate between groups differing in their level of expertise. We found that experts and beginners significantly differed in the functional organization of task-relevant networks. Specifically, networks in expert Tango dancers exhibited less variability and a more robust functional architecture. Notably, these expertise-dependent effects were captured within networks derived from electrophysiological brain activity recorded in a very short time window (2 s). In brief, variability in the organization of task-related networks seems to be a highly sensitive indicator of long-lasting training effects. This finding opens new methodological and theoretical windows to explore the impact of domain-specific expertise on brain plasticity, while highlighting variability as a fruitful measure in neuroimaging research.

1. Introduction

Expertise can be conceptualized as a set of specific skills or abilities acquired through sustained training, which supports outstanding performance in a particular artistic, athletic, professional, or otherwise cognitive domain. Understanding what is special in the expert brain provides a unique window into experience-dependent plasticity changes and learning mechanisms. Several studies have shown that expert deployment of specific functions induces structural changes in brain areas devoted to them. For example, relative to non-expert controls, experienced taxi drivers have greater grey matter volume in the posterior hippocampus, a region subserving navigational skills (Maguire et al., 2000). Moreover, expertise may change long-range cortical connections, allowing top-down control mechanisms to modulate the states (and multiply the function) of sensory and motor circuits (Gilbert and Sigman, 2001; Sigman et al., 2005; Gilbert and Sigman, 2007). In this sense, expertise may involve the functional reorganization of a brain region originally specialized for different

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Table 1
The average and the standard deviation is presented within parentheses.

Group of variables	Variables	Experts (25) *M(SD)*	Beginners (28) *M(SD)*	*p*-Value
Demographics	Age (years)	29.08 (6.20)	29.57 (5.85)	0.76
	Gender (M:F)	11:14	13:15	0.85
	Education (years)	17.4 (3.59)	18.25 (3.40)	0.38
	Handedness (L:R)	0:25	0:28	1.00
Empathy	Perspective taking	26.76 (4.09)	28.82 (3.43)	0.07
	Fantasy	23.16 (4.57)	23.67 (3.43)	0.49
	Empathy	31.6 (3.90)	33 (3.03)	0.11
	Personal distress	14.2 (3.50)	15.5 (3.97)	0.23
Executive functions	IFS Global Score	26.16 (2.3)	26.64 (1.9)	0.66
	Motor series	2.76 (0.66)	2.92 (0.26)	0.57
	Conflicting instructions	2.92 (0.27)	3 (0)	0.62
	Go / no go	2.84 (0.37)	2.96 (0.18)	0.44
	Backward digits span	4.28 (0.84)	4.28 (0.18)	0.81
	Verbal working memory	1.84 (0.37)	1.82 (0.47)	0.95
	Spatial working memory	3.32 (0.69)	3.28 (0.65)	0.83
	Abstraction capacity	2.8 (0.32)	2.75 (0.65)	0.64
	Verbal inhibitory control	5.4 (0.81)	5.60 (0.62)	0.42

domains.
For instance, expertise in recognizing cars and birds is associated with activity in the fusiform face area, a cortical region normally specialized in face recognition (Gauthier et al., 2000).

While these notions have some degree of generalization, how they are instantiated depends on each specific domain and form of expertise. Two interesting questions thus emerge: (a) can a general signature of expertise be reliably identified; and, if so, (b) which could be a suitable approach for its detection and measurement? Fruitful answers may be derived from functional connectivity methods (Rubinov and Sporns, 2010). In particular, graph-theory metrics have been proposed as powerful tools for quantifying properties in complex brain networks (Bullmore and Sporns, 2009; De Vico Fallani et al., 2014). Interestingly, this approach allows capturing inter- and intra-individual variation during task performance. Although variability is an inherent property of the human brain, neuroimaging research has largely neglected its importance or interpreted it as the result of various confounds (Garrett et al., 2013). However, an increasing body of evidence suggests that variability measures constitute a powerful index to study human brain functions (for a review, see Garrett et al., 2013). In line with this idea, we propose that variability in functional brain networks derived from a task-evoked condition would be a natural candidate to track this general signature of expertise. Notably, intense training has been specifically linked to a decrease in variability (Santos et al., 2015), with some demonstrations of a causal role between temporal variability and learning (Tallal et al., 1996; Merzenich et al., 1996). Furthermore, naturalistic everyday stimuli (which can be conceived as stimuli for which we all are naturally experts) evoke highly reliable brain activity across observers, both at the neuronal (Mainen and Sejnowski, 1995; Cecchi et al., 2000) and at the macroscopic (Dmochowski et al., 2014) scales.

Here, we test the hypothesis that expertise results in more reproducible patterns of brain activation across individuals, and that these connectivity patterns can be used as an index to classify participants according to their expertise. Based on the notion that action observation and execution depend on partially shared circuits (Fadiga and Rizzolatti, 1995; Gazzola and Keysers, 2009; de Beukelaar et al., 2016), and that only those actions performable by the observer are mapped onto his/her own motor system (Buccino et al., 2004; Calvo-Merino et al., 2006), we focused on Tango dancers as a model of expertise. Using high-density electroencephalography (EEG), we recorded neural activity from expert and beginner Tango dancers as they observed videos depicting a couple of dancers performing various Tango steps. Importantly, by using videos of dance movements which vary in time and are well-known by the observers, we aimed to measure the reliability of task-evoked functional networks.

Overall, we predicted that: (i) brain functional networks engaged during the dance observation task (Amoruso et al., 2014) would show lower variability in experts than in beginners; and that (ii) network variability would serve as a classifier to identify the observers degree of expertise.

2. Materials and methods

2.1. Participants

The study comprised 53 Tango dancers recruited from three Tango schools: DNI, the *Flor de Milonga* and the *Divino Estudio del Abasto*. Twenty-five (14 females) were expert dancers (mean age=29, SD=6.2), and 28 (15 females) were beginner dancers (mean age=29.5, SD=5.8). The groups were matched for age, education level, gender, and executive skills. Furthermore, previous studies on action observation suggest that empathic abilities may affect action simulation (Kaplan and Iacoboni, 2006; Lepage et al., 2010; Tidoni et al., 2013), including the observation of dance movements (Jola et al., 2012). Therefore, to ensure that expertise-