Relation between clinical measures and fine manipulative control in children with hemiplegic cerebral palsy

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The present investigation examines the relation between various clinical measures and the performance of a functional precision grip–lift task. Fifteen children with hemiplegic cerebral palsy (CP), aged 8 to 14 years, and 15 age-matched control children grasped and lifted an object whose surface texture was varied while their fingertip forces were recorded. The force coordination was compared with tactile sensibility, grip strength, manual dexterity, and spasticity using correlational and regression analyses. The findings highlight the importance of tactile sensibility in this task. However, the manner in which sensibility was related varied for the sensory adaptation of fingertip forces, the anticipatory scaling of the force increase, and the smooth transitions between the temporal phases comprising the grip–lift task. The findings also indicate that spasticity affects some measures of the task, but not others, suggesting that the relation between spasticity and motor performance may not be absolute. The results further suggest that the impairments in grasping in children with hemiplegic CP are largely but not exclusively due to disturbed sensory mechanisms which may have direct implications for therapeutic intervention.

Sensory information is essential for fine manual dexterity (Moberg 1962). Although sensory deficits (e.g. two-point discrimination, stereognosis) are common in children with cerebral palsy (CP) (Brown et al. 1987, Uvebrant 1988, Yokochi et al. 1992, Lesný et al. 1993, Yokochi et al. 1994, Cooper et al. 1995), their impact on fine motor function is not clear because few studies have examined skills which inherently require the discriminant use of sensory information. One movement that does involve such skills and, therefore, is well suited for studying the impact of tactile sensibility on fine motor function, is object manipulation using precision grip. During the lifting of objects with the precision grip, tactile information is used for the adjustment of fingertip forces to the object’s texture, anticipatory scaling of fingertip forces, and triggering sequential phases of the grip–lift task (see Johansson 1996 for a review).

The importance of sensory input during precision grip is particularly clear after local anesthesia of the fingertips (Westling and Johansson 1984) and median nerve injury (Johansson and Westling 1991). In both cases, subjects demonstrated a prolonged force increase and higher grip forces before lifting the object irrespective of its texture. Similar behaviors are observed during object manipulation in children with CP (Eliasson et al. 1991, 1992, 1995; Gordon and Duff 1999; Gordon et al. 1999). An earlier study (Eliasson et al. 1995) documented that some children with CP who had impaired two-point discrimination exhibited effective adaptation of grip force to the object’s texture, whereas others with good discrimination did not. However, the overall relation was not systematically studied. Thus, the issue of whether the impairments in precision grip are primarily related to the specific sensory deficits has not been resolved.

Despite the potential relation between tactile sensibility and the performance of precision grip, the above findings suggest that impaired sensibility may not be the only feature of CP which affects the control of precision grip. For example, children with hemiplegia often also have spasticity, distal weakness, and a general lack of manual dexterity. It is conceivable that several of these factors may contribute to the impaired hand motor control. Thus, the aim of the present study is to examine which clinical measures (sensibility, pinch strength, manual dexterity, or spasticity) best relate to how the fingertip forces are adjusted to the object’s texture, the degree of anticipatory control of the grip force output, and the transition from grasping to lifting (preload phase duration) during a precision grip–lift task. The study also examines how each of the clinical measures relate to each other.

**Method**

**Subjects**

Fifteen children with hemiplegia, between 8 and 14 years of age, and 15 age-matched control children participated in the study (see Gordon and Duff 1999 for details). Participants were recruited from both independent and state schools and clinics in the New York City area, and were generally in the normal range of cognitive abilities (within two standard deviations of the mean) according to the Kaufman Brief Intelligence Test (Kaufman and Kaufman 1990). Each child was screened for eligibility before participation. Children were included in the study if they could grasp and lift a 400 g object, follow simple directions, and attend to a task for at least 1 hour. Informed consent was obtained from all children and their parents.
CLINICAL ASSESSMENTS

The following standard clinical assessments were performed on the dominant hand of the control children and the involved hand of the children with hemiplegia:

Two-point discrimination

With vision occluded, either one or two points of the DiskCriminator (MacKinnon and Dellon 1985) were placed longitudinally and perpendicular to the fingertip pulps along the radial and ulnar sides of the thumb and index finger. The minimal distance subjects could distinguish two discrete points, ranging from 2 mm to 15 mm, in seven out of 10 trials (averaged across the index finger and thumb) was recorded (Stone 1992).

Pressure sensitivity

A Semmes–Weinstein monofilament was placed perpendicular to the finger pulp. With vision occluded, subjects reported when they felt the pressure of the tip (Bell-Krotoski 1990). The lowest threshold (1.65 to 6.65 log10F mg) detected by each subject in two out of three trials (averaged across the index finger and thumb) was recorded.

Stereognosis

The Manual Form Perception Test (from the Southern California Integration Test) was used to assess stereognosis (Ayres 1989). With vision occluded, subjects felt a plastic shape in one hand and picked its match from a group of pictured shapes with the other hand. Eight shapes were separately presented to the subjects in a random order. Because children with hemiplegia have difficulty with ‘in-hand manipulation’, the number of correctly identified items was recorded but not the time taken to identify them.

Pinch strength

Each subject produced three palmar pinches with maximal effort on a dynamometer and the highest force elicited was recorded according to the guidelines of the American Society of Hand Therapists (Mathiowetz et al. 1984, Casanova 1992).

Manual dexterity

Unimanual dexterity was tested using the Jebsen–Taylor Test of Hand Function (Jebsen et al. 1969). The total time taken to complete the following six subtests was recorded: card turning; small object placement; simulated eating; stacking plastic disks; and grasping, transporting, and releasing empty and full cans of food.

Spasticity

Spasticity was measured according to the Modified Ashworth Scale, ranging from 0 points as normal tone to 4 points as severe spasticity. As the lifting movement primarily involved elbow flexion, the response of the elbow flexors to passive flexion and extension was rated according to established criteria (Bohannon and Smith 1987).

Grip instrument

The grip instrument used to assess fingertip force regulation (weight 200 g) had exchangeable contact surfaces (35×35 mm, 20 mm apart) covered with either fine sandpaper (200 grit) or rayon. The grip force at each contact surface and the total load force from both surfaces were measured with strain-gauge force transducers (see Gordon and Duff 1999 for further details).

Each child was instructed to grip the object between their thumb and index finger (precision grip), to lift it 6 cm so it was adjacent to a vertical marker, and hold it in that position for a predetermined time.
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for 5 seconds (see Gordon and Duff 1999 for details). Children with hemiplegia performed the task with their ‘involved’ hand, while the control children used their dominant hand. After 10 practice trials, 15 lifts were performed with the sandpaper and rayon contact surfaces.

DATA ACQUISITION AND ANALYSIS OF PRECISION GRIP
Signals from the grip instrument were sampled at 500 Hz, digitized at 12 bits resolution and stored in a flexible laboratory computer system (SC/ZOOM, Umeå University, Sweden). A graphics terminal was used interactively to define the force and temporal events (see Gordon and Duff 1999 for details). The static grip force and grip-force rate were normalized by comparing the percentage difference between lifts with the sandpaper and rayon textures (rayon/sandpaper × 100) with clinical data. The preload-phase duration was calculated as the time from thumb- and index-finger contact to the initiation of the lifting drive.

The median value was chosen as a representative measure for each subject because of the considerable skew in the data. To determine whether performance on the clinical tests varied between the control children and children with hemiplegia, independent sample t tests were conducted. To assess whether the precision grip measures varied according to the object’s texture, paired t tests for each group of children were performed. Correlational (Pearson) and regressional analyses (at the P<0.05 level) were also conducted to investigate the relations between the clinical variables as well as between these variables and the precision grip measures for the children with CP. The small sample size and skewed data within a very narrow range for the control children (Figs 1 to 3) prevented such relations being quantified for this group. However, the data from each control child are overlaid on the figures for comparison.

Results
RELATIONS IN CLINICAL DATA
As expected, tactile sensibility, pinch strength, and manual dexterity were impaired in the children with hemiplegia but not in the control children (Figs 1 to 3). Two-point discrimination was four times larger in children with hemiplegia than in the control children (t = 5.33, P < 0.001). Pressure sensitivity was also impaired in the children with hemiplegia (t = 4.82, P < 0.001), though to a lesser extent than the two-point discrimination. As expected, the control children generally had intact stereognosis (nearly all subjects correctly identified all eight objects), while the children with hemiplegia displayed marked impairment in comparison (t = −17.86, P < 0.001), performing on average at approximately chance level. Palmar pinch strength was also notably lower (approximately half) in the children with hemiplegia (t = −4.36, P < 0.001). Finally, children with hemiplegia were approximately 10 times slower in the timed manual dexterity test (t = 6.05, P < 0.001). One subject’s score for measurable two-point discrimination using the DiskCriminator was not measurable (i.e. above 15 mm), and was therefore excluded from further analyses.

Table I shows the correlations between each of the clinical measures for children with hemiplegia. There was no obvious relation between two-point discrimination and pressure sensitivity (P > 0.05), but two-point discrimination, stereognosis, and manual dexterity each significantly correlated with pinch strength, most likely reflecting the severity of the disease. In addition, manual dexterity was significantly correlated with

Figure 2: Scatter plots of clinical measures versus grip force (GF) rate scaling for children with hemiplegia and control children. Linear regression lines represent best fit between x and y variables (r = Pearson correlations) for the children with hemiplegia only.
spasticity which ranged from zero to moderate (0 to 2 points) according to the Modified Ashworth Scale. No other significant relations were found among the clinical tests.

RELATIONS BETWEEN CLINICAL DATA AND FINGERTIP FORCE REGULATION

To determine which clinical measures best related to function during the precision grip–lift task, the clinical data were regressed against static grip-force adaptation, grip-force rate scaling, and preload-phase duration in the children with hemiplegic CP.

Static grip force

The grip force during the static phase (Fig. 1) was higher during lifts with the rayon contact surface than during lifts with the sandpaper surface in 10 of 15 children with hemiplegia and 11 of 15 control children (but $P>0.05$ in both cases) (cf. Eliasson et al. 1995, Gordon and Duff 1999). Although little difference occurred in the grip forces employed for the two contact surfaces between the two groups, the extent to which the grip force was adapted to the texture varied greatly between individuals in each group.

The multiple regression analysis indicated that spasticity ($F_{1,13}=14.15$, $P<0.01$, $r^2=0.52$) and two point discrimination ($F_{1,12}=10.44$, $P<0.01$, $r^2=0.47$) were the strongest individual predictors of static grip force adaptation in children with hemiplegia when considered separately. A combined model including both variables explained 78% of the variance ($F_{2,11}=19.61$, $P<0.001$). Although stereognosis individually explained 28% of the variance ($F_{1,13}=4.97$, $P<0.05$), it did not make a significant contribution to the combined model beyond that attributed to the other two variables ($r^2$ increased from 0.78 to 0.79). As seen in Figure 1, all three measures were significantly correlated to static grip-force adaptation. None of the clinical measures (i.e. two-point discrimination pressure, sensitivity, pinch strength, manual dexterity, and spasticity rating) explained

| Table I: Correlations between various clinical measures for children with hemiplegia |
|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| CP                  | Two point          | Pressure           | Stereognosis       | Pinch              | Dexterity          | Spasticity          |
| Two point           | $-$                | 0.10               | $-$                | $-0.61^a$          | $0.31$             | 0.28                |
| Pressure            | 0.10               | $-$                | $-0.23$            | $-0.19$            | 0.47               | 0.38                |
| Stereognosis        | $-0.36$            | $-0.23$            | $-$                | $0.59^a$           | $-0.42$            | $-0.44$            |
| Pinch               | $-0.61^a$          | $-0.19$            | $0.59^a$           | $-$                | $-0.53^a$          | $-0.26$            |
| Dexterity           | 0.31               | 0.47               | $-0.42$            | $-0.53^a$          | $-$                | 0.69$^b$           |
| Spasticity          | 0.28               | 0.38               | $-0.44$            | $-0.26$            | 0.69$^b$           | $-$                |

$^aP<0.05$  
$^bP<0.01$.

Figure 3: Scatter plots of clinical variables versus preload-phase duration for children with hemiplegia and control children. Linear regression lines represent best fit between the x and y variables ($r = Pearson correlations$) for the children with hemiplegia only.
the variance in the mean static force coefficient of variation (not shown).

**Grip-force rate**

Figure 2 shows that the grip-force rates were higher for the rayon contact surfaces than the sandpaper contact surfaces in nine of 15 children with hemiplegia and 11 of 15 control children, i.e. these children exhibited anticipatory control of the force output (Eliasson et al. 1995, Gordon and Duff 1999). The difference in force rates between the two textures, however, was only significant in the control children ($t=2.31$, $P<0.05$). Interestingly, the percentage difference in the grip-force rates employed for each surface (Fig. 2) was highly correlated with the percentage difference in the static grip force employed for each surface (Fig. 1) in the control children ($r=0.899$), but not in the children with hemiplegia ($r=0.316$).

In the children with hemiplegia, two-point discrimination and pinch strength combined to explain 53% of the variance in grip-force-rate scaling ($F_{2,11}=6.07$, $P<0.05$), although neither individual variable significantly predicted the force-rate scaling.

**Preload-phase duration**

As previously reported (Eliasson et al. 1991, Gordon and Duff 1999), the preload-phase duration for both textures was considerably longer in the children with hemiplegia than in the control subjects ($t=6.87$, $P<0.001$) (see Fig. 3). Although lifts with the rayon surfaces were slightly longer for both groups of children, the differences were not significant. Therefore, the median of the pooled data across grip surfaces was chosen to compare with the clinical measures. Spasticity and pressure sensitivity together accounted for 58% of the variability in preload-phase duration ($F_{2,12}=6.03$, $P<0.05$), although neither variable was a significant predictor when regressed separately. While spasticity was moderately (but $P<0.056$) correlated to the preload-phase duration (Fig. 3), the regression slope of pressure sensitivity was in fact negative.

**Discussion**

The results clearly demonstrate the relation between tactile sensibility and fine control of fingertip force regulation during object manipulation, but suggest that the relation may vary according to the specific clinical measure of tactile sensibility. They also indicate that the extent to which the deficits associated with hemiplegic CP (such as impaired tactile sensibility and manual dexterity, spasticity, and distal weakness) relate to performance of functional activities may not only be task dependent, but may also depend on the specific components of the task examined. These findings provide further information regarding the mechanisms underlying impaired hand motor control in hemiplegic CP.

**Relation between tactile sensibility and fingertip force regulation**

Our findings confirm the importance of tactile information for the sensory adaptation of fingertip forces, anticipatory scaling of the force increase, and smooth transitions between the temporal phases comprising the grip–lift task. The strong relation between two-point discrimination and grip-force adaptation indicates that fine discriminatory ability is related to the ability to differentiate the force output based on the object’s texture. These findings are not consistent with the lack of such a relation earlier reported in children with CP (Eliasson et al. 1995). However, the former study included children with diplegia, who generally did not exhibit marked impairment in two-point discrimination. Similarly, the control subjects in the present study did not exhibit a clear relation between their level of two-point discrimination and grip-force adaptation. These results suggest that the relation between tactile sensibility and grip-force adaptation may only be apparent in individuals who are at the impaired end of the spectrum, rather than typically developing individuals or those with other types of CP in whom sensory problems are not as prevalent.

Tactile sensibility was also related to the ability to use anticipatory control. Anticipatory control is based on internal representations of the object’s physical characteristics achieved during prior manipulatory experience (see Gordon et al. 1993). Impaired sensibility would probably not provide enough sensory information to form vivid internal representations of the object’s physical properties. This is consistent with our previous findings that children with hemiplegia can achieve anticipatory control if they are given extensive practice with an object (reinforcing the representations, see Gordon and Duff 1999), or if sensory information is first achieved during lifts with the contralateral ‘non-involved’ hand (Gordon et al. 1999). Together, these results suggest that the impairments in anticipatory control typically observed in children with hemiplegia (Eliasson et al. 1992, 1995; Gordon and Duff 1999) are largely sensory based, although the additional contribution of pinch strength to anticipatory control in the present study implies that a motoric component is also involved.

Pressure sensitivity, which is thought to reflect the integrity of peripheral nerve fibers, was not a useful singular predictor of any measured parameter, whereas two-point discrimination, which is thought to reflect the cortical integration of peripheral impulses, was (see Wilson and Wilson 1967a, b). Two-point discrimination generally remains intact until all sensory conduction has ceased, while pressure-sensitivity thresholds are higher even after minimal sensory conduction loss (Gelberman et al. 1983, Szabo et al. 1984). Preliminary evidence suggests that grip-force adaptation remains intact until nerve conduction is reduced by more than 50% (Cole 1994). Our findings likely reflect the central, rather than peripheral, nervous system damage associated with hemiplegia.

**Relation between spasticity and fingertip force regulation**

There has been considerable controversy regarding the extent to which spasticity contributes to the motor impairment in individuals with CP and other disorders (see Sahrmann and Norton 1977). The results of the present study suggest that not only may the relation between spasticity and motor performance be task dependent, but that it may even vary between different components of a given task. For example, there was a strong relation between spasticity and grip-force adaptation, as well as spasticity and preload-phase duration, but not between spasticity and anticipatory control. Spasticity may limit the ability to finely grade the fingertip force to the object’s properties by adding noise to the system, thus reducing the resolution of the sensory input and/or motor output. On the other hand, spasticity could also influence the preload-phase duration due to its close relation with manual dexterity, perhaps altering the
precise pattern of muscle activation (Maier et al. 1995) required for the transition from the preload (grip) phase to the loading (lift) phase.

CLINICAL IMPLICATIONS
Although the clinical assessments chosen for this study are widely used to evaluate hand function, they may not be routinely performed on children with CP. This is unfortunate as sensorimotor components, which are an integral part of grasping and hand function, are often affected by damage to the CNS. Determining which tests best relate to performance on the precision grip–lift task may provide information about the inherent value of a particular assessment, at least for individuals who have some functional use of the ‘involved’ hand. The results of this study suggest that it may be possible to predict a child’s ability to adapt and scale their grip force during prehensile tasks by assessing two-point discrimination, spasticity, and pinch strength. However, the usefulness of these tests may depend on the severity of impairment, and the results may not predict performance of other fine motor tasks or functional activities of daily living (see Case-Smith 1995).

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