

Reproducibility of Tactile Assessments for Children with Unilateral Cerebral Palsy

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ABSTRACT. A systematic review identified tactile assessments used in children with cerebral palsy (CP), but their reproducibility is unknown. Sixteen children with unilateral CP and 31 typically developing children (TDC) were assessed 2–4 weeks apart. Test–retest percent agreements within one point for children with unilateral CP (and TDC) were Semmes-Weinstein monofilaments: 75% (90%); single-point localization: 69% (97%); static two-point discrimination: 93% (97%); and moving two-point discrimination: 87% (97%). Test–retest reliability for registration and unilateral spatial tactile perception tests was high in children with CP (intraclass correlation coefficient [ICC] = 0.79–0.96). Two tests demonstrated a learning effect for children with CP, double simultaneous and tactile texture perception. Stereognosis had a ceiling effect for TDC (ICC = 0) and variability for children with CP (% exact agreement = 47%–50%). The Semmes-Weinstein monofilaments, single-point localization, and both static and moving two-point discrimination are recommended for use in practice and research. Although recommended to provide a comprehensive assessment, the measures of double simultaneous, stereognosis, and tactile texture perception may not be responsive to change over time in children with unilateral CP.

KEYWORDS. Cerebral palsy, hemiplegia, reliability, sensory, stereognosis, tactile assessment, tactile perception, two-point discrimination

Children with cerebral palsy (CP) primarily affecting one-side of the body (unilateral CP) commonly experience tactile processing deficits that impact on upper

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limb function (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995; Lesny, Stehlik, Tomasek, Tomankova, & Haavlicek, 1993; Van Heest, House, & Putnam, 1993). The percentage of children with unilateral CP who have tactile impairment varies by type of assessment. Arnould, Penta, and Thonnard (2007) reported that 33% of children with unilateral CP had impaired performance using Semmes-Weinstein monofilaments (SWM) and 38% had poor manual form perception. Cooper et al. (1995) reported that 42% of children with unilateral CP had impairments using the SWM, 77% had poor stereognosis, and 57% had poor two-point discrimination (2PD). Yekutieli, Jariwala, and Stretch (1994) reported that 57% of children with unilateral CP had poor stereognosis, while Van Heest et al. (1993) reported 90% of their sample had poor 2PD. These tactile impairments are linked to deficits in grasping and anticipatory control of the involved hand and adaptation of fingertip forces during grip-lift tasks (Gordon, Charles, & Duff, 1999; Gordon & Duff, 1999a, 1999b).

Although these studies indicate that tactile deficits are present in children with unilateral CP, they do not inform practitioners as to how to consistently identify these deficits using reliable assessment tools. Mainly, this is because very few assessments have reported psychometric data for children with unilateral CP (Cooper et al., 1995; Krumlinde-Sundholm & Eliasson, 2002), the tests do not fully assess tactile registration and perception domains (Auld, Johnston, Boyd, & Moseley, 2009), and test methodology is inconsistent among studies. To address this, we recently reported a systematic review detailing assessments suitable for a comprehensive tactile examination framework for children with CP (Auld, Boyd, Moseley, & Johnston, 2011).

The framework for tactile assessment used in this study was developed from empirical literature and a systematic review performed to identify tactile assessments (Auld et al., 2011). The framework includes two phases: tactile registration and tactile perception. Registration, or sensation, is the first phase when an individual detects or becomes aware of sensory information (Williamson & Anzalone, 2001). Sensory perception, the subsequent phase, is where an individual demonstrates the ability to understand, interpret, or give meaning to that sensory information (Colarusso & Hammill, 1996; Gazzaniga & Heatherton, 2006; Kandel, Schwartz, & Jessell, 2000). A comprehensive tactile assessment includes both phases of tactile assessment.

The systematic review identified one test of tactile registration, the SWM (Bell-Krotoski, 1987), and five tests of spatial perception that had been evaluated in children with CP: single-point localization (SPL; Burns, Ensby, & Norrie, 1989), static two-point discrimination (s2PD), moving two-point discrimination (m2PD; MacKinnon & Dellon, 1985), double simultaneous (DS; Burns et al., 1989), and stereognosis (Klingels et al., 2010). Each of these tests was examined in this study. To complete the perceptual domain, the review identified two tests for adults with brain injury: the AsTex, an assessment of texture perception (Miller et al., 2009), and temporal order judgment (TOJ), an assessment of temporal perception (Eskes, Klein, Dove, Coolican, & Shore, 2007; Spence, Baddeley, Zampini, James, & Shore, 2003). The AsTex was examined in this study, however the more complex TOJ will be reported in a subsequent study.

Of the seven tests identified in the systematic review, only s2PD and stereognosis have any evidence of reliability in children with unilateral CP (Klingels et al., 2010). The aim of this study, therefore, was to determine the repeated measures agreement and reliability for each of the seven assessments. Children with typical development were included as a baseline for comparison with children with CP. We hypothesized that agreement for each tactile assessment would (a) produce measurement error small enough for it to be useful in practice and (b) be equivalent between dominant and nondominant hands of the children with typical development and the unimpaired hand of children with unilateral CP, but (c) lower for the impaired hand of children with CP due to inherent variability in performance. For reliability, we hypothesized that, due to the greater heterogeneity of children with CP, tactile assessments would show greater reliability among these children than children with typical development, with highest reliability for the impaired side.

METHODS

Study Design and Participants

We conducted a test–retest reproducibility study including two groups of children aged 5–17 years: a group with unilateral CP and a group of typically developing children (TDC). Ethical approval was received from The University of Queensland, the Cerebral Palsy League and the Royal Children’s Hospital, Brisbane, Australia.

Children with unilateral CP were eligible if they were aged 8–18 years and had a confirmed diagnosis. The exclusion criteria were the following: (a) inability to understand and/or follow test instructions due to intellectual or behavioral difficulties, (b) receipt of upper limb botulinum toxin A injections within 3 months prior to recruitment (no child in this study received botulinum toxin injections within 12 months), and (c) previous upper limb orthopedic surgery. Recruitment information was provided to families of all known children with unilateral CP in Queensland, Australia. Children were identified via two databases: the Cerebral Palsy League database and the Queensland Cerebral Palsy Health Service database. A recruitment letter was sent to the parents of each child and this was followed by a phone call 2 weeks later to discuss the study and to determine their desire to participate in a series of studies on tactile performance, of which this reliability study was one component.

Children with typical development were recruited as community volunteers in response to advertisement fliers and email circulars. Children were excluded if they had any known impairment in the following: (a) intellect (<70 on the Kaufman Brief Intelligence Test), (b) upper limb performance (>1 standard deviation below the normal range on the Jebsen–Taylor Test of Hand Function (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969), (c) behavior (meets the DSM-IV criteria for any behavioral condition), (d) tactile performance (known peripheral nerve lesion), (d) upper limb fractures or injuries within 12 months prior to participation in the study, and (e) uncorrected visual impairment.

Two client database audits identified 253 potential participants with unilateral CP living in Queensland. All children were contacted, and of these, 59 provided

informed parental consent to participate in the overall study and 52 met eligibility criteria. Sixteen families agreed for their child to return for a second time to participate in the reliability component reported in this study (median age 10 years, range 9–16 years; 9 [56%] male; 10 [63%] left side affected; Gross Motor Function Classification System [GMFCS] [Palisano et al., 1997] [level I = 8; level II = 8]; Manual Abilities Classification System [MACS] [Eliasson et al., 2006] [level I = 9; level II = 7]). The reference population comprised 31 TDC (median age 10 years, range 5–17 years; 15 [48%] male; 7 [23%] left handed).

Tests and Measures

Tactile Registration

Tactile registration was measured using the full 20-item SWM kit, newly calibrated at the time of testing. The dermatomes of C6, C7, and C8 were tested on the distal pad of the thumb, index, fourth, and fifth digits. Starting with the monofilament of value 2.83 (lower side of normal sensation), the monofilament was applied to the skin surface of the four fingers three times in a pseudorandom order, with one response out of three taken as an affirmative response, as indicated by the original test methodology (Bell-Krotoski, 1987). The score was the lowest monofilament (value) at which the child was able to correctly identify at least one touch (out of a possible three) on all four fingers and one sham trial in a test set.

Spatial Tactile Perception

Single-point localization. The largest SWM was used to touch three dermatomes (C6, C7, and C8) on four fingers in a pseudorandom order. The child was told that the touch may be on the “front,” “back,” or “side” of one of their fingers and that they were to accurately identify both the finger and the position that was touched. The score was the number correct out of 12.

Two-point discrimination. 2PD was assessed using the Disk-Criminator (MacKinnon & Dellon, 1985); m2PD was tested first, followed by s2PD, with pressure applied to the point of skin blanching (Moberg, 1990). Stimuli were delivered to the palmar side of the distal phalanx of the index finger. The score was the smallest separation (in mm) between the two points that could be perceived on at least 7 of 10 trials.

Double simultaneous. Tactile stimuli were provided by identical bristles attached to wooden rods (similar to the design of the monofilaments) that exerted a supra-threshold force for each child. The thumb, index, fourth and fifth digits were each touched individually and simultaneously with every other finger on the opposite hand in a pseudorandom order (a total of 24 trials). The child reported which fingers were touched either verbally or by touching or moving the relevant fingers. The score was the number of correct responses out of a possible maximum 24.

Intensity/Texture Tactile Perception

AsTex. Texture perception was tested using the AsTex perspex board that displays tactile gratings of reducing tactile discrimination index (Miller et al., 2009). Starting at the “rough” end of the board, movement of the child’s index finger, then thumb, then fifth finger was guided by the examiner along the board at a constant speed

in a standardized manner. Children were instructed to stop immediately when the board felt smooth (gratings became too close together to determine their separation). Each point was recorded, with the final outcome the average of three trials for each digit. The averaged scores were converted to the tactile discrimination index for each finger using the chart available with the test kit.

Motor-Enhanced Tactile Perception

Stereognosis. Nine common objects were placed to the side of the child within the child's view (Boyd et al., 2010). These objects were three unrelated objects, peg, key, and spoon, and six objects that come in associative pairs, a 10-cent coin and a button of similar size, a pen and a pencil, a paperclip, and a safety pin. The examiner had an identical set of objects that were placed in the child's testing hand one at a time in a random order. The child was encouraged to manipulate the object and/or was assisted to touch the object until a response was given. The child was advised to look at the objects to their side and either name or point to the object that was identical to the one placed in their hand. The score was the number of correct responses out of a possible maximum of 9.

Procedure

A physiotherapist, experienced in the evaluation of children with CP (the first author), performed the complete battery of tactile tests on each child on two occasions, 2–4 weeks apart. Both sessions were performed at the same location, either the child's home residence, a Cerebral Palsy League venue, or the Royal Children's Hospital. Prior to assessment, the preferred hand of the child was established using the Edinburgh Handedness Inventory (Oldfield, 1971) and the severity of upper limb impairment for children with unilateral CP was established using the MACS (Eliasson et al., 2006).

Children were seated in a quiet, well-lit room with their arms resting on a table at elbow height. On the table, a foam mould was used to support both forearms in neutral pronation–supination. A frame supporting a curtain was positioned over the upper forearms to prevent the children from viewing their hands. For each test, the less impaired hand (for children with CP) or the dominant hand (for children with typical development) was assessed first. The full battery of tactile assessments was completed in the same order for all children. Testing took less than 30 min.

Data Analysis

Day 1 and day 2 scores for each test item were described using the median and interquartile range (IQR). We then calculated (1) agreement statistics, which assess how close results of repeated measurements are by estimating the measurement error in repeated measurements, and (2) reliability statistics, which assess whether individuals can be distinguished from each other despite measurement errors (de Vet, Terwee, Knol, & Bouter, 2006).

Agreement of scores between days for each test item and each hand was assessed by the percentage of exact agreement (%EA) and percentage of agreement within one point (%EA \pm 1), and the smallest detectable change (SDC). The SDC for each test item was calculated using the equation reported by de Vet et al. (2006). The SDC is a measure of the smallest within participant change in score

that represents a real change in an individual ($p < .05$) that cannot be attributed to measurement error (Terwee et al., 2007). For a test to be useful for evaluative purposes, the SDC should be smaller than the minimal amount of change considered clinically important.

Reliability was assessed using the intraclass correlation coefficient (ICC) for agreement (de Vet et al., 2006; Guyatt, Walter, & Norman, 1987). Between-subjects variance and total variance (between subjects and within subjects) were calculated using an analysis of variance (ANOVA) model; the test score was the independent variable and persons and time were random factors. The correlation coefficients were evaluated using the following criteria: >0.75 excellent reliability, 0.60 – 0.74 good reliability, 0.40 – 0.59 fair reliability, and <0.40 poor reliability (Cicchetti & Sparrow, 1981; McDowell & Newell, 2005).

RESULTS

Test–Retest Percentage of Agreement

For tactile registration on the SWM, the physiotherapist achieved exact test–retest agreement for 38% of the impaired hands and 25% of the unimpaired hands of children with unilateral CP. Test–retest agreement within one monofilament was much higher with 75% on the impaired hand and 63% on the unimpaired hand (see Table 1). The SDC for children with CP was 2.6 for the impaired hand and 4.1 for the unimpaired hand (see Table 2). This indicates that an individual child with unilateral CP needs to demonstrate an improvement of at least three monofilaments for the impaired hand to exclude measurement error and to confirm a real change in tactile registration.

In the typically developing group, the physiotherapist achieved exact test–retest agreement for monofilament values on both days (%EA) for 61% of nondominant hands and 55% of dominant hands. Test–retest agreement within one monofilament was 81% for dominant hands and 90% for the nondominant hands (see Table 3). The SDC for children with typical development was 1.6 filaments for the nondominant hand and 2.2 filaments for the dominant hand (see Table 4).

Test–retest agreement for nonmotor unilateral spatial perception tests (SPL, s2PD, and m2PD) ranged from 31%–93% in children with unilateral CP (impaired hand: %EA = 31%–80%, %EA \pm 1 = 69%–93%; unimpaired hand: %EA = 50%–75%, %EA \pm 1 = 81%–88%; see Table 1). Scores for children with typical development were higher, ranging from 74%–97% (%EA = 74%–87%; %EA \pm 1 = 94%–97%; see Table 3). SDC scores for the impaired hand of children with unilateral CP on each of these tests were sufficiently small to detect clinically relevant change (SDC: SPL = 2.3; s2PD = 1.3; m2PD = 3.0; see Table 2).

Test–retest agreement for DS, the only bilateral spatial perception test, was lower for children with unilateral CP (%EA = 14%; %EA \pm 1 = 43%) than children with typical development (%EA = 48%; %EA \pm 1 = 74%). For AsTex, the texture perception test, between-days agreement was similar for both children with unilateral CP (%EA \pm 1 = 77%–87%) and children with typical development (%EA \pm 1 = 69%–75%; see Tables 1 and 3). For both the DS and the texture perception test,

TABLE 1. Agreement of Tactile Assessments for Children with Unilateral Cerebral Palsy (n = 16)

	Children with Unilateral Cerebral Palsy												
	Impaired						Unimpaired						
	Day 1 Med	Day 1 IQR	Day 2 Med	Day 2 IQR	%EA ± 1	Day 1 Med	Day 1 IQR	Day 2 Med	Day 2 IQR	%EA ± 1	Day 1 Med	Day 2 IQR	
SWM (monofilament number from 1 (log 1.65) to 20 (log 6.65))	4	2-5.5	3	2-5.5	38	1	1-1	3	2-4	25			63
					75								
SPL (no. correct/12)	11	7.5-12	9	7-11	31	12	10.5-12	11.5	10.5-12	56			81
s2PD (mm)	3	3-6	3	3-8	80	2	2-3	3	2-3	50			88
m2PD (mm)	3	2-3	3	2-8	53	2	2-2	2	2-3	75			88
DS* (no. correct/24)	15.5	11-21	19	13.5-21.5	14	43							
Stereognosis (no. correct/9)	6	5-9	7	2-9	47	9	8-9	9	8-9	50			81
AsTex (mm)	0.73	0.31-1.01	0.57	0.32-0.74	**	0.45	0.29-0.77	0.31	0.22-0.55	**			69

Note: SWM = Semmes-Weinstein monofilaments; SPL = single-point localization; s2PD = static two-point discrimination; m2PD = moving two-point discrimination; DS = double simultaneous; Med = median of pooled day 1 and day 2 data; IQR = interquartile range; %EA = % exact agreement; %EA ± 1 = %EA ± 1 test point.

*This test involves two hands.

**As results for the AsTex were calculated as an average of three trials, the ability to achieve exact agreement was not calculated for this measure.

TABLE 2. Reliability and Smallest Detectable Change for Children with Unilateral Cerebral Palsy ($n = 16$)

Test	Maximum Test Score (Minimum Unit)	Children with Unilateral Cerebral Palsy			
		Impaired		Unimpaired	
		SDC	ICC (95% CI)	SDC	ICC (95% CI)
SWM (minimum filament)	20 (1 monofilament)	2.6	0.96 (0.93–1.00)	4.1	0.90 (0.81–1.00)
SPL (no. correct/12)	12 (1)	2.3	0.91 (0.82–1.00)	2.7	0.67 (0.39–0.94)
s2PD (mm)	15 (1 mm)	1.3	0.96 (0.92–1.0)	1.7	0.00 (0.00–0.52)
m2PD (mm)	15 (1 mm)	3.0	0.79 (0.60–0.98)	1.3	0.61 (0.28–0.93)
DS* (no. correct/24)	24 (1)	5.3	0.79 (0.59–0.99)		
Stereognosis (no. correct/9)	9 (1)	4.4	0.75 (0.53–0.98)	1.9	0.07 (0.00–0.58)
AsTex [®] (Index) (mm)	2.5 (0.03)	0.7	0.42 (0.01–0.83)	0.5	0.31 (0.00–0.76)
AsTex [®] (Thumb) (mm)	2.5 (0.03)	0.6	0.48 (0.10–0.86)	0.5	0.59 (0.27–0.92)
AsTex [®] (5th digit) (mm)	2.5 (0.03)	0.7	0.46 (0.07–0.85)	0.6	0.18 (0.00–0.66)

Note: SWM = Semmes-Weinstein monofilaments; SPL = single-point localization; 2PD = two-point discrimination; DS = double simultaneous; SDC = smallest detectable change; ICC = intraclass correlation coefficient; CI = confidence interval.

*This test involves two hands.

there was a positive median change between days for children with unilateral CP, indicating that there may have been a learning effect. For children with unilateral CP, the SDC score for DS was large (5.3); however on a 24-point scale, this may still be sufficiently small to detect clinically relevant change. The SDC scores for AsTex also were large (0.6–0.7; see Table 2).

For stereognosis, test–retest percentage of agreement for children with unilateral CP was slightly lower for the impaired hand (%EA = 47%; %EA \pm 1 = 60%) compared with the unimpaired hand (%EA = 50; %EA \pm 1 = 81%) of children with unilateral CP. However, although the SDC was 1.9 for the unimpaired side, the value for the impaired side (4.4) indicates that within the limits of the test range of 9 points, agreement is insufficient to detect a clinically significant change in children with initial scores above 4. Most children with typical development achieved perfect scores for each hand on both days (median day 1 = day 2 = 9), indicating a ceiling effect when assessed using common objects.

Test–Retest Intraclass Correlation Coefficients

Test–retest reliability was excellent for tactile registration in children with unilateral CP, for both the impaired, ICC = 0.96 (95% CI: 0.93–0.99), and unimpaired hand, ICC = 0.90 (95% CI: 0.81–1.00; see Table 2). However, as expected in children with typical development, low between-subjects variability resulted in only fair to good reliability for each hand (nondominant: ICC = 0.69, 95% CI: 0.50–0.87; dominant: ICC = 0.54; 95% CI: 0.29–0.79; see Table 4).

On the spatial perception tests, ICCs for the impaired hand of children with unilateral CP varied from 0.79 to 0.96 indicating high test–retest reliability. Scores were lower for the unimpaired hand of children with unilateral CP (ICC = 0.00–0.67) and each hand for children with typical development (ICC = 0.00–0.77), indicating poor to moderate reliability (see Tables 2 and 4). The AsTex demonstrated poor to fair

TABLE 3. Agreement of Tactile Assessments for Children with Typical Development (n = 31)

	Children with Typical Development																	
	Non Dominant							Dominant										
	Day 1 Med	Day 1 IQR	Day 2 Med	Day 2 IQR	Day 2 Q1	%EA ± 1	Day 1 Med	Day 1 IQR	Day 2 Med	Day 2 IQR	Day 2 Q1	%EA ± 1	Day 1 Med	Day 1 IQR	Day 2 Med	Day 2 IQR	%EA ± 1	
SWM (monofilament number from 1 [log 1.65] to 20 [log 6.65])	2	1-2	1	1-2	1	61	1	1-1	2	1-2	1	90	1	1-1	2	1-2	55	81
SPL (no. correct/12)	12	11-12	12	12-12	12	74	12	12-12	12	12-12	12	97	12	12-12	12	12-12	84	94
s2PD (mm)	2	2-2	2	2-2	2	87	2	2-2	2	2-2	2	97	2	2-2	2	2-2	81	97
m2PD (mm)	2	2-2	2	2-2	2	77	2	2-2	2	2-2	2	97	2	2-2	2	2-2	84	97
DS* (no. correct/24)	23	21-24	24	22-24	24	48	24	21-24	24	22-24	24	74	24	21-24	24	22-24	84	97
Stereognosis (no. correct/9)	9	9-9	9	9-9	9	94	9	9-9	9	9-9	9	97	9	9-9	9	9-9	94	97
AsTex ^(B) (mm)	0.27	0.21-0.64	0.27	0.21-0.64	0.27	N/A**	0.27	0.21-0.5	0.27	0.21-0.57	0.27	77	0.27	0.21-0.5	0.27	0.21-0.57	N/A**	87

Note: SWM = Semmes-Weinstein monofilaments; SPL = single-point localization; s2PD = static two-point discrimination; m2PD = moving two-point discrimination; DS = double simultaneous; Med = median of pooled day 1 and day 2 data; IQR = interquartile range; %EA = % exact agreement; %EA ± 1 = %EA ± 1 test point.

* This test involves two hands.

** As results for the AsTex were calculated as an average of three trials, the ability to achieve exact agreement was not calculated for this measure.

TABLE 4. Reliability and Smallest Detectable Change for Children with Typical Development ($n = 31$)

Test	Maximum Test Score (Minimum Unit)	Children with Typical Development			
		Nondominant		Dominant	
		SDC	ICC (95% CI)	SDC	ICC (95% CI)
SWM (minimum filament)	20 (1 monofilament)	1.6	0.69 (0.50–0.87)	2.2	0.54 (0.29–0.79)
SPL (no. correct/12)	12 (1)	1.4	0.28 (0.00–0.61)	1.2	0.17 (0.00–0.52)
s2PD (mm)	15 (1 mm)	0.6	0.53 (0.27–0.79)	0.8	0.15 (0.00–0.50)
m2PD (mm)	15 (1 mm)	0.8	0.15 (0.00–0.50)	0.7	0.28 (0.00–0.61)
DS* (no. correct/24)	24 (1)	2.2	0.55 (0.30–0.80)		
Stereognosis (no. correct/9)	9 (1)	0.4	0.00 (0.00–0.36)	0.4	0.00 (0.00–0.36)
AsTex (Index) (mm)	2.5 (0.03)	0.4	0.77 (0.63–0.92)	0.4	0.77 (0.63–0.92)
AsTex (Thumb) (mm)	2.5 (0.03)	0.4	0.68 (0.48–0.87)	0.4	0.75 (0.59–0.91)
AsTex (5th digit) (mm)	2.5 (0.03)	0.3	0.76 (0.61–0.91)	0.4	0.59 (0.35–0.83)

Note: SWM = Semmes-Weinstein monofilaments; SPL = single-point localization; 2PD = two-point discrimination; DS = double simultaneous; SDC = smallest detectable change; ICC = intraclass correlation coefficient; CI = confidence interval.

*This test involves two hands.

test–retest reliability for children with unilateral CP (ICC = 0.18–0.59) and good reliability for children with typical development (ICC = 0.59–0.77).

DISCUSSION

Although test–retest exact agreement was low for all tactile tests in children with unilateral CP (impaired hand: 14%–53%) except s2PD (80%), given the small increments on some tests, agreement within one point was considered clinically acceptable for all tests (impaired hand: 69%–93%) except DS (43%) and stereognosis (60%). Excellent test–retest reliability (ICC > 0.75) for registration and spatial perception tests indicates that these items are able to discriminate among children with unilateral CP, however the AsTex did not show good discriminative ability. The findings for SDC scores for children with unilateral CP indicate that while the SWM, 2PD, and SPL are acceptable for evaluation of change over time, stereognosis and DS as well as AsTex are not. Scores of children with typical development demonstrated moderate to high test–retest exact agreement and agreement within one point. However, test–retest reliability was low, suggesting that the tests cannot be used to discriminate among children with typical development.

An important limitation of this study is that all testing was done by one physiotherapist limiting generalization. The slight variability in age between the children with unilateral CP and children with typical development is potentially significant because of the impact it may have on tactile performance. Ideally, age-standardized scores would be included for more accurate comparison, however due to the small sample size and lack of previous normative data for these assessments, this was not possible.

Based on our findings, we recommend testing tactile registration of children with unilateral CP using the full 20-item SWM kit in both practice and research. At present, this is the only valid method for assessing tactile registration

(Jerosch-Herold, 2005). Our results indicate that when using the full 20-item kit, the SWM demonstrates acceptable test–retest agreement, excellent test–retest reliability, and the SDC for each test is adequate. Clinical utility is excellent, as the test enables perfect reproduction of stimuli across examiners and participants. Therapists are cautioned that improvement may be difficult to quantify with the short-form 5-monofilament procedure (Krumlinde-Sundholm & Eliasson, 2002); however, this was not evaluated in the current study and requires further research. The SWM measures only one aspect of tactile function and should be used in conjunction with other tactile perception assessments that provide more information about how tactile dysfunction may impact motor performance.

These three tests examined all demonstrated suitable properties for inclusion in a tactile test battery for children with unilateral CP. All properties demonstrated acceptable test–retest agreement, excellent test–retest reliability, and the SDCs were adequate, especially for s2PD. Our findings for test–retest reliability of results for s2PD were similar to those of Klingels et al. (2010), who reported an ICC of 0.78 in children with unilateral CP. An important clinical consideration is whether one test may be administered instead of all three. In our opinion, this depends on three factors. First, which test has superior clinimetrics; in our study it was s2PD. Second, whether the tests measure the same tactile ability, which does not appear to be the case. SPL is a unique test of unilateral, uni-dermatomal spatial perception, and we therefore recommend that it be included in a comprehensive tactile assessment. Although the clinimetrics for s2PD were superior, we recommend that both static and moving tests are included in a comprehensive assessment because the two methods target different tactile receptors. A third consideration, which test has the strongest relationship to the functional outcome of interest, usually motor function, cannot be answered at this time. We have commenced a study to examine the relationship between tactile and motor performance.

Although our findings for 2PD are favorable and this test has been readily used in research and practice, it has been criticized for not measuring the limits of spatial resolution and yielding variable results because it does not control nonspatial cues (Bleyenheuft, Wilmotte, & Thonnard, 2010). One test that has been suggested as an alternative is the Johnson–Van Boven–Phillips domes, which have been used in the adult population as an alternative to 2PD and have also been adapted for children (Bleyenheuft et al., 2010; Van Boven & Johnson, 1994a, 1994b). Although this test does not have clinimetric data available for children with CP, it has been used previously in children with diplegia and dystonia (Sanger & Kukke, 2007).

DS, the only bilateral spatial perception test, assesses a unique aspect of spatial perception in a highly discriminative manner, so we recommend that it is included in a comprehensive test battery. However, therapists are cautioned that DS appears to be a more difficult task for children with unilateral CP, as our results showed that reproducibility between days may be compromised by a learning effect. DS requires the distribution of attention to stimuli occurring in both hemispaces, which may require a higher level of concentration and more complex sensory processing, thus contributing to difficulty in achieving peak performance on first exposure. Although this might be a barrier for evaluating intervention effectiveness, the ability of this test to discriminate among children with unilateral CP and typical development is useful for determining tactile function. The large value for SDC suggests a possible

learning effect that would confound efforts to evaluate change over time in children with unilateral CP.

Children with unilateral CP also appeared to demonstrate a learning effect for AsTex. Whether this was due to test novelty, higher attention requirements, or the need for more practice prior to plateau is not known. The high values for SDC for children with unilateral CP (0.6–0.7 mm) compared to children with typical development (0.3–0.4 mm) and a report on adults (0.36 mm) (Miller *et al.*, 2009) indicate that a large change is required before actual change can be concluded for children with unilateral CP. High test–retest variability among children with CP is a limiting factor for use of the AsTex as a discriminative measure. However as alternative options for texture assessment are limited at present (Blennerhassett, Carey, & Matyas, 2008; Carey, Oke, & Matyas, 1997; Wingert, Burford, Sinclair, Brunstrom, & Damiano, 2008), and no psychometric properties have been reported for any of these alternate tests in children with unilateral CP, we recommend retention of the AsTex at this time. Recent developments of other texture assessments that have been used with children (see Bleyenheuft *et al.*, 2010) offer the potential for measures that might be reliable and valid.

Stereognosis, the only motor assisted tactile test, demonstrated a ceiling effect for children with typical development, indicating that use of common objects may be too easy. Use of more complex, unfamiliar, or novel objects may be required to achieve discrimination among children with typical development. Test–retest reliability for children with unilateral CP was lower. This might be because object recognition is more difficult due to their motor impairment limiting prior manipulation experiences and current abilities. Alternatively, variable performance may relate to reliance on additional sensory and cognitive contributors during this task (e.g., proprioceptive function, object memory, or motor skills). A test methodology that controls for these aspects by way of object familiarization and/or altering stimulus presentation to reduce the amount of active exploration and thus motor demands (e.g., the use of only pronation and finger movement similar to that used in the Manual Form Perception test of the Sensory Integration and Praxis test [Ayres, 1989]) is recommended. As stereognosis is the only measure of tactile interaction with everyday objects, we recommend it to be retained in the model, but further research is needed to expand the number and difficulty of items (e.g., to include novel manual forms) and revising the testing procedure to account for children who have neurological and/or musculoskeletal impairments that restrict in-hand manipulation.

Test–retest agreement was acceptable for both hands in children with typical development (%EA $\pm 1 = 74\%$ – 97%) and for the unimpaired hand of children with unilateral CP (%EA $\pm 1 = 63\%$ – 88%). However, as the homogeneity of test scores for those limbs then corresponded with low test–retest reliability, it is recommended that the tests are not appropriate to discriminate levels of ability in children with typical development (de Vet *et al.*, 2006; Mokkink *et al.*, 2009). In several of the tests, the typically developing sample achieved very high scores, with most children achieving 100%. This reduced the variability in the sample, as shown by small IQRs, making any errors seem proportionately larger and thereby lowering the reliability. While test–retest agreement was high, for these tests to be used to distinguish among children with typical development, more variable performance would need to be achieved using a larger, more challenging scale.

The reason for greater variability in the impaired hand of children with unilateral CP in this study is likely to be multifactorial. Methodologically, the procedure and environment were kept consistent to minimize any influence these factors may have on performance. Attention or fatigue may have contributed to variability; however, this was controlled as much as possible by instructing families on pretesting activity levels and taking frequent breaks during testing. It is more likely that variability is a characteristic of performance of children with unilateral CP. It is known that tactile function may be impacted by attention, arousal, memory of past experience, and cognition (Kandel et al., 2000), and in haptic tests, competent motor skills are required (i.e., stereognosis), all of which may vary considerably in children with unilateral CP.

CONCLUSION

The seven tactile assessments evaluated in this study are recommended for inclusion in a tactile test battery evaluating the domains of registration and spatial perception. The SWM, SPL, and both s2PD and m2PD are recommended in their current form. DS and stereognosis provide good discrimination among children with and without CP, but may not be responsive to change over time given large values for SDC. Development of a test of stereognosis is recommended that would increase difficulty for children with and without CP as well as a motor-reduced version to accommodate neurological and/or musculoskeletal impairments that restrict in-hand manipulation in children with unilateral CP. The test of tactile texture perception demonstrated the lowest clinimetrics of the tests examined, however it is the only test of texture perception that has been examined in children with unilateral CP.

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