Fingertip forces during object manipulation in children with hemiplegic cerebral palsy. I: Anticipatory scaling

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Previous studies of grasping and object manipulation in children with cerebral palsy (CP) have suggested a dichotomy in the ability to use anticipatory control (planning) of the fingertip force output, depending on the type of sensory information (tactile or proprioceptive) on which it is based. The present study further explores this issue by testing the ability of 15 children with hemiplegic CP aged between 8 and 14 years to scale the fingertip force output in advance during the lifting of small objects whose weight and surface texture are varied. The results indicate that children with hemiplegia can use anticipatory control based on both the weight and texture of the object, but require a greater number of trials than age-matched children without CP (control children) before they can do so. We suggest that the initial lack of anticipatory control results from an indistinct internal representation of the object’s physical properties due to disturbed sensory mechanisms, which may have direct implications for therapeutic intervention.

The integrity of the motor cortex and corticospinal pathways are often compromised in individuals with hemiplegic cerebral palsy (CP) (e.g. Uvebrant 1988, Yokochi et al. 1992). As a result, skilled independent finger movements do not develop normally (e.g. Lawrence and Kuppers 1968). During tasks requiring fine manipulation, children with CP often employ several fingers, making movements slow and clumsy (Brown et al. 1987). There is often abnormal muscle tone, with posturing into an upper extremity ‘flexion synergy’ (Brown et al. 1987, Yokochi et al. 1992), reduced distal strength, and tactile and proprioceptive disturbances (Brown et al. 1987, Uvebrant 1988, Lesný et al. 1993, Yekutieli et al. 1994), which may further compromise fine motor skills (Moberg 1962, Brown et al. 1987).

Both tactile information (signaled by slow [SA I] and fast [FA I] adapting afferents, see Westling and Johansson 1987) and weight-related information (signaled by muscle spindles and tactile afferents) are used during grasping and object manipulation to adapt the fingertip forces to the object’s weight and texture (Johansson 1996). However, as there are delays in the CNS and as object weight cannot be determined until after the object is lifted, sensory information signalling the object’s physical characteristics is not immediately available. If the initial forces are increased too quickly, excessive force may result, risking damage to fragile objects. Conversely, if they are developed too slowly, heavy or slippery objects would require an inordinate amount of time to lift, and there may be an increased risk of dropping them. To avoid these risks, the isometric force must be scaled (planned) before the initiation of the movement to match the object’s expected weight and texture based on internal representations of the object gained during previous manipulatory experience (Johansson and Westling 1987, 1988; Gordon et al. 1993). Such ‘anticipatory control’ of the force output is characterized by continuous grip (pinch) and load (vertical lift) force increase, with the rate of force increase scaled from the onset towards the target load force (i.e. faster rates for heavier or more slippery objects).

The control of fingertip forces during object manipulation in developing children without CP (control children) generally approximates adult coordination between the ages of 6 and 8 years (Forssberg et al. 1991, 1992, 1995; Gordon et al. 1992, 1994; Eliasson et al. 1995a). In contrast, 6- to 8-year-old children with hemiplegic or diplegic CP often have a force coordination resembling that of 1-year-old children (Eliasson et al. 1991, 1992, 1995b; Gordon and Forssberg 1997). They have prolonged delays between movement phases and sequential generation of grip and load force. While most children with CP are capable of adjusting their grip forces to the object’s weight and texture, their forces are often excessive and variable, with less adaptation than age-matched control children (Eliasson et al. 1992, 1995).

One of the most severe limitations in the ability of children with CP to manipulate objects skillfully may be their impaired anticipatory control. Children with CP are unable to scale the rate of grip- and load-force increase based on the weight of an object (Eliasson et al. 1992). However, they may demonstrate some anticipatory control based on the object’s texture (i.e. a higher rate of force increase for more slippery objects) if they have successive lifts in which the contact surfaces are predictable (Eliasson et al. 1995b). This may suggest a dichotomy in the ability to use anticipatory control, depending on the source of sensory information. However, the latter study by Eliasson et
al. examined a greater number of lifts with each surface \( (N=10) \) than did their former study with each weight \( (N=5) \).

The present study further examines the capability of children with hemiplegic CP to plan the force output based on the object’s weight and texture, using a greater number of trials for each condition \( (N=25) \). An initial lack of anticipatory force scaling based upon both the object’s weight and texture, but subsequent emergence after a number of lifts would suggest that children with hemiplegic CP are capable of anticipatory control but may need extended practice. Conversely, anticipatory force scaling based on an object’s frictional characteristics, but not its weight, would suggest that the deficit in force scaling may depend on the type of sensory information on which it is based.

**Method**

**SUBJECTS**

Fifteen children (10 males and five females) with hemiplegic CP and 15 age-matched children (five males and 10 females) without CP (control children) participated in the study. All children were recruited from schools and clinics in the New York city metropolitan area and were between 8 and 14 years of age. This age range was chosen because the grasping behavior in developing children with CP approximates that of adults by 8 years of age (Gordon and Forssberg 1997). Each child with CP was individually screened for eligibility before participation. Inclusion criteria were as follows: the ability to grasp and lift a small object between the fingertips, an attention span of at least one hour, the ability to follow verbal instructions, attendance of a mainstream school, normal cognitive abilities according to the Kaufman Brief Intelligence Test (Kaufman and Kaufman 1990). Spasticity in the involved extremity of the children with hemiplegia ranged from zero to moderate \( (0 \text{ to } 2) \) according to the Modified Ashworth Scale \( (0 \text{ to } 4) \) (Bohannon and Smith 1987). Informed consent was obtained from all children and their parents.

**APPARATUS**

The grip instrument (Fig. 1) had exchangeable contact surfaces \( (35 \times 35 \text{ mm}, 20 \text{ mm apart}) \) covered with either fine (200 grit) sandpaper or rayon. The object’s weight was adjusted to either 200g or 400g using an exchangeable mass. The grip force at each contact surface and the total load force were measured with strain-gauge transducers \( (dc \text{ 160Hz}) \). The instrument contained an infrared light-emitting diode, which projected to a position-sensing camera 50cm away, and an accelerometer to detect slips between the skin and contact surfaces.

**PROCEDURE**

All children washed their hands before the experiment to remove sweat and excessive oil from the skin. They sat on a chair in front of a table, which was adjusted to position the forearm horizontal to the table when the object was grasped. Children with hemiplegia lifted the object with their involved hand. As our earlier work suggested that force coordination is similar in the dominant and non-dominant hands of individuals without CP (Gordon et al. 1994), the control children lifted the object with their dominant hand for comparison. Children were instructed to grasp the object between the thumb and index finger (precision grip) and lift it so that it was adjacent to a marker 6cm high. The children with hemiplegia often used additional fingers (‘three-digit pinch’) and/or lifted the instrument between the thumb and lateral portion of their index finger (‘lateral pinch’). However, the use of lateral pinch may result in some subjects taking longer and using slightly higher grip forces (due to the lower density of mechanoreceptors innervating the lateral skin), it generally does not influence coordination of forces or anticipatory control (see Figs 7 and 8). Four of the children with hemiplegia tended to posture the wrist into flexion.

After a demonstration, children performed a series of 25 lifts with the object’s weight adjusted to 200g. This was followed by 25 lifts with the weight adjusted to 400g. The sandpaper grip surfaces were used for these two lifting series. Finally, the children performed 25 lifts with the rayon contact surfaces and the weight adjusted to 200g. The children’s eyes were open, and they were aware when the object’s properties were altered. The object was held in the air for 5 seconds during each trial. Rest periods \( (15 \text{ to } 20 \text{ minutes}) \) were provided between each lifting series. One child with CP performed the weight and texture series during separate sessions.

After these trials, subjects were asked to hold the object in the air and gradually release the grip until the object slipped from the digits so the slip grip force (the minimal grip force required) could be measured. This was repeated for each weight and texture.

**DATA ACQUISITION AND ANALYSIS**

Data were sampled at 500Hz, digitized with 12-bit resolution and stored in a flexible data acquisition/analysis system \( (SC/ZOOM, Umeå University, Sweden) \). The grip-force rate \( (dGF/dt) \) and load-force rate \( (dLF/dt) \) were calculated within

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**Figure 1**: Schematic drawing of the grip instrument. (a) Exchangeable grip surfaces (sandpaper or rayon) covering strain-gauge force transducers at the thumb \( (\text{th}) \) and index finger \( (\text{ind}) \), (b) exchangeable mass \( (200g \text{ or } 400g) \), and (c) infrared light-emitting diode projecting to a photoelectric position-sensing camera (not shown).
A ±10 ms window. A graphics terminal was used to define the time, events, and force amplitudes.

The grip force at the initiation of a positive load force was measured to determine the extent to which grip and load force are produced simultaneously. The peak rate of development of grip and load forces (i.e., force rates) were measured to determine whether they are higher for heavier or more slippery objects, indicating anticipatory force scaling. The grip force at lift-off was also measured to determine whether higher forces are achieved at this point for the heavier or more slippery object. The durations between contact of each digit (finger contact) and load-force onset (preload-phase), and between positive load-force onset and movement onset (load phase) were measured.

The grip force during the static phase (when the object was held in the air) was analyzed by taking the mean and SD of all samples for 2 seconds, starting 1.5 seconds after the peak grip force. The coefficient of variation (SD divided by the mean) was used to quantify the variability in grasping forces. The slip at the end of each measured trial was signaled by the accelerometer and a sudden drop in the load force. The mean safety margin was calculated by subtracting the grip force at slip from the mean grip force.

Preliminary analysis of each subject’s data indicated skewness (for example, the skewness for grip and load-force rates averaged approximately 1.3, and was as high as 3.5 for some individuals). The median value was thus chosen as a representative measure to ensure robustness of our statistical tests. To assess the influence of the object’s weight and texture on the measured parameters at various points during the lifting series, each series of 25 lifts was divided into five blocks of five trials. We performed both non-parametric (Wilcoxon sign-rank and Mann–Whitney U tests) and parametric (weight [2] × group [2] × trial block [5] ANOVAs) on each measure at the P<0.05 level. While the results were qualitatively similar, independent of the statistical methods

Figure 2: Grip force, grip-force rate, load force, load-force rate and position from a representative control subject and child with hemiplegic CP during one lift with 200 g (---) and one lift with 400 g (-----) during the first and fifth trial blocks. The traces are aligned at the onset of vertical movement and the grip- and load-force rates are shown using a ±20-point numerical differentiation. Note the higher force rates for the 400 g object during both the first and fifth blocks in the control child, but only during the fifth block for the child with hemiplegia.
employed, we report the results of the ANOVA due to the large number of tests associated with comparisons of measures during each trial block. Newman–Keuls post-hoc tests were subsequently performed where appropriate.

Results
ANTICIPATORY CONTROL BASED ON OBJECT WEIGHT
In contrast to earlier findings (Eliasson et al. 1992), anticipatory control according to the object’s weight was observed during the 25 lifts. Figure 2 shows recordings from a representative control subject and child with hemiplegia for lifts with each weight during the first trial block (trials 1 to 5) and fifth trial block (trials 21 to 25). A higher rate of load-force increase can already be seen for the 400g object during the first block for the control child, which typifies intact anticipatory control. This was maintained during the fifth block. In contrast, the child with hemiplegic CP showed little difference in the force rates during the first block, but the force rates were considerably higher for the heavier object by the fifth block.

These results were representative of the children in the control and hemiplegic groups (Fig. 3). The load-force rates were higher for lifts with the 400 g object for both the control children and children with hemiplegic CP ($F=77.1, P<0.001$). While the employed grip-force rates were slightly higher for the 400g object for both the control children and children with hemiplegia, surprisingly the differences did not reach significance ($P<0.1$) in either case. Overall, the load-force rates (but not grip-force rates) were higher in the control children than in the children with hemiplegia ($F=5.33, P<0.05$). For the control children, there were differences in the load-force rates already during the first block with only minor changes during practice. In contrast, the children with hemiplegia exhibited only small differences between the load-force rates employed for each weight during the initial blocks, with the difference increasing across blocks. Despite a weight × block interaction ($F=3.51, P<0.01$), the weight × block × group interaction failed to reach significance, presumably because of the variability between the CP and control groups. In order to evaluate this issue further, we performed a separate weight × block ANOVA on each group. The results indicated no interaction for the control group ($P>0.05$), but a significant interaction for the CP group ($F=3.19, P<0.05$). Post-hoc analysis indicated that the differences in force rates did not reach significance in the children with hemiplegia until the third trial block. Thus, anticipatory control of the load force according to the object’s weight was achieved only after extended practice with the object in the children with hemiplegia.

Fourteen of the 15 children with hemiplegia exhibited

![Figure 3](image-url)

**Figure 3:** Mean ± SEM load-force rates and grip-force rates employed for the 200 g (---) and 400 g (-----) object (sandpaper contact surfaces) during each block of trials across all 15 children in the control and hemiplegic CP group. Note the large differences in the load-force rates for the control children during all blocks and small initial differences which increase across blocks for the children with hemiplegia.
higher load-force rates and 12 of 15 exhibited higher grip-force rates for the heavier object by the last trial block, indicating that most children were capable of achieving anticipatory control. Interestingly, the relative change in load-force rate was significantly correlated with the relative change in grip-force rate from the 200g to the 400g object for the children with hemiplegia ($r=0.60$, $P<0.05$), but not for the control children ($r=0.03$), suggesting proximal and distal anticipatory control tend to be affected in a similar manner in children with hemiplegia. Neither the relative change in grip-force rate nor the load-force rate significantly correlated with the spasticity ratings ($r=-0.04$ and $r=-0.34$, respectively).

**Anticipatory Control Based on Object Texture**

Figure 4 shows recordings from a representative control child and a child with hemiplegia for a lift with the non-slippery (sandpaper) and slippery (rayon) grip surfaces during the first and fifth trial blocks. Neither subject displayed large differences in the grip-force rates for the two grip surfaces during the first block, while the grip-force rate is clearly higher for the rayon surface by the fifth block in both cases.

These results are representative of both groups of subjects (Fig. 5). Overall, the children with hemiplegia and control children showed a slight influence of object texture on the grip-force rates (higher force rates for the rayon surfaces) across the 25 trials with both the rayon and sandpaper grip surfaces, though surprisingly the differences were not significant. Neither the control children nor the children with hemiplegia exhibited clear differences between the grip-force rates employed for the sandpaper or rayon surfaces during the initial blocks, but by the last trial block, some differences can be seen. This was true in 11 of 15 children with hemiplegia. Despite a texture $\times$ block interaction ($F=4.83$, $P<0.001$), the texture $\times$ block $\times$ group interaction failed to reach significance. When a separate texture $\times$ block ANOVA was performed on each group, a significant interaction ($F=3.02$, $P<0.05$) was seen for the children with hemiplegia, with the post-hoc analysis yielding significant differences by the fifth trial block (but, $F=2.30$, $P<0.07$ for the control children). Thus weak anticipatory control appears to be present, but only after considerable practice with each grip surface.

The general lack of anticipatory control of the grip force in the control children and children with hemiplegia contradicts the results of Eliasson et al. (1995b). To explore this issue further, we measured the grip force at slip for each texture and weight (see horizontal lines in Fig. 6g) to determine

![Figure 4: Grip force, grip-force rate, load force and position from a representative control subject and child with hemiplegic CP during one lift with the sandpaper (-----) and one lift with rayon (---) grip surfaces during the first and fifth trial blocks. The traces are aligned at the onset of vertical movement and the grip-force rates are shown using a ±20-point numerical differentiation. Note that the grip-force rates only differ in the fifth block for both children.](image-url)
the minimum grip force required to maintain contact with the object. Overall, the grip force at slip did not differ between the children with hemiplegia and control children. However, it was not as high for the rayon surfaces (1.7 N for both groups of children) as it was for the 400 g weight (2.0 N and 1.9 N for the children with hemiplegia and control children, respectively), i.e. the differences between coefficients of friction of the two surfaces may not have been large enough to necessitate entirely anticipatory control.

Interestingly, the relative change in grip-force rate from the sandpaper to the rayon surfaces was significantly correlated with the relative change from the 200 g to the 400 g object in the previous experiment ($r=0.71$ for the children with CP and $r=0.68$ for the control children, $P<0.01$ in both cases). This suggests that these object properties influence the scaling of the grip force output in a similar manner. As in the weight experiment, the relative change in grip-force rate between textures did not significantly correlate with the object’s weight or texture ($P>0.05$ in all cases), suggesting that if these behaviors are compensatory, they are not dependent on the specific physical properties of the object. The longer loading phases in the children with hemiplegia (particularly for the 400 g object) resulted in a higher grip force at lift-off (Fig. 6f) for the heavier ($F=6.74$, $P<0.05$) and more slippery (but $P<0.09$) objects, which were maintained during the subsequent static phase ($F=9.17$, $P<0.01$ and $P<0.14$, respectively) (Fig. 6g). In contrast to previous results (Eliasson et al. 1991, 1992), the children with hemiplegia did not have significantly higher grip forces in the static phase or safety margins (area above the horizontal lines, Fig. 6g) than the control children. Their coefficient of variation (Fig. 6h) was greater during the weight ($F=5.55$, $P<0.05$) but not texture ($P<0.15$) experiment compared with control children.

The above temporal and force measures suggest that despite the general lack of anticipatory control based on the object’s weight and texture during the initial trial blocks, the children with hemiplegia achieved higher forces for the heavier or more slippery objects mainly by developing the grip and load force sequentially, prolonging the durations of force increase and by adjusting their grip force using sensory feedback. The longer phase durations and higher forces would reduce the need to modulate the rate of force increase during the subsequent loading phase.

**Influence of Grasping Posture on Fingertip Coordination**

In order to investigate whether the ‘three-digit’ or ‘lateral’ pinch grips frequently employed by the children with hemiplegia influenced the force coordination and anticipatory control, six of the control subjects were asked to grasp and

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**Figure 5:** Mean ± SEM grip-force rates employed for the sandpaper (---) and rayon (-----) grip surfaces during each block of trials across all 15 children in the control and hemiplegic CP group. Note the small initial differences in grip-force rates which increase across blocks for both the controls and the children with hemiplegia.
lift the object five times with each weight using these grasp patterns. Representative recordings from one of these subjects are shown in Figure 7. Overall, the coordination is not greatly influenced by the different grips used by the control subject. In general, the grip and load force continue to increase in parallel and the grip- and load-force rates, when plotted on a graph, are largely bell-shaped as previously described for precision grip (Gordon and Forssberg 1997).

Despite the general similarities in force coordination, some differences in the temporal and force measures occur during each of the three grip patterns. The difference in finger contact (Fig. 8a) was longer for the lateral pinch \( (F=7.49, P<0.05) \). Similarly, the preload phase \( (F=5.10, P<0.07) \) and loading phase \( (F=9.49, P<0.05) \) (Fig. 8c) were also longer for the lateral pinch. The mean static grip force \( (Fig. 8g) \) increased by 72 and 122\% \( (F=9.29 P<0.05) \) for the 200 g and 400 g weights, respectively, and the static grip force coefficient of variation \( (Fig. 8h) \) increased by 42 and 70\% \( (F=10.58, P<0.05) \), respectively, compared with the precision grip. In contrast, except for an increased coefficient of variation in static grip force \( (F=7.56, P<0.05) \) (Fig. 8h), none of the measured parameters was different between the three-digit pinch and precision grip.

Despite the slight differences between the temporal and force parameters seen during precision grip and lateral pinch, these six control subjects still exhibited anticipatory control during lifts with each grip. This can be seen in Figure 8e and 8f, which show that the load-force rates (but not grip-force rates) were higher for the 400 g object during all three grips \( (P<0.05 \text{ in all cases}) \). Thus, the employment of alternative grasping patterns in children with hemiplegia may contribute to the higher and more variable forces and longer phase durations, but do not account for the apparent initial lack of anticipatory control in children with CP.

**Discussion**

The results indicate that the ability of children with hemiplegic CP to use anticipatory control of fingertip forces is not dependent on the type of sensory information on which it is based. Rather, they suggest that children with hemiplegia have a general deficit in the scaling of fingertip forces in advance, but may develop anticipatory control based on the object’s weight or texture if provided with enough practice.

**POSSIBLE MECHANISMS OF IMPAIRED ANTICIPATORY CONTROL**

The initially impaired capability of children with hemiplegic CP to scale the rate of force increase could be a result of the general impairment in motor output in CP (e.g. Leonard et al. Neilsen et al. 1990, Eliasson et al. 1991). During the grasping and lifting of an object between the fingertips, children with CP have an impaired ability to coordinate the grip force and load force simultaneously (Eliasson et al. 1991); they typically first increase their grip force (often excessively) in conjunction with a negative load force (pushing the object down against its support). Instead of the continuous force increase typically associated with anticipatory control, they show a discontinuous force increase. In addition, the phases comprising the grip-lift movement are greatly prolonged. Similarly, voluntary control of isometric contractions is impaired in children with CP (Neilson et al. 1990).

![Figure 6](image-url)

**Figure 6:** Mean ± SEM temporal and force measures associated with lifts with the 200 g and 400 g weights, and the rayon surface: (a) duration between contact of the thumb and index finger, (b) preload-phase duration, (c) loading-phase duration, (d) negative load force (LF), (e) grip force (GF) at positive load-force (LF) onset, (f) grip force (GF) at lift-off, (g) grip force (GF) during static phase (horizontal lines represent grip force at slip, and area above line represents employed safety margin), and (h) coefficient of variation of static grip force (GF CV). Note the longer latencies and higher forces before lift-off for the children with hemiplegia.
Nevertheless, the amount and coordination of forces did not change during the repeated lifts with a given object in the present study (Neilson et al. 1990). Other than the ability to scale the rate of force increase, the measured temporal or force parameters remained the same for both groups. Thus, impaired motor output does not preclude anticipatory force scaling, and its emergence after practice was not a result of a general improvement in motor output.

The impaired anticipatory control in children with CP could be a result of the spasticity often associated with the movement disorder. However, for several reasons this is unlikely. Firstly, considerable training of force production reduces the spasticity, but has little influence on the efficiency of motor commands (Neilson et al. 1990). Secondly, there is no conclusive evidence that pharmacological treatment of spasticity improves motor performance (Nathan 1969, McLellan 1977). Finally, the children we tested had spasticity ratings ranging from normal to moderate. Nevertheless, even the children without spasticity initially exhibited impaired anticipatory control, and we did not find a relation between anticipatory control and spasticity.

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The use of the lateral pinch grasping pattern also could have contributed to the impaired force scaling. For example, Woollacott et al. (1996) showed that when in a crouched position (approximating the posture of children with hemiplegia) and subjected to standing postural perturbations, control children exhibit temporal disorganization of muscle activation patterns as well as increased antagonistic muscle activity, which is similar to that of children with CP. Similarly, when control children are asked to walk with their knees bent and trunk inclined forward, they also exhibit abnormalities in muscle activation which resemble those in CP (Sienko-Thomas et al. 1996). Thus, it is conceivable that musculoskeletal constraints or altered biomechanical patterns may underlie the movement impairments in CP and contribute to impaired anticipatory control. Overall, the use of the lateral pinch resulted in higher grip forces and small increases in some temporal parameters in control children, most likely due to the decreased density of mechanoreceptors located in the lateral skin (Johansson and Vallbo 1983). However, their overall coordination was not greatly affected and anticipatory force scaling persisted in these children. Yet

![Figure 7: Grip force, grip-force rate, load force, load-force rate and position from a control subject lifting the 200 g object using the precision grip, three-digit pinch and lateral pinch, compared with a lift with the precision grip from one child with hemiplegic CP. The traces are aligned at the onset of vertical movement and the grip and load-force rates are shown using a ±20-point numerical differentiation. Note the different time scale for the child with CP and overall similarity in coordination for the three grips in the control.](image-url)
the lateral pinch, while being less flexible than a precision grip, is a grip that is routinely employed (e.g. when turning a key). Four of the children with hemiplegia in the present study tended to grasp and lift objects with the wrist postured in flexion. The changed length–tension relation in the finger flexors may weaken pinch force (cf. An et al. 1985) and influence the motor output. Nevertheless, all of them still exhibited anticipatory control by the fifth trial block. Thus, the altered grip patterns and hand posturing were not likely to be the cause of the impaired anticipatory control.

The impaired anticipatory control may have resulted from sensory disturbances which are common in CP. Anticipatory control of fingertip forces during grasping and manipulating objects is based on an internal representation of the object’s physical characteristics. This is achieved through tactile and proprioceptive signals during earlier manipulatory experience conveying information about the object’s weight and texture (Johansson and Westling 1987, 1988; Gordon et al. 1993). Normally, anticipatory control can be used after minimal manipulatory experience with an object as only one or two trials are necessary to achieve such representations (Gordon et al. 1995).

While many children with CP have sensory disturbances, previous results suggest that they do not clearly relate to the ability to adjust the fingertip forces to the object’s texture (Eliasson et al. 1995b), which all of the children in the present study could do. However, children with hemiplegic CP may not be able to extract enough sensory information during single lifts to form vivid internal representations of the object’s properties (i.e. their initial representations may be distorted). When the texture of the object is presented in a random order, control children scale the fingertip forces according to the previous lift, and rapidly adapt their grip force to the new texture when it is erroneously scaled toward an unexpected surface (Forssberg et al. 1995). In contrast, children with hemiplegia or diplegia do not alter their grip force according to the previous texture, nor do they adapt their motor output to the actual texture when it is inappropriate (Eliasson et al. 1995b). Similarly, 6- to 8-year-old control children are capable of scaling their forces according to an object’s weight after one or two lifts (Forssberg et al. 1992), whereas children with CP were not, even after five lifts (Eliasson et al. 1992). Children with CP appear to have the capacity to scale the grip force when the same weights or textures are presented repeatedly (cf. Steenbergen et al. 1998). This indicates that they are capable of modulating the rate of force increase to some extent. Thus, children with CP appear to have impaired abilities to form the internal representations unless considerable ‘blocked’ practice is provided.

**CLINICAL IMPLICATIONS**

The results suggest that children with hemiplegic CP may be able to acquire representations of new objects, but take longer to do so than control children. Therefore, children with CP could benefit if the environment is structured to match their capabilities. For example, objects could be kept consistent within the child’s environment, and new ones introduced gradually. Therapists could also encourage use of

![Figure 8: Mean ± SEM temporal and force measures associated with lifts with the precision grip, three-digit pinch and lateral pinch with the 200 g and 400 g object for six control subjects.](image-url)
alternative, compensatory strategies such as to grasp first the object while simultaneously pushing it down against its support. This would provide additional sensory information (e.g. friction) about the object, stabilize it in the hand before lifting and reduce the need for anticipatory control, potentially reducing functional impairments. Children with CP could also be taught to rely on visual information signifying the object’s size, weight, and texture. These interventions, which may minimize the requirement of anticipatory control, could potentially improve hand function in children with CP, a possibility which requires further testing.

Accepted for publication 17th July 1998.

Acknowledgements
This project was supported by a grant from the United Cerebral Palsy Research and Education Foundation (#R-709-96), the VIDDA Foundation and an Untenured Faculty Research Grant from Teachers College, Columbia University to Andrew Gordon. We are grateful to Ellen Godwin, Sheila Walsh, Lauren Robertson, Molly Roffman, Gail Lavender, Amy Shrank and the other therapists who assisted with recruiting subjects, and the parents and children who made this project possible. We also thank Jeanne Charles for assistance with data collection, and Dr Ann Gentle for helpful comments.

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