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

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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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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

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Table 1
Baseline participant characteristics.

Characteristics	TD ($n = 10$)	CP ($n = 10$)
Mean age ± SD	9.7 ± 2.3	8.6 ± 2.7
Hand dominance		
Right	9	6
Left	1	4
Lesion side		
Right	NA	4
Left	NA	6
Gender		
Male	4	6
Female	6	4
MACS		
I	NA	6
II	NA	4
Jebsen (score ± SD)		
Less affected	NA	88s ± 94s
More affected	NA	393s ± 360s

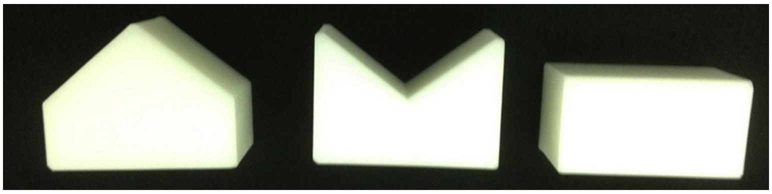

Fig. 1. Top down view of objects.

width and height dimensions scaled to hand size: small (3 cm height × 6 cm wide), medium (4 cm × 8 cm) or large (5 cm × 10 cm). Object size was determined by the width of the object closest to 30% (±5%) of hand span (distance between the distal tip of the thumb and small finger with the hand placed palm down on a flat surface and the fingers in maximum abduction) based on criteria reported (Santello & Soechting, 1998).

2.3. Equipment

Kinematic data were collected using a 12-camera system (Motion Analysis Corporation, Santa Rosa, CA). Digital video and still cameras provided qualitative documentation of the test sessions. 21 passive reflective markers were placed on the hand and wrist to calculate orientation and joint angles based on a valid model (Cook, Baker, Cham, Hale, & Redfern, 2007). Seven additional markers were placed on bony landmarks of the shoulders (bilateral acromium processes), trunk (C7, jugular notch), and pelvis (bilateral ASIS, and lumbro-sacral joint) to define a reference frame. Data were collected at 120 Hz, filtered with a low pass Butterworth filter (6 Hz), and recorded continuously from the verbal command go until object lift-off.

2.4. Procedure

Testing was conducted in the motion analysis laboratory of XXX. Subjects were seated on an adjustable height chair with feet supported on the ground. An adjustable table was set at elbow height. In the starting position, the shoulder was in 0° abduction, elbow in 90° of flexion, and palm facing down on a semi-rigid mold. The object was placed on the table with the flat side facing and, aligned to the testing hand in the sagittal plane, at 75% arm's length distance (range = 31.5–52.5 cm). Arm length distance was measured from the acromion process to the tip of the middle finger with the arm extended in front of the body. The testing commenced with the dominant hand. Subjects were instructed to reach toward the object at a self-selected speed on the verbal cue "go", grasp the object by placing the thumb on the flat side and all four fingers on the contoured side, and lift it off the table after all digits contacted the object. The task was demonstrated by the investigator, and replicated by the subjects. Two practice trials were followed by seven consecutive recorded trials per shape. A minimum of seven trials was required for the statistical analysis of the VME. The order of presentation of the objects was randomized across participants. A trial was successful when the investigator confirmed that all fingers were in contact with the object during the lift. Unsuccessful trials were repeated once or twice. Children unable to complete multiple trials were excluded.

2.5. Data analysis

2.5.1. Grasp kinematics

Grasp kinematics for each hand were analyzed in both groups. Reach onset and offset were defined as the points in time above and below 5% of each subject's average peak wrist velocity. Duration of movement was defined as time from reach-

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onset to object lift-off (determined at 5% of the object marker's vertical peak velocity). The movement was divided into three phases: reach acceleration (reach-onset to peak wrist velocity), reach deceleration (peak velocity to reach-offset), and grasp (reach-offset to object lift-off). The timing of peak aperture (maximum distance between the distal thumb and middle finger) was also computed. To illustrate hand posture differentiation to object shape we analyzed a single representative joint, the abduction angle between the middle and ring finger (digit 3–4 abduction), which was selected because the shape of the objects requires variable displacement of this digit, i.e. abduction for convex and adduction for the concave shape. All finger joint positions were analyzed separately at object contact.

2.5.2. Discrimination of hand posture to object shape (VME)

To capture hand discrimination to object shape, a VME was calculated using an analysis originally described by Sakitt (1980) and used in multiple grasp studies of healthy and and clinical adult populations (Raghavan et al., 2010; Santello & Soechting, 1998; Santello et al., 2002; Thullier et al., 2008). VME is a statistical approach that is a form of a discriminant analysis that recognizes patterns. Each trial was normalized to the duration of the movement from reach-onset to lift-off, and the data extracted at each 5% interval of the normalized movement time (20 bins per trial). Information from 14 joint angles (5 metacarpal phalangeal (MP), 5 proximal interphalangeal (PIP) flexion/extension and 4 finger abduction angles) were derived from the reflective markers and used to determine the hand posture for each shape (Santello & Soechting, 1998). Discriminant analysis reduced the multivariate data contributing to hand posture using a custom MATLAB (Mathworks, Natick, MA) program. At each 5% interval of reach, the hand posture was classified into a shape category (straight, concave, or convex) by calculating the statistical (Mahalanobis) distance between the cumulative data per shape (Puthenveettil, Fluet, Qui, & Adamovich, 2012). To determine when during reach the relative ability to discriminate hand posture to object shape emerges, the shape category at each interval was entered into a matrix that summarized the extent to which hand posture during each trial correctly predicted object shape (see Santello & Soechting, 1998 for details). Each entry in the matrix represents the number of trials that matches the target shape. A ratio was then computed between the correctly matched trials and the maximum possible number of trials (3 hand shapes associated with 3 object shapes), which is the VME score for that interval. A VME of 100 reflects perfect discrimination, while a VME of 40 or below is reflective of random noise. The VME was computed separately for each hand.

2.6. Statistical analysis

Kinematic (movement time, velocity, peak aperture time) and functional variables (JTTHF scores) were analyzed using descriptive statistics and independent t-tests to examine the differences between groups, $p < 0.05$. To examine the timing and extent of hand posture differentiation (VME) between children with USCP and TD children, separate analyses were conducted on the dominant and non-dominant sides between groups. Single joint angles and VME were analyzed using a mixed-design ANOVA (group × shape × time) with repeated measures on time to compare the dominant hand of TD children to the less affected hand of children with USCP. Post-hoc pairwise comparisons between times were conducted to compare the change in VME during discreet phases between groups. Degrees of freedom were corrected using Huynh–Feldt estimates ($\varepsilon = 0.838$) when sphericity was violated. To test the effect of shape and group on hand posture, a mixed-design ANOVA with repeated measures on shape was performed on each joint angle at object contact, with post-hoc pairwise comparisons between shapes.

3. Results

3.1. Grasp kinematics

Results of comparisons between (1) the dominant side in TD children and less affected side in children with USCP and (2) the non-dominant side in TD children and affected side in children with USCP are reported below. As expected, reach movement times (MT) were longer in the affected hand of children with USCP compared to TD children, and peak velocity was lower ($p < 0.05$ in both cases) (Table 2). However, there were no differences in the relative duration of the acceleration, deceleration and grasp phases, maximum aperture or the timing of maximum aperture. Thus, despite slower movement and

Table 2
Mean kinematic variables (±SD).

Event	TD $_{\text{dominant}}$	CP $_{\text{dominant}}$	TD $_{\text{non-dominant}}$	CP $_{\text{non-dominant}}$
Peak velocity (m/s)	.66 ± .16	.62 ± .17	.56 ± .11[*]	.38 ± .12[*]
Peak aperture (m)	.035 ± .009	.036 ± .01	.036 ± .02	.037 ± .01
Movement time (s)	1.8 ± .3	1.6 ± .7	1.8 ± .5[*]	3.9 ± 1.9[*]
% MT Acceleration	31.5 ± 5.2	23.1 ± 9	32.1 ± 8	33.6 ± 13.2
% MT deceleration	58.3 ± 7.9	56.3 ± 6.8	60.3 ± 7.2	54.6 ± 10.8
% MT grasp	10.2 ± 4.3	20.6 ± 3.9	7.6 ± 2.7	11.7 ± 12.2
% MT max aperture	70.8 ± **15**.9	74.4 ± 27.1	75.5 ± 20.4	79 ± 12.9

[*] $p < .05$.

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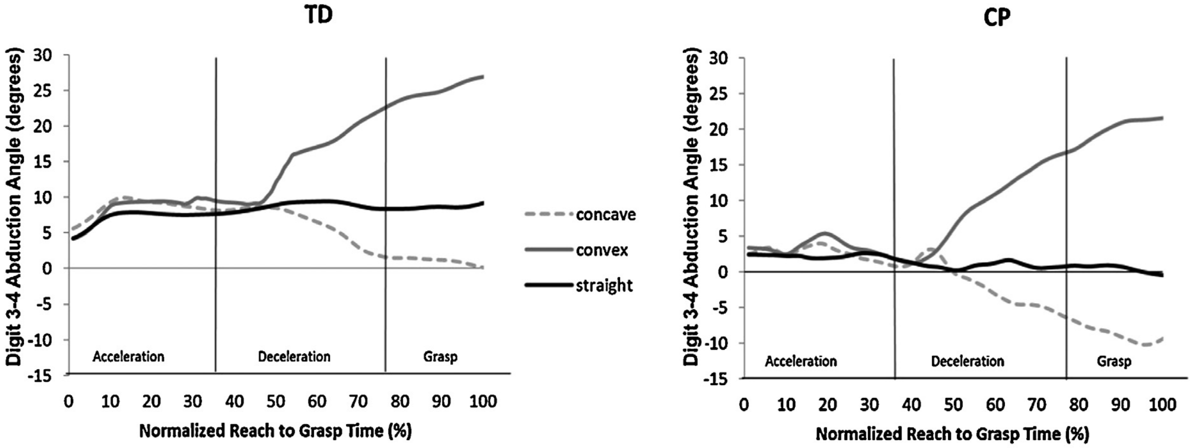

Fig. 2. Differentiation of a single joint angle across the reach cycle. Sample abduction motion of middle and ring fingers (digit 3–4) is shown during reach to concave, convex, and straight object in a typically developing child (right) and a child with USCP (left).

decreased functional grasp performance as evidenced by the JTTHF (Table 1), children with USCP demonstrated typical behavior with regard to the relative timing of reach kinematics in both hands.

3.2. Single joint differentiation: digit 3–4 abduction

On the dominant/less affected side both TD and children with USCP differentiated the abduction angle between the middle and ring finger (digit 3–4 abduction) to object shape with no differences between groups (not shown). On the non-dominant/affected side (Fig. 2), both groups differentiated digit 3–4 abduction starting at the first third of deceleration, and continued to differentiate throughout deceleration and grasp; there were no differences between groups in timing (group × shape × time, $p > 0.05$). However, the magnitude of the angular change differed between groups (group effect, $F_{1,180} = 5.14$, $p = 0.025$). Specifically, children with USCP demonstrated more digit adduction and finger crossing (negative values) for the concave object (Fig. 2).

3.3. Whole hand posture differentiation: VME

Fig. 3 shows VME, derived from all joints of each hand, during each 5% interval of reach in each group. The extent of hand posture differentiation is described by maximum VME (VME_{max}) achieved during each interval of reach, and the timing is defined by the change in VME during acceleration, deceleration and grasp. On the dominant/ less-affected side VME_{max} was not different between the groups (93 in TD children compared to 83 in children with USCP out of a maximum of 100). There was also no difference in the timing of differentiation of hand posture (group VME × time, $p > 0.05$). On the non-dominant/ more affected side, children with USCP demonstrated a lower VME_{max} compared to TD children, indicating greater overlap and less differentiation between the trials for the different shapes (group effect, $F_{(1,18)} = 7.69$, $p = 0.013$). However, despite a lower VME_{max} (87 in TD children compared to 70 in children with USCP), children with USCP demonstrated a change in VME of 23 (from a baseline VME of 47 at the start of reach to 70 at the end, $p = 0.001$). There was also a difference in the timing of evolution of VME during reach in children with USCP compared to TD children (group VME × time, $F_{(16,287)} = 2.06$, $p = 0.006$). Specifically, VME_{max} approximated the time of peak aperture (75%MT) in TD children, whereas in children with USCP VME_{max} did not occur until the end of reach (100% MT) ($p = 0.001$), well after peak aperture. Post-hoc analysis on time showed that VME did not increase during reach acceleration in either group. However, during reach deceleration, TD children show a continuous increase in VME from the start of deceleration (45%MT) to peak aperture (75%MT), while children with USCP show a minimal change (TD VME change = 23, USCP VME change = 7, $p = 0.001$). From peak aperture to object contact (last 25% of MT), the score continues to increase in both groups (TD VME change = 13, USCP VME change = 10, $p = 0.54$). Thus, in children with USCP differentiation of hand posture was both more limited in extent and emerged later during reach.

3.4. Hand posture at object contact

While the VME captures the ability to discriminate overall hand posture it does not indicate how individual joints are modulated to object shape. To explore the pattern of individual joint modulation and understand the cause of lower VME in children with USCP, we examined the finger joint angular positions at object contact in the non-dominant/affected hand (Fig. 4). TD children demonstrated differences in 6 angles: index-middle, middle-ring and ring-small abduction, middle and

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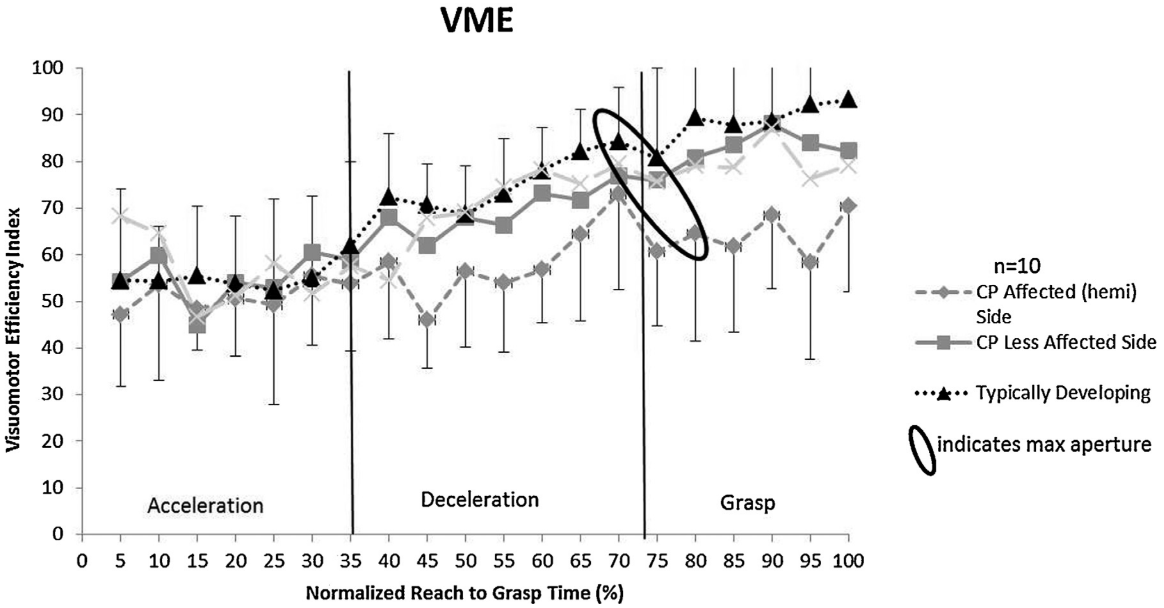

Fig. 3. Differentiation of hand posture to object shape using the Visuomotor Efficiency Index (VME). The average VME (±SD) at each 5% interval of the reach is shown across the reach cycle (horizontal axis) and in relation to the key temporal phases of reach (acceleration, deceleration, and grasp). A VME of 100 reflects perfect differentiation of hand posture. Note that in typically developing children (TD) the VME increases throughout deceleration and grasp, whereas in USCP children the VME begins to increase towards the end of deceleration.

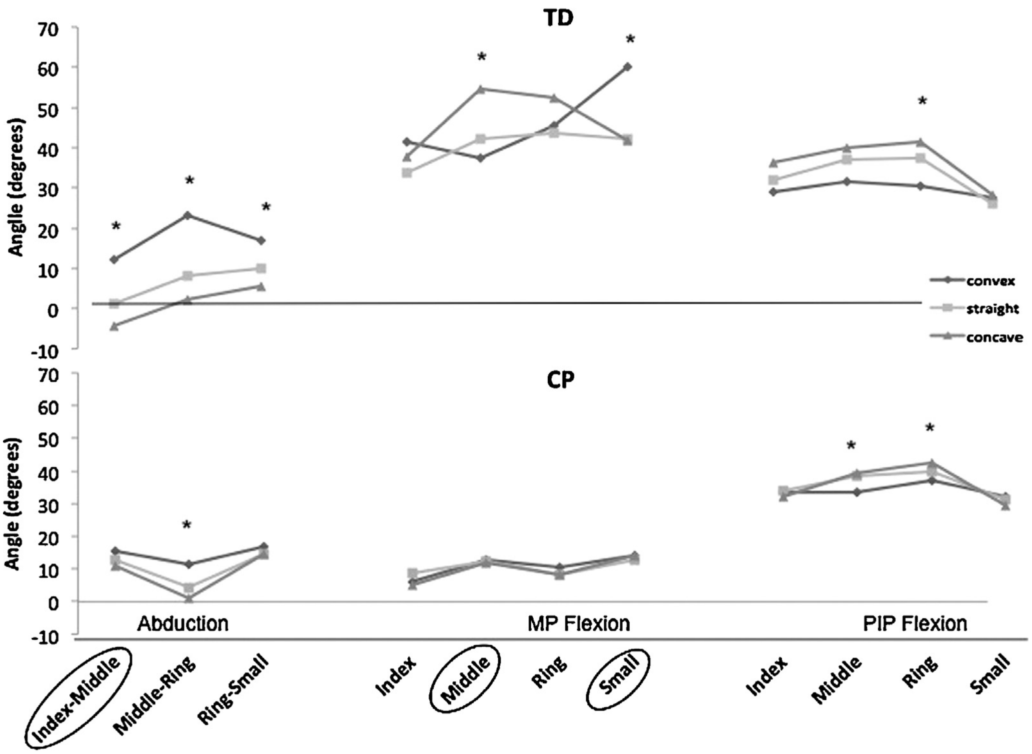

Fig. 4. Differentiation of individual joint angles to object shape at contact. Top figure shows joint angles in typically developing children, and bottom figure shows children with USCP. *significant differentiation of joint angle between shapes (shape effect), oval = significant difference between TD and USCP, $p < 0.05$.

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small MP flexion, and ring PIP flexion (shape effect, $p < 0.05$) compared to only three angles in children with USCP: middle-ring abduction, middle, and ring PIP flexion. The main differences in joint position between the groups were in the MP joints for index-middle abduction (USCP = 5°, TD = 16°, $p = 0.002$), middle MP flexion (USCP = 6°, TD = 41°, $p < 0.05$) and small MP flexion (USCP = 2°,TD = 19°, $p < 0.05$), which were overall more abducted/flexed in TD children compared to children with USCP (group × shape, $p < 0.05$) demonstrating that TD differentiated these joints, while USCP did not.

4. Discussion

Despite limitations in hand movement and function, indicated by increased movement time and lower JTTHF, children with USCP did not use a default hand posture for all objects and were able to differentiate hand posture to object shape. However, the posture of their more affected hand was differentiated to a lesser degree than in TD children, as evidenced by lower VME. Furthermore, children with USCP modulated fewer joints than TD children, accounting for the lower shaping ability. Contrary to our expectations of a bilateral shaping impairment, children with USCP demonstrated unilateral deficits, confined to the more affected hand in both overall ability to shape the hand to the object and the timing of the final posture. In contrast to studies that report a bilateral deficit in the planning of grasp control, these findings suggest a shaping deficit that is isolated to the affected side and possibly results from combined impaired motor control and decreased sensorimotor experience, reflective of limited feedback control.

4.1. Quantifying deficits in hand posture to object shape

Our findings of no differences between groups in the timing and amplitude of peak aperture differ from reports of a bilateral delay in children with moderate USCP. In one study, the less affected hand showed delayed aperture formation during reach and the more affected hand demonstrated no anticipatory shaping at all (Ronnqvist & Rosblad, 2007), while another cohort of children achieved peak aperture at 90% of reach in both hands, compared to 50% in TD children (Steenberger & van der Kamp, 2004). There are two possible explanations for this discrepancy. Subjects in prior studies were classified as having moderate USCP, which may explain a greater delay in aperture formation than children with mild USCP. Our subjects were mild (MACS Levels I, II) and therefore demonstrated a greater ability to modulate aperture. Second, although aperture is correlated with object size, the relationship between shape and hand posture is complex. In prior studies of aperture modulation, the size of similarly shaped cylinders was varied (Jeannerod, 1986; Ronnqvist & Rosblad, 2007; Steenberger & van der Kamp, 2004), whereas our objects were similar in size, but varied in shape. Thus, prior studies reflect aperture control for size accommodation rather than shape. The objects used in our study varied in width at the center, yet aperture, even of the corresponding middle digit, was not predictive of shape. This may be due to the range of possible placements for digit contact along the object surface. Many objects are irregularly shaped and, require unique configurations of each finger for efficient lifting. Under these conditions, aperture is not an appropriate measure of task demands because it is a measure of width and not inter-digit coordination.

Analysis of single joint differentiation may be useful in capturing gross differences in hand shape, but not sensitive in capturing subtle joint differences. Digit 3–4 abduction was selected as a representative joint motion because the shape of the objects required a substantial change in this joint's orientation. As expected, the abduction angle differed depending on object shape in both groups, reflecting differentiation, but was not robust enough to tease out differences between groups. Thus, a single joint analysis does not provide adequate information with regard to subtle hand-shaping differences between subjects, and an approach that accounts for contributions from all relevant joints is necessary.

The VME provided a more detailed analysis of the entire hand posture and detected differences in both overall shaping ability and timing of posture differentiation between groups.

In our study, VME increased throughout reach deceleration and peaked at 75% of MT in both hands of TD children and in the less affected hand of children with USCP, consistent with the VME reported for healthy adults (Raghavan et al., 2010; Santello & Soechting, 1998). However, unlike healthy adults, who begin shaping during reach acceleration, indicative of feed-forward control, the TD children did not begin shaping until the start of deceleration indicating that anticipatory hand-shaping has not fully developed (Craje et al., 2010; Steenbergen et al., 2007; Steenberger & van der Kamp, 2004). Children with USCP demonstrated an even greater delay in shaping the affected hand, during reach deceleration, suggesting that they have difficulty with the feedback modulation of hand posture control.

4.2. Joint strategy and feedback control

To further analyze the differences in VME, between groups, individual joint positions were analyzed at object contact. In TD children, six joints were differentiated to object shape, while only three joints were differentiated in children with USCP. This subset of joints accounted for the entire differentiation seen in USCP. Impaired VME in children with USCP may be explained by a lower number of joints contributing to hand-shaping that also demonstrate a smaller magnitude of movement.

Comparison of joint angles at contact showed a pattern of greater MP extension and adduction among the children with USCP compared to TD children. Long-standing flexor spasticity and shortening, common in USCP, results in a resting "claw hand" looking posture characterized by wrist flexion, MP extension, and PIP extension (van Heest, Ramachandran, Stout,

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Wervey, & Garcia, 2008). In this position, grasp is most effectively accomplished by PIP modulation. In contrast, adult hemiplegics often demonstrate MP flexion and PIP extension and use the MPs to modulate grasp (Raghavan et al., 2010). While both adult hemiplegia and children with USCP differ in joint differentiation patterns from controls, specific differences between these groups may be explained by the nature, type and extent of the lesion, and the effect of these lesions on limb biomechanics.

There are two important aspects to successful grasp—motor control and the sensorimotor experience. When motor control is impaired, the hand is used less often, limiting the sensorimotor experience. Here we demonstrate that children with USCP are able to differentiate their hand posture within the limitations of motor control, yet demonstrate a delay during the feedback phase of reach-to-grasp. From a perceptual point of view, subjects were able to extract key visual attributes of the object since they were utilized "normally" in the less affected hand. A possible explanation for the delay in the affected hand may be a lack of adequate sensorimotor experience to make rapid feedback adjustments. Routine grasping of a variety of differently shaped objects leads to the development of a repertoire of sensorimotor experience, which may be limited in USCP due to reduced use of the affected hand. Alternatively, there may be impaired sensorimotor integration; i.e., an inability to use this visual information for modulating the motor commands in the affected hand (Gordon, Charles, & Steenbergen, 2006).

4.3. Unilateral versus bilateral motor planning deficits?

An important question regarding planning of grasp in children with USCP is whether the impairment impacts both hands as reported in aperture and grip orientation studies (Craje et al., 2010; Lukos, Ansuini, & Santello, 2008; Mutsaarts, Steenberger, & Bekkering, 2006; Steenberger & van der Kamp, 2004), or whether it is unilateral and limited to the affected side as reported in anticipatory force control studies (Gordon & Duff, 1999; Prabhu, Diermayr, Gysin, & Gordon, 2011). Our findings suggest that anticipatory hand-shaping impairment is unilateral. Grip orientation studies reported bilateral impairment in tasks requiring anticipation of end posture for intended use, such as orienting and inserting a sword into a sheath (Craje et al., 2010). These tasks require more complex temporal processing and sequencing in addition to visuo/sensorimotor transformation, which the children with USCP may not have had adequate opportunities to practice and learn. Our task only required modulation of hand posture for a relatively simple end goal of grasping without an intended specific use, and examined motor control rather than task-specific learning. Similarly, studies on anticipatory control of fingertip forces showed a lateralized impairment (Gordon & Duff, 1999; Prabhu et al., 2011). Nevertheless, Gordon and Duff (1999) demonstrated that anticipatory control can emerge in the affected hand following extensive practice, suggesting that task-specific training is important.

4.4. Limitations

This study was limited to children with USCP with a MACS classification of l and II and does not reflect the full spectrum of USCP. Additionally, it is difficult to determine how much of the limited hand differentiation is due to motoric constraints versus visuo/sensorimotor transformation deficits. Lastly, by altering the placement of objects in this protocol to accommodate for limited forearm supination, we limit direct comparison of our results to previous studies.

5. Conclusion

Quantifying hand-shaping in children with USCP is the first step in understanding the grasp impairment. Children with USCP were able to differentiate their hand posture to objects of different shapes, but demonstrated deficits in the timing and magnitude of hand-shaping that were isolated to the affected side. Using VME to quantify hand-shaping permits detection of subtle coordination deficits in grasp performance and demonstrates motor control impairments. An important question is whether these deficits may be amenable to interventions to improve joint mobility and hand motor control. Improved joint mobility in the wrist and fingers followed by opportunities for extensive grasping practice could conceivably lead to improved motor control. Recent studies show that intensive, motor-learning approaches are efficacious in improving clinical UE (Novak et al., 2013; Sakzewski, Gordon, & Eliasson, 2014) and biomechanical (Hung, Casertano, Hillman, & Gordon, 2011) measures of upper extremity activity in children with USCP. The present study suggests it may be important to consider the quality of hand activity using quantitative approaches such as VME analyses.

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