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Deficits in upper limb position sense of children with Spastic Hemiparetic Cerebral Palsy are distance-dependent

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ABSTRACT

This study examined the arm position sense in children with Spastic Hemiparetic Cerebral Palsy (SHCP) and typically developing children (TD) by means of a contralateral matching task. This task required participants to match the position of one arm with the position of the other arm for different target distances and from different starting positions. Results showed that children with SHCP exhibited with both arms larger matching errors than the TD group, but only when the distance between the arms at the start of the movement was large. In addition, the difference in errors between the less-impaired and the impaired limb changed as a function of the distance in the SHCP group whereas no interlimb differences were found in the TD group. Finally, spasticity and restricted range of motion in children with SHCP were not related to the proportion of undershoot and size of absolute error. This suggests that SHCP could be associated with sensory problems in conjunction with their motor problems. In conclusion, the current study showed that accurate matching of the arms is greatly impaired in SHCP when compared to TD children, irrespective of which arm is used. Moreover, this deficit is particularly present for large movement amplitudes.

1. Introduction

Proprioception refers to the sense of body parts in space and comprises a static (sense of static limb position or position sense) and a dynamic component (sense of movement or kinaesthesia). It is a complex somatosensory modality that is imperative for the control of movement.

A large body of evidence details the critical role of proprioception in controlling muscle interaction torques (e.g. Sainburg, Ghilardi, Poizner, & Ghez, 1995) in timing the coordination between limb segments (Cordo, Carlton, Bevan, Carlton, & Kerr, 1994), in monitoring movement trajectories (Ghez, Gordon, Ghilardi, Christakos, & Cooper, 1990), and in establishing internal representations used during the acquisition and adaptation of skilled movement (Kawato & Wolpert, 1998). It is therefore not surprising that impaired proprioception is often suggested to be implicated in motor dysfunction such as in Parkinson's disease (Adamovich, Berkinblit, Hening, Sage, & Poizner, 2001), hemiparetic stroke (Niessen, Veeger, Koppe, Konijnenbelt, van Dieen, & Janssen, 2008), cerebellar disorders (Cody, Lovgreen, & Schady, 1993) or cerebral palsy (CP) (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995; Opila-Lehman, Short, & Trombly, 1985). Still, to facilitate the design of tailored therapeutic interventions, empirical research is required to get a detailed and more complete view of the deficits encountered by disabled individuals.

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A number of studies have already shed light on proprioception in CP. CP is a group of permanent disorders of movement and posture due to a non-progressive lesion in the fetal or infant brain (Miller, 2007). In children with Spastic Hemiparetic CP (SHCP) impaired control of muscle tone and spasticity in the limbs on one side of the body (the impaired side) severely complicates normal daily movement function. These deficits in daily functioning become predominantly evident for movements executed with the arm, which is usually more affected than the lower extremity (Charles & Gordon, 2006). Goble, Hurvitz, and Brown (2009) examined joint-position sense in this population using an arm flexion/extension task. This task required the participants to match the position of the elbow (occluded from view) to a target position to which elbow had been extended passively before the start of the trial. Larger errors were made with the impaired limb than with the less-impaired limb, and the latter was as accurate as the limbs of typically developing (TD) control children. It should be noted however, that in a sub-sample of the CP-population the condition is accompanied with memory deficits (Bottcher, 2010; Kolk & Talvik, 2000), which may have contributed to the reduced ability to match a previously felt position and complicates the interpretation of the results. Indeed, the contrasting findings of Chrysagis, Skordilis, Koutsouki, and Evans (2007) who showed with a similar task that children with SHCP made significantly larger errors than TD children with the impaired as well as the less-impaired arm, might be due to differences in the children's ability to memorize positions. Wingert, Burton, Sinclair, Brunstrom and Damiano (2009) used an alternative approach and tested joint-position sense using a forearm pronation/supination task in which the position of the occluded hand was to be aligned with a visual target. The 'cross-modal matching' required in this task, i.e., mapping between visual and proprioceptive information, adds another degree of difficulty (e.g. von Hofsten & Rosblad, 1988; Wann, 1991) and again implies that this task cannot be completed using somatosensory information only. In agreement with other work, this study showed that larger errors were made with the impaired limb than with the less-impaired limb. However, the overall performance of the hemiplegic group did not differ from the control group. Taken together, it thus seems that the accuracy of the joint-position sense (and the associated proprioceptive cues) is dependent on the joint (and the related muscle group) tested. In addition, these studies illustrate that it is difficult to assess joint-position sense in isolation (i.e. without confounding factors such as memory load or multi-modal mapping). Still, one aspect of joint-position sense that has not been considered in the study of SHCP is the ability to match the position of limbs in a contralateral matching task where the participant is instructed to copy the position of one limb by placing the other, contralateral limb, in the same mirror symmetric position. Such an intra-modal matching test, which does not require re-mapping between sensory inputs and in which the involvement of memory is considerably reduced, can provide us with useful information about how problems with proprioception influence tasks that involve both arms. This is particularly relevant for the study of children with SHCP whose motor impairments appear to be limited to one body side, but are known to hamper bimanual actions (Charles & Gordon, 2006). Therefore, in this study we will explore to what extent matching movements, in which both hands are involved, are hindered in children with SHCP by means of a contralateral matching task.

It has been suggested that position sense is dependent on the location (relative to the body) at which the measurement is performed. Localization of the hand is more precise in proximity of the body (i.e. at smaller distances relative to the body) than at larger distances from the body (van Beers, Sittig, & Denier van der Gon, 1998; Wilson, Wong, & Gribble, 2010). This phenomenon has been reported in studies of young (Goble & Brown, 2008; Goble, Lewis, & Brown, 2006) and elderly (Adamo, Martin, & Brown, 2007), supporting the notion that this effect is common and probably robust against neurodegeneration. van Beers et al. (1998) suggested that better localization at distances closer to the body may be understood from the geometry of the arm, alongside anatomical and physiological properties such as the fact that the number of muscle spindles acting about the joints in the arm increase in proximal direction (Scott & Loeb, 1994; c.i. van Beers et al., 1998). Verifying whether the accuracy in a proprioceptive-guided matching task in children with SHCP follows a similar trend (i.e. decrease in precision for locations further away from the body) may thus serve to test whether they are subject to similar anatomical and physiological constraints and use similar cues to localize the position of their hands as compared to TD children. To the best of our knowledge, this aspect has been largely overlooked in previous research into position sense of children with SHCP.

The aim of this study was therefore to add to the existing body of knowledge on proprioception in children with SHCP, and more specifically to gain insight into the accuracy of position sense of the impaired and less-impaired arm in a contralateral matching task. In a case study ($N = 2$) using a similar task Lee, Daniel, Turnbull, and Cook (1990) found that children with SHCP experienced difficulties with matching for both the impaired and less-impaired arm. The purpose of the current study was to substantiate these findings. In addition, considering the location-dependent effect on position sense, this study aimed to examine whether the accuracy of matching performance and possible differences between the SHCP and TD group on a contralateral matching task are location-dependent (i.e. dependent on the distance relative to the body). If the distance effect in children with SHCP does not significantly deviate from TD children, this could suggest that both groups use similar sensory cues to localize the hand and are subject to similar anatomical and physiological constraints, despite possible disturbances in the input and/or processing of sensory information.

2. Methods

2.1. Participants

Fourteen children with SHCP participated in this study (mean age 12.5 ± 1.9 years) of which six had a right and eight had a left hemiplegia (see Table 1 for further details). The participants were free from any neuromuscular disorders other than CP, did not have visual impairments or pain in either of the upper limbs, and they were not treated with Botulinum toxin in the past six