Research in Developmental Disabilities 45–46 (2015) 422–430

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Differentiation of hand posture to object shape in children with unilateral spastic cerebral palsy

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ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form 30 June 2015
Accepted 7 July 2015
Available online 18 July 2015

Keywords:
Hand-shaping
Hemiplegia
Cerebral palsy
Kinematics
Fingers
Motor planning

ABSTRACT

Quantifying hand-shaping in children with unilateral spastic cerebral palsy (USCP) is the first step in understanding hand posture differentiation. To quantify this ability and determine how hand posture evolves during reach toward various object shapes in children with unilateral spastic cerebral palsy (USCP), 2 groups of children (10 typically developing, and 10 USCP, ages 6–13) were studied in a single-session cross-sectional study. Subjects grasped rectangular, concave, and convex objects with each hand. Metacarpal and proximal interphalangeal joint finger flexion and finger abduction angles were calculated. The extent to which hand posture reflects object shape was calculated using a "visuomotor efficiency (VME) index" (a score of 100 reflects perfect discrimination between objects). A mixed design ANOVA with repeated measures on time was used to compare the VME between groups. Children with USCP demonstrated a lower VME than controls in the affected hand, indicating less effective hand-shaping; $p < .01$. There was also a difference between groups in the evolution of VME throughout reach; $p < .01$. No difference in hand-shaping in the less affected hand in USCP was observed. Analysis of joint angles at contact and VME throughout reach demonstrated that children with USCP differentiated their hand posture to objects of different shapes, but demonstrated deficits in the timing and magnitude of hand-shaping isolated to the affected side. The present study suggests it may be important to consider the quality of hand activity using quantitative approaches such as VME analyses. Rehabilitation approaches that target these deficits to improve joint mobility and motor control are worth testing.

What this paper adds

This paper describes hand-shaping ability in both the affected and less affected hands in children with USCP compared to typically developing children. By quantifying the ability of children with USCP to shape the hand to object contour, we hope to add to the existing grasp control literature, and lay a foundation for future studies that can explore specific intervention strategies that can target these deficits.

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http://dx.doi.org/10.1016/j.ridd.2015.07.002
0891-4222/

1. Introduction

The act of grasping is a skilled activity that involves motor planning and fine motor coordination to control multiple degrees of freedom available to the hand and fingers (Gordon, Bleyenfeuft, & Steenbergen, 2013). Children with unilateral spastic cerebral palsy (USCP) display deficits in motor planning and execution that impact the timing and coordination of joint movements, orientation of the hand to object size and use, and calibration of fingertip forces (Coluccini, Maini, Martelloni, Sgandurra, & Cioni, 2007;Gordon et al., 2013; Mutsaarts, Steenberger, & Bekkering, 2006; Steenbergen, Verrel, & Gordon, 2007; Steenberger & van der Kamp, 2004). Bilateral impaired modulation of aperture (distance between thumb and index finger) to object size, an indicator of hand-shaping, was described in children with USCP (Steenberger & van der Kamp, 2004; Ronnqvist & Rosblad, 2007). Decreased bilateral ability to orient the hand prior to object contact based on forthcoming actions with the object was also reported (Craje, Aaers, van der Sanden, & Steenberger, 2010.

Contoured objects require complex configurations of multiple digits for accurate grasp. Aperture alone does not capture the finger coordination patterns used for grasping because joint angles of each digit differ based on object shape. To quantify this complex coordination, a computational approach, the "Visual Motor Efficiency (VME) index", was employed to measure differences in hand configurations during reach for differently shaped objects (Sakitt, 1980; Santello & Soechting, 1998; Santello, Flanders, & Soechting, 2002; Thullier, Lepelley, & Lestienne, 2008). It is derived from all hand joint angles at multiple intervals throughout reach and provides temporal and spatial information on the evolution of hand posture to object shape. Hence, it is sensitive to subtle differences in joint configurations of overall hand posture throughout reach (Santello & Soechting, 1998; Santello, Baud-Bovy, & Jorntell, 2013). Furthermore, the VME is a within-subject measure of differentiation, and thus is unaffected by between-subject differences in hand-shaping strategies.

In healthy adults, hand-shaping (defined by the VME) begins to approximate object shape early during reach acceleration. This preliminary shaping, based on prior experience with similar objects, is further refined via sensory and visual feedback control during reach deceleration (Raghavan, Santello, Gordon, & Krakauer, 2010; Schettino, Adamovich, & Poizner, 2003; Santello & Soechting, 1998; Winges, Weber, & Santello, 2003). In contrast, adults with acquired hemiplegia show poor hand-shaping early in reach, reflecting impairment in feed-forward/anticipatory control. The hand posture is also less differentiated compared to healthy adults at grasp contact (Raghavan et al., 2010).

The aim of this study was to describe hand posture evolution during reach toward various object shapes in children with USCP compared to typically developing (TD) children. Specifically, we asked: Is the timing and extent of hand posture differentiation to different shapes impaired in children with USCP compared with TD children in (1) the less affected versus dominant side and (2) the affected versus non-dominant side? We hypothesized that children with USCP will have bilateral impaired hand-shaping demonstrated by lower VME compared to TD children, and that posture differentiation will emerge later during reach bilaterally in children with USCP.

2. Methods

Two groups of children, ages 6–13 (10 TD and 10 with USCP, MACS levels I and II) were studied in a single session cross-sectional study design.

2.1. Subjects

The inclusion criteria were the ability to: (1) grasp and lift test objects with each hand, (2) perceive direction of passive displacements of the MP joints in all digits (Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2009), (3) bisect a straight line within 5% of the midpoint, (4) identify 8/12 objects on stereognosis test (van Heest, House, & Putman, 1993) (5) distinguish shapes of test objects with eyes closed using the affected hand, and (6) follow multi-step instructions. Exclusion criteria were: (1) Coexisting medical problems unrelated to USCP that interfere with task performance, (2) Poor vision not corrected with glasses, (3) fixed hand joint contractures, and (4) botulinum toxin injections in the upper extremities in the last six months. Subjects were recruited from the outpatient CP clinic of Hospital for Special Surgery between 2009 and 2013. Thirty-six potentially eligible subjects with a diagnosis of USCP were screened. Nineteen subjects met inclusion criteria and were deemed eligible for the study. Fifteen of the eligible subjects completed the testing protocol. Upon analysis, data of five subjects were excluded due to motion tracking errors and marker visualization difficulty. Ultimately, 10 children with USCP, aged 6–13, and 10 aged matched children, with a full set of data were included. This range was selected based on evidence that by age 6 grasp patterns (Steenberger & van der Kamp, 2004) and visual size information cues used to estimate required grasping forces approximate that of adults (Gordon, Johanssen, Forssberg, Eliasson, & Westing, 1992). All subjects were ambulatory, mainstreamed in school, and classified with a Manual ability classification (MACS) level I and II. Baseline subject characteristics and descriptive impairment scores (Jebsen Taylor Test of Hand Function, JTTHF) are listed in Table 1. Consent and assent were obtained from the caregiver and child. The local Institutional Review Board approved the study.

2.2. Materials

Three differently shaped plastic objects (rectangular, concave, and convex) were used (Fig. 1). These shapes require distinct hand postures (Raghavan et al., 2010; Santello & Soechting, 1998; Schettino et al., 2003). Each object had similar