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Developmental changes in lateralized inhibition of symmetric movements in children with and without Developmental Coordination Disorder

Jessica Tallet [a,*], Jean-Michel Albaret [a], Jérôme Barral [b]

[a] *Université de Toulouse, UPS, PRISSMH-LAPMA, Toulouse, France*
[b] *Institut des Sciences du Sport, de l'Université de Lausanne, Switzerland*

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ABSTRACT

The present study investigates developmental changes in selective inhibition of symmetric movements with a lateralized switching task from bimanual to unimanual tapping in typically developing (TD) children and with Developmental Coordination Disorder (DCD) from 7 to 10 years old. Twelve right-handed TD children and twelve gender-matched children with DCD and probable DCD produce a motor switching task in which they have (1) to synchronize with the beat of an auditory metronome to produce bimanual symmetrical tapping and (2) to selectively inhibit their left finger's tapping while continuing their right finger's tapping and conversely. We assess (1) the development of the capacity to inhibit the stopping finger (number of supplementary taps after the stopping instruction) and (2) the development of the capacity to maintain the continuing finger (changes in the mean tempo and its variability for the continuing finger's tapping) and (3) the evolution of performance through trials. Results indicate that (1) TD children present an age-related increase in the capacity to inhibit and to maintain the left finger's tapping, (2) DCD exhibits persistent difficulties to inhibit the left finger's tapping, and (3) both groups improve their capacity to inhibit the left finger's movements through trials. In conclusion, the lateralized switching task provides a simple and fine tool to reveal differences in selective inhibition of symmetric movements in TD children and children with DCD. More theoretically, the specific improvement in selective inhibition of the left finger suggests a progressive development of inter-hemispheric communication during typical development that is absent or delayed in children with DCD.

1. Introduction

Many activities in daily-life require decoupling movements of the right and left hands in order to produce successful unimanual and bimanual movements (lacing the shoes, using a knife and a fork, taping on a keyboard or a phone, writing, etc.). The problem is that human beings exhibit a spontaneous tendency to produce symmetric movements of both hands. Symmetric tendency comes from mirror movements (Armatas, Summers, & Bradshaw, 1996), also called motor overflows (Addamo, Farrow, Hoy, Bradshaw, & Georgiou-Karistianis, 2007; Hoy, Fitzgerald, Bradshaw, Armatas, & Georgiou-Karistianis, 2004), associated movements (Largo et al., 2001), reproductive associated movements (de Ajuriaguerra, 1969), contralateral

* Corresponding author at: Université de Toulouse, UPS, PRISSMH-LAPMA, 118 Route de Narbonne, 31062 Toulouse, France. Tel.: +33 05 61 55 64 65; fax: +33 05 61 55 82 80.
E-mail address: jessica.tallet@univ-tlse3.fr (J. Tallet).

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motor irradiations (Cernacek, 1961) or imitative synkinesia (‘‘syncinésies d'imitation’’, de Ajuriaguerra & Stambak, 1955). Mirror movements refer to non-intentional movements that accompany intentional unilateral movements of homologous muscles of the opposite side (Abercombie, Lindon, & Tyson, 1964). Despite the neural mechanisms underlying the generation of mirror movements are still in debate (see Addamo et al., 2007; Hoy et al., 2004; for reviews of theories), it is well accepted that mirror movements result from a lack of inhibition of contralateral movements. Many studies show that the suppression of mirror movements requires neural inter-hemispheric inhibitory transfer, in part from the controlateral to the ipsilateral hemisphere (Arányi & Rösler, 2002; Cardoso de Oliveira, Gribova, Donchin, Bergman, & Vaadia, 2001; Cernacek, 1961; Fling & Seidler, 2012; Liuzzi, Hörniss, Zimerman, Gerloff, & Hummel, 2011; Rao et al., 1993; Sadato et al., 1996).

Behavioral and neuroimaging studies reveal that normal right-handed adults present more mirror movements in the dominant right side compared to the non-dominant left side during contralateral unimanual movements (Armatas, Summers, & Bradshaw, 1994; Armatas et al., 1996; Cernacek, 1961; Liederman & Foley, 1987; Todor & Lazarus, 1986; Wolff, Gunnoe, & Cohen, 1983). This suggests a greater capacity to inhibit movements of the left hand compared to movements of the right hand. The present study aims at testing behavioral age-related improvement in the capacity to inhibit selectively the left and right hands in right-handed children. During the typical course of neurological development, the cortical activation theory (Todor & Lazarus, 1986) postulates that the inhibition of mirror movements depends on the refinement of cortical activations associated with the manipulative function of the moving effector. As right-handed children grow up, the right effector is increasingly utilized and the left cortical activations are refined. Hence, the left motor cortex becomes more prone to send inhibitory outputs to the right motor cortex, leading to less mirror movements of the left hand. This theory is supported by neuroimaging studies in adults suggesting a greater capacity of the left hemisphere to inhibit right motor regions (Beltramello et al., 1998; Kim et al., 1993; Kobayashi, Hutchinson, Théoret, Schlaug, & Pascual-Leone, 2004; Netz, Ziemann, & Hömberg, 1995). As right-handed typically-developed (TD) children grow up, we can expect a greater improvement in the capacity to inhibit the left hand than the right hand, due to a progressive increase in motor experience of the right hand.

We also test the development of the capacity to inhibit movements of the left and right hand's movements in 7–10 years old children with Developmental Coordination Disorder (DCD). Children with DCD represent 5–6% of the school-aged children and manifests principally by clumsiness and slowness, which is not due to the child's age or intellect or to a known neurological disorder (DSM-IV, American Psychiatric Association, 1994; Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). Among other hypotheses, one challenging neural mechanism explaining DCD relates to a deficit in inter-hemispheric inhibitory transfer (Wilson & Butson, 2007). First, children with DCD exhibit significantly more mirror movements than TD children (Licari, Larkin, & Miyahara, 2006; Licari & Larkin, 2008). Second, Sigmundsson and colleagues reveal that a subgroup of children with DCD exhibit more difficulties than TD children in target location using their left hand to match with their right hand and using their right hand to match with their left hand (Sigmundsson, Whiting, & Ingvaldsen, 1999). The authors conclude that children with DCD could suffer from a deficit either in inter-hemispheric transfer or in the right hemisphere controlling their non-dominant left hand. In addition, children with DCD present less hand preference. In TD children and adults, the right hand is preferentially used for manual movements (Oldfield, 1971) and the preferred hand is generally more stable than the non-preferred hand (Fagard, 1987; Peters & Durding, 1978; Truman & Hammond, 1990). In DCD children, there is less difference in the right or left hand preference (Armitage & Larkin, 1993; Hill & Bishop, 1998). For example, the results of Hill and Bishop (1998) reveal that right-handed TD children from 7 to 11 years old use preferentially their right hand to locate cards whatever their spatial position (right or left of their body's midline) whereas right-handed DCD reach spatial positions locate to the right of their body's midline predominantly with their right hand and spatial positions locate to the left of their body's midline predominantly with their left hand. DCD children present the same pattern of results than younger right-handed TD children (5–6 years old), which lead the authors conclude that DCD children present an immaturity in the lateralization process. Taken together, these results and the cortical activation theory lead to the hypothesis that DCD children would exhibit less improvement in the capacity to inhibit the left hand movements compared to their TD peers.

We propose to test these hypotheses with a switching task from bimanual symmetrical tapping to unimanual tapping (Barral, De Pretto, Debû, & Hauert, 2010; Tallet, Barral, & Hauert, 2009). This task involves decoupling symmetric movements of right and left hands thanks to the inhibition of one finger's tapping. Previous results suggest that switching induces a destabilization of the tempo of the continuing right hand whilst switching in adults (Tallet et al., 2009). Moreover, TD children increase their capacity to maintain the tempo of the continuing finger from 5 to 11 years old (Barral et al., 2010). These results suggest that motor perturbation induced by selective inhibition decreases during childhood. An alternative measure of perturbation could be the number of supplementary taps of the stopping finger after the instruction to stop. Given that supplementary taps lead to symmetric movements, we can reasonably postulate that inhibition of supplementary taps would require shared neural mechanisms with inhibition of mirror movements, i.e., inter-hemispheric inhibitory transfer. Previous distinct studies support this idea. In one hand, inhibition of mirror movements requires inter-hemispheric inhibitory transfer (e.g., Hoy et al., 2004). In other hand, a previous EEG study suggests that selective inhibition of symmetric movements leads to cerebral asymmetrization in functional couplings over the left and the right hemispheres that could reflect inhibitory transfer (Tallet et al., 2009). Hence, investigating behavioral perturbation of the stopping hand and continuing hand whilst switching from bimanual symmetric to unimanual movements would provide a complete experimental window to understand selective inhibition of symmetric movements. Thanks to a lateralized switching task that requires stopping selectively the left or the right finger's tapping while continuing the other finger's tapping, we can assess selective inhibition of right and left sides.