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Revealing hot executive function in children with motor coordination problems: What's the go?

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ABSTRACT

Recent research suggests that children with Developmental Coordination Disorder (DCD) often show deficits in executive functioning (EF) and, more specifically, the ability to use inhibitory control in 'hot', emotionally rewarding contexts. This study optimized the assessment of sensitivity of children with DCD to emotionally significant stimuli by using easily discriminable emotional expressions in a go/no-go task. Thirty-six children (12 with DCD), aged 7–12 years, completed an emotional go/no-go task in which neutral facial expressions were paired with either happy or sad ones. Each expression was used as both, a go and no-go target in different runs of the task. There were no group differences in omission errors; however, the DCD group made significantly more commission errors to happy no-go faces. The particular pattern of performance in DCD confirms earlier reports of (hot) EF deficits. Specifically, a problem of inhibitory control appears to underlie the atypical pattern of performance seen in DCD on both cold and hot EF tasks. Disrupted coupling between cognitive control and emotion processing networks, such as fronto-parietal and fronto-striatal networks, may contribute to reduced inhibitory control in DCD. The implications for a broader theoretical account of DCD are discussed, as are implications for intervention.

1. Introduction

Recent experimental work has raised several viable hypotheses about the neurocognitive underpinnings of atypical motor development (or Developmental Coordination Disorder—DCD). In a recent meta-analysis of the literature (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013), the pattern of motor and cognitive performance in children with and without DCD was compared across 129 studies between 1998 and 2011. In addition to a broad cluster of motor control and learning issues, what was striking about this work was the consistent pattern of executive dysfunction (Cohen's $d > 1$) across inhibitory control, working memory and executive attention tasks. Executive function (EF) refers to a group of neurocognitive processes involved in conscious and effortful control of thought, emotion, and behavior. More specifically, EF encompasses working memory, executive attention, mental flexibility, and inhibition (Diamond, 2013). In recent studies, we have shown executive dysfunction in DCD extends to tasks that require so-called 'hot EF'. These tasks have superimposed the requirement that emotional cues (positive and negative) be processed in order to achieve a task goal—hence the term *hot EF*. The issue of hot EF in children with DCD is particularly salient given other work showing that these children have difficulty with self-regulation (Sangster Jokic & Whitebread, 2011) and a higher incidence of anxiety associated with their motor problems (e.g., Missiuna et al., 2014; Skinner & Piek, 2001; Tseng, Howe, Chuang, & Hsieh, 2007). In the study reported here, we investigated hot EF using a go/no-go paradigm that used facial stimuli that were readily discriminable by children. Critically, we tested the specificity of the putative deficit in DCD that relates to the ability to inhibit responses to salient no-go stimuli.

The general consensus is that DCD occurs in about 5–6% of children (DSM-5; American Psychiatric Association (APA), 2013); however, other estimates range from 1.8% for 'definite DCD' (Lingam, Hunt, Golding, Jongmans, & Emond, 2009) to as high as 19% of school-aged children (Tsiotra et al., 2006). DCD is characterized by problems in learning fine and/or gross motor skills, with resultant disruptions in daily living activities and/or academic achievement (APA, 2013). Also associated with the disorder are a range of psychosocial issues including poor self-esteem, low self-efficacy

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(particularly for physical tasks), and impaired social relations (Poulsen, Ziviani, Cuskelly, & Smith, 2007). A relationship between motor and cognitive development (Diamond, 2000; Koziol, Budding, & Chidekel, 2012) in DCD is supported by data showing concurrent deficits in each domain (Zwicker, Missiuna, Harris, & Boyd, 2011). EF deficits in DCD have led some to postulate that DCD is more than a purely motor disorder, but rather a broader neurodevelopmental syndrome (Wilson et al., 2013), one also associated with poor social-emotional adjustment (Zwicker, Harris, & Klassen, 2012). As a result, efforts to understand the underlying basis of DCD have centred on examination of motor control and EF.

While the classification of EF varies from one theorist to another (see Welsh & Peterson, 2014), two points have been brought into clear focus by recent work: first, the emotional valence of stimuli is critical in determining what nodes in a neural network are enlisted when performing an EF task, and second, component processes like *inhibition* are shared between 'cold' and 'hot' EF. Cold EF, subserved by dorsolateral prefrontal cortex (DL-PFC), is enlisted when one interacts with abstract, decontexualized stimuli, such as in the traditional lab-based tests of EF used to assess working memory, mental flexibility, and inhibition (Zelazo & Carlson, 2012). Hot EF, associated with ventromedial prefrontal cortex (VM-PFC), is more relevant to everyday decision-making, and incorporates the ability to reappraise the emotional-motivational significance of stimuli in order to voluntarily inhibit or activate a particular behavior. The hot EF tasks, such as the delay of gratification and gambling tasks (e.g., Iowa Gambling Task (IGT); Bechara, Damasio, Damasio, & Anderson, 1994), mimic aspects of real-life decision-making through the use of rewards and losses. We recently showed that in the case of DCD, atypical patterns of performance were evident not only for traditional (cold) EF tasks but also so-called hot EF. Intriguingly, there may be a reduced ability in DCD to resist stimuli that offer high immediate reward, but longer term loss (Rahimi-Golkhandan, Piek, Steenbergen, & Wilson, 2014). Impaired inhibitory control may contribute to this.

Response inhibition is believed to be an important determinant of not only cold EFs (e.g., working memory and set-shifting), but also the ability to resist temptation (Aron, Robbins, & Poldrack, 2004; Diamond, 2013; van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012). For instance, some regions (e.g., anterior cingulate) that are active during inhibitory control tasks (e.g., go/no-go; Braver, Barch, Gray, Molfese, & Snyder, 2001) also predict optimal performance (i.e., higher net scores) on the IGT and its variants which tap into both the reward and inhibitory circuitry of the brain (Ernst et al., 2002; Smith, Xiao, & Bechara, 2012). Poor response inhibition prevents the contemplation and implementation of other response options, and eventually leads to low self-control and impulsive behaviors in children (Riggs, Blair, & Greenberg, 2004).

Recent fMRI data suggest that hypo-activity of DL-PFC in children with DCD may explain their reduced ability to switch (i.e., mentally shift) between go and no-go motor responses (Querne et al., 2008). Moreover, given the extensive connections between VM-PFC and the emotion circuitry of the brain, disruption of prefrontal regulation could underlie reduced emotional regulation that has been observed in DCD (Deng et al., 2014). Although cognitive inhibition – integral to interference control and selective attention – has been tested extensively in DCD, there is a dire need to investigate behavioral inhibition (i.e., self-control, resistance to temptation) (Diamond, 2013) in this cohort. Understanding the mutually interactive relationship between motor, cognitive and affective processes is a critical issue in both typical and atypical child development (Zelazo & Müller, 2011) and, in the case of DCD, holds significant implications for the design of interventions that target motor and/or behavioral issues, e.g. how training tasks can accommodate EF deficits in children.

1.1. Deficits of hot EF in DCD

In an earlier study (Rahimi-Golkhandan, Piek, et al., 2014), we investigated EF in DCD using a child-friendly variant of the IGT, called the Hungry Donkey Task (HDT; Crone & van der Molen, 2004). The optimal performance on the HDT relies on ignoring options that are initially rewarding but lead to an overall loss, and instead choose those associated with lower immediate reward (see Crone & van der Molen, 2004 for a description of the HDT). Children with DCD had a significantly lower total net score than typically developing (TD) children, and opted for the disadvantageous (high immediate reward) options. Moreover, even though the reaction time (RT) of the TD group did not depend on the type of option, the DCD group responded significantly faster to the disadvantageous options. One of the possible reasons for this pattern of performance in the DCD group is a deficit of inhibitory control (Rahimi-Golkhandan, Steenbergen, Piek, & Wilson, 2014).

The follow-up study (Rahimi-Golkhandan, Steenbergen, et al., 2014), with the same groups of children, used an emotional go/no-go task to investigate specifically the role of inhibition in the heightened sensitivity of the DCD cohort to rewarding stimuli. In any go/no-go task, some stimuli ('go' targets: e.g., sad faces) are to be approached – for instance, by touching a screen or pressing a key on a keyboard – and some others (no-go targets: e.g., happy faces) are to be avoided. The main outcome measures in a go/no-go paradigm are omission and commission errors. Omission error, defined as a failure to respond to the relevant 'go' stimuli, provides a measure of attention and reflects the tendency to respond to a particular stimulus (Schulz et al., 2007). On the other hand, commission errors are defined as a failure to withhold responding to a 'no-go' stimulus. This index provides a measure of behavioral inhibition, in that the lower the number of commission errors, the better is the ability to exert inhibitory control (Tottenham, Hare, & Casey, 2011). In Rahimi-Golkhandan, Steenbergen and others study, children completed both 'cold' (neutral facial expressions) and 'hot' (happy and fearful faces) versions of the task. There were no significant group differences in omission errors. As well, analysis of d' – a measure of perceptual sensitivity – did not reveal any significant group differences, indicating that the emotional valence of the stimuli was apparent to both groups, and that both children with DCD and the controls were equally adept at recognizing facial expressions. However, commission error rate was similar between the two groups for all the no-go stimuli except when the target was a happy face. The DCD group made significantly more errors, and failed to withhold responses to happy no-go faces on more than half of the trials. This result suggests that poor affective decision-making of children with DCD on a hot EF task (i.e., the IGT) could be attributed to their heightened sensitivity to emotionally and motivationally significant stimuli, and their reduced inhibitory control in emotionally rewarding contexts. We suggest the interaction between emotion processing and cognitive control networks underlies this deficit (Rahimi-Golkhandan, Steenbergen, et al., 2014). More generally, these results suggest that what characterizes the performance pattern of children with DCD may be a deficit of emotion regulation.

The effects we observed, however, may have been moderated by the choice of no-go stimuli. Being intrinsically rewarding, the presentation of happy no-go faces on 30% of the trials may have created an approach bias (or tendency to respond) that also influenced responses to go stimuli (Hare, Tottenham, Davidson, Glover, & Casey, 2005). For instance, RT to a fearful go face might be quicker immediately after exposure to a happy no-go face. Because sensitivity to rewarding stimuli was shown to be heightened in children with DCD, this "priming effect" could be enhanced, masking real differences between groups in their response to 'negative' stimuli. Moreover, commission errors of the DCD group to fearful