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Review article

Precision grip control, sensory impairments and their interactions in children with hemiplegic cerebral palsy: A systematic review☆

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A B S T R A C T

Children with hemiplegic cerebral palsy (HCP) exhibit long-term functional deficits. One of the most debilitating is the loss of prehension since this may impair functional independence. This loss of prehension could be partly due to sensory deficits. Identifying the underlying causes of prehension deficits and their potential link with sensory disorders is important to better adapt neurorehabilitation.

Here we provide an overview of precision grip and sensory impairments in individuals with HCP, and the relation between them, in order to determine whether the sensory impairments influence the type and magnitude of deficits as measured by studies of prehensile force control.

Pubmed and Scopus databases were used to search studies from 1990 to 2012, using combinations of the following keywords: fingertip force; grip force; precision grip; sensory deficit; sensory impairment; tactile discrimination; with cerebral palsy. Of the 190 studies detected through the systematic search; 38 were finally included in the systematic part of this review.

This review shows that sensory deficits are common and are likely underestimated using standard clinical assessments in HCP. Some studies suggest these deficits are the basis of predictive motor control impairments in these individuals. However, children with HCP retain some ability to use predictive control, even if it is impaired in the more affected hand. Intensive practice and initial use of the less affected hand, which has only subtle sensory deficits, has been shown to remediate impairments in anticipatory motor control during subsequent use of the more affected hand. Implications for motor and sensory rehabilitation of individuals with HCP are discussed.

Contents

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1. Introduction – background

Cerebral palsy occurs in 2–3.6 out of 1000 children (Murphy, Yeargin-Allsopp, Decouflé, & Drews, 1993; Stanley, Blair, & Alberman, 2000; cdc.gov: http://www.cdc.gov). Among the different clinical forms of cerebral palsy, hemiplegic cerebral palsy (HCP) is one of the most common, affecting ~30% of the children with CP (Stanley et al., 2000). One of their most debilitating long-term functional deficits is impaired manual dexterity (Uvebrant, 1988). In pediatric HCP, skilled hand movements are typically impaired and there are sensory impairments as well. One approach used to quantify these impairments is the study of the coordination of fingertip forces during object manipulation using the precision grip (Eliasson, Gordon, & Forssberg, 1991, 1992, 1995a; Forssberg, Eliasson, Redon-Zouitenn, Mercuri, & Dubowitz, 1999; Gordon & Duff, 1999a, 1999b; Gordon, Charles, & Duff, 1999; Mackenzie, Getchell, Modlesky, Miller, & Jaric, 2009). This task is ideal as it has been shown through digital nerve block (Augurelle, Smith, Lejeune, & Thonnard, 2003; Johansson, Hger, & Bäckström, 1992; Monzée, Lamarre, & Smith, 2003), and force adaptation to texture (Johansson & Westling, 1988) in healthy subjects that the integrity of sensory information is necessary for precision grip tasks. Thus systematically describing precision grip and sensory impairments in children and adolescents with HCP and the relationship between both could help understanding whether the sensory impairments influence the type and magnitude of deficits observed in precision grip for these children. We also discuss how the specific impairments documented have influenced the neurorehabilitation practice to develop new interventions, notably unimanual intensive practice adapted to children with HCP and bimanual interventions, and how this knowledge may continue to help us to more precisely focus neurorehabilitation interventions in the future.

1.1. Precision grip

Precision grip, even in simple tasks such as a grip-lift movement, requires a subtle coordination between the grip force (GF, perpendicular to contact surfaces) and tangential load forces (LF) opposing gravity (Johansson & Westling, 1984, 1988). Both tactile information (signaled by slow and fast adapting afferents, Westling & Johansson, 1987) and weight-related information (signaled by muscle spindles and tactile afferents) are used during grasping and object manipulation to adapt the fingertip forces to the object's physical properties (Johansson, 1996). However, due to delays in the transmission of sensory information, such information signaling the object's physical characteristics is not immediately available. To avoid dropping or crushing objects, the fingertip forces must be scaled (planned) before the initiation of the movement to match the object's expected properties based on internal representations of the object gained during prior manipulatory experience (Johansson & Westling, 1987, 1988; Gordon, Westling, Cole, & Johansson, 1993). Such 'anticipatory control' of the force output is characterized by continuous grip and load force increase in parallel (force coupling), with the rate of force increase scaled from the onset toward the target load force (i.e. faster rates for heavier or more slippery objects). Fig. 1 (left panel) shows the normal force application during a prehension (grip/lift) task in healthy adults. During the preload phase (a), GF increases prior to LF onset. Afterwards, both GF and LF increase in parallel during the loading phase (b). The rate of the forces during this forces increase is characterized by single peaks that are well-timed. After a static phase, the release of the object (see right panel of Fig. 1) is characterized by a replacement phase (T0–T1) where the object is repositioned on the table, followed, after the contact with the table, by a rapid decrease in the grip and load forces (T1–T2) until the digits are removed from the object in quick succession (T2–T3).

The grip and lift parts of object manipulation have been largely studied. The parallel development of grip force (GF) and load force (LF) is also particularly well highlighted when the GF is plotted relative to LF (see right lower panel, Fig. 2). Adaptation to different friction and load conditions during the grip and lift phases has been well demonstrated (Fig. 2A and B). In typically developing children, this coordination between GF and LF approximates that of adults around 8–10 years of age (Forssberg, Eliasson, Kinoshita, Johansson, & Westling, 1991). Before this age, as showed by Forssberg and colleagues (Fig. 3) children showed a reversed coordination whereby the object is pressed downward against the table inducing a large GF and a negative LF. During the loading phase, the GF and the LF are not generated in parallel but sequentially. Indeed, the greatest part of the total GF is generated during the preload phase before the load forces are initiated.

Bimanual precision grip tasks have been investigated recently in order to examine fingertip forces coordination in the two hands when opposite or concomitant patterns of force are required in the hands (Islam, Gordon, Sköld, Forssberg, & Eliasson, 2011; Smits-Engelsman, Klingels, & Feys, 2011). For instance placing a handheld object on the top of another object statically