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Feedforward motor control in developmental dyslexia and developmental coordination disorder: Does comorbidity matter?

Fabien Cignetti[a,b,c,*], Marianne Vaugoyeau[a,b], Aurelie Fontan[a,b], Marianne Jover[d], Marie-Odile Livet[e], Catherine Hugonenq[f], Frédérique Audic[f], Brigitte Chabrol[f], Christine Assaiante[a,b]

[a] *Aix-Marseille Université, CNRS, LNC UMR 7291, Marseille, France*
[b] *Aix-Marseille Université, CNRS, FR 3512, Marseille, France*
[c] *Univ. Grenoble Alpes, CNRS, TIMC-IMAG, F-38000 Grenoble, France*
[d] *Aix Marseille Univ, PSYCLE, Aix-en-Provence, France*
[e] *Service de Pédiatrie, Centre Hospitalier du pays d'Aix, Aix-en-Provence, France*
[f] *Service de Neurologie Pédiatrique, CHU Timone-Enfants, Marseille, France*

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ABSTRACT

Background and aim: Feedforward and online controls are two facets of predictive motor control from internal models, which is suspected to be impaired in learning disorders. We examined whether the feedforward component is affected in children (8–12 years) with developmental dyslexia (DD) and/or with developmental coordination disorder (DCD) compared to typically developing (TD) children.
Methods: Children underwent a bimanual unloading paradigm during which a load supported to one arm, the postural arm, was either unexpectedly unloaded by a computer or voluntary unloaded by the subject with the other arm.
Results: All children showed a better stabilization (lower flexion) of the postural arm and an earlier inhibition of the arm flexors during voluntary unloading, indicating anticipation of unloading. Between-group comparisons of kinematics and electromyographic activity of the postural arm revealed that the difference during voluntary unloading was between DD-DCD children and the other groups, with the former showing a delayed inhibition of the flexor muscles.
Conclusion: Deficit of the feedforward component of motor control may particularly apply to comorbid subtypes, here the DD-DCD subtype. The development of a comprehensive framework for motor performance deficits in children with learning disorders will be achieved only by dissociating key components of motor prediction and focusing on subtypes and comorbidities.

What this paper adds?

Children with developmentalcoordination disorder (DCD) experience difficulties in predictive motor control. It is hypothesised that these difficulties result from a deficit to use properly internal models. Several studies also reported poor motor abilities in children with developmental dyslexia (DD), which are grouped under the term sensorimotor syndrome. Thus, impaired motor control related to internal model deficits may not be specific to DCD but may constitute a hallmark of developmental learning disorders. However, it is imperative to address this issue by considering (i) the fact that models of motor control divide movements into two

* Corresponding author at: Université Grenoble-Alpes, CNRS, Laboratoire TIMC-IMAG, Grenoble, France.
E-mail address: fabien.cignetti@univ-grenoble-alpes.fr (F. Cignetti).

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components, namely a feedforward component and an online component, and (ii) the co-occurrence of developmental learning disorders. In the present study we sought to determine whether children with DD and/or DCD demonstrate impaired feedforward control in the task of bimanual unloading. This task requires anticipating for a perturbation in one hand that is the result of a volitional action of the other hand. Results demonstrated that only children with both DD and DCD were impaired in bimanual unloading. This outcome suggests that feedforward control deficit may not apply uniformly to all DCD children but may rather apply to comorbid subtypes, here the DD-DCD subtype. Future research needs to examine the issue of motor dysfunction in children with learning disorders while monitoring components of predictive motor control and subtypes and comorbidities.

1. Introduction

Humans demonstrate a remarkable ability to evaluate the future states of their body segments, referred as motor prediction. Over the past 20 years scientists gathered evidence that this predictive ability results from internal models or representations and includes both the pre-programming of the motor command before the onset of movement, aka the feedforward control, and the adjustment of the motor command in near real time, aka the online control (Desmurget & Grafton, 2000; Kawato, 1999; Shadmehr & Krakauer, 2008; Wolpert & Ghahramani, 2000). Feedforward motor commands are generated by inverse internal models given desired movement trajectories and initial conditions. Online control results from forward internal models that predict the future state of the motor system given a copy of the issued motor commands and the actual state of the system. If actual and predicted body states differ, the difference is used to adjust the set of motor commands in real time. As such, error signals from forward models are particularly important for learning of inverse models (Lalazar & Vaadia, 2008; Wolpert & Ghahramani, 2000), so that feedforward and online controls are engaged in mutual and progressive development.

How motor prediction develops during infancy and childhood is a key question as regard sensorimotor development. Internal models need to be continually updated based on sensorimotor experiences as well as changes in body shape. Many studies on this issue have considered the development of feedforward or anticipatory postural adjustments (APAs), which is a motor command that occurs in anticipation of a perturbation (either self-induced through the voluntary movement or externally-triggered) to counteract its expected effect on posture (Bouisset & Zattara, 1981; Massion, Ioffe, Schmitz, Viallet, & Gantcheva, 1999). There is evidence for the existence of APAs as soon as the first year of life in the sitting position to activate the postural neck and trunk muscles before initiating voluntary arm movements (de Graaf-Peters, Bakker, van Eykern, Otten, & Hadders-Algra, 2007; van Balen, Dijkstra, & Hadders-Algra, 2012; Van Der Fits & Hadders-Algra, 1998; van der Fits, Klip, van Eykern, & Hadders-Algra, 1999). Furthermore, APAs become more consistent once independent walking is acquired (Barela, Jeka, & Clark, 1999; Cignetti, Zedka, Vaugoyeau, & Assaiante, 2013; van der Fits, Otten, Klip, Van Eykern, & Hadders-Algra, 1999; Witherington et al., 2002). Using a bimanual unloading task in which the participant anticipates unloading consequences of an object in one hand with the other hand (Massion et al., 1999), authors also showed that APAs are not fully mature at 8 years of age (Schmitz, Martin, & Assaiante, 2002; Schmitz, Martineau, Barthelemy, & Assaiante, 2003), and are even not yet mature in adolescents (Barlaam, Fortin, Vaugoyeau, Schmitz, & Assaiante, 2012). Moreover, it appears that adolescent unloading performances do not differ greatly from those of children aged 7–8-years old, and that they are still far from equaling those of adults. Thus, despite the early emergence of anticipatory adjustments from the age of 3 years, feedforward control continues to mature in late childhood and adolescence. Other studies on motor planning also supported the idea of an extended development of feedforward motor control from young ages to adulthood. Prospective planning of grip for end-state comfort improves substantially from 4 to 12 years and keeps improving thereafter, although to a lower extent (Fuelscher, Williams, Wilmut, Enticott, & Hyde, 2016; Smyth & Mason, 1997; Stöckel, Hughes, & Schack, 2012; Thibaut & Toussaint, 2010). Finally, studies on rapid correction of arm movement following change in target location also demonstrated an ability to make online adjustments using forward estimates of limb position that improves during childhood and that continues to improve until adulthood (Fuelscher, Williams, & Hyde, 2015a; Ruddock, Hyde, et al., 2014; Wilson & Hyde, 2013).

A large array of studies summarized in recent meta-analyses suggests that children with developmental coordination disorder (DCD) have a core deficit in predictive motor control (see Adams, Lust, Wilson, & Steenbergen, 2014; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013; Wilson et al., 2017 for reviews and references therein). This was established mainly by examining how (reaching/grasping) movements are either controlled online (e.g. Fuelscher, Williams, Enticott, & Hyde, 2015; Hyde and Wilson, 2011a,2011b; Hyde & Wilson, 2013; Plumb et al., 2008; Ruddock, Piek, et al., 2014; Wilmut, Wann, & Brown, 2006) or planned in advance (e.g. Adams, Lust, Wilson, & Steenbergen, 2016a; Adams, Lust, Wilson, & Steenbergen, 2017; Adams, Ferguson, Lust, Steenbergen, & Smits-Engelsman, 2016b; Fuelscher et al., 2016; Jover, Schmitz, Centelles, Chabrol, & Assaiante, 2010; Jucaite, Fernell, Forssberg, & Hadders-Algra, 2003; Pereira, Landgren, Gillberg, & Forssberg, 2001; Smyth & Mason, 1997). However, all studies on motor planning did not report deficit in DCD, nor did they all provide evidence that the deficit is specific to DCD. For instance, planning of grip selection for end-state comfort sometimes did not differ between DCD children and typically developing children (Adams, Fergusonm, et al., 2016; Smyth & Mason, 1997), possibly when tasks are not complex enough. In addition, planning of grip force and posture during manual load lifting was reported as being impaired in DCD but without controlling for comorbidities (Jover et al., 2010), and where it had, showed deficits also displayed in attention deficit hyperactivity disorder (ADHD; Jucaite et al., 2003). Thus, pursuing studies on the issue of impaired feedforward motor control in children with DCD using different tasks and while clarifying the role of comorbidity on it is particularly important. In this latter framework, DCD does not only co-occur with ADHD but also with learning disabilities and speech/language impairment (see Zwicker, Missiuna, Harris, & Boyd, 2012 for a review). There is even some evidence that motor problems are more pronounced when speech production is affected (Visscher, Houwen, Scherder, Moolenaar, & Hartman, 2007).

Impairments in postural stability, eye movement control, motor coordination, and implicit motor learning have been reported for