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Deviations in upper-limb function of the less-affected side in congenital hemiparesis

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Abstract

In the present study we examined upper-limb function of the less-affected side in young adolescents with congenital hemiparesis (cerebral palsy: CP). Five participants with hemiparetic CP and five control participants performed a cyclical reach-and-grasp task with the less-affected hand towards targets placed at 60%, 100%, and 140% of the participant's arm-length. Trunk involvement, end-effector kinematics and activation of the biceps and triceps were examined together with several clinical measures. Movements at the less-affected side were slower and peak velocity was reached later in the experimental group. Even though total trunk involvement was identical in both groups, it was selectively limited to forward bending in participants with CP. Elbow amplitudes of these participants were smaller for the 60% and 100% arm-length target distances. Additionally, participants with CP showed weak positive correlations between agonist (triceps) activity and elbow amplitude, suggesting that deficient agonist rather than antagonist innervation was responsible for the decreased elbow involvement. Especially the more severely affected participants with CP proved to compensate their relatively small elbow amplitudes by increased forward bending. Collectively, the findings demonstrate deviations in upper-limb control of the less-affected body side in congenital hemiparesis.

Keywords: Cerebral palsy; Prehension; Ipsilateral side; Trunk; EMG

1. Introduction

Understanding the nature of movement deviations following brain damage is crucial for the development and systematic application of rehabilitation therapies. In the case of lateralized brain damage, movement deficits are most evident on the contralesional side of the hemispheric lesion, leading to a disorder known as hemiparesis. Research into upper-limb control of the contralesional side in patients with hemiparesis, either from stroke or cerebral palsy (CP), has revealed several characteristic movement deficits such as weakness of specific muscles (Bourbonnais & Vandennoven, 1989), abnormal muscle tone (Lance, 1980), increased levels of co-contraction (Brouwer & Ahsby, 1991; Damiano, Martellotta, Sullivan, Granata, & Abel, 2000; Lamontagne, Richards, & Malouin, 2000; but see Van Roon, Steenbergen, & Meulenbroek, 2005), decreased involvement of the shoulder and elbow combined with increased trunk involvement (Cirstea & Levin, 2000; Steenbergen, Van Thiel, Hulstijn, & Meulenbroek, 2000; Van Thiel & Steenbergen, 2001), less fluent movements (e.g. Trombly, 1992, 1993) and, generally, slower movements (e.g. Utley & Sugden, 1998; Utley & Steenbergen, 2006; Utley, Steenbergen, & Sugden, 2004).

Relatively few experimental studies have examined the movement capabilities of the less-affected extremity. However, conservation of upper-limb function of the less-affected side is highly important for individuals with hemiparesis, because this side is often employed as a compensatory 'tool' in performing activities of daily living (ADL). Neuropsychological testing of the less-affected limb indeed revealed subtle deficits (e.g. Dellatolas, Filho, Souza, Nunes, & Braga, 2005), that were also shown for reaching and grasping (Carey, Baxter, & DiFabio, 1998; Debaere, Van Assche, Kiekens, Verschueren, & Swinnen, 2001; Desrosiers, Bourbonnais, Bravo, & Roy, 1996; Hermesdörfer, Laimgruber, Kerkhoff, Mai, & Goldenberg, 1999; Sunderland, Bowers, Sluman, Wilcock, & Ardron, 1999; Yarosh, Hoffman, & Strick, 2004).

Abbreviations: CP, cerebral palsy; EMG, electromyography; IQ, intelligence coefficient; WISC II, Wechsler intelligence scale for children; IRED, infrared light emitting diode; ADL, activities of daily living

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Despite these insights, there have been no systematic studies of the functional loss in upper-limb function of the less-affected side following congenital unilateral brain damage that simultaneously address processes at the level of muscle activation, upper-limb movement kinematics, and body-segment coordination. Such an approach is, in our view, important since the incidence of CP in developed countries is relatively high at about 2–2.5/1000 live births (Lin, 2003), but at the same time the understanding of the neuropathophysiology and motor systems dysfunctions of CP remains limited (Steenbergen & Utley, 2005). Consequently, the present study was set up to examine the functional loss in upper-limb movements of the less-affected side in young adolescents with hemiparetic CP. To that aim, muscle activation patterns, upper-limb and trunk movement kinematics, and arm and body-segment coordination patterns were examined.

A recurrent finding in upper-limb tasks performed with the contralesional limb in hemiparesis (either as a consequence of stroke or CP) is the excessive use of the trunk, even when the object to be picked up is placed well within the limits of the stretched arm (e.g. Cirstea & Levin, 2000; Levin, Michaelsen, Cirstea, & Roby-Brami, 2002; Van Roon, Steenbergen, & Meulenbroek, 2004). In individuals without neurological disorders, the trunk is naturally recruited when movement distance exceeds a distance of 90% of the length of the arm, the so-called 'critical boundary' (Dean, Shephard, & Adams, 1999; Kaminski, Bock, & Gentile, 1995; Mark et al., 1997; Saling, Stelmach, Mescheriakov, & Berger, 1996). Such a preferred critical boundary may correspond to an arm configuration for grasping in which relative comfort is attained that may be associated with the orientation of the hand or the avoidance of extreme angular positions (Gentilucci, Deprati, Gangitano, Saetti, & Toni, 1997; Kamper & Rymer, 1999; Roby-Brami, Bennis, Mokhtari, & Baraduc, 2000). In individuals with hemiparetic stroke, this critical boundary is dramatically reduced to 50% of the length of the arm (Levin et al., 2002). This may be due to a decreased ability to fully extend the arm due to weakness of agonist muscles (e.g. anterior deltoid and triceps, Colebatch & Gandieva, 1989) or to an excessive antagonist muscle activation, or co-contraction (Wing, Lough, Turton, Fraser, & Jenner, 1990). According to Levin et al. (2002) the poor cooperation between the antagonistic muscles pairs of the upper arm (increased co-activation) and excessive stretch reflexes lead to a limited ability to fully stretch the arm. As a consequence, the trunk is recruited to reach the movement goal.

To examine in detail the role of co-activation of the trunk with arm movements in individuals with hemiparetic CP, we evaluated the pattern of recruitment of the less-affected shoulder, elbow and wrist concurrent with the contribution of the trunk when natural reaching movements were made to targets placed both within and beyond the reach of the arm at three different distances. While most studies have examined trunk involvement by looking at trunk displacement in the sagittal movement direction only (e.g. Michaelsen, Jacobs, Roby-Brami, & Levin, 2004; Steenbergen et al., 2000; Van Roon et al., 2004), we performed a more detailed analysis by examining the three components of trunk involvement along the *X*-, *Y*-, and *Z*-axis separately. Next to movement recording, we monitored EMG activity of the biceps–triceps muscles pair (prime movers) to examine the alleged role of upper-limb musculature in relation to the involvement of the trunk.

In sum, to uncover the deviations in control at the less-affected side we analysed trunk involvement and segmental contribution of the shoulder and elbow as participants with hemiparetic CP performed cyclical grasping movements with the less-affected hand to targets at three distances. Since an analysis of trunk involvement along the *X*-, *Y*-, and *Z*-axis has not been performed before in hemiparetic CP, it is unavoidable that such an analysis is in part descriptive. To capture the possible causes of the pattern of trunk involvement we performed correlational analyses between elbow and trunk involvement. Based on previous research on the affected side in hemiparetic CP (e.g. Van Roon et al., 2004; Steenbergen et al., 2000), we hypothesised that increased trunk involvement may compensate for the altered (possibly limited) segmental contribution of the shoulder and elbow joints. We also examined muscle activation patterns of the prime movers to test the hypothesis that increased antagonist activity is related to trunk involvement.

2. Methods

2.1. Participants

Five participants with hemiparetic CP and five controls participated on a voluntary basis in the study. The hemiparetic participants were students at a school for special education called 'Werkenrode' where they followed an adapted educational program (all male, mean age = 16.3 years/months, S.D. = 1.1 years/months). Selection of the hemiparetic participants was based on information in school records made available to the experimenters with full permission of the participants and their tutors. Due to the fact that the hemiparetic participants were students at a school rather than patients at a medical clinic, the information laid down in the files about the individual neuropathology was limited.

To provide a good clinical picture, each participant underwent a series of clinical assessments administered by a trained physiotherapist. This was done in the weeks following the experiment. Hand function of the affected and less-affected side was established through the administration of the Purdue–Pegboard test (Tiffin, 1968) and the Box-and-Block test (Mathiowetz, Volland, Kashman, & Weber, 1985) according to the instructions in the test protocols. While the Purdue–Pegboard is a test of fine manipulative skills, gross dexterity is typically measured by the Box-and-Block test. In addition, IQ scores were obtained (WISC II), both verbal and performal. Spasticity levels at the wrist and elbow flexors and extensors of the affected and less-affected arm were assessed via scores on the Ashworth Scale of Spasticity (Bohannon & Smith, 1987). We were not able to assess the level of spasticity of one participant as this participant had departed from the school after the experiment was done.

All participants selected were able to understand the task instruction. In addition, only participants were selected who were diagnosed with hemiparesis as a consequence of CP. For three participants the affected side was the left side and for two it was the right side. Likewise, participants without functional sitting balance or lacking the cognitive capacities to perform the experiment were not included. Due to the relatively long duration of the complete experimental session (approximately 2 h) only participants were selected who had sufficient attentional capacities to concentrate for such a long time. All hemiparetic participants had undergone extensive rehabilitation programs and their situations were described as non-progressive, or stable. Participants with receptive aphasia, hemi-neglect or apraxia were not included in the study.

The control group (two males and three females, mean age = 22.6 years/months, S.D. = 1.5 years/months) consisted of psychology students from the Radboud University Nijmegen who participated as part of a college research