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Kinematic parameters of hand movement during a disparate bimanual movement task in children with unilateral Cerebral Palsy

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ABSTRACT

Children with unilateral Cerebral Palsy (uCP) experience problems performing tasks requiring the coordinated use of both hands (bimanual coordination; BC). Additionally, some children with uCP display involuntary symmetrical activation of the opposing hand (mirrored movements). Measures, used to investigate therapy-related improvements focus on the functionality of the affected hand during unimanual or bimanual tasks. None however specifically address spatiotemporal integration of both hands. We explored the kinematics of hand movements during a bimanual task to identify parameters of BC. Thirty-seven children (aged 10.9 ± 2.6 years, 20 male) diagnosed with uCP participated. 3D kinematic motion analysis was performed during the task requiring opening of a box with their affected- (AH) or less-affected hand (LAH), and pressing a button inside with the opposite hand. Temporal and spatial components of data were extracted and related to measures of hand function and level of impairment. Total task duration was correlated with the Jebsen–Taylor Test of Hand Function in both conditions (either hand leading with the lid-opening). Spatial accuracy of the LAH when the box was opened with their AH was correlated with outcomes on the Children's Hand Use Experience Questionnaire. Additionally, we found a subgroup of children displaying non-symmetrical movement interference associated with greater movement overlap when their affected hand opened the box. This subgroup also demonstrated decreased use of the affected hand during bimanual tasks. Further investigation of bimanual interference, which goes beyond small scaled symmetrical mirrored movements, is needed to consider its impact on bimanual task performance following early unilateral brain injury.

1. Introduction

Many tasks in everyday life require the coordinated and simultaneous use of both hands, i.e. bimanual coordination (BC). Adequate temporal and spatial integration of each hand, with limited interference between hands, usually develops with age and is often crucial for successful execution of these tasks (Birtles et al., 2011; de Boer, Peper, & Beek, 2012). Differences in

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the difficulty between various bimanual movement tasks can be substantial and partly determined by the similarity or divergence of movement characteristics between both hands. On a model level, symmetrical so called in-phase movements during which homologous muscles are activated at the same time, have been shown to be preferred over their asymmetrical counterpart, anti-phase movements (Haken, Kelso, & Bunz, 1985; Kelso & Schoner, 1988; Swinnen, 2002). Phase-modes that are neither in- nor anti-phase are generally the least stable within the intrinsic dynamics of a system but can be improved with practice (Kostrubiec & Zanone, 2002; Kostrubiec, Zanone, Fuchs, & Kelso, 2012). Bimanual tasks in daily life are however neither purely in-phase (e.g. clapping) nor anti phase (e.g. a drum roll), but rather characterised by completely disparate movements of both hands that have to be aligned while not interfering with each other (e.g. using cutlery). In adults, the differentiation of hand function in bimanual tasks typically shows the non-dominant hand to take on the more stabilising role (Birtles et al., 2011). Based on the model of a kinematic chain, where the proximal segment acts as the reference frame for the motion of the distal segment, Guiard (1987) proposes that the holding or stabilizing action (often carried out by the non-dominant hand) during a bimanual movement task acts as a spatial frame of reference to which the manipulating action (carried out by the dominant hand) adjusts.

Apart from characteristics of the task itself, the structural integrity of central nervous system areas associated with motor control has a significant impact on the capability of inter-limb movement execution (Gooijers & Swinnen, 2014; Liuzzi, Horniss, Zimerman, Gerloff, & Hummel, 2011; Swinnen, 2002; Weinstein et al., 2013). With an incidence of 2–3 per 1000 life-births (Cans et al., 2000), Cerebral Palsy (CP) incorporates a wide range of non-progressive brain disorders affecting areas related to motor control. Causal factors are disturbances in brain development during infancy or early childhood (Rosenbaum et al., 2007) which affect motor output and sensory feedback of the affected limbs (Rosenbaum et al., 2007). Approximately one third of the concerned group have lesions that are located predominantly in one hemisphere, causing unilateral motor impairments (Arnfield, Guzzetta, & Boyd, 2013; Krageloh-Mann & Cans, 2009). Individuals who suffer from unilateral CP (uCP) generally use their less affected hand during unimanual tasks, with similar (or slightly worse) skills than their healthy peers. Bimanual activities, however, are often avoided or different strategies are sought to avoid the use of the affected hand (Sköld, Josephsson, & Eliasson, 2004). As a result and due to the lack of practice, the actual performance of the affected hand might be worse than its capacity. This imbalance of capacity and actual performance might lead to a phenomenon referred to as "Developmental Disregard" (DD) (Houwink, Aarts, Geurts, & Steenbergen, 2011; Zielinski, Jongsma, Baas, Aarts, & Steenbergen, 2014). Children with DD avoid using their affected hand despite some unimanual skill.

In addition, children with uCP often experience an involuntary symmetrical activation of the contralateral hand, i.e. mirrored movements (MMs). Such MMs are usually more pronounced in the less affected hand (Kuhtz-Buschbeck, Sundholm, Eliasson, & Forssberg, 2000; Woods & Teuber, 1978) and can have a negative impact on bimanual activities of daily living that require disparate use of both hands (Adler, Berweck, Lidzba, Becher, & Staudt, 2015). A causal factor for extensive MMs may be due to ipsilateral corticospinal projection patterns (Balbi, Trojano, Ragno, Perretti, & Santoro, 2000; Norton, Thompson, Chan, Wilman, & Stein, 2008). Ipsilateral retention of corticospinal projections from the less affected hemisphere to the affected hand are sometimes retained in children with uCP, possibly dependent on the timing of their congenital brain lesion (Staudt et al., 2004). Ipsilateral projection patterns are present during typical development but become redundant during early development, hypothesised to be due to activity dependent withdrawal (Eyre, Taylor, Villagra, Smith, & Miller, 2001). MMs are also evident in patients with hypogenesis of the corpus callosum (CC; Yucel et al., 2012), thus suggesting a potential mediating role of the CC for inter-hemispheric inhibition (Gooijers & Swinnen, 2014; Weinstein et al., 2013).

A variety of different motor therapy programmes have been developed to address these motor impairments, some of which have been shown to be effective in improving upper limb function (Sakzewski, Gordon, & Eliasson, 2014; Sakzewski, Ziviani, & Boyd, 2014). Generally, the existing therapeutic concepts can be classified into (i) unimanual therapies such as Constraint Induced Movement Therapy (CIMT) (Hoare, Imms, Carey, & Wasiak, 2007) and (ii) bimanual therapies such as Hand Arm Bimanual Intensive Therapy (HABIT) (Charles & Gordon, 2006; Green et al., 2013) or (iii) a combination of the two (Aarts et al., 2012; Boyd et al., 2013). Therapy interventions of the second category in particular are designed specifically to improve BC, rather than just the functionality of the affected hand (Charles & Gordon, 2006; Gordon et al., 2011). A great variety of clinical assessments are currently used to estimate treatment success. They can be roughly categorized into measures that determine the ability of the affected hand during unimanual tasks, e.g. the Jebsen–Taylor Test of Hand Function (JTTHF; Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969; Taylor, Sand, & Jebsen, 1973) or during bimanual tasks, e.g. the Children's Hand Use Experience Questionnaire (CHEQ) (Skold, Hermansson, Krumlinde-Sundholm, & Eliasson, 2011) and the Assisting Hand Assessment (AHA) (Krumlinde-Sundholm & Eliasson, 2003). These tests measure discrete skills, such as timing of grasp and release (e.g. JTTHF), spontaneous use and movement capacity of the AH during bimanual tasks (e.g. AHA) or report on functional performance of bimanual tasks (e.g. CHEQ).

Even though therapy programmes are aimed specifically at the improvement of bimanual coordination, the outcome measures which are used tend to focus on the functionality of the affected hand, rather than measuring the integration of both hands. This is despite sophisticated methods having been developed on a more experimental level. Steenbergen, Hulstijn, de Vries, and Berger (1996), as well as Utley and Sugden (1998), investigated uni- and bi-manual reaching in children with uCP and showed that movement patterns were very similar when both hands reached at the same time, despite very dissimilar patterns when the same actions were performed one hand at a time. They demonstrated a coupling effect during bimanual hand use which was mainly due to a decrease in performance of the less affected hand. Looking at changes of BC during different developmental stages in typical developing children and adults, Birtles et al. (2011) used a bimanual