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# Lycra® arm splints improve movement fluency in children with cerebral palsy

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ABSTRACT

*Aims:* To determine changes in upper limb movement substructures that denote fluency of movement in children with cerebral palsy (CP) following lycra® splint wear. Secondarily, to explore the efficacy of lycra® splints for those with spastic and dystonic hypertonia.
*Design:* Randomised clinical trial whereby participants were randomised to parallel groups with waiting list control.
*Method:* Sixteen children (mean age 11.5 years SD = 2.2) with hypertonic upper limb involvement (13 hemiplegia, 4 quadriplegia) were recruited. Children were randomly allocated either to a control group or to wear the lycra® splint for a period of three months. Three-dimensional (3D) upper limb kinematics was used to assess four functional tasks at baseline, on initial lycra® splint application, three months after lycra® splint wear, and immediately after splint removal. Movement substructures of the motion of the wrist joint center were analysed.
*Results:* A significant difference was observed between baseline and three months of lycra® splint wear in the movement substructures; movement time, percentage of time and distance in primary movement, jerk index, normalised jerk and percentage of jerk in primary and secondary movements. The magnitude of changes in normalised jerk and the percentage of jerk in the primary movement from baseline to three months was greatest in children with dystonic hypertonia.
*Conclusions:* The results indicate that lycra® arm splinting induced significant changes in movement substructures and motor performance in children with CP. This research demonstrates that fluency of movement can be quantified and is amenable to change with intervention.


Cerebral palsy (CP) is a disorder of movement or posture resulting from non-progressive, permanent damage to the immature brain [1]. CP frequently results in impairment(s) of the upper limb including weakness, associated mirror movements, decreased velocity, overactive reflexes, muscular contractures, altered biomechanics, disuse, sensory impairment and hypertonia [2,3].

Hypertonia, may present as velocity-dependant (spastic); non-velocity dependant (rigid); and/or extrapyramidal (dystonic) hypertonia [4]. Functionally, hypertonia can result in prolonged reaction times, decreased velocity, disrupted 'jerky' or 'dysfluent' movement and increased spatial errors [5]. Ultimately, these impairments can lead to dysfunctional voluntary motion.

Upper limb splinting is a therapeutic modality designed to combat hypertonicity for clients with CP [6]. Splints are devices worn on the body with a variety of uses including support; positioning; immobilisation; to prevent contractures and deformities; to aid function; or to reduce spasticity [7]. Dynamic lycra® splints are purported to modify hypertonicity due to the effects of neutral warmth, circumferential pressure and by creating a low intensity prolonged stretch on hypertonic muscles [8], all of which contribute to increased sensory awareness of the involved limb. Lycra® arm splints comprise circumferential lycra segments that are orientated to produce a specific 'direction of pull' [9]. Lycra® arm splints specifically aim to influence hypertonicity, posture and patterns of movement. All of which are expected to result in improved movement performance, particularly fluency or smoothness of movement and to contribute to improved function. However, these expectations have not been experimentally demonstrated.

To date the majority of measures of the fluency of movement employed in clinical outcome studies of children with CP have been qualitative. The Melbourne Assessment of Unilateral Upper Limb Function [10] (Melbourne Assessment) is a criterion-referenced test for children with neurological impairment, in

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which movement fluency is qualitatively assessed as a sub-skill [11]. In this context, fluency is defined as the 'ability of the movement to flow smoothly and freely without jerkiness or tremor' [10] (p. 45), and is used in the assessment of movements involving reaching, grasping, releasing and manipulating objects [11].

Other quantitative measures of fluency include movement units (movement elements), jerk and normalised jerk. A movement unit is defined as an oscillating pattern of an acceleration followed by a deceleration [12]. The lower the number of movement units the greater the control, and therefore fluency of the movement task [13]. It has been reported that adults without a neurological impairment require a single movement unit to perform reaching tasks, whereas people with neurological impairment display multiple movement units performing the same task [13]. Simple upper limb movements in subjects with no known neurological condition can be considered to have two parts—the primary (reflecting the ballistic controlled phase) and secondary movement (reflecting the final corrective phase) [17]. Quantitatively, jerkiness may be described as the rate of change of acceleration or the third time derivative of position, and has been used to denote fluency of upper limb movement [14]. It has been shown that participants with spasticity exhibit greater average jerk in comparison to participants without spasticity [14].

Other measures of movement that have been shown to discriminate between people with and without neurological impairment include movement time [15], directness [14], average jerk [14], and percentage(s) of distance, time and jerk in the primary movement [16].

However, no studies of alterations in movement substructures of upper limb movement following lycra® arm splinting in children with CP have been reported. Therefore, the primary aim of this study is to establish if the movement substructures that contribute to fluency of movement in children with CP are altered as a result of lycra® splint wear. Given that children with hypertonia may present with various movement difficulties, the secondary aim of the study is to compare the effects of lycra® arm splints between children with dystonic and spastic hypertonicity.

## 1. Methods

This study employed a randomised parallel group trial with waiting list control research design. Participants were randomised to one of two groups. Group one ($n = 8$) completed the lycra® arm splint wearing regime for three months, whilst group two ($n = 8$) received no intervention and acted as the control group. Subsequently, group two completed the lycra® arm splint wearing regime for three months, whilst group one wore no arm splint. The study obtained ethical approval from the University of Western Australia and written informed consent was obtained from each participating family.

All participants completed assessments at baseline and across three splinting wearing conditions, initial splint wear, after three months of splint wear, and immediately following splint removal. Data analysed included the control data from the non-splint wearing period of group two ($n = 8$), and the pre-post splint wearing data of the combined cohort ($n = 16$).

### 1.1. Participants

Sixteen children diagnosed with hypertonic CP volunteered to participate in the study, all were aged 8–15 ($m = 11.5$ years $SD = 2.2$). No child had received upper limb Botulinum-A Neurotoxin, or lycra® splinting within the last two years. Eight participants were male and eight female. Three children had quadriplegia and 13 hemiplegia. Ten children had hypertonic responses characterised as spastic, five as dystonic and one as rigid as displayed in Table 1.

### 1.2. Splinting

Second Skin™ lycra® splints are individually custom designed for clients with neurological impairments. They consist of sections of lycra stitched together under tension with a specific direction of pull [18,19]. The inherent properties of lycra® create a low force that resists the hypertonic muscle, whilst also facilitating the antagonist action [20]. The dynamic lycra® arm splint extends from the wrist to the axilla with a zip for easy application. The splint is designed to promote better hand and arm function by addressing postural and tonal issues impacting on the elbow [21] by addressing either pronation–flexion or supination–extension. The pronation–flexion arm splint is designed for clients whose functional performance is limited by strong elbow extension and supination and the supination–extension splint is designed for clients whose performance is limited by strong elbow flexion and pronation [21]. Participants wore their lycra® arm splint, on a single limb, during school hours, approximately 6 h per day, 5 days per week for 3 three months.

### 1.3. Procedures

All participants completed the Melbourne Assessment [10] at each assessment session. The assessment involved performing 16 common upper limb tasks involving: reach, grasp, release and manipulation, all of which a typically developing child of five years can easily complete [10,11,22]. Psychometric studies have indicated that the Melbourne Assessment is a reliable and valid tool for measuring the quality of upper limb movement in children with cerebral palsy [10,22]. Children's performances on the Melbourne Assessment were video recorded and were assessed by an experienced therapist blind to group allocation. The fluency score was determined by the sum of eight fluency sub-skill scores in the assessment.

Three-dimensional (3D) upper limb movement of participants performing four upper limb tasks was collected using a seven-camera Vicon 370 motion analysis system (Oxford Metrics, Oxford, U.K.) operating at 50 Hz. The tasks included: reach forwards, reach forwards to an elevated position, reach sideways to an elevated position and hand to mouth and down. These tasks include the specific components of elbow motion that lycra® splints aim to influence.

Retro-reflective markers were placed on the upper limb and trunk in accordance with that described by Lloyd et al. [23] and Reid et al. [24]. The 3D positions of the markers throughout the movement trials were analysed using a customised model developed with Vicon BodyBuilder® software (Oxford Metrics, Oxford, U.K.). The wrist joint center (WJC) was selected to best reflect movement jerkiness of the distal segment of the upper limb. The WJC was defined as the mid-point between the radial and styloid processes reconstructed relative to the technical coordinate system of the forearm segment. The data were filtered using a Woltring spline with a mean standard square error (MSSE) of 20. Three successful trials of each task were analysed. 3D movement substructures of the WJC were calculated from 3D positional data using a custom written 'Jerk Analysis' computer software (Labview, National Instruments Inc., TX, U.S.A.). Movement substructures and their definitions are presented in Table 2.

### 1.4. Data analysis

As displayed in Table 1, for 13 out of the 16 children the aim of the splint was to externally rotate the shoulder, extend the elbow and supinate the forearm. Child 10 had a forearm pronation design feature incorporated into her splint. Her data were removed from the analysis, and consequently each task involving elbow supination/pronation was conducted with 45 trials (15 subjects × 3 trials). When analysing the data for elbow flexion/extension data from 13 out of the 16 participants were included. Excluded from this sample were participants 2, 8 and 10, as their splints were not designed to promote elbow extension. During the data collection Child 3 sat in a high backed wood foam insert (bilateral thoracic and pelvic supports) with a head-rest and harness in her wheelchair. Data for this child were not included in the data analysis for the thorax, subsequently thorax data were conducted for 45 trials (15 subjects × 3 trials) for each of the five tasks.

Paired $t$-tests were used to evaluate the data of the control period of group two ($n = 8$). To determine equivalence between the groups at baseline ($n = 16$) independent $t$-tests were used. To determine the overall effect of the lycra® arm splints on the dependent variables, repeated measures ANOVAs were conducted to analyse differences between the splinting conditions for the entire cohort of participants with CP ($n = 16$). Each independent variable had four levels ($k = 4$), baseline, immediate splint wear, three months after splint wear and immediate splint removal. The assumptions of normality, homogeneity of variance and sphericity were met for all independent variables. The level of significance was adjusted using a Bonferroni correction and set at $\alpha = 0.01$ for these comparisons. Non-parametric techniques (Mann–Witney $U$-test) were used to analyse the data investigating the effects of lycra® arm splints in sub-populations due to the unequal sample sizes.

## 2. Results

A two-tailed paired $t$-test found no significant difference in normalised jerk ($p = 0.126$) for the control period of group 2, from assessment one ($m = 284$, $SD = 492$) to assessment two ($m = 265$, $SD = 486$). Neither was a significant difference established for percentage of time in the primary movement ($p = 0.505$) over the control period of group two (assessment one $m = 53.80\%$, $SD = 20.96$; assessment two $m = 52.24\%$, $SD = 19.62$).

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Table 1
Participant characteristics.

| ID | Age | Gender | Distribution | Hypertonia | Melbourne score | Aim of splint |
|---|---|---|---|---|---|---|
| 1 | 11.9 | Male | Quadriplegia | Dystonia | 27.05 | Ext rotation, elbow extension, supination |
| 2 | 14.1 | Female | Quadriplegia | Dystonia | 36.89 | Ext rotation, reduce hyperextension, supination |
| 3 | 14.8 | Female | Quadriplegia | Spastic | 39.34 | Ext rotation, elbow extension, supination |
| 4 | 9.1 | Female | Hemiplegia | Spastic | 41.80 | Ext rotation, elbow extension, supination |
| 5 | 10.7 | Female | Hemiplegia | Dystonia | 51.64 | Ext rotation, elbow extension, supination |
| 6 | 14.6 | Male | Hemiplegia | Dystonia | 51.64 | Ext rotation, elbow extension, supination |
| 7 | 14.7 | Male | Hemiplegia | Spastic | 55.74 | Ext rotation, elbow extension, supination |
| 8 | 8.9 | Male | Hemiplegia | Spastic | 55.74 | Ext rotation, neutral elbow, supination |
| 9 | 12.8 | Male | Hemiplegia | Spastic | 55.56 | Ext rotation, elbow extension, supination |
| 10 | 10.9 | Female | Hemiplegia | Rigid | 56.74 | Ext rotation, elbow flexion, pronation |
| 11 | 9.2 | Male | Hemiplegia | Spastic | 57.38 | Ext rotation, elbow extension, supination |
| 12 | 10.6 | Female | Hemiplegia | Spastic | 65.57 | Ext rotation, elbow extension, supination |
| 13 | 10.1 | Female | Hemiplegia | Spastic | 65.57 | Ext rotation, elbow extension, supination |
| 14 | 9.1 | Female | Hemiplegia | Spastic | 67.21 | Ext rotation, elbow extension, supination |
| 15 | 13.0 | Male | Hemiplegia | Dystonia | 76.23 | Ext rotation, elbow extension, supination |
| 16 | 9.1 | Male | Hemiplegia | Spastic | 85.25 | Ext rotation, elbow extension, supination |

A two tailed independent $t$-test found no significant difference in normalised jerk ($p = 0.841$) between baseline values for group 1 ($m = 301$, $SD = 643$) and group 2 ($m = 284$, $SD = 492$). Furthermore, no significant difference was established for percentage of time in the primary movement ($p = 0.080$) between group 1 ($m = 48.85\%$, $SD = 17.83$) and group 2 ($m = 53.80$, $SD = 20.97$).

As the control data demonstrated no change, and group equivalence was established at baseline, data from the entire cohort ($n = 16$) were pooled to establish the effect of lycra® arm splinting on the movement variables.

### 2.1. Qualitative assessment of movement fluency

A two-tailed $t$-test for paired samples indicated that there was no change in fluency sub-skill scores on the Melbourne Assessment between baseline and three months of splint wear ($p = 1.00$) for the entire cohort (Table 3). However, a qualitative review of the 3D trajectories of the WJC appears to demonstrate differences in the pattern of movement from baseline to three months of splint wear, this was consistent across tasks (Fig. 1). Furthermore there was a significant decrease in task movement time whilst wearing the lycra® arm splint compared to baseline ($p = 0.002$) (Table 2).

### 2.2. Changes in movement sub-structures

No significant difference was established for directness index ($p = 0.410$) across the splinting conditions (Table 3), however significant differences were established for normalised jerk across the splint wear conditions ($p = 0.002$) (Table 3). Post hoc analysis established a significant reduction in normalised jerk between:

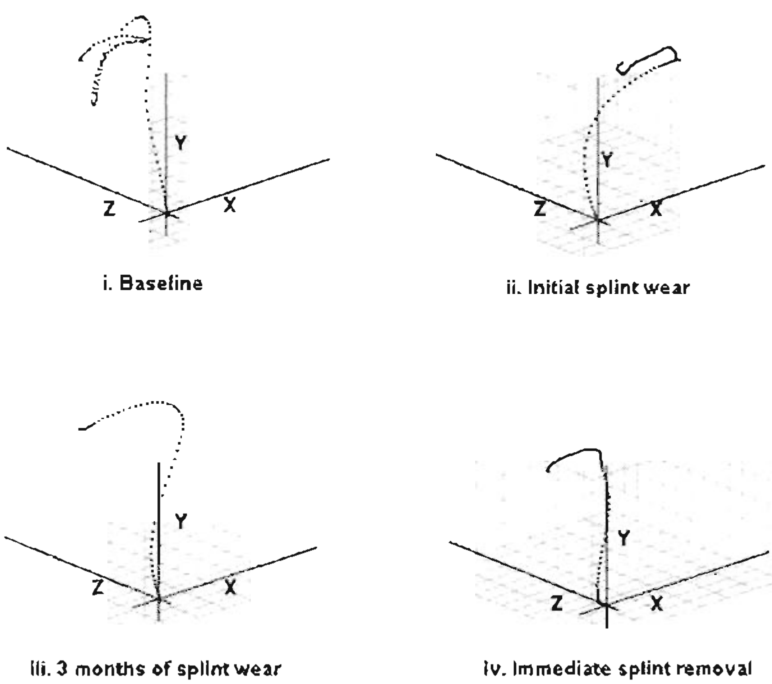


Fig. 1. 3D trajectories for a representative child with cerebral palsy completing the task reach sideways to an elevated target at (i) baseline; (ii) initial splint wear; (iii) following 3 months of splint wear; and (iv) immediately following splint removal.

Table 2
Movement substructures and definitions.

| Movement substructure | Definition |
|---|---|
| Movement time | Sum of the three trials across the four upper limb tasks, given in seconds (s) |
| Directness index | The ratio of actual path of the hand and the theoretical shortest path of the hand (Bernhardt et al. [29]). More direct movements result in a directness index closer to unity. |
| Normalised jerk | Jerk normalised to movement duration and length (Teulings et al. [30]; Thomas et al. [17]; Yan et al. [31]). |
| Primary movement | The initial ballistic movement determined by the maximum slope on the acceleration curve adjusted to the minimum slope on the velocity curve. |
| Percent jerk in the primary movement | Jerk in the primary sub-movement divided by overall movement jerk (Thomas et al. [17]). |
| Percent time in the primary movement | Time to complete the primary movement divided by overall movement time (Thomas et al. [17]). |

baseline ($m = 309$, $SD = 338$) and three months of splint wear ($m = 192$, $SD = 230$), and between baseline and splint removal ($m = 219$, $SD = 352$).

A significant difference was established for the percentage of time in the primary movement ($p = 0.002$). The post hoc analysis established a significant increase the percentage of time in the primary movement from baseline ($m = 49\%$, $SD = 21$) to three months after splint wear ($m = 57\%$, $SD = 23$) (Table 3).

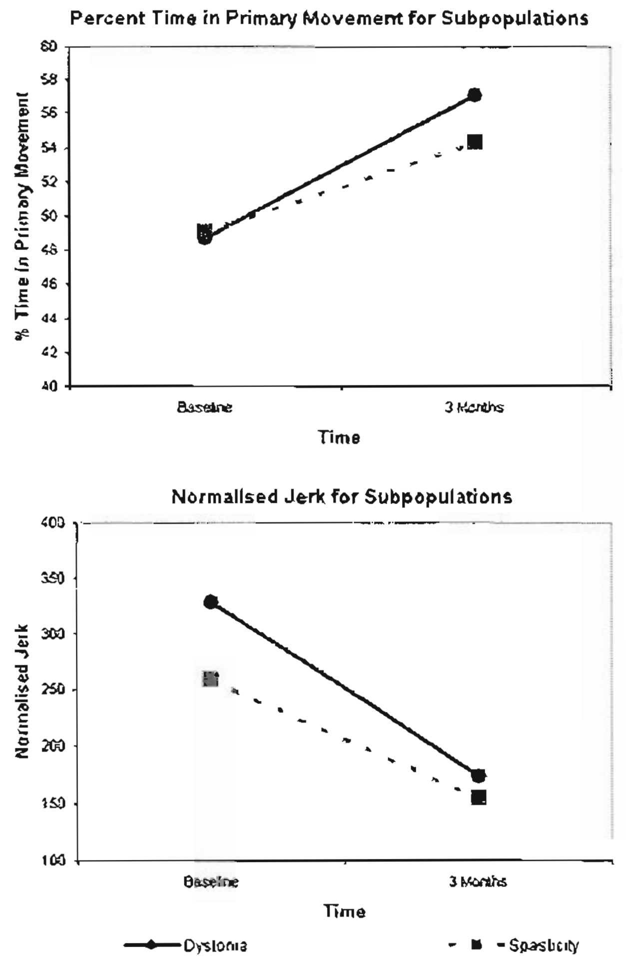


Fig. 2. Change in percentage of time in primary movement and normalised jerk in subpopulations of children with cerebral palsy from baseline to three months of lycra® arm splint wear.

Moreover, significant differences were established for percentage of jerk in the primary ($p = 0.001$) and secondary ($p = 0.001$) movements. Significant increases were established for percentage of jerk in the primary movement between baseline ($m = 56\%$, $SD = 30$) and 3 months of splint wear ($m = 67\%$, $SD = 27$); and between initial splint wear ($m = 57\%$, $SD = 27$) and three months of splint wear (Table 3). Whereas significant decreases in percentage of jerk in the secondary movement were established between baseline ($m = 44\%$, $SD = 30$) and three months of splint wear ($m = 33\%$, $SD = 27$); and between initial splint wear ($m = 43\%$, $SD = 27$) and three months of splint wear (Table 3). It is noteworthy that immediately following splint removal the percentage of jerk in the primary ($m = 59\%$, $SD = 28$) and in the secondary ($m = 40\%$, $SD = 28$) movements progressed nearer the baseline values.

### 2.3. *Movement substructures in sub-populations*

The Mann–Witney *U*-test was used to compare movement jerkiness of children within the different hypertonicity classifications. Children with dystonic hypertonicity returned significantly greater normalised jerk scores at baseline ($p = 0.000$) ($MED = 329$, $RANK = 360$) compared to those with spastic hypertonicity ($MED = 259$, $RANK = 287$). However, at baseline there was no significant difference in percentage of time in the primary movement between children with dystonic hypertonicity ($MED = 48\%$, $RANK = 22$) compared to those with spastic hypertonicity ($MED = 49\%$, $RANK = 21$) ($p = 0.788$).

A two-tailed Wilcoxon signed-ranks test was used to establish changes in movement sub-structures following splint wear for children with dystonic and spastic hypertonicity. A significant increase in percentage of time in the primary movement was established from baseline to three months for both children with dystonic hypertonicity ($p = 0.001$) and spastic hypertonicity ($p = 0.048$) (Fig. 2). In addition a significant decrease in normalised jerk was established between baseline and three months for both children with dystonic hypertonicity ($p = 0.001$), and spastic hypertonicity ($p = 0.016$) (Fig. 2).

## 3. Discussion

Hypertonicity is thought to interfere with the quality of upper limb movement. Dynamic lycra® splints are believed to modify hypertonicity resulting in improved fluency of movement, and enhanced functional performance. The aim of this study was to investigate the effect of lycra® arm splints on the movement substructures that denote movement fluency in children with CP.

The fluency sub-section of the Melbourne Assessment aims to qualitatively assess smoothness of unilateral upper limb movement [10,24]. The results on the fluency sub-scale revealed no

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Table 3
Descriptive statistics of sub-movements across all treatment conditions.

| Movement variable | Baseline | Initial wear | 3 months | Immediate removal | F | p |
|---|---|---|---|---|---|---|
| Melbourne Ax fluency subscale | 54.40% (14.57%) | 54.20% (15.96%) | 55.84% (13.52%) | 55.88% (14.81%) | 0.781 | 1.00 |
| Movement time | 57.03 s (23.18 s) | 51.56 s (22.10 s) | 48.76 s (21.44 s) | 51.03 s (22.68 s) | 5.065 | 0.002 |
| Directness index | 1.68 (1.36) | 1.62 (1.31) | 1.51 (1.06) | 1.53 (0.94) | 0.941 | 0.410 |
| % time in primary movement | 48.76% (21.44%) | 51.56% (22.10%) | 57.10% (23.04%) | 52.32% (20.93%) | 5.149 | 0.002 |
| Normalised jerk | 308.71 (338.27) | 269.63 (398.69) | 191.68 (229.87) | 219.19 (350.96) | 5.052 | 0.002 |
| % jerk in primary movement | 56.40% (30.18%) | 57.24% (27.03%) | 67.14% (27.27%) | 59.60% (28.66%) | 5.813 | 0.001 |
| % jerk in secondary movement | 43.60% (30.18%) | 42.76% (27.03%) | 32.86% (27.27%) | 40.40% (28.66%) | 5.813 | 0.001 |

change across the splinting period. However, this qualitative evaluation of movement jerkiness may lack the sensitivity with which to assess change. Whereas, normalised jerk has been shown to be sensitive and indicative of smoothness of movement and movement efficiency [17]. We found a significant decrease in normalised jerk over the three month splinting period, suggesting that the children's movement was indeed smoother and more efficient. Whilst the data does not reveal a decrease in directness index, there was evidence of a decrease in movement time following three months of lycra® arm splinting for children with CP. One may predict with greater velocity, spasticity would induce greater jerkiness of movement. To the contrary, normalised jerk decreased suggesting that lycra® splints have the potential to impact upon the debilitating effects of hypertonicity on voluntary movement, assisting children to perform activities at increased velocities.

Furthermore, the percentage time in the primary movement improved over the splinting period. The primary movement is considered to be under central control, and essentially 'pre-programmed', whilst the secondary movement relies on sensory feedback and integration [17]. A movement with a proportionally larger primary movement may be regarded as more efficient as it relies less on integration of sensory information. At the baseline assessment, children spent relatively little time in the primary movement, preferring to complete the tasks by relying on several corrective adjustments during the secondary movement. By the completion of three months of splint wear the percentage of time in the primary movement increased, hence the movement is more efficient, and this may be suggestive of increased central control of upper limb movement.

As percentage of time in the primary movement increased so too did the percentage of jerk in the primary movement, whilst, the percentage of jerk in the secondary movement decreased across the splinting period. It is noteworthy that jerkiness of movement increased immediately on removal of the splint. This result mars the suggestion that short term carry over effects of the splint exist. However, it does support the notion that changes in jerk are directly related to the lycra® arm splint itself and not extraneous factors.

The secondary aim of the study was to investigate if the lycra® arm splints resulted in differential effects on movement sub-structures for children of predominately spastic type hypertonicity compared to predominately dystonic type hypertonicity. Previously, Brownlee et al. [25] identified that the children who benefited the most from lycra garments had ataxia or dystonic types of motor disorders.

Significant differences existed for normalised jerk at baseline between the two sub-populations (Fig. 2), whereby children with dystonic hypertonia displayed increased normalised jerk. Whilst, we recognise that the limited group numbers make interpretation difficult, this result is comparable to the clinical presentation of excessive, clumsy, uncoordinated movements during activity for children with dystonia [26]. At the conclusion of three months of splinting normalised jerk had significantly decreased for both groups, resulting in no difference between the sub-populations. These results are in direct opposition to those of Nicholson et al. [27] who reported that for children with spasticity the use of lycra garments resulted in an increase in movement jerkiness.

It appears that children with dystonic hypertonia showed the greatest improvements in movement jerkiness following splinting. Previously it has been reported that lycra garments increased movement smoothness for children with athetosis, ataxia and hypotonia [27,28]. The additional somatosensory information provided when wearing the splint may be of increased benefit to children with dystonic hypertonia who often to have difficulty with movement control through range of motion [4]. It could be viewed that the proprioceptive input provided by the splint improves feedback to the somatosensory system and consequently motor control in children throughout range of motion.

## 4. Conclusions

This study provides clinicians' and therapists with evidence on which to base clinical decisions about lycra® splinting in children with CP. Past research into the efficacy of lycra® splints has been compromised due to the lack of sensitivity of measures to detect clinically significant change in motor function. This research provides unique information about the change in motor patterns and movement substructures in children with CP as a result of lycra® splinting.

Following the wearing of lycra® arm splints for three months, children with CP displayed movements that were faster, more efficient, and required less secondary corrections. This was evident by the significant improvements in movement time, normalised jerk, jerk index, percentage of time and jerk in the primary and secondary movements. Notably, children with dystonia showed the greatest improvements in movement jerkiness with splinting. Combined, these results indicate that lycra® splinting has the potential to improve movement outcomes for children with CP.

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## Conflict of interest

All authors declare no financial and personal relationships with other people or organisations that could inappropriately influence (bias) this work.

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