Lycra Garments Designed for Patients With Upper Limb Spasticity: Mechanical Effects in Normal Subjects

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ABSTRACT. Gracies J-M, Fitzpatrick R, Wilson L, Burke D, Gandevia SC. Lycra garments designed for patients with upper limb spasticity: mechanical effects in normal subjects. Arch Phys Med Rehabil 1997;78:1066-71.

Objective: To assess the stretch of pronator muscles produced by a specifically designed upper-limb Lycra garment that could have a better acceptability than rigid splints in treating upper-limb spasticity.

Design: Double-blind comparison among three garments. They were designed to produce a supinating, a pronating, and no torsional force, and were individually manufactured and tested in 10 healthy volunteers.

Main Outcome Measure: Angular position and passive rotational stiffness of the forearm were measured with and without each of the garments immediately after the garment was fitted and every hour for 6 hours.

Results: When put on by a trained person, the supinator garment supinated the forearm in all subjects (mean, 17°; $p < .01$; range, 5° to 44°) while the pronator garment pronated the forearm in 8 of 10 subjects (mean, 5°; $p < .01$). These effects gradually decayed over 6 hours, as garment position was not readjusted. Passive rotational stiffness of the forearm increased by about 30% with each type of garment. The garments designed to produce no torsional force exerted no intrinsic rotational effect.

Conclusion: Individually made Lycra garments can produce continuous stretch of muscles for several hours and may be useful in the treatment of spasticity. The garments, however, must be put on by a trained person and their position adjusted when necessary.

MUSCLE STRETCH has long been considered a mainstay of the treatment of spasticity and the prevention of contracture in spastic patients. This study analyzes the mechanical effects of elastic Lycra garments designed to produce a continuous stretch of spastic muscles, without the discomfort of classical rigid splints.

In addition to preventing contractures, muscle stretch may have an intrinsic antispastic effect (spasticity being understood in its classical definition of a velocity-dependent increase in stretch reflex activity[1]) by interrupting a cycle whereby spasticity leads to muscle contracture, which in turn increases spasticity.[2] It is clinically accepted that chronic spasticity shortens muscles. Experimentally (with overactivity produced by tetanus toxin), there is an alteration in the elastic properties of muscle accompanied by structural changes.[3,4] Stretch is an important stimulus to muscle growth,[5-7] and its absence or diminution due to overactivity can account for diminished growth, as well as contracture in spastic muscle.[4,8,9] Evidence, however, also supports an effect of contracture on spasticity. First, if a muscle is shortened by contracture, then a given change in joint angle will stretch muscle fibers relatively more than normal, thus evoking an increased reflex response. Second, a muscle that has been contracting in a shortened position has bigger stretch responses than if it has been contracting in a normal resting position.[10] Clinically, braces for children with cerebral palsy (CP) may lead to suppression of abnormal muscle contractions responsible for muscle shortening,[6] as could be predicted from the inhibitory effect of muscle extension on the stretch reflex of certain muscles.[11] Therapeutic approaches to break the spasticity-contracture-spasticity loop have involved muscle relaxation (produced by general and local antispastic medications) and muscle stretch. The degree of muscle relaxation produced by drugs in dosages that do not produce unacceptable side effects is usually insufficient to therapeutically affect hemiplegic spasticity. As for muscle stretch, "passive range of motion" exercises performed in physiotherapy sessions or by the patient are often unable to prevent progressive muscle contracture, presumably because they provide only intermittent muscle stretch. In children with CP, it is probably essential to stretch spastic muscles continuously for several hours each day to prevent contractures.[12] Splints and plaster casts have been used to provide "continuous" stretch and thereby to promote muscle growth,[13] but they usually interfere with function and are uncomfortable to wear, and any benefit may be lost when treatment ceases.

Lycra garments have been prescribed to produce a continuous low-level stretching force on the limb in patients with CP or adult hemiparesis in several rehabilitation centers in Australia.[14] Although the garments appear to be beneficial in anecdotal video-documented cases, there has been no controlled trial. Importantly, there is no objective evidence that such garments do exert stretching forces, or that the pattern of force can be predetermined by careful design of the garment.

The present study was undertaken to assess objectively whether custom-designed Lycra garments exert continuous stretch in predetermined directions. The experiments were conducted in healthy adults and focused on a supinator action. The primary hypothesis was that these garments could produce a steady supination of the forearm and thus exert continuous stretch of pronator muscles. In addition to measuring the angular position of the forearm, we also assessed changes in its rotational stiffness to estimate the forces that the garment could make to oppose spastic contractions of pronator muscles in patients.

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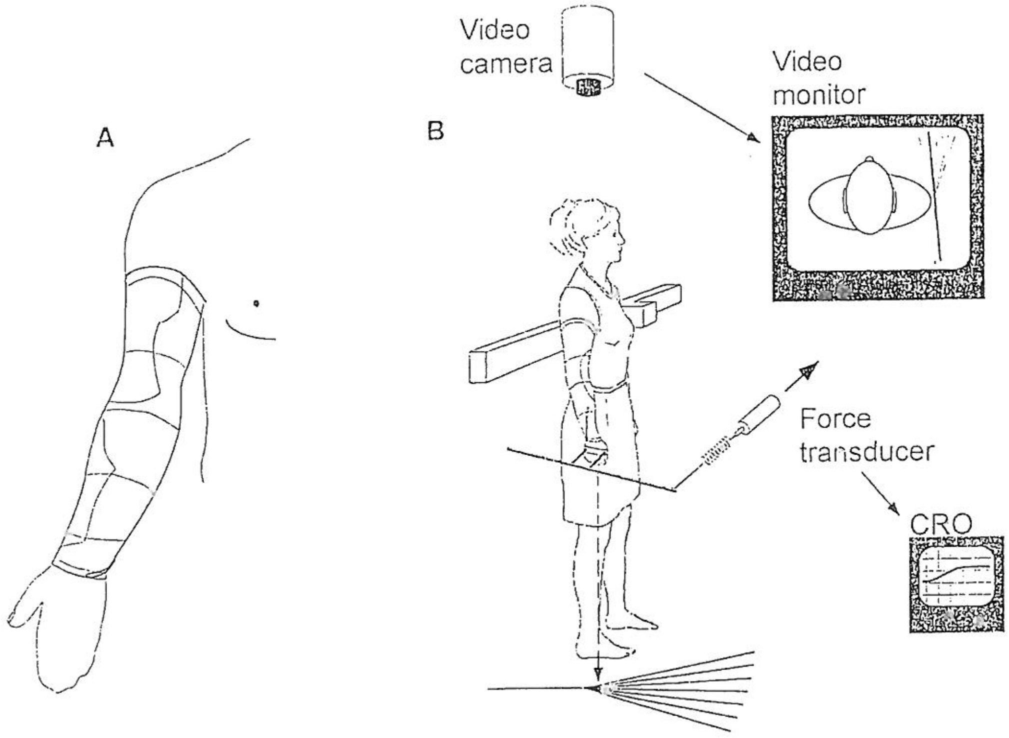

Fig 1. (A) The garment is made of a number of transverse Lycra segments, sewn from top to bottom. (B) Experimental set-up.

MATERIAL AND METHODS

Subjects and Garments

The subjects were 10 healthy volunteers, 4 women and 6 men aged 21 to 51 years. The garment[a] incorporates a series of circumferential Lycra segments sewn to one another from the top to the bottom of a sleeve (fig 1A). These segments are stretched in the orientation appropriate to produce the chosen direction of pull and then sewn together. For optimal fitting, individual measurements of a patient's arm are required. To position the garment, two landmarks are used, a label at the top that must be posterior and a zip at the bottom that should be over the ulnar styloid process. Provided that the garment has a tight grip on the skin, the elasticity of the material should exert a directional stress on the arm and forearm. In addition, the stretch induced by the garment may be enhanced or diminished according to the way it is fitted and zipped at the wrist.

To assess objectively the mechanical properties of the garments designed to produce supination, three garments, designed to supinate the forearm, pronate the forearm, or produce no pronation or supination (ie, neutral), were manufactured for each subject. Subjects were not aware of the type of garment being fitted. In other tests, no garment was worn. The way the garment was fitted to the arm proved to be critical and this fitting always required help by one of the experimenters (blinded in the first two series of experiments, and unblinded for the last two).

Experimental Procedures

The experiments were performed with the informed consent of the subjects, in accordance with the declaration of Helsinki. The subject stood with the back and the opposite shoulder against a board at right angles so that the standing position was reproducible for each assessment with both arms hanging freely. A 60cm-long lightweight stick was clamped to the hand securely and reproducibly using skin landmarks. A video camera was mounted above the subject. The subject was properly positioned when the centers of rotation of the angular landmarks of the floor and of the stick, visualized by the videocamera, superimposed on the monitor screen. To measure the rotational resistance over 5°, the experimenter pulled gently at right angles to the stick through a strain gauge and a rubber band, displacing the stick through 5°. While maintaining the stick in this rotated position the torque opposing the rotation was measured directly from the oscilloscope.

This angular movement was chosen to be within a range over which any overactive pronator contraction might be expected to rotate the forearm in spastic patients, but sufficiently large for accurate measurement. During these externally applied rotations, relaxation of the subject's upper limb was checked by

Table 1: Experimental Paradigms

Series	Situations Tested	Paradigm, 6 Trials/Situation	Garment Fitter	Subject and Measurer
I	No garment; Supinator; Pronator; Neutral	6 trials in a row without change	Unaware of desired effect	Blinded
II	No garment; Supinator; Pronator; Neutral	Change garment for each trial, random order	Unaware of desired effect	Blinded
III	No garment; Supinator; Pronator	Change garment for each trial, random order	Aware of desired effect	Blinded
IV	Supinator; Pronator	One garment worn for 6 hours, 1 trial every hour	Aware of desired effect	Blinded

monitoring the electromyography (EMG) activity from surface electrodes placed on both sides of the forearm, over the biceps and over the posterior aspect of the shoulder.

There were four series of experiments (table 1), three to study the immediate effects of the garment on the angular position of the forearm and on its passive rotational stiffness, and one to study these effects over 6 hours in freely moving subjects. In the first three series, 24 measurements were made for each subject, each of the four situations (subject wearing the three types of garment or wearing no garment) being tested six times. The first series assessed the variability of the assessments when keeping the fitting the same between each measurement: six assessments in a row were made for each situation, the subject was only asked to walk about and then come back as accurately as possible over the landmarks against the board to be reassessed. For the second series, the garments were changed between measurements, alternating test situations in a random order. In both first and second series, subjects and experimenters were not aware of the type of garment worn for each measurement. The third series was designed to determine whether it was important for the person fitting the garment to know the mechanical effect that it was designed to produce. The succession of measurements was arranged as in the second series, but the experimenter who fitted the garments on the subjects was unblinded and able to fit them to optimise the intended effect. A separate experimenter made the measurements, and both he and the subject remained blinded. In the fourth series of experiments, six subjects wore one of the supinator or pronator garments over a 6-hour period, unaware of the type of garment. During the period, they were allowed to work normally and the position of the garment on the arm was not adjusted. The angular position of the forearm was measured every hour.

Statistics

In each series, the results of angular position and rotational resistance for each of the four situations (each of the three types of garment and no garment) were compared using a two-tailed paired *t* test. To estimate the relationships between resistance opposing pronation and resistance opposing supination (situation with no garment), and between angular position and rotational resistances, linear regression was used. Statistical significance was set at the 5% level.

RESULTS

Control Studies Without Garment

The passive resistance opposing 5° of externally applied supination and the resistance opposing 5° of pronation were correlated, the latter being significantly greater than the former over the 120 measurements (*t* test) (fig 2A). The resting angular position of the forearm was plotted against the resistance opposing supination (fig 2B). The forearm was pronated in all 10 subjects and the resting angular forearm position remained fairly steady in a given subject (vertical error bars ± SEM), but varied between subjects, covering more than 25°. There was a significant positive correlation between the degree of pronation at rest and resistance opposing rotation ($p < .05$): "stiffer" subjects had a tendency to be naturally more pronated.

Studies With Garments

Figure 3 plots the initial resting position for each of the 10 subjects (position of the open circles relative to the Y axis) and the angular displacements produced by the supinator garment (open arrows) and by the pronator garment (black arrows) when the experimenter fitting the garment was aware of the "desired" effect of the garment (third series of experiments). Each arrow length represents the number of degrees of displacement due to the garment. The displacement into supination by the supinator garment occurred in every subject. On average, the pronator garment had opposite effects but through a smaller angle, and not in the two most pronated subjects (the last two circles on the right of fig 3). The figure suggests that larger effects were seen in those arms that were initially more pronated, but the correlation was not significant. In experiments in which the person fitting the garments was blinded (second series), the supinator garment effectively supinated the forearm in only 6 of the 10 subjects (individual data not shown). Therefore, the technique of fitting the garment is probably as important as the design characteristics of the garments.

Group data are shown in figure 4. On the left of figure 4A,

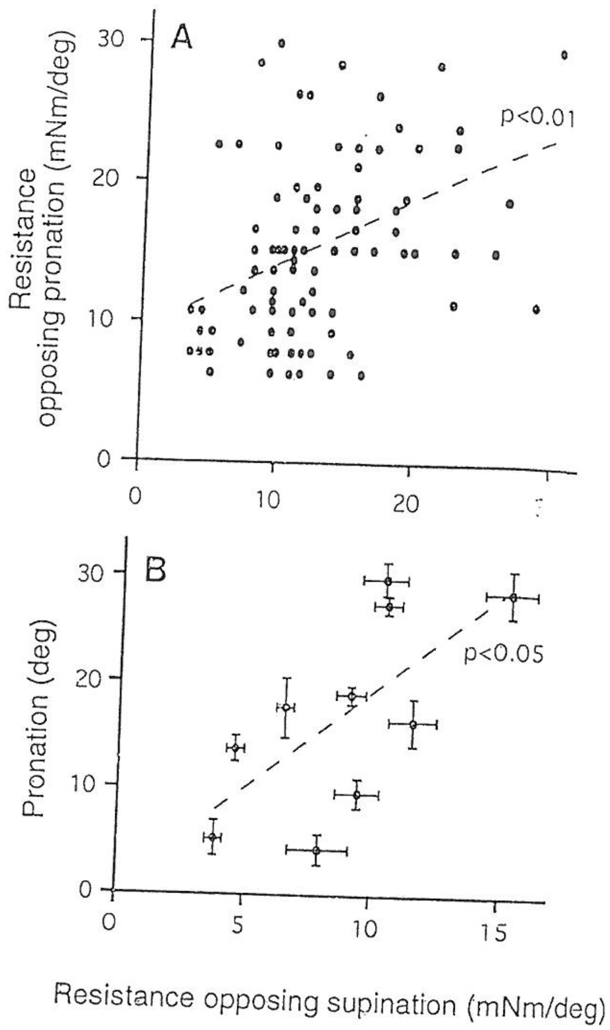

Fig 2. (A) Resistances opposing supination and pronation over [illegible] en wearing no garment). Each data point represents an individual assessment of the bidirectional stiffness in one subject, on the abscissa by the force opposing a 5° supination and on the ordinate by the force opposing 5° pronation, both expressed in milliNewton-metres per degree. The results from the second and third series of experiments are plotted together. Resistance against pronation was correlated with resistance against supination. (B) Pronation as a function of rotational resistance (control data with no garment). Each symbol represents data from one subject, characterized on abscissa by the passive resistance opposed by the subject's forearm to an external supination of 5°, and on ordinate by the resting angular position; error bars: SEM. Interrupted line is the linear regression line.

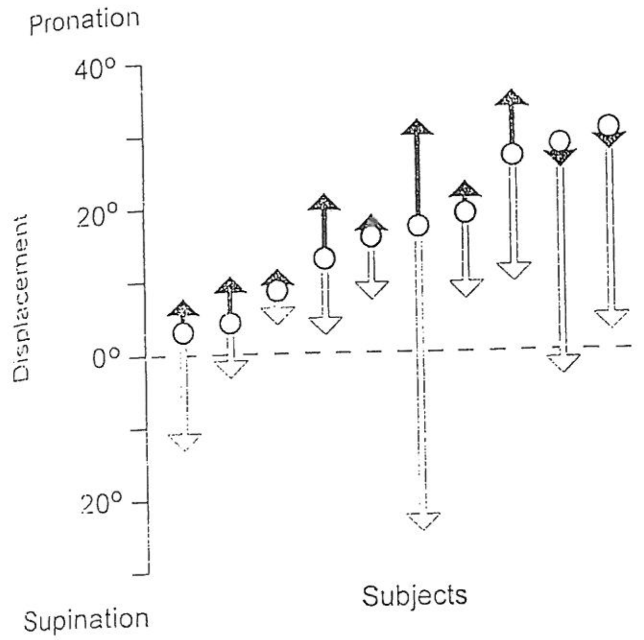

Fig 3. Angular displacement—individual data with unblinded fitting. Each open circle is data from one subject, positioned along the vertical axis according to the resting forearm position with no garment. Data for 10 subjects are displayed from left to right by increasing order of resting pronation. For each subject, the open arrow represents the angular change produced by the supinator garment and the filled arrow represents the angular change produced by the pronator garment.

the person fitting the garments was unaware of the type of garment (series II), on the right he was aware (series III). In both cases, both the subjects and the experimenter making the measurements remained blinded. There was a clear difference between the two series of experiments for the supinator garment (columns in light grey), from a nonsignificant change of −2.3° ± 2.5° supination to a highly significant −17° ± 2° ($p < .001$). The displacement due to the pronator garment (columns in dark grey) also became significant when the person fitting the garment knew the desired effect.

To assess factors of variability of the effect measured, the stretch provided by the garments was compared when 6 consecutive measurements were made for the same fitting (series II) and when 6 fittings were tried with 1 measurement per fitting (series I). The average standard deviations observed for the 6 repeated measurements are shown in figure 4B. On the left, the average standard deviation when the subjects wore no garment (same in the two series) was ≈4°. When 6 consecutive measurements were made without removing the garment (middle of figure), the average standard deviation was significantly lower at ≈2°. When garments were changed between measurements (right handside of figure), the standard deviation was higher at ≈6° (significantly for neutral and pronator garments, $p = .06$ for the supinator garment).

Measurements of resistances to an applied external rotation are plotted in figure 5. Both resistances opposing supination and pronation were significantly increased by all three types of garment, by about 30%. For each type of garment, there was no significant directional specificity to the change in stiffness. Similar results were obtained whether the person fitting the garments was or was not blinded.

Duration of Effects

In six subjects the effects of pronator or supinator garments were assessed over 6 hours, four with supinator garments, two with pronator garments. Both the subjects and the experimenter assessing the forearm angular position were unaware of the garment type being worn. The rotation produced by the garments decayed significantly over 6 hours (fig 6), but was still present at 3 hours. The position of the garment on the arm was not adjusted even when it had been obviously disturbed by movement.

DISCUSSION

Our results demonstrate: (1) specifically designed Lycra garments rotated the forearm in healthy subjects but this effect was significant only when the garments were carefully fitted to obtain the desired effect; (2) this effect decreased progressively

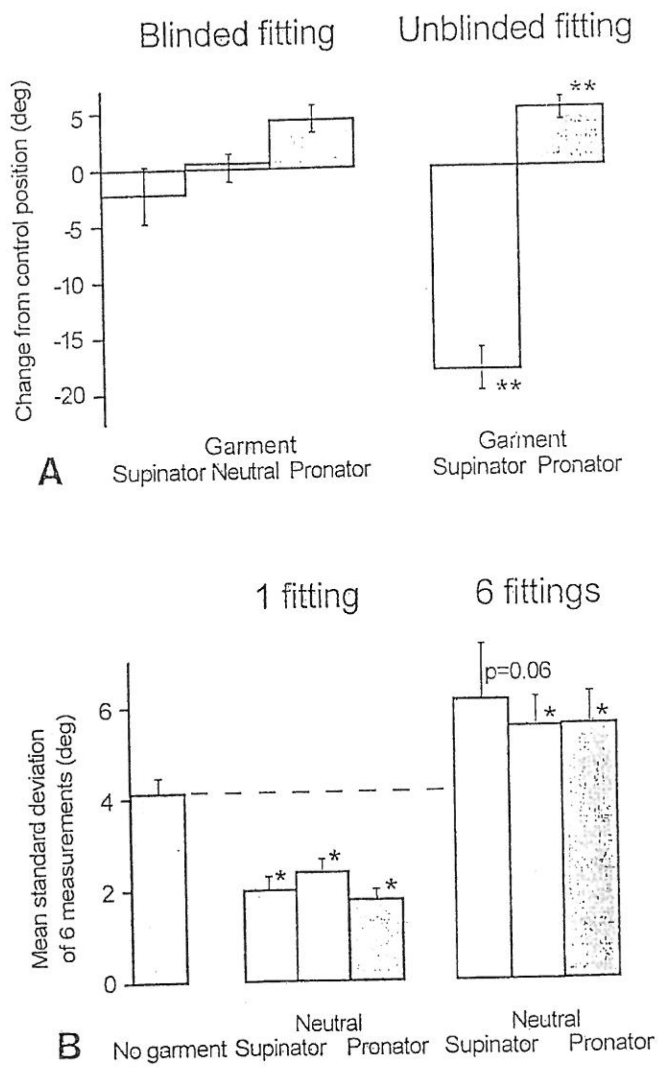

Fig 4. (A) Angular displacement—group data with the two ways of fitting. "Blinded fitting" indicates the situation in which the garment fitter was unaware of the desired effect of the garment and "unblinded fitting" the situation in which the fitter was aware of the desired effect. Columns show the average angle changes (± SEM) due to each garment in 10 subjects (*$p < .05$; **$p < .01$ tested against the resting position with no garment). (B) Variability of angle assessments with and without change in fittings between each. Each column represents the average standard deviation in 10 subjects for six measurements of forearm angular position per subject. In the central group of columns, six consecutive measurements were made without changing fittings; in the right group, the fitting was changed between measurements. (Error bars: SEM. *$p < .05$ tested relative to the standard deviation with no garment.) All differences were significant except for the supinator/6 fittings ($p = .06$).

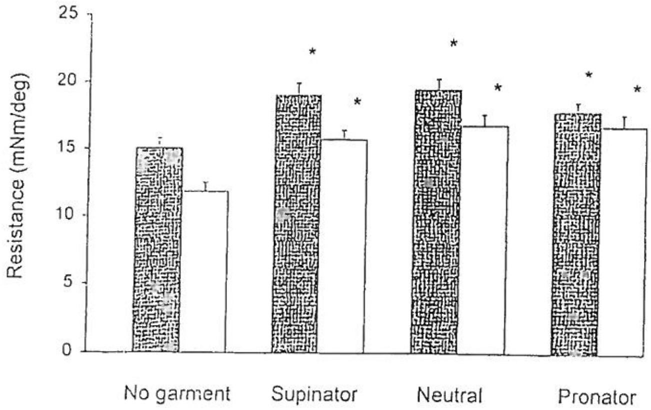

Fig 5. Resistances opposing rotation without and with garments (▦, opposing pronation; □, opposing supination). Torque opposing a 5° rotation was measured in each direction. Dividing this torque by 5 gave an estimation of the average "stiffness" over this range of motion in milliNewton-metres/degree (Error bars: SEM. $*p \leq .05$, tested against the resistance opposing rotation without garment).

over 6 hours, perhaps because of altered position of the garment by use of the limb; and (3) the garments increased the rotational stiffness of the forearm, and thus, the resistance to an applied pronation and supination.

Perspectives for Therapy

In spastic hemiplegic patients, the increased resistance against pronation provided by these garments should oppose involuntary pronator contraction. Individual data showed a trend for the supinator garment to exert a greater effect in more pronated healthy subjects. This would be appropriate for the treatment of spastic arms that are naturally more pronated. The increase in passive rotational stiffness should also help stabilize forearm position. Indeed, wearing a garment considerably stabilized the forearm of the subjects; it reduced the variability of the forearm angular position by half (measured as standard deviation of assessments, fig 4B), compared with that when no garment was worn.

Importance of the Way of Fitting the Garments

The increase in variability of forearm position when changing fittings between measurements reveals the impact of the way the garments are fitted. The increase in efficacy when the garments were fitted reliably (fig 4A) confirms that the garments must be fitted accurately to obtain the desired stretching effect. The unblinded fitter was careful to position the distal end of the zip anterior or posterior to the medial aspect of the wrist, according to the effect sought, thereby inducing a directional twist in the garment. It is even possible that careful application of a neutral garment might produce some supination (we have not tested for this possibility in this study), though this is unlikely to be as great as with a specifically designed garment. In therapy, such a skill should probably be taught to carers responsible for the fitting.

Duration of Rotational Effect

Unlike bandages that rarely produce long-lasting stretch of underlying tissues, the current garment produces significant stretch lasting more than 3 hours. The progressive loss of efficacy over 6 hours was probably produced by the displacement of the garment from optimal fit. This problem was more obvious in subjects who used their arms actively over the 6-hour period, and would be less in patients with diminished motor power. One corollary is that persons fitting the garments should check the positioning intermittently and readjust the fit to maintain an optimal effect over a longer period.

Theoretical Considerations: How Is Arm Posture Determined?

The positive correlation between rotational forearm stiffness and natural resting pronation (fig 2B) raises the question of whether the more pronated posture in spastic hemiplegic persons merely represents an extreme of this same relationship. In other words, the more increased the tone in upper limb muscles, the more it would be distributed in favor of pronator muscles in the forearm, whether or not there was a cerebral lesion. This hypothesis is consistent with some of our data without the garment: if tone is greater in pronators, then supinators would become relatively stretched. Hence, an externally applied extrapronation would reach maximal supinator stretch and so be limited by the resistance of stiffer structures (eg, ligaments, capsules) more rapidly than an extrasupination. This may explain the consistently higher resistance opposing extrapronation observed in figure 2A as against that measured for an extrasupination.

CONCLUSION

The present study showed that Lycra garments designed to supinate the forearm produced immediate and potentially long-lasting supination of the forearm of the healthy subjects tested. The effects were significant only if the garments are fitted properly. It is likely that both garment design and application of the garment by a skilled assistant are important to produce the rotational effects described. In patients with unwanted pronation of the forearm, the increase in rotational stiffness produced by the garment might be expected to oppose pronator spastic overactivity and decrease the risk of pronator contracture. The design of the garments can be adapted to the pattern of overactivity presented by individual patients in hemiplegia; it is most commonly prepared to combine the rotational supinator effect studied in the present work with an extensor effect at the elbow. The continuous stretching forces exerted are low compared with the transient forces applied during a

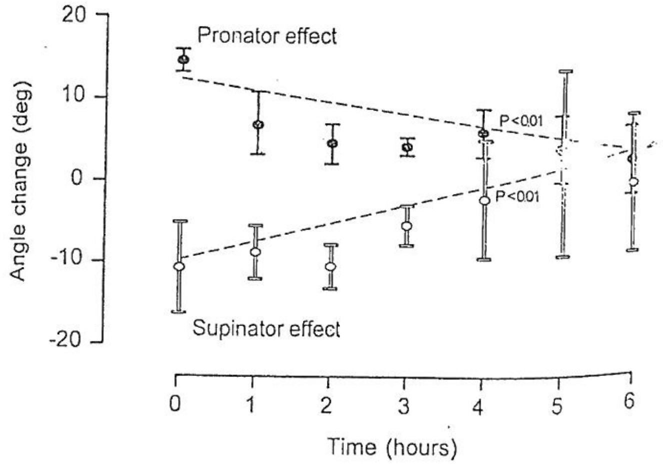

Fig 6. Time course of the effects of the supinator and pronator garments. Average angle changes produced by the supinator garment in 4 subjects are represented as black circles. Data for the pronator garment in 2 additional subjects are shown as open circles. Time zero was when the garments were put on. (Error bars: SEM)

manual stretch made by a physiotherapist or with the constraint of a rigid splint. This suggests that these garments may be more appropriate for early stages of recovery, to minimize contractures, rather that when muscles are already shortened.

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