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Lycra arm splints in conjunction with goal-directed training can improve movement in children with cerebral palsy

Catherine M. Elliott[a,b,c,*], Siobhan L. Reid[c], Jacqueline A. Alderson[c] and Bruce C. Elliott[c]
[a]*Department of Paediatric Rehabilitation, Princess Margaret Hospital for Children, Perth, Australia*
[b]*School of Paediatrics and Child Health, University of Western Australia, Perth, Australia*
[c]*School of Sport Science, Exercise and Health, University of Western Australia, Perth, Australia*

Abstract. *Objectives*: To investigate the effects of lycra® arm splint wear on goal attainment and three dimensional (3D) kinematics of the upper limb and trunk in children with cerebral palsy (CP).
Design: Randomised clinical trial whereby participants were randomised to parallel groups with waiting list control.
Participants: Sixteen children with CP (hypertonia) aged 9 to14 years.
Intervention: Three months lycra arm splint wear combined with goal directed training.
Main outcome measure: Goal attainment scale, and 3D upper limb and trunk kinematics across four upper limb movement tasks.
Results: 17/18 children achieved their movement goals following three months of splinting. Selected joint kinematics improved on immediate splint application. Further improvements in joint kinematics were demonstrated following 3months of splint wear, particularly in elbow extension, shoulder flexion and abduction and in thorax flexion. Only improvements in movement compensations at the thorax remained following removal of the splint.
Conclusions: The lycra® arm splint, made a quantifiable change to the attainment of movement goals of importance to the child. Furthermore, improvements were demonstrated in selected maximum range of movement and joint kinematics during functional tasks at the elbow and shoulder joints and thorax segment in children with CP.

Keywords: Cerebral Palsy, upper limb kinematics, lycra splinting, 3D motion analysis, goal attainment scale

1. Introduction

Cerebral palsy (CP), a disorder of movement and posture resulting from a deficit or lesion of the immature brain [1], is the most common physical disability in childhood [2]. These permanent disorders manifest early in life and are non-progressive although the musculoskeletal effects often change as the child grows [3, 4].

*Corresponding author: Dr. Catherine Elliott, School of Sport Science, Exercise and Health, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia. Tel.: +61 8 6488 2361; Fax: +61 8 6488 1039; E-mail: catherine.elliott@health.wa.gov.au.

Impairments present in children with CP either occur directly, as a result of the brain injury or indirectly as movement compensations. Impairments at the upper limb may include; abnormal muscle tone, contractures, altered biomechanics, weakness, decreased movement velocity, limited muscle synergies and posturing that interferes with every day activities and functioning [5, 6]. The most common posture of the upper limb in children with spastic hemiplegic type CP is a flexed posture at the elbow, wrist and fingers, together with internal rotation at the shoulder and pronation of the forearm resulting in impaired functional performance of the hand and arm [7]. Therapeutic interventions devised to minimise the functional impact of these impairments include splinting, strengthening and positioning [3]. However, it is important to recognise that therapeutic

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interventions aimed at minimising functional impairment should focus on the child's movement goals.

Lycra® arm splints aim to alleviate movement difficulties by reducing tone, improving posture and the co-ordination of synergistic patterns in children with CP. The semi-dynamic splints comprise of a series of segments sewn together in an orientation that produces a low force to resist the spastic muscles, while also facilitating the antagonist muscles [7,8]. The mechanical properties of lycra® arm splints have been established in patients without neurological involvement [9]. Quantitative data suggest that lycra® arm splints can improve resting limb posture in adults with hemiplegia [8]. However, there is a paucity of quantitative data investigating the efficacy of arm splints on children with neurological dysfunction (CP) [10].

Qualitative data regarding the effectiveness of lycra® splinting in children is inconclusive. Corn et al. [11], investigated the impact of lycra® arm and hand splints on upper limb movements and reported inconclusive results using the Melbourne Assessment of unilateral upper limb function [12]. They concluded that either the measure was not sensitive enough to identify change or that lycra® arm splint did not result in significant changes to the quality of upper limb movement [11]. Similarly, Blair et al. [13] reported improved postural stability following 10 weeks splint wear [13], and Knox et al. [14] reported improvements in gross motor function [14], however, this study involved a small sample size ($n = 4$). A recent review by Coghill and Simkiss [10] describing the evidence for lycra arm splinting in children with Cerebral Palsy, concluded that the garments help to improve proximal stability and function in some children, but that the evidence is limited due to the lack of objective outcome measures [10]. These results indicate that assessments with greater accuracy and sensitivity are required to determine the efficacy of splinting in children with CP.

One tool which may be applied to assess the efficacy of splinting is three-dimensional motion analysis (3DMA). 3DMA is a powerful and sensitive tool with which to quantitatively determine movement in all degrees of freedom [15,16]. Motion analysis can provide valuable information about real and compensatory movements used by children with CP at the level of impairment [17]. Three-dimensional motion analysis is often thought of as the 'gold standard' measurement technique to quantify movement, and has been successfully employed in the past to analyse the 3D kinematics of the upper limb in children with CP [17–19].

Similarly, the Goal Attainment Scale (GAS) is a sensitive tool with which to detect discrete changes in movement performance of importance to the child and their family [20]. The GAS is an individualized criterion referenced measure that can be used to assess qualitative changes and small but clinically important improvements in motor development and function [21] The GAS provides a framework for the development of movement or functional goals that are measurable, attainable, and socially, functionally and contextually relevant [22].

The purpose of the study was to determine the efficacy of upper limb lycra arm splinting. It is predicted that splinting will improve upper limb movement performance in four ways;

1. Splint wear will assist children in achieving personal movement goals
2. Splint wear will immediately improve movement
3. Splint wear plus goal directed training will improve movement over three months
4. Improvement in movements will still exist following cessation of splint wear.

2. Methods

2.1. Design

This study employed a randomised parallel group trial with waiting list control research design. Participants were randomised to two groups. Group One ($n = 8$) completed the lycra® arm splint wearing regime combined with goal directed training for three months, whilst Group Two ($n = 8$) completed goal directed training only, thereby acting as the control population. Subsequent to this, Group Two then completed the lycra® arm splint wearing regime combined with goal directed training for three months. The study obtained ethical approval from the University of Western Australia and written informed consent was attained from each participating family. All participants completed assessments at baseline and across three splinting wearing conditions, immediately upon splint application, after three months of splint wear, and immediately upon splint removal.

2.2. Participants

Sixteen children diagnosed with hypertonic CP volunteered to participate in the study, all were aged 8–15 ($m = 11.5$ years SD $= 2.2$). Eight participants were male and eight female. Three children had quadriplegia and 13 hemiplegia. No child had previous upper limb

Botulinum Neurotoxin-A, nor lycra® splinting within the last two years. Ten children had hypertonic responses characterised as spastic, five dystonic and one rigid. Functional ability of the affected upper limb of participants ranged from 27–85 on the Melbourne Assessment of Unilateral Upper Limb Function (Melbourne Assessment) [12].

2.3. Intervention

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 [11, 23]. The inherent properties of lycra® create a low force that resists the hypertonic muscle, while also facilitating the antagonist action [7]. 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 [24] 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 [24]. Participants wore their Lycra® arm splints during school hours, approximately 6 hours per day, 5 days per week. The goal directed training involved active practice of task specific activities related to the child's functional goals. Active practice was incorporated into the child's daily routine taking approximately 25 minutes to complete.

2.4. Procedures

The GAS was administered to all participants at the three assessment time points to measure change at the level of participation. The most frequent categories of goals selected were self care (29%), community, social and civic life (leisure) (33%), domestic life (19%) and mobility (17%) as defined by the International Classification of Functioning (ICF) [25]. Three-dimensional (3D) upper limb movement of participants performing four upper limb tasks were collected using a seven-camera Vicon 370 motion analysis system (Oxford Metrics, Oxford, UK). The tasks included; reach forwards to an elevated position, reach sideways to an elevated position, supination/pronation and hand to mouth. 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 [26] and Reid [17]. The 3D positions of the markers throughout the movement trials were analysed using a customised model developed with Vicon BodyBuilder® software (Oxford Metrics, Oxford, UK). 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.

All baseline assessments were completed with the second skin splint off. The 'immediate splint wear' condition denotes data collected immediately upon splint application, this data was collected at the same assessment session as baseline. The 'three months of splint wear' condition was performed wearing the splint following the three month splinting intervention. Finally, the 'immediate removal' condition was completed directly upon splint removal and data was collected in the same assessment session as the 'three months of splint wear' condition.

2.5. Data analysis

To determine the effects of the splinting on goal attainment the GAS data of the splint wearing period of Group 1 ($n = 8$) was compared to the data of the control period of Group 2 ($n = 8$). To determine equivalence between the groups at baseline ($n = 16$) independent t-tests were used. To determine the effect of the lycra® arm splints on the dependent variables, repeated measures ANOVA's 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. A medium effect size (ES) of 0.5 was also used to establish functional differences between changes over time that were shown to be significantly different.

3. Results

To determine the effects of splinting of goal attainment, the outcomes of the GAS from Group 1, during

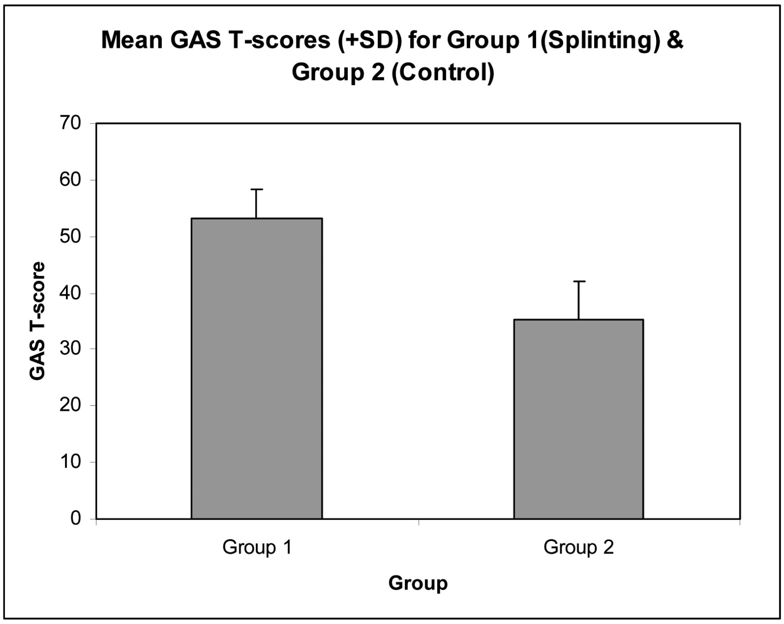

Fig. 1. Mean change in GAS t-scores (+SD) for Group 1 ($n = 8$) across the three months of splint wear, compared to Group 2 ($n = 8$) across the three month control period.

three months of splint wear was compared to that of Group 2 during the control period (Fig. 1). Group 1 mean change in GAS T-scores was 53 (SD = 5.0) as compared to 35 (SD = 6.8) of Group 2. A change score of 50 or more represents the expected change in goal attainment over the three month period. Seven out of the eight children in Group 1 achieved this level of change compared to 1 out of the eight children in Group 2. Therefore, Group 2 displayed little change over the control period.

Baseline equivalence between the groups was determined by comparing the mean score on the Melbourne Assessment [12]. No significant difference ($p = 0.952$) was demonstrated between Group 1 ($m = 56.17$, SD = 17.76) and Group 2 ($m = 56.67$, SD = 14.03) on the Melbourne Assessment. Baseline equivalence was also demonstrated in the mean maximum elbow extension for the functional task 'reach forwards' and maximum supination for the 'pronation/supination' task. Independent sample t-tests show no significant difference between Groups (Group 1 = 134.9° and Group 2 = 138.3°) for maximum elbow extension ($p > 0.05$) and (Group 1 = 2.2° and Group 2 = 0.8°), for maximum supination ($p > 0.05$).

As no change occurred over the control period of Group 2, and there was equivalence between the groups at baseline, the data of the splinting period was collated for the entire cohort ($n = 16$). The change in GAS T-scores for the entire cohort demonstrate that 15/16 children achieved their movement related goals at the completion of 3 months of splint wear. At the conclusion of splint wear children had, on average, achieved a 25% increase in movement proficiency related to their goals. Data for the changes in joint range of motion across the splinting conditions for each task are presented in Tables 1–4.

The immediate effect of the splint was demonstrated in range of supination/pronation in the hand to mouth task which improved significantly ($p < 0.01$), from baseline (34°) to initial splint wear (23° - ES = 0.65) (Table 4). Furthermore, maximum shoulder flexion during the reach forwards task revealed a significant improvement ($p < 0.01$) between baseline (45°) and immediate splint application (50°), although this change only recorded an ES of 0.33 (Table 1). Shoulder abduction in sideways reaching also improved significantly ($p > 0.01$) from baseline (65°) to initial splint application (81°–ES = 0.58) (Table 2). However, no improvements were observed in elbow extension on immediate application of the splint across any task (Tables 1–3).

However, at the completion of three months of splinting combined with goal directed training; many improvements in functional range of motion were observed across the upper limb tasks. In the reach forwards task (Table 1), significant improvements were demonstrated in maximum elbow extension ($p < 0.01$)

Table 1
Mean (SD) joint kinematics and range of motion for variables of interest during the front reach task across the splinting conditions for the entire cohort ($n = 16$)

Front reach task		Splint conditions					
Joint	Angle°	Baseline	Initial wear	3 months wear	Initial removal	F value	P value
Thorax F/E	Max Flex	39.5 (10.1)	38.0 (12.5)	32.7† (7.3)	35.8† (10.0)	4.977*	0.003
	RoM	13.0 (10.4)	12.3 (7.0)	10.1 (8.3)	11.6 (12.6)	0.895	0.446
Shoulder F/E	Max Flex	48.9 (18.4)	61.3† (19.9)	62.1† (17.2)	58.0 (21.6)	5.731*	0.001
	RoM	39.0 (17.3)	47.7 (27.8)	56.4† (31.5)	55.4† (30.4)	4.704*	0.004
Elbow F/E	Max Flex	118.8 SD 16.8	125.3 (21.1)	126.1† (16.5)	118.2 (13.6)	3.491*	0.018
	RoM	42.8 (25.2)	41.5 (24.9)	46.9 (25.3)	46.4 (29.9)	1.117	0.345
Elbow Sup/Pro	Max Pro	27.3 (34.8)	35.9 (23.4)	52.7† (30.4)	44.3 (20.8)	9.140*	0.000
	RoM	31.1 (19.6)	22.3† (15.7)	20.5† (15.5)	30.6 (16.9)	5.843*	0.001

*Alpha < 0.01;
†Significantly different to baseline.

Table 2
Mean (SD) joint kinematics and range of motion for variables of interest during the side reach task across the splinting conditions for the entire cohort ($n = 16$)

Side reach task		Splint conditions					
Joint	Angle°	Baseline	Initial wear	3 months wear	Initial removal	F value	P value
Thorax Lat Flex	Max Lat Flex	−14.4 (11.9)	−12.5 (11.7)	−12.4 (12.6)	−11.4 (10.3)	1.887	0.135
	RoM	19.7 (8.1)	21.8 (8.7)	18.1 (8.2)	19.9 (12.9)	1.804	0.150
Shoulder Abd/Add	Max Abd	64.8 (10.2)	81.3† (46.5)	75.7† (12.3)	68.0 (43.3)	3.755*	0.012
	RoM	36.73 (27.0)	44.0 (18.5)	43.6 (17.1)	41.7 (27.2)	1.143	0.334
Elbow F/E	Max Flex	120.7 (21.8)	125.7 (15.5)	130.1† (15.8)	125.2 (20.5)	3.729*	0.013
	RoM	42.1 (22.3)	48.9 (37.3)	48.8 (24.7)	47.6 (21.7)	1.243	0.298
Elbow Sup/Pro	Max Pro	42.9 (40.5)	42.0 (41.1)	39.5 (41.3)	45.3 (49.8)	0.996	0.397
	RoM	27.2 (15.2)	34.0 (21.4)	37.2 (26.2)	33.7 (19.1)	2.128	0.099

*Alpha < 0.01;
†Significantly different to baseline.

improving from baseline ($m = 118°$) to 3 months of splint wear ($m = 126°$ – ES 0.44). Similarly, elbow pronation improved significantly ($p < 0.01$) over the splinting period from 27° to 53° following three months of wear, equating to an effect size change of 0.78. Shoulder flexion improved significantly ($p < 0.01$) from 45° to 57° at the conclusion of splinting, with an effect size of 0.87. Similarly, total range of shoulder flexion increasing from 39° at baseline to a total of 56° following splinting, a significant improvement ($p < 0.01$) with an effect size of 0.71. Significant improvements were also demonstrated in thorax flexion ($p < 0.01$), decreasing from baseline (40°) to the completion of splinting (33° - ES = 0.78). Small but significant improvements ($p < 0.01$) were also established for thorax rotation, decreasing from 15° to 11° at the conclusion of splinting, an effect size change of 0.50.

For the side reaching task, elbow extension improved significantly ($p < 0.01$) from baseline (120°) to the conclusion of three months of splint wear (130°) which was also shown to be functionally different with an effect size change of 0.5 (Table 2). As too did shoulder abduction, which improved from 65° to 76° following splinting ($p < 0.01$, ES = 0.97).

However, as can be seen in Table 3, no significant improvements in kinematics were observed in the pronation/supination task as a result of splinting. Whilst a trend was evident for improved maximum supination at the conclusion of three months of splint wear (−1.5°) compared to baseline (−13.4°), this trend did not reach statistical significance at the level of $p < 0.01$.

Three months of splint wear also improved functional range of motion during the hand to mouth task (Table 3). Children completed the task with more forearm pronation following splinting (37°) as compared to baseline (23°), a significant improvement ($p < 0.01$), with an effect size of 0.71. Total range of pronation/supination also improved significantly ($p < 0.01$) in the hand to mouth task, improving from 34° to 24° following splinting, with an effect size of 0.53. Finally, maximum thorax extension reduced significantly ($p < 0.01$) across the splinting period from 39° to 34° equating to an effect size change of 0.66.

Not all of these improvements in functional kinematics were maintained immediately following splint removal. During the reach forwards task (Table 1), the

Table 3
Mean (SD) joint kinematics and range of motion for variables of interest during the pronation/supination task across the splinting conditions for the entire cohort ($n = 16$)

Pronation/supination task		Splint conditions					
Joint	Angle°	Baseline	Initial wear	3 months wear	Initial removal	F value	P value
Thorax Lat Flex	Max Lat Flex	−2.0 (11.9)	−2.5 (9.9)	−0.6 (10.5)	−0.4 (11.8)	0.616	0.606
	RoM	11.6 (10.1)	11.5 (8.8)	11.6 (9.8)	13.6 (10.4)	0.594	0.620
Thorax Rotation	Max Rot	−8.2 (11.3)	−11.5 (8.7)	−11.2 (9.9)	−9.2 (13.1)	1.640	0.183
	RoM	6.8 (7.8)	7.3 (5.5)	6.8 (4.6)	9.3 (7.6)	1.736	0.163
Elbow Sup/Pro	Max Supi	−13.4 (54.0)	−28.9 (53.9)	−1.5 (50.7)	−17.2 (28.6)	3.034	0.031
	RoM	29.5 (13.4)	28.5 (22.0)	36.5 (32.0)	32.2 (16.4)	1.171	0.323

Table 4
Mean (SD) joint kinematics and range of motion for variables of interest during the hand to mouth task across the splinting conditions for the entire cohort ($n = 16$)

Hand to mouth task		Splint conditions					
Joint	Angle°	Baseline	Initial wear	3 months wear	Initial removal	F value	p value
Thorax F/E	Max Flex	39.0 (11.9)	38.4 (12.8)	34.2† (7.1)	32.4† (8.0)	7.334*	0.000
	RoM	9.6 (9.4)	9.1 (9.9)	7.5 (5.0)	8.5 (5.9)	0.768	0.514
Shoulder F/E	Max Flex	38.2 (16.3)	35.3 (14.9)	36.5 (14.9)	38.1 (15.3)	0.673	0.569
	RoM	24.5 (14.8)	27.1 (11.8)	29.5 (15.0)	25.9 (17.4)	1.289	0.281
Elbow Sup/Pro	Max Pro	23.1 (20.6)	29.4 (21.2)	36.9† (18.2)	35.8† (23.9)	5.305*	0.002
	RoM	33.7 (16.9)	23.1† (15.9)	24.3† (18.2)	27.5 (18.8)	4.867*	0.003

*Alpha < 0.01;
†Significantly different to baseline.

significant improvements ($p < 0.01$) in total range of shoulder flexion were retained following splint removal (56°) as compared to baseline (39°), equating to an effect size of 0.69. Maximum thorax flexion remained reduced ($p < 0.01$) on immediate splint removal (36°) compared to baseline (40°), during the reach forwards task, with an effect size of 0.78.

Carryover effects were also demonstrated in the hand to mouth task (Table 3). Whereby, maximum pronation remained elevated ($p < 0.01$) following splint removal (36°) as compared to baseline (23°), resulting in an effect size change of 0.57. Similarly, maximum thorax flexion also remained reduced ($p < 0.01$) on immediate splint removal (32°) as compared to baseline (39°), during the hand to mouth task, equating to an effect size of 0.50.

4. Discussion

The aim of this study was to evaluate the efficacy of lycra® arm splinting for children with CP. The results demonstrate that splint wear in combination with goal directed training clearly enabled children to achieve self determined movement goals. At the completion of three months of splint wear a total of 15/16 participants had achieved their personal movement goals, resulting in increases in movement proficiency of greater than 25%. Whilst these changes were evident, goal directed training alone did not demonstrate the same level of improvement toward goal achievement in this group of children. Therefore, the addition of the lycra® arm splint improved goal related movement outcomes for children with CP.

We also assessed the immediate change in movement upon application of a lycra® upper limb splint. Splint wear improved movement immediately, but only in total range of pronation/supination during the hand to mouth task and in maximum shoulder flexion when reaching forwards to a target. Functional elbow extension was not increased during any reaching task and this is one of the main objectives of upper limb splinting for children with CP. These results pertaining to children expand upon those of Gracies et al., who found no short-term benefit of Lycra® splints in adults with hemiplegia [8]. Our results suggest that Lycra® arm splinting is not an isolated short-term therapeutic tool.

To have a more enduring impact on functional movement, our results indicate that Lycra® arm splinting may need to be used in conjunction with movement practice over longer periods of time. The outcome of the 3D motion analysis demonstrated improved performance of elbow pronation (front reach, hand to mouth tasks) shoulder flexion (front reach task) and shoulder abduction (side reach task) following three months of splint wear. Furthermore, significant improvements in elbow extension were evident across the reaching tasks. This outcome provides crucial evidence in support of the main aim of the supination–extension lycra® splint for children with CP, that is to improve range of elbow extension.

The supination–extension lycra splints also aims to provide a prolonged stretch to the supinators through the pull of the fabric. This line of pull is also thought to encourage movement in the direction of supination. However, our results demonstrate no significant improvement in maximum forearm supination following splinting, affirming the results of Gracies et al. [8]. That being said, a trend of improved elbow supination was evident after three months of splint wear. Whilst, the participants still demonstrated significant impairment in active supination, these small gains might be important to their success with functional tasks. At baseline children could achieve $-13.4°$ (pronation), indicating they would have difficulty with tasks requiring greater supination, for example, rising from a chair (10°) or reading a book (7°) [27]. By the completion of three months of splint wear this small improvement in supination ($-1.5°$) would have enabled children to achieve both these functional tasks.

Additionally, unexpected improvements in postural control were demonstrated at the conclusion of the splint wearing period. Previously, Blair et al. [13] have described improvements in postural control following 10 weeks of lycra suit wear, whereby the suit was specifically designed to affect stability at the torso [13]. Our participants displayed decreased thorax flexion (reach front, hand to mouth tasks) following splinting, suggesting less reliance on movement compensations to complete functional tasks. This result indicates that the lycra® arm splint also improves whole body coordination rather than merely affecting movement of the splinted limb in isolation. Taken all together, these outcomes demonstrate that, when combined with goal directed training, longer term splint wear can improve upper limb movement of children with CP.

Whilst these alterations to upper limb kinematics resulted from long term wear of the splint, few of the improvements were evident upon immediate removal of the splint. Improvements in range of movement at the elbow (front reach, side reach and hand to mouth tasks) and shoulder (front and side reach tasks) were no longer apparent once the splint was removed. However, the reduction of compensatory movements remained. This was evident in the significant decrease in thorax flexion in the reach forward and hand to mouth tasks. These data suggest that lycra® splints are most effective when worn, however small carryover improvements in movement compensations may be achieved following splint removal.

Previous assessments of the outcomes of splinting may not have been sensitive enough to detect discrete improvements in movement, nor have they focused on movements that have been meaningful to the child and their families [11]. Discrete alterations in the performance of movement tasks (i.e. 12° increased supination range) may be of great importance in the context of family functioning (i.e. ability to hold a book). New technologies (3D motion analysis) when combined with client centered assessments (GAS) allow clinicians to assess the efficacy of treatment in ways that a meaningful not only to the clinician but to the child and their family.

5. Conclusion

Clinically this research has established that long term wear of lycra® arm splints, when combined with goal directed training, can result in the achievement of movement goals and can have a positive effect on 3D upper limb kinematics in children with CP during selected functional tasks.

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