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Bimanual force coordination in children with spastic unilateral cerebral palsy

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ABSTRACT

In this study bimanual grip–force coordination was quantified using a novel "Gripper" system that records grip forces produced while holding a lower and upper unit, in combination with the lift force necessary to separate these units. Children with unilateral cerebral palsy (CP) (aged 5–14 years, $n = 12$) were compared to age matched typically developing (TD) children ($n = 23$). Compared to TD, the CP-group is much slower and takes 50% more time to generate grip and lift forces with more fixating force before lifting the upper unit. In addition the coordination between forces in both hands is reduced. The CP-group increases the lift force in the upper hand 2.5 times more than the holding force when pulling the two units apart, while this is only 1.5 times in TD. Moreover, the correlation between forces generated in both hands in the CP-group is lower. The lack of fine tuning of the forces, measured by the linearity error is increased, especially when the magnet load keeping the unit together is low. The results indicate an impaired pull–hold synergy between upper and lower hand and the lift force. Bimanual tasks evaluating bimanual grip and lift forces in children with CP and can give us new insights in the underlying force control mechanisms of the spastic hand.

1. Introduction

Hemiplegia or unilateral spastic cerebral palsy (CP) is the most common type of CP in children born at term and the second most common type of CP in premature infants (Himmelman, Hagberg, Beckung, Hagberg, & Uvebrant, 2005; Odding, Roebroeck, & Stam, 2006). Children with hemiplegia present with unilateral impairments, primarily as a result of periventricular white matter and cortical and subcortical lesions (Cioni et al., 1999; Robinson et al., 2009). Resultant impairments in the more severely affected hand are slowness, weakness, uncoordinated movements and spasticity.

Most activities of daily living require some kind of bimanual involvement, where one hand stabilizes or fixates the object to be manipulated. Moreover being able to react quickly to changing circumstances is of critical importance to make bimanual movements in everyday life. Coordination between forces in the fixating and manipulating hand is complex because the fixating hand should counter act the pulling or shearing force generated in the manipulating hand. The necessity of fast motor adaptation increases even more if the bimanual task includes a perturbation aspect, for instance if pulling a cap from a pen. The moment the cap releases fast adaptations have to be made to prevent large overshoots or losing the object. Because many, every day tasks, involve this kind of force coordination a growing demand exists for sensitive, quantitative,

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objective measures to assess bimanual force regulation (Rameckers, Duysens, Speth, Vles, & Smits-Engelsman, 2010). The topic of this study was the measurement, in an objective way, of force adaptations in a pulling and holding task with suddenly changing circumstances.

Another reason why bimanual force evaluation is needed is because of expanded therapeutic options in rehabilitation e.g., bimanual training like HABIT (Hand-Arm Bimanual Intensive Therapy) (Gordon, Schneider, Chinnan, & Charles, 2007) and forced unilateral training or Constraint-Induced Movement Therapy (CIMT) (Taub, Ramey, DeLuca, & Echols, 2004). The question with CIMT, a promising therapeutic strategy to overcome developmental disuse in hemiplegia, is whether the unilateral training transfers to bimanual activities (Aarts, Jongerius, Geerdink, van Limbeek, & Geurts, 2000). An additional intervention frequently used is Botulinum Toxin-A (BTX) (Wasiak, Hoare, & Wallen, 2004). BTX decreases spasticity but has a temporarily paralyzing effect on the injected muscles. Consequently, BTX worsens the already poor strength in the affected arm (Rameckers, Speth, Duysens, Vles, & Smits-Engelsman, 2009). Notably, force generation analysis and bimanual assessments are required to decide between treatment options. Greaves, Imms, Dodd, and Krumlinde-Sundholm (2010) confirm that researchers and clinicians consider the evaluation of bimanual performance important in hemiplegic CP. In general, bimanual performance is assessed using direct observation or video recording. However, quantitative measures of how children generate and coordinate forces in bimanual activities are still lacking.

Unimanual lifting (Eliasson & Gordon, 2000; Forssberg, Eliasson, Redon-Zouitenn, Mercuri, & Dubowitz, 1999) and unilaterally moving objects (Smits-Engelsman, Rameckers, & Duysens, 2004, 2005) have been extensively studied. In the unimanual tasks, grasp stability is normally obtained by a small increase in the grip force during the initial phase where the hand grasps the object followed by a large, proportional increase of both the grip and lift forces during the lift phase. Studies on synergies in unimanual grip-lift tasks appear sensitive to force coordination deficits in children with CP, who do not increase grip and lift forces smoothly nor proportionally. Children with CP often push the object they are grasping first down against the table surface. They produce large and variable grip forces before the onset of the lift phase. Additionally, they show a sequential generation of grip and lift forces, larger variations between subsequent lifts, and display extreme delays between the different phases of the lift.

Although current instrumented *unimanual* grip-lift data yield relevant results, they say little about the bimanual capacity. As most activities in daily life require the coordination of both hands, the challenge is to quantify *bimanual* grip–force coordination. Only a few studies have investigated bimanual force coordination in children with unilateral CP (Hung, Charles, & Gordon, 2004; Steenbergen, Hulstijn, De Vries, & Berger, 1996; Sugden and Utley, 1995; Utley and Sugden, 1998; Volman, 2005). Moreover, these studies have examined kinematics but not force generation. Alberts, Tresilian, and Stelmach (1998) proposed a device to simultaneously measure the grip forces by left and right hand and the lift force necessary to separate the two objects. In this study, we used an advanced development of this grip–force coordination measurement system (see Fig. 1) in typically developing children (TD) and in children with unilateral CP.

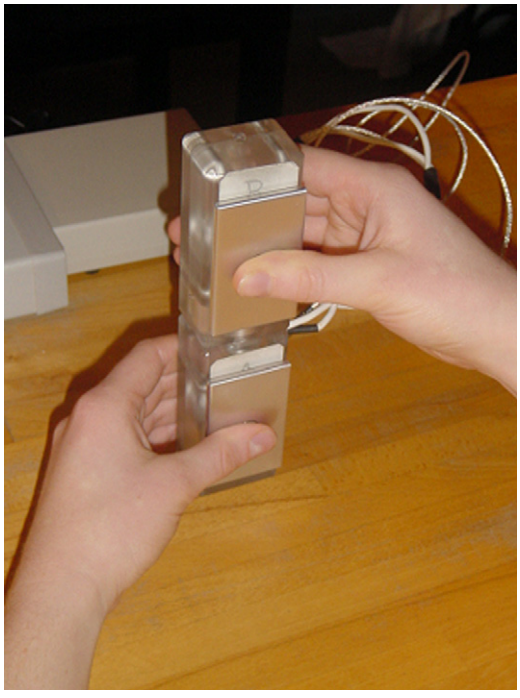

Fig. 1. The child holds the lower unit with one hand to stabilize it on the table and the upper unit with the other hand to lift the upper unit. The child is instructed to place the thumbs in the middle on the grip force plate while the other fingers hold the unit at the opposite side. After the GO-signal the child pulls the upper unit apart from the lower unit, while the lower unit has to be stabilized on the table surface.