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A specific impairment in cognitive control in individuals with high-functioning autism

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ABSTRACT

Although it is largely demonstrated that Autism Spectrum Disorders (ASDs) are characterized by executive dysfunctions, little is known about the fine-grained levels of this impairment. Here, we investigated the hierarchical architecture of control modules in autism using an experimental paradigm based upon a multistage model of executive functions. This model postulates that executive functions are hierarchically organized as a cascade of three different control processes, which are implemented according to information conveyed by sensory signals (sensory control), the immediate perceptual context (contextual control), and the temporal episode in which stimuli occur (episodic control). Sixteen high-functioning adults with autism or Asperger Syndrome (HFA/AS) and sixteen matched comparison participants took part in two distinct visuo–motor association experiments designed to separately vary the demands of sensory and episodic controls (first experiment) and contextual and episodic controls (second experiment). Participants with HFA/AS demonstrated no significant differences in performances with comparison participants when they had to control sensory or contextual information. However, they showed decreased accuracy when having to control information related to episodic signals. Remarkably, performances in episodic control were associated to the autism spectrum quotient in both groups, suggesting that this episodic control impairment might be at the core of ASDs. Those results plead for a specific, rather than generalised, deficit in executive functions in autism. Our study contributes to a better understanding of the impaired cognitive processes that are unique to autism and warrants confirmation using other models of executive functions.

1. Introduction

Autism spectrum disorder is a pervasive neurodevelopmental disorder characterized by impairments in social interaction and communication, as well as repetitive, restricted and stereotyped patterns of behaviour, interests and activities (American Psychiatric Association, 2000). One of the prevailing theories of this complex and poorly understood disorder states that autistic individuals' core dysfunction stems from their difficulties in executive functions, the cognitive processes that allow the selection of actions appropriate to our current activities or goals (Hill, 2004). It has been suggested that executive dysfunctions would indeed account for all the symptoms of autism. As an example, the executive dysfunction hypothesis postulates that impairments in social interaction and communication could be explained by an inability to shift social behaviour or conversational topics, while repetitive behaviours could be underpinned by an inability to shift attention from one interest to another (Geurts et al., 2009).

To date, three executive processes have been suggested to be impaired in autism: planning (the ability to prepare future action plans), mental flexibility (the ability to switch between competing representations) and inhibition (the ability to retain a prepotent response) (Geurts et al., 2009; Hill, 2004). However, their investigation has raised at least two main problems. First, those executive processes are thought to be dysfunctional in other neurodevelopmental disorders classically associated with executive dysfunctions, such as schizophrenia (Eisenberg and Berman, 2009). This failure to demonstrate a specific profile of executive

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dysfunctions in autism could stem from the fact that the tasks that have been used usually implement multiple cognitive components that can confuse the interpretation of results (Geurts et al., 2009). For example, tasks such as the Wisconsin Card Sorting Task (WCST) involve multiple executive processes such as mental flexibility, working memory, or inhibition, and are therefore not appropriate to investigate the cognitive mechanisms specifically impaired in such a complex disorder. Second, while a growing number of studies have demonstrated executive deficits in participants with autism spectrum disorders, numerous attempts to replicate those findings have been proven inconclusive (Barnard et al., 2008; Goldberg et al., 2005; Kleinhans et al., 2005; Landa & Goldberg, 2005; Poljac et al., 2010). In other words, those with autistic spectrum disorders demonstrate an important individual variation in their executive dysfunctions. Therefore, there is an urgent need to use more precise models of executive processes in order to better characterise the profiles of executive dysfunctions that are unique to autism, as well as to account for their individual variability.

An interesting way to better understand executive dysfunctions in autism is to use recent conceptual models which postulate that executive processes are organised as a set of hierarchical modules involved in the selection of the most appropriate action (e.g. Badre and D'Esposito, 2009; Koechlin and Summerfield, 2007). Each of those different modules is thought to process information conveyed by specific external signals and to be involved in the selection of representations at lower levels of the hierarchy. For example, consider the main goal of watching a movie at the cinema. This main, abstract goal can be subdivided into different hierarchical subgoals, such as finding a suitable movie and going to the cinema. Then, each of those two high-level subgoals can itself be subdivided into more concrete subgoals at a lower level. For instance, finding a suitable movie (high-level subgoal) would involve reading reviews, asking some friends for their feedbacks, and looking up the dates of those movies (low-level subgoals). Likewise, going to the cinema (high-level subgoal) would involve driving to the theatre, buying a ticket, and sitting comfortably in front of the screen (low-level subgoals). In this trivial example, the key point is that a cognitive module at each level of the hierarchy controls (i.e. influences) the implementation of another, more concrete, module at a lower-level of the hierarchy.

In the current study, we investigated the hierarchical organisation of executive functions in individuals with high-functioning autism or Asperger syndrome (HFA/AS). We used an influential model that describes the organisation of executive functions as a cascade of three executive modules that are implemented according to the temporal framing of information (Koechlin et al., 2003) (Fig. 1). At the lower level of this hierarchy, this model first includes a sensory control level involved in selecting the motor responses that are the most appropriate to the incoming stimulus. For example, when a phone rings (stimulus), this triggers an appropriate behaviour, which is to pick up the phone (motor response). Second, a contextual control level is involved in selecting appropriate stimulus-response associations according to immediate contextual signals that accompany the occurrence of stimuli. For example, if on its screen the phone displays the number of a loved one (context 1) whilst ringing (stimulus), people will pick it up (response); but if it displays the number of a colleague from work (context 2), the same stimulus might be associated to a different response: people might let it ring. In other words, the stimulus-response associations depend on the immediate context accompanying the occurrence of the stimulus. The third, higher-level of this control hierarchy is the episodic control level, which is involved in selecting consistent sets of stimulus-response associations evoked in the same immediate context according to the temporal episode in which stimuli occur. Here, an episode is defined as a

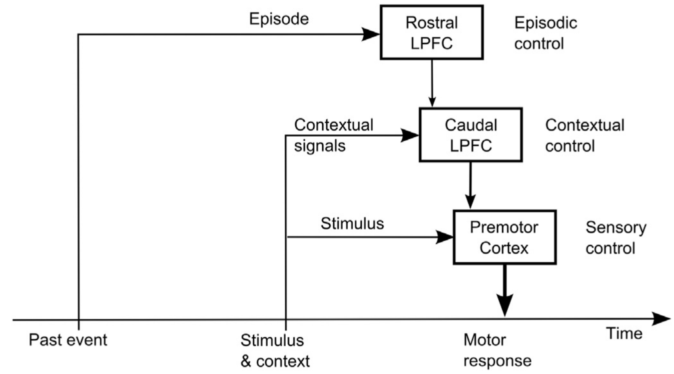

Fig. 1. The cascade model of cognitive control. The multistage organization of information processing includes a SENSORY control level involved in selecting the motor responses that are the most appropriate to stimuli that occur. This control is subserved by the lateral premotor regions. The CONTEXTUAL control level is involved in selecting stimulus-response (SR) associations according to contextual signals accompanying stimuli occurrences. This control is subserved by the caudal part of the lateral prefrontal cortex. The EPISODIC control level is involved in selecting task-sets or consistent sets of SR associations evoked in the same context according to the temporal episode in which stimuli occur; that is, according to events that previously occurred or to ongoing internal goals. This control is subserved by the rostral part of the lateral prefrontal cortex.

particular situation in which the person is acting, and is based on past events, instructions or ongoing internal goals. For example, in the situation where a person is at home (episode 1), a call from a loved one (context 1) will be associated to a pick up response, but a call from a work colleague (context 2) will be associated to a non-response. Conversely, in the situation where a person is at work (episode 2), context 1 will be associated to a non-response, whereas context 2 will be associated to a pick-up response. In other words, each stimulus-response association evoked in a specific context depends on the specific situation (or temporal episode) in which the person is acting.

The top-down hierarchical, cascading nature of this model is derived from the idea that processing carried out at each level of this hierarchy is informed by the processing driven by progressively higher levels, just as in the examples cited above (sensory control processing is informed by contextual control, which is itself influenced by episodic control).[1] The cascade model is in agreement with previous descriptions of the anatomical connections' network in the frontal cortex (Pandya and Yeterian, 1996) and lesions studies (Grafman, 1989; Sirigu et al., 1995, 1996; Zalla et al., 2001, 2003). In their seminal study, Koechlin et al. (2003) demonstrated that sensory, contextual and episodic control processes was subserved by a cascade of functional activations along a rostro–caudal axis of the frontal lobe. More recently, the model has received further biological evidence by using functional neuroimaging technics (Barbalat et al., 2009, 2011; Kouneiher et al., 2009) and by research involving patients with frontal cortex lesions (Azuar et al., 2014; Badre et al., 2009).

In the current study, we investigated the temporal organisation of executive functions in adults with HFA/AS by adapting the experimental paradigm of Koechlin et al. (2003), which modelled sensory, contextual and episodic control processes. The study consisted of two behavioural experiments that were designed to

[1] Note that while the cascade model differentiates three types of executive processes hierarchically recruited according to the temporal structure of information, it does not make any assumptions on the functional organisation of the other executive sub-processes that we mentioned above (i.e. planning, mental flexibility, and inhibition).