Observations of improvement of reaching in five subjects with left hemiparesis

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Abstract
Kinematic analysis and surface electromyography were used to study reaching by five subjects with left hemiparesis as they attempted to touch each of three targets. The targets were placed to require movement within and out of extensor synergy. Each subject was tested five times over a nine week period. Over this time, amplitude of peak velocity and sense of limb position significantly improved in the paretic arms. The increase of amplitude of peak velocity was more strongly related to a decrease in the discontinuity of movement (r = -0.48) than to maximal level of contraction of the prime movers (anterior deltoid: r = 0.25; biceps: r = 0.39). This finding may be a sign of learning or increased maturity of reach. These results, if replicated in a larger sample, would support therapy designed to improve learning of new sensorimotor relationships in the hemiparetic limb.

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<th>Table 1 Patient characteristics</th>
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*First testing period. †As recorded in medical record. FMFT = Fugl-Meyer motor function test; Spasticity = upper limb subtest; Sensation = control of individual movements of the proximal upper extremity.

Procedure

Procedure

Kinematic recording. The Waterloo spatial analysis and recording technique (WATSMART™, version 2.7), a non-contact, optoelectronic system was used to track an infrared light-emitting diode attached to the base of the index finger. The instantaneous position of the diode was monitored by two infrared sensors mounted approximately 1.5 m above the seated subject. A computer (Hewlett-Packard, Waltham, Massachusetts) controlled the strobing of the diode as well as data acquisition. The position of the diode was digitized at a rate of 100 Hz and these data were stored for offline analysis. To reduce the likelihood of error due to reflected light, the room and target supports were painted with infrared absorbing black paint and the subject and table were draped with black cloth. Before each experiment with each arm, the sensors were calibrated in relation to the test area. Maximum accepted error was 2.0 mm; average error was 1.73 mm (SD 0.26).

Experimental set-up Multiple targets were used because experience and the literature indicated that stroke survivors at various stages of recovery have limited ability to move freely, especially outside of stereotyped synergy patterns. Each of the three targets was a 7.6 cm circle mounted on a shoulder-high standard. All were equidistant from the subject's hand. Target 1 was placed to require only movement within extensor synergy (shoulder abduction and elbow extension). Target 2 required reaching directly forward, a movement requiring beginning combination of flexion and extension synergies. Target 3 required movement free of synergy (shoulder abduction coupled with elbow extension). Light-emitting diode displays, positioned above each target, reminded the subject which target he or she was aiming for. Data collection started automatically with activation of the display. Start of reach was signalled by a microswitch located under the subject's hand. End of reach was signalled by a microswitch which responded to touch anywhere on the target. The output from all microswitches was processed through the WATScope™ A/D converter and software. Subject 1 was unable to touch any of the targets during the early visits, so end of reach was determined as the least distance between the diode on her hand and diodes on the targets.

According to Fitts' Index of Difficulty, the reaching task is rated as 3-70, which classifies it as an open loop task (4-58 or less). We would expect, therefore, to see reaches consisting of one continuous movement, which is the shared strategy of normal, mature humans and monkeys when reaching to touch a large target. 10 17 18

Data reduction

Scores were derived from the raw data using the following procedures. The EMG values for each muscle during reach were normalised in relation to maximum voluntary contraction and reported as %MVC. MVC refers to the amount of electrical activity generated by a muscle during a maximum isometric control contraction done with the muscle in shortened range. Coactivity ratios were calculated for the biceps and triceps, for the anterior deltoid and biceps, and for the anterior deltoid and pectoralis major using the formula of Hammond et al. 19

The two-dimensional kinematic data were converted to three-dimensional coordinates using a direct linear transformation algorithm and filtered at 5 Hz. Values for the speed of the endpoint, here referred to as
“velocity”, and rate of change of speed, here referred to as “acceleration”, were obtained for every 0·01 s from the WATSMART processed files using a custom-written program. The terms velocity and acceleration are used in order to be congruent with the literature. Speed and rate of change of speed are scalar, not vector, quantities, however, and as such, describe movement in three dimensions simultaneously as was the case in this study.

From these files, the variables derived for each reach were: amplitude of peak velocity; time to peak velocity; smoothness of movement (number of steps or movement units); and percentage of first movement unit at which peak velocity occurred.

Data analysis

The data were grouped for analysis. Given the low number of subjects and expected variability among them,14 this was a conservative approach chosen to discern general effects that would be useful for guiding therapy and would offer insight into the reorganisation of voluntary movement of left hemiparetics. The non-parametric Friedman two-way analysis of variance (subject x condition) for related samples was used.15 The resulting statistic was distributed $\chi^2$. Relationships among variables were examined using averaged correlations.24

Results

Subject 1 lacked endurance to attempt more than six reaches on the first visit; otherwise all subjects were able to reach towards all three targets on all visits, regardless of clinical motor control score. Control of reaching generally improved for subjects 1, 2, 4 and 5, but subject 3’s performance deteriorated over time. The results reported here include all subjects, unless noted.

The only significant difference among targets was due to the biomechanical demands of the target locations, that is, the pectoralis major/anterior deltoid co-activity ratio (PM/AD) significantly decreased ($\chi^2 = 8·4$, df = 2, $p < 0·02$) between targets 1 and 3. This indicates that the pectoralis major was less active relative to the anterior deltoid for target 3, which required shoulder abduction, compared with target 1, which required shoulder horizontal adduction. All scores were collapsed across targets for further analysis.

In the non-affected arm, reaching performance was essentially normal18 and did not change significantly over the course of the study.

One clinical variable, awareness of limb position, improved significantly ($\chi^2 = 9·64$, df = 4, $p < 0·05$) over time (fig 1). In the affected arm, amplitude of peak velocity also improved significantly ($\chi^2 = 10·72$, df = 4, $p < 0·05$) over the five visits (fig 2).

The location of peak velocity within the first movement unit was about normal (~50%) (fig 2). Over the five visits, time to peak velocity also became more normal as described by Wing and Miller.25 The number of movement units decreased, especially between visits 2 and 3 (fig 2). When Subject 3’s scores are eliminated, the decrease is marginally significant ($\chi^2 = 9·0$, df = 4, $p < 0·10$). There is reason to exclude her scores because, although the clinical evaluations indicated normal tone and awareness of limb position and ability to move the arm voluntarily within limited patterns, her performance became more erratic over the course of the study, perhaps because of her secondary diagnosis of cerebral atrophy.

MVC, %MVC, and co-activity scores did not improve significantly across visits.

As amplitude of peak velocity increased, both movement time and number of movement units decreased (table 2). There were positive, but weak, relationships between amplitude of peak velocity and maximum contraction of the anterior deltoid, biceps and triceps. The %MVC of the anterior deltoid, the prime mover,26,27 was positively, moderately related to increased amplitude of peak velocity over the five visits. Similarly, the relationship between amplitude of peak velocity and the PM/AD co-activity index indicated that as the peak velocity increased, the anterior deltoid became more active relative to the pectoralis major.

| Movement time | -0·63 |
| Movement units | -0·48 |
| MVC (control contraction)$\dagger$ | -0·25 |
| Anterior deltoid | 0·07 |
| Pectoralis major | 0·39 |
| Biceps | 0·30 |
| Triceps | 0·49 |
| % MVC | -0·49 |
| Anterior deltoid | 0·34 |
| Pectoralis major | 0·16 |
| Biceps | 0·07 |
| Triceps | 0·01 |

$\dagger$The average scores (3 trials x 3 targets) of each visit of each subject were correlated across visits. The Pearson Product Moment correlation coefficients related to each subject were then converted to Fisher’s $Z_0$, averaged across subjects, and reconverted to $r$. No coefficient reached critical value of 0·878 ($a = 0·05$, df = 3).
Figure 2 Means and standard deviations of kinematic variables.

Discussion
This study supports the finding of the previous two studies that amplitude of peak velocity increased over time in subjects after a stroke. In the present study, movement time decreased concomitantly with improved peak velocity, as observed by Lough et al. The location of the peak at a normal point in the velocity profiles of the first movement unit suggests that the motor plan was preserved in the affected arm. It was ineffective, however, possibly because of weakness or disturbance in sensory motor relationships.

The improvement in amplitude of peak velocity of these subjects does not seem to be associated with increased strength. The electrical activity generated by the prime movers during maximum isometric contraction showed no trend of improvement over the five visits. This was true even though two of the subjects were engaged in weight-lifting programmes. There was a trend towards use of a greater percentage of the available activity of the anterior deltoid during the unrestricted reaching task over the course of the study. These findings seem to contradict the suggestions of Lough et al. and Wing et al. that increased amplitude of peak velocity is associated with greater force or reduced biceps/triceps co-contraction. Further examination of these relationships in a larger sample of subjects is warranted.

Learning is an alternate explanation for increased amplitude of peak velocity. Brooks and Watts found increased amplitude of peak velocity to be related to learning the strategy of smooth, direct reaching in normal monkeys, that is, peak velocity increased as the monkeys changed from discontinuous (closed loop, non-programmed) movement to continuous (open loop, programmed) movement. The subject in the study by Lough et al. seemed to undergo similar learning: he changed his performance from indirect, discontinuous movement during the early weeks to direct, continuous movement in the later weeks. Wing et al. did not report information related to this possibility. Although the present study was deliberately designed to make motor learning unlikely, four out of five subjects learned to move their affected arm more smoothly despite the lack of change in levels of muscular activity. It seems that the subjects of this study were learning, with very little practice, to apply old programmes to the new conditions of weakness and sensory disturbances.

From the acceleration and velocity traces (fig 3), for example, it appears that the subjects of the present study experimented with strategies that sometimes resulted in smoother, more programmed reaches and at other times resulted in discontinuous, sensory-guided reaches. A similar “trying out” of guided and programmed strategies was seen in monkey subjects and in children as they learned simple reaching tasks. Programmed and guided modes of control are normally integrated in adults and older children who use each selectively as the situation warrants. However, this level of control is learned. Not only are the two modes of motor control not integrated during childhood, but the predominance of one system over the other changes with maturity. Ballistic, triggered movement is replaced by guided control of a movement response which, in turn, is supplanted by programmed control and finally, integration of
guided and programmed modes of control occurs. This developmental sequence from guided to programmed modes was apparent in four of the subjects. However, subject 3 showed the reverse: the programmed mode deteriorated to guided and then to ballistic, triggered type control mode.

Scores of variables indicative of coordinated motor control (speed and smoothness) were not significantly different among targets. Even subject 1, who was rated by the Fugl-Meyer motor function test as being in flexor synergy, was able to move towards all three targets as soon as she had the endurance to complete the experiment. This finding is contrary to expectation based on Brunnstrom’s sequence of recovery of voluntary arm movement.

Conclusions

Earlier findings were confirmed: amplitude of peak velocity improved over time in a way not attributable to chance. Because this occurred during a post-rehabilitation period when little improvement is expected, it seems that amplitude of peak velocity could serve as a sensitive outcome variable for use in future studies of effectiveness of intensive therapy to remediate motor control deficits of stroke patients.

Level of muscular activity did not improve, but the discontinuity of movement decreased (guided control became programmed control) over the nine-week test period in four of the five subjects. It appears that the increase in amplitude of peak velocity seen in these subjects was related more to learning than to improved muscle activation. If this observation is confirmed in future studies, then therapy that provides the opportunity for relearning sensorimotor relationships would be warranted for patients similar to the subjects in this study.

The level and pattern of muscle activity of these subjects depended on the biomechanical demands of the task rather than any stereotypy of neural linkage between muscles. This finding would not support a treatment approach for these subjects in which developmental principles, such as movement within synergy pattern preceding movement outside of synergy pattern, are applied.

I am particularly grateful to the five subjects who completed the study. I want to recognize the cooperation of Spaulding Rehabilitation Hospital, Boston, Massachusetts; Braintree Hospital, Braintree, Massachusetts; and New England Rehabilitation Hospital, Woburn, Massachusetts and the assistance of Ramesh Murthy, and Michael Baker.

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John Locke and the trigeminal neuralgia of the Countess of Northumberland

Although early descriptions of tic douloureux can be inferred from the writings of Avicenna, the most convincing early description was of the suffering physician and philosopher Johannes Laurentius Bausch (1605–65) described by Drs JM Fehr and Elias Schmidt in volume 2 of the published proceedings of the Imperial Leopoldian Academy of Natural Sciences in 1671. 1 Of the English contributions, John Locke the famous physician and philosopher described the condition in a series of letters to Dr John Mapletott in 1677. 2 The unfortunate patient was the Countess of Northumberland, wife of the Ambassador to France:

Paris, 4th December, 1677

"... On Thursday night last I was sent for to My Lady Ambassador, whom I found in a fit of such violent and intolerable torment that it forced her to such cries and shrieks as you would expect from one upon the rack, to which I believe hers was an equal torment, which extended itself all over the right side of her face and mouth. When the fit came, there was, to use My Lady's own expression of it, as it were a flash of fire all of a suddaine shot into all those parts, and at every one of those twitches made her shreeke out, her mouth was constantly drawn on the right side towards the right eare by repeated convulsive motions... These violent fits terminated on a suddaine, and then My Lady seemed to be perfectly well... Speaking was apt to put her into these fitts; sometimes opening her mouth to take anything, or touching her gums, especially in places where she used to finde these throbings; pressing the side of her face by lying on it were also apt to put her in these fitts. These fitts lasted sometimes longer, sometimes shorter... at intervals between them not halfe an hour, commonly much shorter..."

Paris, 22 December, '77

"... I believe the drawing of those two teeth, especially the last, hath injur'd some nerve, and soe makes it very apt to be provoked, and draws its neighbours into consent; yet by what My Lady informed me, since violence of her pains have been over, I have reason to suspect there is an ancienter fault in the nerves of that side..."

Lately accounts by Dr Kepler, Nicolaus André (who called it tic douloureux), John and his nephew Samuel Fothergill, and later Charles Bell were to elaborate and elucidate some of the features, possible causes and treatments.

JMS PEARCE