# Short-Term Effects of Dynamic Lycra Splints on Upper Limb in Hemiplegic Patients

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ABSTRACT. Gracies J-M, Marosszeky JE, Renton R, Sandanam J, Gandevia SC, Burke D. Short-term effects of dynamic Lycra splints on upper limb in hemiplegic patients. Arch Phys Med Rehabil 2000;81:1547-55.

**Objective:** To assess acceptability, effects on swelling, resting posture, spasticity, and active (AROM) and passive range of motion (PROM) of individually tailored upper limb Lycra® garments, designed as dynamic splints to exert directional pull on certain limb segments, when worn for 3 hours by hemiplegic patients.

**Design:** Crossover trial.

**Setting:** Outpatient and inpatient rehabilitation center.

**Patients:** Convenience sample of 16 patients with hemiparesis and upper limb spasticity caused by a stroke more than 3 weeks before the study.

**Interventions:** Assessments performed at the start and end of a 3-hour period during a standard rehabilitation day when the patients were and were not wearing the garment.

**Main Outcome Measures:** (1) Comfort assessed by questionnaire; (2) circumference of each limb segment; (3) resting posture at elbow and wrist; (4) spasticity at shoulder, elbow, and wrist using the Tardieu scale; and (5) AROM and PROM at shoulder, elbow, and wrist measured using a goniometer; (6) elbow proprioception using McCloskey's method; (7) visual neglect syndrome using the line bisection test. Differences between changes occurring with and without the garment were compared using Wilcoxon's signed rank test for ordinal variables (spasticity grading) and Student's $t$ test for continuous variables (all other data).

**Results:** During 3 hours, garments worn on the arm by patients with hemiplegia (1) were comfortable, (2) improved wrist posture and reduced wrist and finger flexor spasticity, (3) reduced swelling in patients with swollen limbs (digit circumference decreased by 4%; $p < .01$), (4) improved PROM at shoulder (mean increase in range, 4.1° ± 13.0° per shoulder movement; $p < .01$); and (5) impaired ability to flex fingers (range of voluntary flexion of digit III reduced from 107.3° ± 79.6° to 91.4° ± 74.1°; $p < .05$).

**Conclusion:** Lycra garments, designed to produce continuous stretch of spastic muscles when worn for several hours each day, have rapid splinting and antispastic effects on wrist and fingers in patients with hemiplegia. These garments may help severely affected patients with major spasticity or painful swollen limbs.

**Key Words:** Hemiparesis; Range of motion, articular; Rehabilitation; Splints; Spasticity; Tardieu scale.



PATIENTS WITH HEMIPLEGIA often develop abnormal patterns of muscle activity in the paretic limbs in the weeks after stroke, with overactivity primarily affecting flexors and pronators of the upper limb.[1] Muscle overactivity can lead to muscle shortening, abnormal postures, and pain[2]; therefore, its evaluation and treatment may be important.

We find it useful to distinguish 3 main types of muscle overactivity that often coexist in patients with damage to the corticospinal pathways. Spastic dystonia, well recognized by Denny-Brown,[1] is the phenomenon of tonic muscle contraction in the absence of phasic stretch or volitional activity. Pathologic antagonistic cocontraction is triggered by volitional activity and occurs in the antagonists of voluntarily recruited muscles.[3] Spasticity is a velocity-dependent increase in stretch reflex activity,[4] ie, an excessive muscle contraction in response to phasic stretch.

The only type of muscle overactivity quantifiable in bedside practice is spasticity. Neurologists have long used methods to rate spasticity,[5,6] although it has not been proved that increased stretch reflex activity by itself is functionally disabling.[7,8] Furthermore, weakness (associated with slow motor unit recruitment), muscle shortening, pathologic antagonistic cocontraction, and spastic dystonia are probably more disabling than spasticity itself. Nevertheless, the grade of spasticity may be viewed as an index of global muscle overactivity severity because it may reflect the degree of hypersensitivity of alpha motoneurons to excitatory input.[9]

In experiments with animals, muscle shortening produced by immobilization increased spindle sensitivity.[10-12] It is therefore likely that muscle contracture, spasticity, and muscle overactivity in general are intertwined. For optimal efficacy, therapies aimed at improving function should address both muscle shortening and muscle overactivity; measures to relax overactive muscles should be combined with physical treatment to lengthen them.[13] The mainstay of physical treatment is muscle stretch, which should be started as early as possible to prevent muscle shortening.[13] Physical therapy sessions commonly involve passive range of motion (PROM) exercises or short posturing sessions. However, to prevent contractures in the long term, muscle stretch is probably more effective when applied continuously for several hours daily.[14] Rigid splints are often poorly tolerated when used for long periods of time; they restrain motion and may induce learned disuse.[15]

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Lycra® garments have been prescribed for patients with cerebral palsy or adult hemiparesis in a number of rehabilitation centers in Australia.[16] These garments appear to be beneficial in anecdotal video-documented cases, but no controlled trial has documented their efficacy. In healthy subjects, we found that a garment designed to supinate the forearm could stretch pronator muscles by producing significant supination lasting 2 to 3 hours and increase rotational stiffness of the forearm.[17]

The present study was performed to evaluate the garments in hemiplegic patients and address the following hypotheses. (1) An individually tailored supinator-extensor garment, together with a glove splint, stretches pronator and flexor muscles in spastic patients for several hours if the caregiver fits the garment properly and adjusts the fitting when necessary. Because there is a physiologic rationale to support the antispasticity effect of maintained stretch,[10-12] the garments will reduce pronator and flexor spasticity when worn for a few hours. (2) The garments are comfortable and acceptable when worn for several hours. (3) By relaxing opposing spastic muscles, the garment improves the active range of motion (AROM) of the antagonists. (4) The garments have other physiologic effects caused by the steady pressure on the skin, such as reduced pain, increased PROM, and improved awareness of limb position (proprioception). In addition, based on previous reports that sensory inputs from the neglected side may improve awareness of that side,[18,19] the garments may improve visual neglect in patients with minor hemisphere syndrome.

## METHODS

### Subjects and Garments

Subjects were 16 patients with hemiplegia (5 women, 11 men; age, 36–85yr; mean age, 65yr) recruited from current inpatients in the rehabilitation units of The Prince Henry Hospital (Little Bay, NSW, Australia) and current outpatients at St Joseph's Hospital (Auburn, NSW, Australia). Inclusion criteria were age from 18 to 85 years, hemiparesis, and flexor and pronator spasticity in the upper limb caused by a stroke more than 3 weeks before the study. Exclusion criteria were (1) cognitive impairment, behavioral disturbance, or serious independent chronic disease likely to interfere with the ability to give informed consent or cooperate in the study, assessed by the physician; (2) major contracture affecting muscles of the spastic arm at the time of recruitment; (3) cutaneous or joint pathologic states in the upper limb other than that directly related to hemiparesis; and (4) hypersensitivity to Lycra. Table 1 lists patients' clinical details. All patients gave informed consent to the experimental procedures, which had been approved by the institutional ethics committee.

The design of the arm garment is described elsewhere.[17] Briefly, it incorporates a series of circumferential Lycra segments, sewn together from the top to the bottom of a sleeve. These segments are stretched in the orientation appropriate to produce the chosen direction of pull and then sewn together. The garment is custom made to fit the arm dimensions of each patient. A well-fitted garment has a tight grip on the skin, and the material's elasticity exerts a directional stress on the arm and forearm. This stress may be enhanced or diminished according to how it is fitted and zipped at the wrist.[17]

Subjects also wore a custom-fitted glove splint made of Lycra. The glove splint was designed with 2 semiflexible plastic sticks in the glove, extending from midforearm on the palmar aspect to the palm of the hand. This plastic boning strongly opposed wrist flexion.

### Study Design

A crossover design was used because a blinded protocol is impractical with this type of intervention. In the crossover design, subjects were tested on 2 different days. On each day, they were assessed at the beginning and end of a 3-hour period. On 1 day, they wore the garment for 3 hours; on the other day, they did not wear the garment. Changes occurring over 3 hours with garment were then compared with changes occurring over 3 hours without garment. This design was used to account for the effects of time and learning in those tasks for which this was relevant. Because the way in which the garment is fitted to the arm may be important,[17] the fitting was performed by the same trained investigator.

**Table 1: Patient Characteristics**

| Subject No. | Sex | Age (yr) | Time Since Stroke (wk) | Affected Side | Sling | Swelling, Sweating, Coldness, or Soreness | Sensory Deficit | Neglect Syndrome |
|---|---|---|---|---|---|---|---|---|
| 1 | F | 69 | 3 | L | + | – | – | – |
| 2 | M | 57 | 10 | R | + | + | + | – |
| 3 | M | 47 | 6 | R | + | + | + | – |
| 4 | F | 84 | 7 | L | – | – | – | – |
| 5 | M | 76 | 9 | R | + | + | – | – |
| 6 | M | 53 | 10 | L | – | + | – | – |
| 7 | M | 57 | 8 | L | + | + | + | + |
| 8 | M | 54 | 12 | L | + | + | + | + |
| 9 | M | 69 | 10 | R | – | + | – | + |
| 10 | F | 67 | 10 | L | + | + | + | – |
| 11 | F | 85 | 36 | L | – | + | – | – |
| 12 | M | 72 | 4 | R | – | + | ? | – |
| 13 | M | 72 | 32 | R | + | + | – | – |
| 14 | F | 80 | 8 | R | + | + | + | – |
| 15 | M | 36 | 3 | R | – | – | – | – |
| 16 | M | 55 | 12 | R | + | + | + | – |
| Total | 11M/5F | 65 ± 14 | 11 ± 9 | 7L/9R | 10+/16 | 13+/16 | 7+/16 | 3+/16 |

Abbreviations: L, left; R, right.

### Assessments

All assessments were made while the patient was sitting on a stool, with the paretic arm hanging freely alongside the body. All assessments at the end of the 3-hour period with the garment were performed while the garment was still on the arm, except for limb swelling, which was assessed just after garment removal.

Limb circumference was measured at 3 sites (midarm, midforearm, middle segment of the third finger) using a tape measure, 15cm above and below the olecranon for arm and forearm and around the second phalanx for the middle finger. Resting angular position was assessed for elbow pronation-supination using a modification of the technique previously described.[17] Two lightweight sticks were mounted in a reproducible manner on the patient's arm; 1 was just above the elbow, securely fixed to stay parallel to the line between medial and lateral epicondyle, and the other was mounted at the wrist parallel to the line between the ulnar and radial styloids. Measurement of the angle between the 2 sticks in the horizontal plane (pronation-supination angle) was made using a photograph[a] taken from above the patient's shoulder. To measure resting elbow flexion and wrist flexion, adhesive landmarks were taped over the fifth metacarpophalangeal joint, ulnar styloid, olecranon, and acromion, and the angles were measured on a photograph taken from the patient's side.

Spasticity was assessed using the Tardieu scale, adapted from Tardieu's method by Held and Pierrot-Deseilligny[20] (appendix 1). When measuring spasticity according to its definition,[4] this scale has specificity and sensitivity advantages over the Ashworth scale.[6] In the Tardieu scale, each grade (catch-and-release, fatigable or unfatigable clonus) corresponds to an objective clinical event and has only been described as muscle reaction to stretch,[21,22] not as any other type of muscle overactivity or passive tissue resistance. In addition, the velocity of the applied stretch is considered. Finally, the Tardieu scale is probably more sensitive than a mere ordinal scale because it involves a second quantitative parameter, the angle at which a catch or clonus occurs. For statistical calculations, this angle was considered to be 180° when the grade of spasticity was 0 (no muscle reaction) or 1 (slight resistance throughout the ROM). AROM and PROM were measured for all movements of shoulder, elbow, wrist, and fingers using a goniometer.[b]

Proprioception was measured at the elbow for flexion-extension using the method of McCloskey.[23] A vertical sheet of Perspex®[c] marked in degrees of rotation was set on the table in front of the patient between the 2 arms. The patient was blindfolded, with both elbows and hands initially resting on the table on each side of the Perspex sheet so that the initial elbow angle of flexion was approximately 30°. The affected arm was moved passively from that position to a certain degree of flexion (elbow resting on the table), and the patient indicated his/her assessment of the new position of the paretic arm by flexing the nonparetic arm to the corresponding position on the opposite side of the Perspex sheet. Each assessment measured the accuracy of matching for 2 different angles of elbow flexion, 50° and 80°, 5 trials per angle. The 10 matching tasks were presented to the patient in a pseudorandom order.

Visual neglect syndrome was assessed using the technique of line bisection, described by Halligan and Marshall.[24,25] Eleven horizontal black lines were individually drawn on sheets of white paper (280 × 298mm). Each line was approximately 1-mm wide and varied in length from 25 to 279mm in increments of 26mm. Each line was presented on a separate sheet and placed on the desk so that the objective midpoint was positioned in the sagittal midplane of the subject's trunk. The lines were centered on the page, both horizontally and vertically. Subjects were instructed to mark the midpoint of each line with a fine pen or pencil using the unaffected hand. Because a reversal of the spontaneous lateral displacement of the responses occurs for lines smaller than 51mm,[24] analysis was restricted to the 10 lengths of 51 to 279mm.

Finally, each patient completed a questionnaire at the end of the session with the garment to document their impressions (appendix 2). All other assessments were made at the beginning and end of each 3-hour period, during which the patients performed their normal rehabilitation activities. Staff were present to remove the garment if requested, but this was not requested.

### Statistics

For parametric data (circumferences, resting position, angle of muscle reaction in spasticity assessments, ROM, angular errors in the proprioception tests, distances to midline in the line bisection tests), differences between changes occurring in the 3-hour period with and without the garment were compared using 2-tailed paired $t$ tests. Nonparametric data (grading muscle reaction in spasticity assessments) were analyzed using Wilcoxon's signed rank test. Statistical analysis was performed using StatView 4.5.[d] Statistical significance was set at the 5% level.

## RESULTS

During the 3-hour observation period, the garment was well tolerated and produced significant changes in some of the parameters assessed compared with sessions without the garment. These changes were potentially beneficial, apart from the restriction of finger flexion. When the garment was not worn, the mere elapse of time or involvement in a routine rehabilitation program also resulted in some changes; therefore, the following data compare the changes that occurred during the 3 hours without intervention to those that occurred when the patient wore the garment.

### Limb Swelling

Clinically, 6 patients initially had a swollen hemiparetic arm, and the swelling increased over the study period when no garment was worn. In these patients, wearing the garment produced a small but significant reduction in swelling at the fingers and forearm at the end of the 3-hour period (fig 1A). At the third digit, the mean change in circumference was a 4% reduction with the garment (table 2). At the forearm, the mean change in circumference was a 2% reduction with the garment (table 2). There was a similar tendency at the arm. In the patients without swelling in the hemiparetic arm, wearing the garment did not change the circumference of the limb segments.

### Resting Posture

Resting posture was significantly improved at the wrist; flexion was decreased. As seen in figure 1B and C, this effect was greater in patients who did not wear a shoulder sling. At the elbow level, pronation and flexion both decreased, but not significantly (table 2).

### Spasticity

In shoulder vertical and horizontal adductor and internal rotator muscles, there was no change in spasticity over the 3-hour period whether or not patients wore the garment. In elbow flexors, extensors, and pronators, there was no differential change in spasticity with or without the garment. In the 3

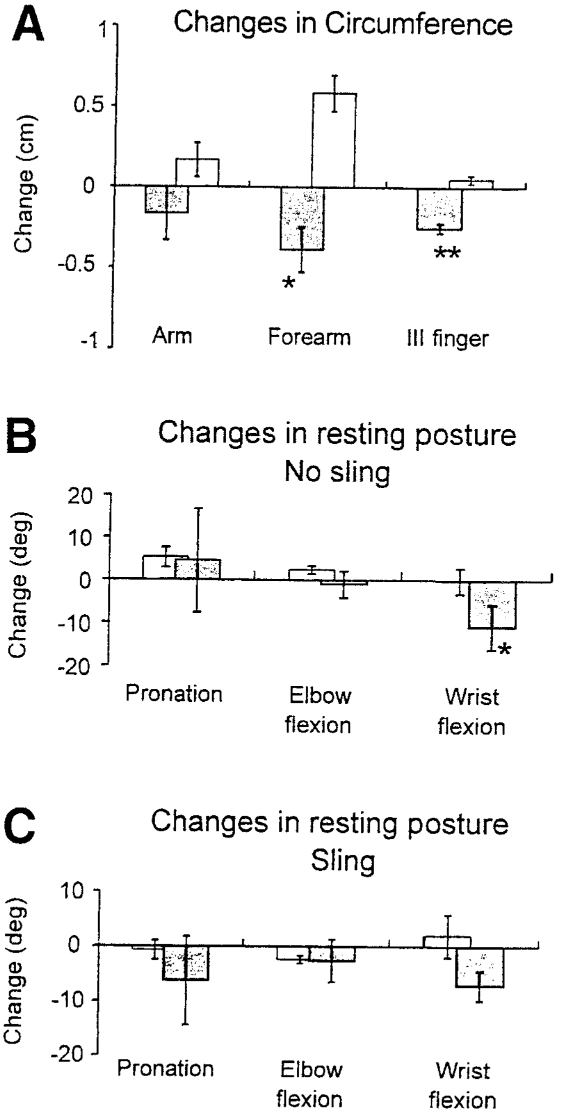


**Fig 1. Changes in upper limb circumferences and resting posture. (A) Each column indicates the change in absolute circumference for the limb segment studied among the 6 patients who clinically had swelling before intervention. (B) Improvement in wrist flexion was significant only in the patients not wearing a sling. (C) Changes in resting posture while wearing the sling. *$p < .05$. **$p < .01$. Error bars = SEM. (■), garment; (□), no garment.**

groups, there was a similar small trend toward spasticity reduction over the 3-hour period, measured by the change in angle of muscle reaction, both with and without the garment. Spasticity in elbow supinators and wrist extensors was close to nil (same values of X = 0.1° ± 0.28°; Y = 180° ± 0° for both muscle groups) at the onset of the 3-hour period and at the same level at the end of the study period.

We selected for illustration the change in spasticity in the wrist and finger flexors (fig 2) because they were the only muscle groups in which we found a differential effect between the 2 situations with and without the garment. Spasticity in the wrist and finger flexors, measured as ROM possible before muscle reaction (fig 2A), was significantly reduced by wearing the garment. In both wrist and finger flexors, the angle of catch increased with the garment and decreased without it (table 2). When measured as the change in reaction type (from a clonus

**Table 2: Results of Tests With or Without Garments**

| | With Garment | Without Garment | *p* |
|---|---|---|---|
| Limb swelling* | | | |
| Third digit | −0.25 ± 0.2 | 0.05 ± 0.2 | .012*t* |
| Forearm | −0.38 ± 0.9 | 0.58 ± 0.7 | .049*t* |
| Resting posture (deg) | | | |
| Wrist flexion | | | |
| B | 22.4 ± 7.3 | 23.2 ± 5.9 | |
| A | 13.9 ± 6.8 | 24.2 ± 8.4 | .011*t* |
| Elbow pronation | | | |
| B | 94.9 ± 24.9 | 94.6 ± 29.9 | |
| A | 91.1 ± 20.8 | 97.7 ± 25.5 | >.05*t* |
| Elbow flexion | | | |
| B | 25.6 ± 6.1 | 25.9 ± 4.5 | |
| A | 23.6 ± 7.8 | 25.7 ± 5.2 | >.05*t* |
| Spasticity—angle of catch (deg) | | | |
| Wrist flexors | | | |
| B | 120.8 ± 40.5 | 124.2 ± 37.9 | |
| A | 145.4 ± 36.9 | 119.2 ± 33.3 | .014*t* |
| Finger flexors | | | |
| B | 163.1 ± 31.5 | 166.5 ± 20.5 | |
| A | 169.2 ± 25.3 | 156.5 ± 34.2 | .042*t* |
| Spasticity—grade of muscle reaction | | | |
| Wrist flexors | | | |
| B | 1.8 ± 0.9 | 1.9 ± 1.0 | |
| A | 1.2 ± 0.9 | 1.8 ± 0.9 | >.05W |
| Finger flexors | | | |
| B | 1.4 ± 1.0 | 1.2 ± 0.9 | |
| A | 0.9 ± 1.3 | 1.2 ± 0.9 | >.05W |
| AROM (deg) | | | |
| Flexion Digit III | | | |
| B | 107.3 ± 79.6 | 110.5 ± 82.4 | |
| A | 91.4 ± 74.1 | 124 ± 78.8 | .019*t* |
| Elbow supination | | | |
| B | 23.3 ± 30.4 | 32.8 ± 35.3 | |
| A | 35.0 ± 34.5 | 32.8 ± 37.7 | >.05*t* |
| PROM (deg) | | | |
| Shoulder extension | | | |
| B | 66.2 ± 15.3 | 65.8 ± 17.2 | |
| A | 70.4 ± 16.1 | 61.5 ± 18.2 | .031*t* |
| Fingers flexion | | | |
| B | 162.1 ± 51.4 | 182.5 ± 36.1 | |
| A | 147.1 ± 58.9 | 181.7 ± 37.2 | >.05*t* |
| Fingers extension | | | |
| B | 31.1 ± 20.7 | 43.3 ± 26.8 | |
| A | 40.6 ± 17.6 | 43.3 ± 31.9 | >.05*t* |
| Proprioception† | | | |
| B | 8.4 ± 11.4 | | |
| A | 3.5 ± 7.9 | | .037*t* |
| Hemispace perception‡ | | | |
| Left B | 54.8 ± 5.8 | | |
| A | 53.1 ± 4.6 | | |
| Right B | 48.7 ± 2.2 | | |
| A | 48.9 ± 2 | | >.05*t* |

Abbreviations: B, before; A, after (3-hr test); *t* test; W, Wilcoxon's signed rank test. All values = mean ± SD. For proprioception and hemispace perception, the data with and without garment are pooled together (see text).
*Mean change in circumference, mm.
†Average distance from the target, deg.
‡Percentage of line length.

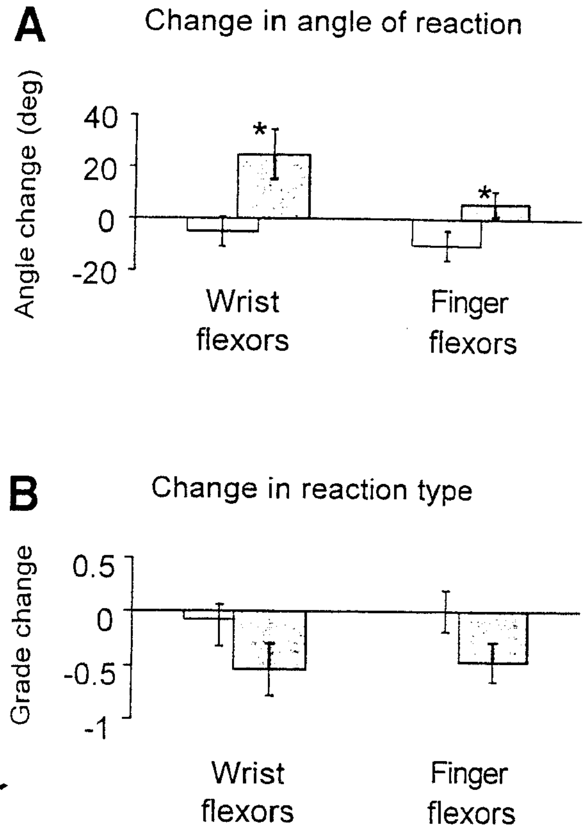


**Fig 2. Spasticity in wrist and finger flexors, measured with the Tardieu scale (appendix 1), decreased significantly only (A) when measured as the angle of muscle reaction and (B) not with change in reaction type. *$p < .05$. Error bars = SEM. (■), garment; (□), no garment.**

to a simple catch or from a catch to a slight continuous resistance; fig 2B), there was also a trend for reduced spasticity. In the wrist flexors, grading of muscle reaction type decreased with and without the garment, but in the finger flexors, grading of muscle reaction type decreased with the garment and did not change without the garment.

### Active Range of Motion

The range of voluntary flexion of digit III significantly decreased with the garment but increased without it (table 2). At elbow and shoulder level (fig 3B, C), there was a trend toward improved supination and shoulder rotation, but these changes were not significant; at the elbow, the range of active supination increased with the garment but remained unchanged without it (table 2).

### Passive Range of Motion

When data for all shoulder movements were considered, there was an average increase in range of 4.1° ± 13° per shoulder movement during the 3-hour period as opposed to a decline of 1.5° ± 10.7° during the same period without the garment ($p = .009$, *t* test, data not shown). The effect was greatest for shoulder extension and was statistically significant when considered by itself; the range of passive shoulder extension increased with the garment and decreased without it (fig 4A; table 2). At the fingers (fig 4B), the garment tended to reduce the range of passive finger flexion and increase the range of passive finger extension (table 2). No change was detected at the elbow.

### Proprioception and Hemispace Perception

In the elbow proprioception task, performance was improved at the second assessment for both angular targets whether measured as the average distance from the target or standard deviation of the different trials (see reduction in range of responses from left to right; fig 5A). This improvement was similar with and without the garment. Likewise, in the line bisection task, the lateral displacement error from the midline was consistently reduced during the 3-hour sessions, but this improvement was similar whether or not the subject wore a garment (fig 5B).

When considering the data with and without the garment, the improvement in proprioception from the first test to the repeat 3 hours later was significant (pooling data for both targets 50° and 80°, average distance from target was reduced; data not

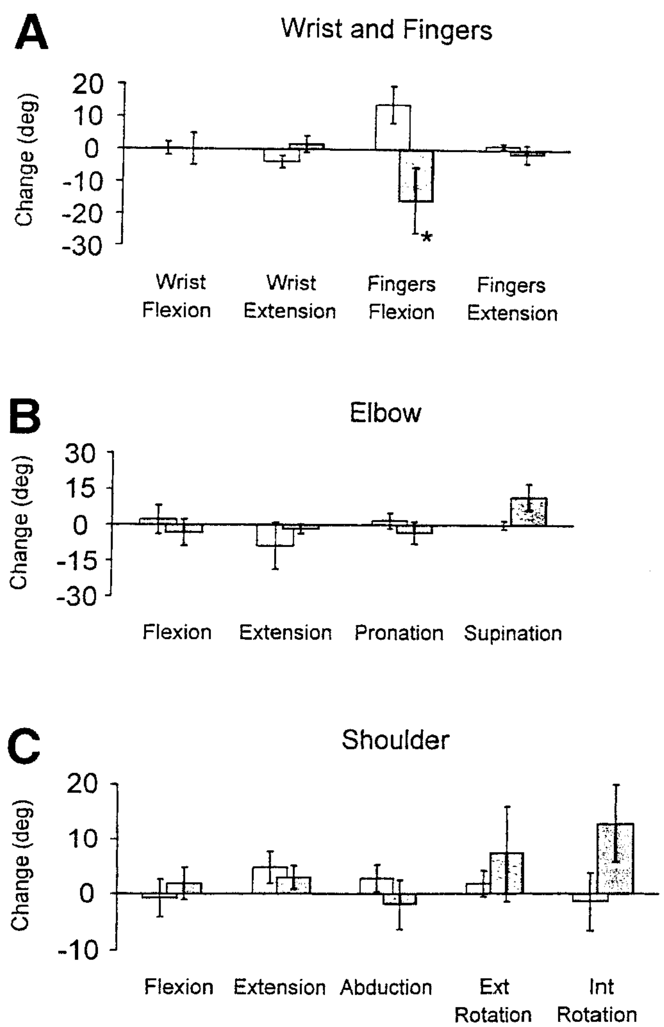


**Fig 3. Changes in AROM in (A) wrist and fingers, (B) elbow, and (C) shoulder. There was a trend toward improvement in the range of active rotation at the shoulder and elbow supination with the garments, the latter in keeping with the supinator effect of the garment shown elsewhere.[17] The only significant change was a reduced range of active finger flexion, consistent with the glove design that includes a directional line of pull toward finger extension, to oppose finger flexor overactivity. Ext, external; Int, internal. *$p < .05$. Error bars = SEM. (□), garment; (□), no garment.**

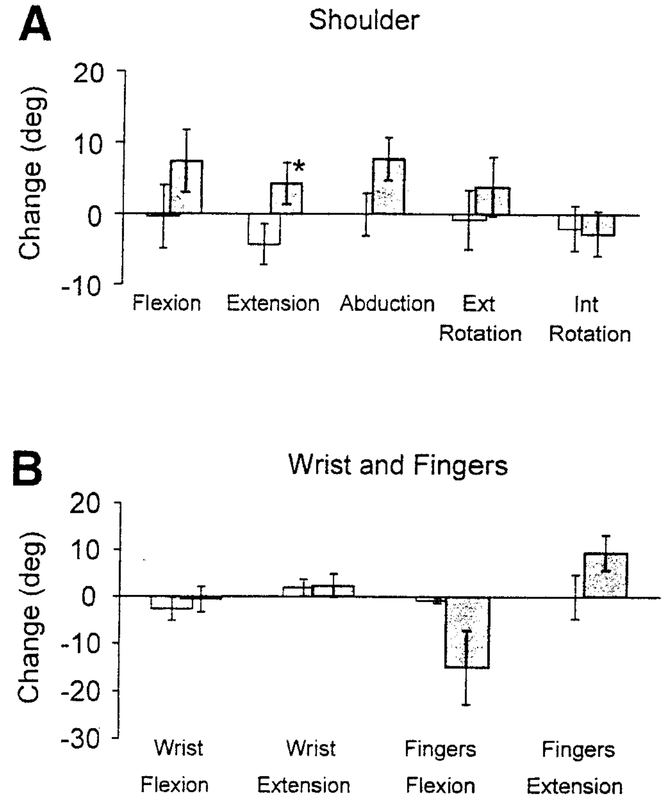


**Fig 4. Changes in PROM. (A) Improvement occurred at the shoulder even though the garment did not cover the shoulder. (B) At the wrist and fingers, reverse changes in range of passive finger flexion and passive finger extension were noted. These changes were not significant but are consistent with the garment design and the data in figure 3 for AROM. Ext, external; Int, internal. *$p < .05$. Error bars = SEM. (■), garment; (□), no garment.**

shown; table 2). With hemispace perception, the improvement was not significant whether in left or right hemiparetics (table 2).

### Subjective Impressions: Questionnaire

From an analog scale with 10 grades (appendix 2), comfort was rated an average of 7.7. All patients responded affirmatively to whether they would wear the garment for a few hours each day for a few weeks. A consistent comment was having greater "confidence in the arm," reported by 7 of 16 patients. Other subjective impressions of functional improvement are listed in table 3.

## DISCUSSION

The results showed that custom-fitted Lycra garments worn on the paretic arm for a few hours in patients with hemiplegia: (1) were comfortable, (2) improved wrist posture and reduced spasticity of wrist and finger flexors, (3) reduced swelling in those patients with a swollen paretic arm, (4) improved PROM at the shoulder, and (5) impaired the ability to flex the fingers.

### Plastic Boning Compared With the Garment Alone in Producing Muscle Stretch

Because the Lycra garment can produce a continuous stretching force on pronator muscles in healthy subjects,[17] it is surprising to find no significant effect on these muscles over 3 hours in this patient sample, whether in terms of resting posture or spasticity. Also, no effect was shown on the elbow flexors, which these garments were also designed to stretch. The only significant postural effect was found in muscle groups subjected to an extra stretching force from the plastic boning incorporated into the palmar half of the glove splint. This reinforced the stretch of the flexor muscles that cross the wrist, ie, the wrist and finger flexors (although our methods did not allow us to assess postural changes in the latter muscle group). This suggests that the stretching forces exerted by Lycra alone at the elbow, which we showed in healthy subjects,[17] were insufficient in patients to achieve significant muscle stretch

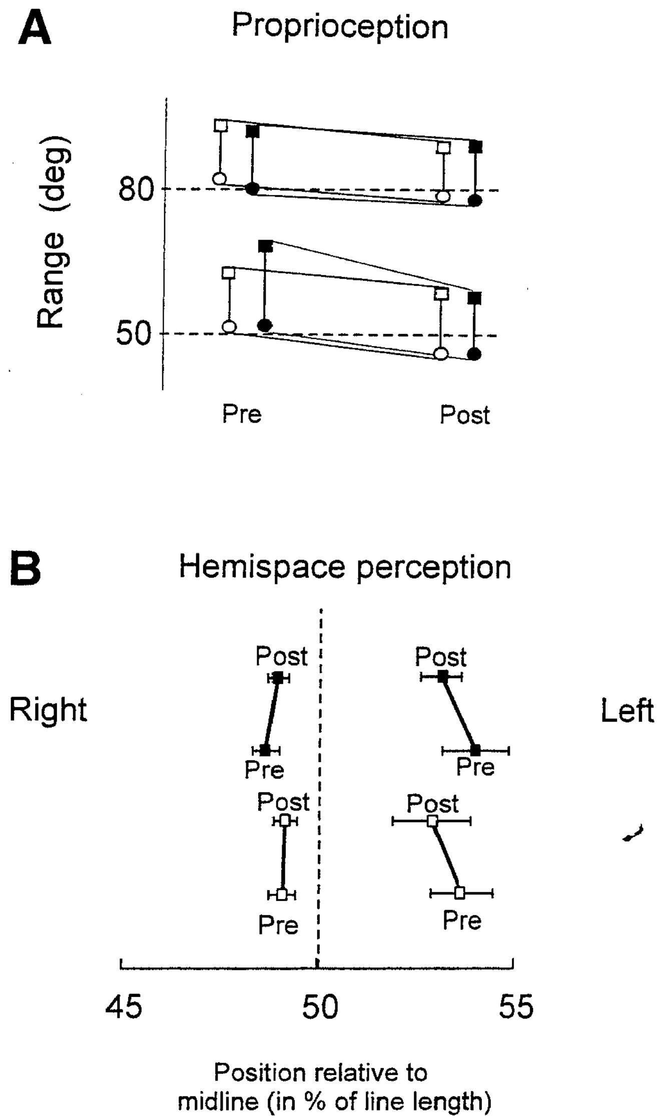


**Fig 5. (A) Range of average distances from the target indicated by the contralateral arm for the 50° and 80° of flexion of the affected elbow, from the smallest average angle response (circles) to the biggest (squares). The width of the range of responses was not significantly different with and without the garment. In both situations, responses were better in the second test after 3 hours (post), with a range of responses overlapping the correct angle. The improvement in accuracy (mean distance from the target, pooling data with and without garment on the 2 angles) was significant ($p = .04$, *t* test). (B) Average site of line bisection for each group of patients: patients with no left neglect syndrome (Right), and patients with neglect syndrome (Left). Performance did not differ with and without garment. In both situations, performance tended to improve in the second test ($p = .08$ for the left neglect, *t* test). (■), garment, (□), no garment.**

**Table 3: Answers to Questionnaire**

| Patient No. | Time Garment Worn (min) | Comfort Rate/10 | Walking | Toileting | Eating | Dressing | Ease of Movement | Confidence in Arm | Would Wear it for Longer Period | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 180 | 9.5 | Better | | No change | Better | Better | | Yes | |
| 2 | 150 | 6.8 | No change | | No change | Better | No change | | Yes | |
| 3 | 240 | 8.5 | Better | No change | No change | | Better | Better | Yes | |
| 4 | 285 | 7.6 | No change | | Better | | Worse (thumb) | | Yes | |
| 5 | 180 | 9.3 | No change | No change | No change | No change | No change | No change | Yes | * |
| 6 | 180 | 9.4 | Better | | Better | No change | Better | Better | Yes | "A little tight" |
| 7 | 165 | 9.2 | Better | | No change | Better | No change | No change | Yes | * |
| 8 | 180 | 6 | No change | No change | No change | No change | No change | Better | Yes | |
| 9 | 180 | 6.5 | No change | Better | Better | Better | Worse | Better | Yes | "Restrictive but more stable" |
| 10 | 180 | 5 | No change | No change | No change | No change | No change | No change | Yes | * |
| 11 | 180 | 9 | No change | No change | Better | | Better | Better | Yes | * |
| 12 | 195 | 4.5 | No change | No change | No change | | No change | No change | Yes | "Too tight" |
| 13 | 270 | 7.5 | No change | | No change | No change | No change | No change | Yes | |
| 14 | 180 | 10 | | | No change | | Better | Better | Yes | |
| 15 | 180 | 5 | Better | | Better | | Better | | Yes | * |
| 16 | 480 | 9.2 | Better | No change | No change | No change | Better | Better | Yes | * |
| Average | 213 (3hr 30min) | 7.7 | 6 Better† 9 same | 1 Better 7 same | 5 Better 11 same | 4 Better 6 same | 2 Worse‡ 7 better 7 same | 7 Better§ 5 same | 100% Yes | |

* Patient spontaneously requested a longer trial with the garment (not a part of the questionnaire).
† Patients indicated that they walked more comfortably.
‡ Patients 4 and 9, who had reported movements to be more difficult, had already made a good motor recovery (see text).
§ Patients reported "greater confidence," mainly those with severely paretic arms.

during the 3-hour trial period. This does not imply that a significant effect would not occur with the garment alone if used daily over an extended period. Nevertheless, the present results suggest that the garment might be improved by also incorporating reinforcement at the elbow by adding plastic boning across the elbow crease to oppose flexor and pronator torque.

### Beneficial Effects of Prolonged Stretch on Spasticity

Of the 10 muscle groups analyzed in the upper limb, the only muscle groups in which we found a differential effect on spasticity between the situations with and without the garment were the wrist and finger flexors. The 2 main physiologic inputs exerted by the garment are stretch on some muscles and cutaneous stimulation from the tight skin contact. The muscles with improved spasticity when wearing the garment were those subjected to the strongest postural effects, ie, the wrist (figs 1, 2) and finger flexors. It is unlikely that this focal decrease in spasticity is caused by the diffuse cutaneous input resulting from contact with the garment because a wider distribution of an antispastic effect would be expected. It is likely that the antispastic effect observed for the wrist and finger flexors in this study was causally related to the tonic stretch that the reinforced garment produced on these muscles because they were opposed by the plastic boning and Lycra.

If this assumption is correct, it reinforces a theoretical point about the factors aggravating spasticity. If a muscle is not released from a shortened posture, a greater degree of spasticity is maintained in the muscle (elbow flexors and pronators in this instance). This is expected given the results obtained in animals on the effects of muscle immobilization in a shortened position on spindle sensitivity.[10-12] The potential influence of muscle shortening on spasticity is also suggested by experimental results from Proske and his group in both animals[26] and humans[27]: a muscle has bigger stretch reflex responses after contraction in a shortened position than after contraction in a lengthened position. We recently verified that this phenomenon also occurs in hemiplegic patients.[28] The fusimotor activity accompanying a voluntary contraction causes actin-myosin bonds to form in intrafusal fibers at the prevailing muscle length. After contraction at short length, muscle spindles become taut when the joint is returned to the midposition and therefore more sensitive to applied stretch. The same mechanism renders spindles slack and less sensitive when the contraction occurs at long muscle length. When muscle contractions are not volitional but occur because of spastic dystonia or pathologic antagonistic cocontractions, the phenomenon of spasticity increase after contractions in shortened position is likely to be similar.

In agreement with classic studies,[29,30] muscle shortening in the acute phase after the paresis caused by central nervous system damage may result from both muscle immobilization and overactivity (spastic dystonia, pathologic antagonistic cocontraction, spasticity). Experimental data[10-12,26-28] and our present observations of selective spasticity reduction at the muscles lengthened during the study period (wrist flexors, finger flexors) are consistent with the hypothesis that muscle shortening may in turn participate in the generation and maintenance of spasticity. If so, this may be a reason for the delay between a stroke and the emergence of spasticity.

### Adverse Effects of the Slings

The increased efficacy on wrist posture observed in patients without a sling may have occurred because most arm slings support the pronated forearm without support for the weight of the hand and passively contribute to increased wrist flexion.

### Potential Value of Decreasing Swelling

To reduce shoulder subluxation in hemiplegia, several support methods have been tried,[31-34] all aimed at decreasing the magnitude of the vertical component of the internal resultant force on the shoulder. Reducing arm weight may also contribute to this endeavor. The effect of the garment on limb swelling was significant at the finger and forearm level but not at the arm level (fig 1). The question may arise whether this statistical significance translates into clinical significance because the changes over 3 hours appear to be small. First, the effects might have been more striking had we measured volume. Second, although we have no quantitative correlation in this study to indicate how much arm weight reduction results from the swelling reduction that we observed with the garment, we assume that weight reduction of the upper limb decreases the vertical force on the shoulder and therefore might minimize subluxation and possibly pain. This mechanism may have accounted for some increase in PROM at the shoulder after only 3 hours and for the comfort reported by the patients.

### The Garment and Hand Function Impairment

Active finger flexion was reduced by an average of 16° (fig 3A). This was noticed by the patients or their occupational therapists; it usually occurred in the patients who had recovered useful upper limb function. Typically, such patients could hold out their arm and partially open the hand, and the antiflexion effect at the fingers was not disadvantageous. Most were impaired by excessive finger flexion when attempting to grasp and release objects. Even so, the garment may be better suited to more severely affected patients or those in early stages of recovery.

It is worth noting that the hindrance to active finger flexion did not translate into better active finger extension. This might have been expected because of the physical characteristics of the fingers, which have small joints with low intrinsic stiffness but are covered by a garment of the same texture and thickness as the rest of the sleeve. Accordingly, the relative increase in passive stiffness conferred by wearing the garment is probably greater at the fingers than at the forearm, where it was calculated to be 30% in rotation in healthy subjects.[17] Therefore, this increased stiffness (also opposing extension) may negate a positive effect of the stretch of finger flexors. However, at the elbow, the muscular forces developed are greater than at the fingers and should more easily overcome the intrinsic garment stiffness. Thus, the trend to improved active supination (fig 3B) was consistent with the antipronation effect reported in healthy subjects wearing similar garments.[17]

### Cutaneous Input From the Garment: Gate Control Effect

A striking observation was the increase in PROM at the shoulder, a joint not covered by the garment (fig 4A). This improvement must be caused by changes occurring distally, but the precise cause cannot be identified. It is conceivable that a regional gate control effect[35,36] was produced at the spinal level by the multisegmental, large-fiber, cutaneous input from the skin to garment contact. This effect may be associated with other factors, such as decreased swelling. The decrease in range of passive finger flexion probably results from the physical interference of the glove. The increased range of passive finger extension is presumably related to a stretch of the finger flexors.

### Comfort and Efficacy in More Severely Affected Patients

One clear study outcome is that the garments were deemed comfortable by the patients. Only 2 patients reported that despite the overall comfort, the garment was "a little restrictive." These patients had already experienced the best recovery from their stroke, with a lack of finger dexterity as the only persistent upper limb deficit. These patients also did not show objective improvement for any parameter. Further analysis of individual results indicated that those patients with a severely affected upper limb consistently benefited most in terms of swelling reduction, postural improvement, ROM increase, and spasticity reduction (data not shown); this was more likely with marked coldness, soreness, swelling, sensorimotor deficit, or limb spasticity. It is in this type of patient that further long-term trials would be worthwhile.

### Improvement of Sensory Perception With Repetition

In the proprioception task, there was a slight but significant improvement between the first and second tests regardless of whether the patients wore the garment. This practice effect after 1 test repetition suggests that sensory perception may be trainable on the affected side in patients with hemiplegia. The alternative is that practice improved performance only in the practiced test rather than for other tasks. The former possibility may have significance for rehabilitation strategies, and further studies are required.

## CONCLUSION

Custom-tailored Lycra garments and glove splints, designed to supinate and extend the elbow and extend the wrist and fingers, are comfortable when worn over 3 hours. In the distal limb, they reduce swelling, improve wrist posture, and reduce wrist and finger flexor spasticity. More proximally, the effects are less marked, with a small improvement in PROM at the shoulder and a trend toward better elbow supination. The garments produce changes that should benefit the most severely affected stroke patients, and a long-term trial in such patients is warranted.

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### Suppliers

a. Polaroid Australia Pty. Ltd., 3rd Floor, 13-15 Lyon Park Rd, North Ryde, NSW, 2113, Australia.
b. Whitehall Manufacturing, PO Box 3527, City of Industry, CA 91744-0527.
c. Perspex, Ballina Fibreglass Supplies, 3/g Piper Dr, Ballina NSW 2478, Australia.
d. SAS Institute Inc, SAS Campus Dr, Cary NC 27513.

## APPENDIX 1: TARDIEU SCALE

Grading is always performed at the same time of the day, in a constant position of the body for a given limb. Other joints, particularly the neck, must also remain in a constant position throughout the test and between tests. For each muscle group, reaction to stretch is rated at a specified stretch velocity with 2 parameters, X and Y.

Velocity of stretch:

V1: As slow as possible (minimizing stretch reflex).
V2: Speed of the limb segment falling under gravity.
V3: As fast as possible (faster than the rate of the natural drop of the limb segment under gravity).

V1 is used to measure the passive range of motion (PROM). Only V2 or V3 are used to rate spasticity.

**Quality of muscle reaction (X):**

0: No resistance throughout the course of the passive movement.
1: Slight resistance throughout the course of the passive movement, with no clear catch at a precise angle.
2: Clear catch at a precise angle, interrupting the passive movement, followed by release.
3: Fatigable clonus (<10 seconds when maintaining pressure) occurring at a precise angle.
4: Infatigable clonus (>10 seconds when maintaining pressure) occurring at a precise angle.

**Angle of muscle reaction (Y):** measured relative to the position of minimal stretch of the muscle (corresponding to angle 0) for all joints except hip, where it is relative to the resting anatomic position.

Adapted from Tardieu's method[5] by Held and Pierrot-Deseilligny.[20]

## APPENDIX 2: PATIENT QUESTIONNAIRE

1. How long did you wear the garment today? ______ hrs
2. How did your arm feel when wearing the garment?

|_|_|_|_|_|_|_|_|_|_|

Extremely uncomfortable — Extremely comfortable

3. Did you notice any change while wearing the garment?

| Please Check: | Worse | No Change | Better |
|---|---|---|---|
| When you are walking | ☐ | ☐ | ☐ |
| In your personal self care: | | | |
| Toileting | ☐ | ☐ | ☐ |
| Eating | ☐ | ☐ | ☐ |
| Dressing | ☐ | ☐ | ☐ |
| In ease of movement (muscle tone) | ☐ | ☐ | ☐ |
| Confidence in your arm | ☐ | ☐ | ☐ |

4. If it was recommended to you, would you wear the garment every day for a few weeks?

No ☐ Yes ☐

Comments ______________________