Effectiveness of hand splints in children with cerebral palsy: a systematic review with meta-analysis

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ABBREVIATIONS

Melbourne	Melbourne Unilateral Upper Limb Function Assessment
QUEST	Quality of Upper Extremity Skills Test
SMD	Standard mean difference

AIM The aim of this review was to determine the effectiveness of hand splinting for improving hand function in children with cerebral palsy (CP) and brain injury.
METHOD A systematic review with meta-analyses was conducted. Only randomized and quasi-randomized controlled trials in which all participants were children aged 0 to 18 years with CP or brain injury and a hand splint (cast, brace, or orthosis) were included.
RESULTS Six studies met the inclusion criteria. No study included participants with a brain injury; therefore, the results relate only to CP. Five studies investigated 'non-functional hand splints' and one investigated a 'functional hand splint'. Moderate-quality evidence indicated a small benefit of non-functional hand splints plus therapy on upper limb skills over therapy alone (standard mean difference [SMD]=0.81, 95% confidence interval [CI]=0.03–1.58), although benefits were diminished 2 to 3 months after splint wearing stopped (SMD=0.35, CI −0.06 to 0.77).
INTERPRETATION In children with CP, hand splints may have a small benefit for upper limb skills. However, results are diminished after splint wearing stops. Given the costs – potential negative cosmesis and discomfort for the child – clinicians must consider whether hand splinting is clinically worthwhile. Further methodologically sound research regarding hand splinting combined with evidence-based therapy is needed to investigate whether the small clinical effect is meaningful.

Cerebral palsy (CP) and brain injury can have devastating effects on children's ability to use their hands.[1] Up to 60% of this population experience substantial difficulties with hand skills,[2] and for this reason it is important for therapeutic approaches to be effective and evidence based. Although there is little published evidence to support the use of hand splints in children with neurological conditions,[3–5] they continue to be widely prescribed in an effort to improve upper limb skills and functional activities.[6] The evidence that is available suggests that hand splints should be provided in conjunction with therapy, although this includes a broad spectrum of conjunct therapies, some of which have not been proven to be effective.[7,8] There is emerging evidence to support the use of motor training interventions to improve upper limb skills in the subgroup of this population with hemiplegia, such as bimanual training[1,9,10] and constraint-induced movement therapy.[1,9,10] In line with the International Classification of Functioning, Disability and Health (ICF) model,[11] the focus of many therapeutic modalities is changing from one based on outcomes in body function and structure to one centred on outcomes in activity and participation that are meaningful to the child and family. Although there have been previous systematic reviews of splinting, there is a need for an updated review because no previous reviews have included a meta-analysis, previous reviews also concurrently evaluated lower limb evidence,[3,4] and new trials have been published since the previous reviews were conducted. Furthermore, the change in therapeutic focus, combined with the need for evidence-based interventions, highlights the importance of reviewing the current evidence to support the use of hand splints in children with CP and brain injury.

CP and brain injury are non-progressive neurological conditions in which children may experience similar physical limitations, including those challenges related to upper limb skills that impact on a child's ability to participate in age-appropriate activities.[3,12] In both of these diagnostic groups, hand splints may be commonly used as a therapeutic modality to assist with developmentally meaningful skills.[3]

Hand splints (also known as orthoses or upper limb splints) are removable external devices designed to support a weak or ineffective joint or muscle.[13] Under the ICF framework, hand splints may be classified as an environmental factor (such as a physical support) influencing the

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overall interaction of ICF domains that can impact on a child's body function and structure as well as on activity and participation. In children with CP and brain injury, a variety of splints made from various materials are used in clinical practice, but with two overarching purposes.

The first type are 'non-functional hand splints', which are designed for the primary purpose of improving outcomes in the body function and structure domain of ICF.[11] For example, 'resting hand splints' are used to prevent or correct muscle contracture[14] or a 'supination cast' can be used to lengthen muscles or inhibit muscle tone. Non-functional hand splints, owing to their physical form, generally interfere with voluntary hand function and are therefore worn either at night or for short periods of time (e.g. 1wk) to achieve a particular goal, for example increased muscle length. Clinicians' views vary about how long these types of splints should be worn. In general, removable splints designed to stretch muscles are prescribed for long-term wear as a contracture preventative measure. However, serial casts designed to stretch muscles are prescribed only for short-term wear so as to minimize adverse events (such as unwanted weakness from immobilization) in the expectation of medium- to long-term muscle length gains after cast removal. A systematic review of the evidence suggests that the use of such splints to maintain or prevent joint mobility is not effective,[15] although this review was across all ages and diagnostic groups, and included few studies specific to upper limb splinting in the paediatric neurological population. Splinting for the purpose of maintaining or preventing joint mobility continues to be utilized as a therapeutic modality for children with neurological conditions, although evidence to support this intervention continues to be unclear.[4,15]

The second type of hand splint are 'functional hand splints', which are designed with the primary purpose of improving outcomes in the activity and participation domain of the ICF,[16] such as handwriting or utensil use during meal times. Functional hand splints are therefore worn during tasks or activities and prescribed to promote optimal functional activities performance via optimal upper limb positioning for task performance.[17] For example, a 'wrist cock-up splint' is designed to stabilize and position the wrist joint during functional activities.[17] Some clinicians treat functional hand splints like 'spectacles' to improve vision, or in this case hand function, whilst being worn. However, other clinicians believe that functional hand splints provide a longer-term training effect and that the gains experienced during splint wearing are eventually generalized and carried over to hand function when the splint is not in use. Insufficient evidence exists to support or refute this accepted wisdom. There is emerging evidence to suggest that functional hand splints may improve goal achievement of functional activities[18] by having an immediate positive effect on upper-limb skills during task performance,[19] although there is limited rigorous evidence available regarding the use of functional hand splints for children with neurological conditions.

What this paper adds

- Non-functional hand splints may provide a small augmenting effect to therapy in children with CP.
- Benefits of non-functional splints are not maintained after splint wearing stops.
- Insufficient evidence exists on whether functional hand splints provide benefits.

The aim of this systematic review was to assess the efficacy of the evidence in regard to the following question: do hand splints lead to improvements in hand function when prescribed for children with CP or brain injury? All outcomes constituting an improvement in hand function were examined, including outcomes in the body function and structure domain as well as the activity and participation domain of the ICF.

METHOD

Selection of articles

Selection of articles was based on the following inclusion criteria: (1) study design was a randomized or quasi-randomized controlled trial, (2) 100% of participants were children aged 0 to 18 years, (3) 100% of participants had a diagnosis of CP and/or brain injury (all phases post injury included), (4) the intervention was a hand splint applied to the upper limb, and (5) studies were excluded if the hand splints were designed to constrain or restrain the upper limb for the purpose of inducing improved upper limb skills in the non-splinted hand. A 'hand splint' encompasses any brace, orthosis, tape, cast, or external device used to position one or more joints of the upper limb (including elbow, wrist, hand, thumb, or fingers). Hand splints applied to the shoulder only were not included in the study. Studies in which hand splints were used in combination with any therapeutic co-interventions were included because this is consistent with literature recommendations about how splints should be used. Handsplint use of any duration and dosage were included. All outcome measures and outcome time-frames were included in the review.

Search strategy

Search terms are listed in Table SI (online supporting information). These terms were used to search the following databases: the Cochrane Controlled Trials Register/CENTRAL (inclusive of MEDLINE and EMBASE), MEDLINE, CINAHL, and PEDro. Hand searches of the reference lists of included studies were carried out to ensure additional relevant references were identified.

Selection of studies

Two independent reviewers reviewed the titles and abstracts of the studies identified using the specified eligibility criteria. Studies that did not meet inclusion criteria were immediately excluded. For all studies that could not be excluded based on the title and abstract (when available), the full text was retrieved and examined by two independent reviewers. Where multiple publications reporting on the same study existed, the relevant data were extracted

and the data from the study reviewed only once. Where necessary, the reviewers corresponded with investigators to gather additional information. The process and results of the search strategy were reported according to PRISMA guidelines.[20]

Quality of studies

Quality of included studies was rated using the PEDro scale[21] (Table I). Where available, PEDro scores were obtained from the PEDro database. Where not available, two independent reviewers rated the studies according to the number of criteria satisfied on the PEDro scale.

Data extraction

Data extracted from each study were tabulated. Two reviewers independently rated all studies for quality and extracted data investigating the effects of hand splints. The interrater reliability of quality ratings was evaluated to assess percentage agreement. In instances where data were not presented in the published paper, raw data were requested from authors.

Data analysis

Randomized controlled trial data were summarized statistically if the data were sufficiently similar and of adequate quality. Where two or more published studies were comparable in terms of type of splint, patient demographics, outcomes, and length of wearing regimen, the data were pooled for meta-analysis using Review Manager software (RevMan5; Cochrane Information Management System). We pooled odds ratios for immediate and carry-over effects separately. A random effects model was used for all analyses as data came from different outcome measures and were not considered homogeneous.

RESULTS

A flow diagram outlining the results of the search strategy is shown in Figure 1. The initial search yielded 798 unique references. Of these, 766 were excluded based on initial screening of the title and abstract (where the abstract was available). Thirty-two full-text articles were reviewed. Twenty-five references were excluded following review of the full text, for reasons including not meeting the criteria for a randomized controlled trial, not all participants being aged 0 to 18 years, and splinting of the upper limb not being the intervention of interest in the study. Seven articles met the inclusion criteria and were included in this review. Two of these articles[18,22] reported on data from the same study; therefore, the data from these two papers was treated as one study, leading to a total of six unique studies being included in this review. These six studies included one study investigating efficacy of functional hand splints[18,22] and five investigating non-functional hand splints.[23–27] All studies met the criteria for level two evidence according to the Oxford Levels of Evidence.[28] The quality of included studies ranged from 3 out of 10[23] to 6 out of 10[25–27] on the PEDro scale, as shown in Table I.

Table I: PEDro ratings for included studies

Citation	Eligibility criteria[a]	Random allocation	Concealed allocation	Baseline comparability	Blind participants	Blind therapists	Blind assessors	Adequate follow-up	Intention to treat	Between group comparisons	Point estimates and variability	Total (out of 10)
Elliott et al.[18,22]	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	5
Kanellopoulos et al.[23]	Yes	Yes	No	No	No	No	No	Yes	No	Yes	No	3
Kitis and Kayihan[24]	No	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Law et al.[25]	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	6
Law et al.[26]	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	6
Ozer et al.[27]	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	6

[a]Criterion 1 does not contribute to the total score.

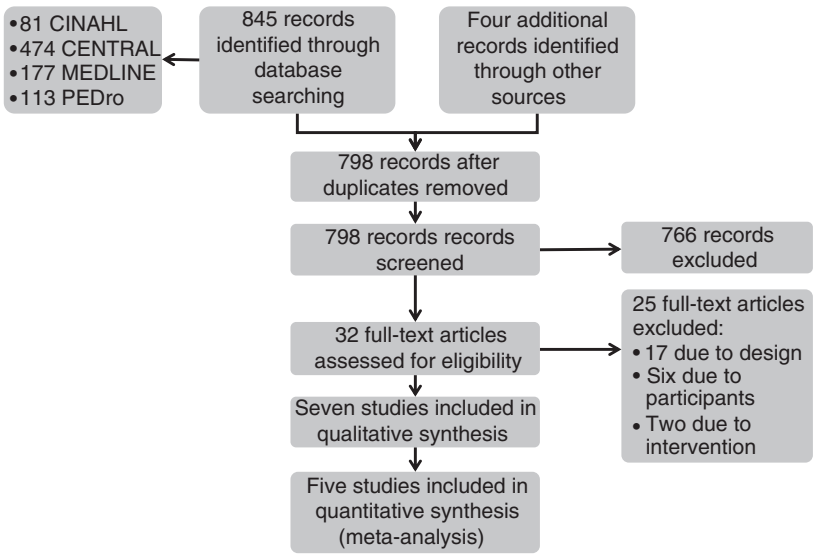

Figure 1: Flow diagram of included studies.

Common reasons for lower PEDro scores included participants and therapists not being blinded to the intervention because it was methodologically impossible to conceal the hand splint (six out of six studies[18,22–27]); analysis was not conducted on an intention-to-treat basis (six out of six studies[18,22–27]); lack of concealed group allocation (five out of six studies[18,22–26]); and assessors not blinded to the treatment group (three out of six studies[18,22–24]). In summary, none of the included studies was completely free from any risk of bias and the most common risk of bias was lack of blinding. However, blinding of participants and raters is almost methodologically impossible to conduct in splinting studies, when the treatment being measured is easily observable and to create safe sham devices is problematic.

An overview of the included studies is shown in Table II. Across the six studies that met inclusion criteria, there were a total of 224 participants. All participants were children with CP, ranging in age from 18 months to 18 years. No included study used participants with a brain injury.

Included studies used a variety of hand splints constructed from different materials, including Lycra splints,[18,22] Johnstone pressure splints,[24] static thermoplastic night splints,[23] bivalved fibreglass casts,[25,26] and dynamic bracing with lockable hinges.[27] Hand splints in the included studies targeted the wrist either in isolation (two out of six studies[25,26]) or in combination with the elbow, thumb, or fingers (four out of six studies[18,22–24,27]). Most studies (five out of six[23–27]) used non-functional hand splints. The study by Ozer et al.[27] used a dynamic splint, which is usually associated with functional hand splinting. However, Ozer et al.[27] used the splint for the purpose of addressing deficits in body function and structure (muscle tone and joint range of motion) and the splint was not worn during the performance of a functional activity. The splint of Ozer et al. was therefore categorized as a non-functional hand splint. Only one study (reported across two papers: Elliott et al.[18,22]) used a functional hand splint.

All six included studies[18,22–27] measured changes from hand splinting in the body function and structure domain, and half of the studies also measured changes in the activity and participation domain (three out of six studies[18,24,26]). The decision about whether an assessment measured outcomes in the body function and structure domain or the activity and participation domain of the ICF was determined from literature where published evidence existed.[29,30] This is not a simple classification to apply because some tools measure constructs that span across both the body function and structure domain and the activity and participation domain of the ICF. For example, the Melbourne Unilateral Upper Limb Function Assessment (Melbourne) and the Quality of Upper Extremity Skills Test (QUEST)[29] predominantly measure body function and structure, with a small number of items that measure activity and participation. Since the tools are not designed to be analysed at the item level, but rather by subtest or total score, we were unable to tease the data apart for analysis of separate ICF domains and, therefore, needed to report the data by the most predominant ICF domain treated. It is conceivable that gains reported from studies using these measures may also have an impact at the activity and participation level, but it is not possible to be methodologically certain. Body function and structure outcome measures included range of motion, 3D motion analysis, QUEST, Melbourne, the Ayres Southern California Sensory Integration Scale, the modified Ashworth Scale, the Peabody Developmental Motor and Activity Scales, and grip and pinch strength (dynamometry). Outcomes at the activity and participation level included the Goal Attainment Scale, the Functional Independence

Measure, the Canadian Occupational Performance Measure, and the Jebsen–Taylor Test of Hand Function. The finding that outcome measures in the activity and participation domain primarily measured activity, not participation, is an important finding. It is unclear whether the omission of evaluation of participation is a result of the lack of sensitive participation outcome measures available at the time these trials were published or whether researchers failed to prioritize evaluation of participation, despite the importance of participation outcomes to the child and family.

Consistent with literature assumptions about splinting, all studies investigated the use of hand splints in conjunction with therapy. Conjunct therapy included approaches targeting outcomes in the activity and participation domain of the ICF such as goal-directed training,[18,22] and also approaches targeting outcomes at the body function and structure domain of the ICF, such as neurodevelopmental therapy,[24–26] botulinum toxin A,[23] electromyographic feedback,[24] and neuromuscular electrical stimulation.[27] Elliott et al.[18,22] were the only authors to use a motor training approach (goal-directed training) as a conjunct therapy. Treatment time-frames of included studies ranged from 3 to 6 months of splint wearing, and follow-up beyond the splint wearing ranged from 0 to 6 months.

There were an adequate number of studies (four out of six[23,25–27]) that were sufficiently homogeneous in regard to the purpose of the splint, participants, and outcome measures in order to conduct two meta-analyses addressing (1) the immediate effect of non-functional hand splints on upper limb skills after 3 to 6 months of splint wear (Fig. 2a); and (2) the carry-over effect of non-functional hand splints on upper limb skills after splint wearing stopped (Fig. 2b). While the wearing regimens differed slightly, they were all considered consistent with standard clinical practice and, therefore, substantially homogeneous enough for meta-analysis.

Immediate effects of splinting in cerebral palsy

Data from outcome measures related to body function and structure improvements in upper limb skills were used in the meta-analysis, as these types of tools were utilized across all studies, in the form of either the Melbourne or QUEST. Data from Kitis and Kayihan[24] were published in such a way that they could not be inputted into RevMan5 for meta-analysis and alternative, more detailed data were not contributed by the authors in response to written correspondence. For this reason, data from this study could not be included in the meta-analysis. The four-group study by Law et al.[25] compared hand splints plus therapy at two different intensities with therapy alone at two different intensities. To deal with this within the meta-analyses, the study by Law et al.[25] was treated as two sub-studies: sub-study one compared hand splint plus high-intensity therapy with high-intensity therapy alone; and sub-study two compared hand splint plus regular-intensity therapy with regular-intensity therapy alone. The study by Elliott et al.[18,22] was not included as it studied the effect of functional hand splints. For the purposes of this article, the purpose of a functional hand splint is different from that of a non-functional splint and thus the data relating to these two types of splint are not considered sufficiently homogeneous to be combined for meta-analysis. There were four studies[23,25–27] with a total of 158 participants that provided data regarding the effect of non-functional hand splints on upper limb skills immediately following splint removal (Fig. 2a). A total standard mean difference (SMD) value of 0.81 (95% confidence interval [CI]=0.03–1.58) favoured the hand splint plus therapy group over the therapy alone group. The confidence interval crossed below the zero line (line of no effect) in three out of five[23,25,26] studies and in the study by Law et al.[25] almost touched the zero line. The study by Ozer et al.[27] (which had a small number of participants) was the only study that strongly favoured the splint group. The I^2 statistic was 78% (χ^2=18.48), indicating a high level of heterogeneity among included studies, which was markedly affected by the outlying and underpowered Ozer et al. study. The QUEST data from Kanellopoulos et al.[23] accounted for 20.4% of the overall result, with an SMD of 0.58 (CI −0.32 to 1.48). The QUEST data from Law et al.[25] accounted for 23.3% of the overall results, with an SMD of 0.74 (CI 0.07–1.41). The QUEST data from Law et al.[25] accounted for 23.3% of the overall result, with an SMD of 0.13 (CI −0.53 to 0.80). The QUEST data from Law et al.[26] accounted for 24.6% of the overall results, with an SMD of 0.23 (CI −0.32 to 0.79). The Melbourne data from Ozer et al.[27] accounted for 8.4% of the overall result, with an SMD of 5.08 (CI 2.83–7.33).

Carry-over effects of splinting in cerebral palsy

Three studies,[25–27] involving a total of 138 participants, provided data on the maintained effect of splinting plus therapy beyond the splinting period, compared with therapy alone, as shown in Figure 2b. The study by Kanellopoulos et al.[23] was excluded from the meta-analysis as no follow-up data were provided. The follow-up closest to 3 months beyond the treatment period was chosen, as this was the most consistent follow-up time-frame reported across included studies. The included studies reported two sets of data at 3 months' follow-up[25,27] and one set of data at 2 months' follow-up.[26] There was greater homogeneity among studies included in the meta-analysis on the maintained effect of splint use (χ^2=4.29; I^2=30%), which showed a diminished and possibly transient effect (SMD=0.35, CI −0.06 to 0.77) of splint use on upper limb skills 2 to 3 months after splint removal. Notably, the confidence interval drops below zero, indicating imprecision in the estimate of this effect. Law et al.[25] accounted for 25.4% of the overall result, with an SMD of 0.97 (CI 0.28–1.65). Law et al.[25] accounted for 26.6% of the overall result, with an SMD of 0.05 (CI=−0.61 to 0.72). Law et al.[26] accounted for 33.3% of the overall result with an SMD of 0.21 (CI −0.35 to 0.77). Ozer et al.[27] accounted for 14.7% of the overall results with an SMD of 0.16 (CI −0.83 to 1.14).

Table II: Overview of included studies

Author	Study design	Participants			Total *n* groups	Interventions
		n	Age	Diagnosis		
Elliott et al.[18,22]	RCT with crossover	16	9–14y	CP	2	Group 1: Lycra functional splint+goal-directed training. Group 2: goal-directed training (crossed over after 3mo but GAS data not analysed)
Elliott et al.[22,a]						
Kanellopoulos et al.[23]	RCT	20	2y 6mo–12y	CP, hemiplegia	2	Group 1: BoNT-A+static night splint+OT. Group 2: BoNT-A+OT
Kitis and Kayihan[24]	RCT	38	5–12y	CP, hemiplegic	2	Group 1: NDT+EMG biofeedback. Group 2: NDT+UL pressure splint
Law et al.[25]	RCT. Two-by-two factorial design	76	18mo–8y	CP	4	Group 1: intensive NDT (OT 45min 2 times/wk and 30min daily home programme)+cast. Group 2: regular NDT (OT weekly+15min daily home programme)+cast. Group 3: intensive NDT (OT 45min 2 times/wk+30min daily home programme). Group 4: regular NDT (OT weekly+15min daily home programme)
Law et al.[26]	RCT with cross over	50	18mo–4y	CP	2	Group 1: NDT (45min 2 times/wk+3min daily home programme)+cast. Group 2: Regular OT (maximum 1 session/wk, minimum 1 session/mo)
Ozer et al.[27]	RCT	24	3y–18y	CP, hemiplegia	3	Group 1: NMES+static night brace. Group 2: dynamic bracing+static night brace. Group 3: NMES+dynamic bracing+static night brace

[a]Elliott published two papers including the same patients; in accordance with meta-analysis conventions, only one study was included, but data were extracted from both papers to ensure comprehensive findings. RCT, randomized control trial; CP, cerebral palsy; GAS, Goal Attainment Scale; BS&F, body structures and functions; AROM, active range of motion; A&P, activity and participation; Melbourne, Melbourne Unilateral Upper Limb Function Assessment; BoNT-A, botulinum toxin A; QUEST, Quality of Upper Extremity Skills Test; OT, occupational therapy; NDT, neurodevelopmental therapy; EMG, electromyography; MAS, Modified Ashworth Scale; ASCSIS, Ayres Southern California Sensory Integration Scale; FIM, Functional Independence Measure; JTTHF, Jebsen–Taylor Test of Hand Function; Peabody, Peabody Developmental Motor and Activity Scales; COPM, Canadian Occupational Performance Measure; NMES, neuromuscular electrical stimulation.

Splint					
Type	Construction	Joints splinted	Wearing regime	Outcome measures	Results
Functional splint based upon neurophysiological theory	Custom-fitted Lycra garment	Elbow and wrist	6h/d 5 times/wk for 3mo	BS&F: AROM. A&P: GAS	GAS improved in both groups but favoured Lycra splinting+goal-directedtraining during splint wear. AROM improved for supination, shoulder forward flexion and shoulder abduction but not elbow extension (during splint wear). Authors conclude splints should be used in combination with motor training
				BS&F: 3D movement analysis, Melbourne	No improvement in fluency on the Melbourne from splint wear; however, 3D analysis detected a decrease in normalized jerk and an increase in speed of task performance from splint wear. Both dystonic and spastic subgroups improved their normalized jerk scores and task performance speed, but there was no statistical differences between the groups
Non-functional	Thermoplastic	Wrist, thumb and fingers	Nightly for 6mo	BS&F: QUEST	No differences between groups at 2mo, both improved; but statistically significant difference between QUEST scores at 6mo post injection favouring BoNT-A+splint group
Non-functional	Inflatable	Elbow and wrist	3d/wk (50min) for 3mo	BS&F: MAS, ASCSIS. A&P: FIM, JTTHF	Both groups showed significant improvement at 3mo and 6mo on the MAS, ASCISIS and components of the FIM and JTTHF. Greater improvements favouring EMG biofeedback group
Non-functional	Bivalved cast	Wrist	Minimum of 4h daily for 6mo	BS&F: Peabody, QUEST	No difference in hand function on the Peabody between groups. QUEST scores improved significantly at 6mo only in favour of the casting groups. PROM improved and favoured the casting groups
Non-functional	Fibreglass bivalve cast	Wrist	Minimum 4h daily for 4mo	BS&F: Peabody, QUEST. A&P: COPM	No difference between groups on Peabody, QUEST and COPM: both groups showed significant improvement
Non-functional	Metal with lockable hinge at elbow, wrist and fingers	Elbow, wrist, thumb and fingers	Two 30min sessions daily for 6mo	BS&F: grip and pinch strength (dynamometer), Melbourne	Statistically significant improvements on the Melbourne and grip strength at 3–7mo favouring NMES+brace group. This effect was not maintained at 9mo

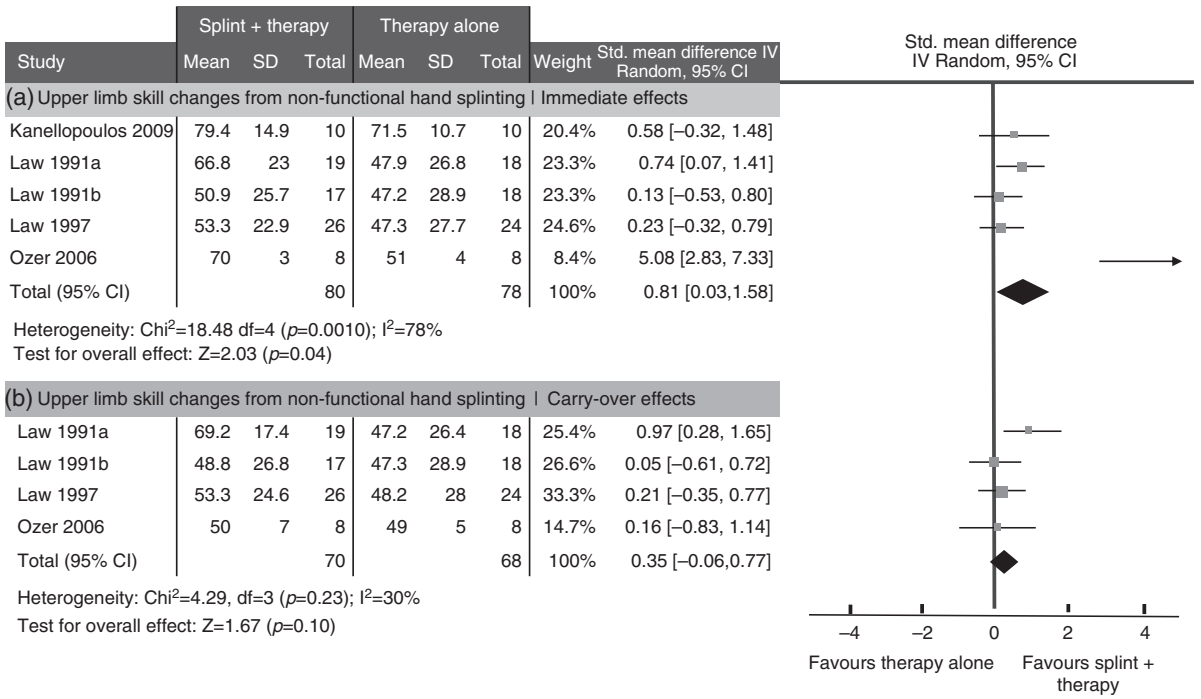

Figure 2: Forest plot of immediate and carry-over effects of hand splinting on upper limb skills.

DISCUSSION

The aim of this review was to evaluate the current level of evidence regarding the use of upper limb hand splints for children with CP and brain injury; however, no study regarding brain injury and splint use was found. The major findings of this review suggest that, in CP, hand splints may have a very small positive effect on upper limb skills when combined with therapy; however, this effect is diminished and possibly not maintained at 2 to 3 months after splint removal. The body of evidence supporting the effectiveness of hand splinting was graded as of moderate quality, i.e. further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.[31] Splinting continues to be mainstream practice in this population, and clinicians may need to consider these findings, combined with the impact of splint use on a child and their family,[32,33] as well as healthcare costs associated with splint provision, when making decisions regarding the use of hand splints. Although splinting is a core area of practice, this review could locate only six trials regarding splint use, only one of which investigated the use of a functional splint. Consistent with previous studies,[3–5,34,35] the findings support the need for further methodologically sound research regarding the effectiveness of upper limb hand splints to improve outcomes for children with CP and brain injury.

A meta-analysis of four studies regarding the effect of hand splints plus therapy on upper limb skills immediately following splint removal showed a slight trend in favour of the splint group. In practice, this positive effect may lead to a very small improvement (e.g. one additional point score on an assessment of upper limb skills such as the QUEST or Melbourne) for children with CP receiving a splint plus therapy, compared with children receiving therapy alone. Included studies were of variable quality, some with very large confidence intervals, and there was significant heterogeneity. For this reason, clear conclusions regarding the effectiveness of non-functional hand splints on upper limb skills cannot be drawn. Furthermore, findings regarding the use of non-functional hand splints are difficult to interpret as included studies provided co-interventions that may no longer be recommended for use,[7,8] or that are yet to be proven effective[36] in this population. Outcomes may be different if studies had combined hand splints with modern practices in therapy, such as task-specific or motor training-based interventions.

A meta-analysis of three studies looking at the carry-over effect of hand splints on upper limb skills in children with CP 2 to 3 months post splint removal indicated no difference between splint plus therapy group and the therapy alone group, indicating that there is little ongoing effect of hand splints once the splint is removed. This highlights an important consideration regarding the ongoing effect of interventions, and whether splint use is the most effective upper limb intervention for children with CP when considering long-term outcomes. It is particularly important to consider the lasting effects of interventions in regard to the impact of splint use on the children and their family[37] and in light of alternative therapeutic interventions whose long-term effects are supported by evidence.[9,10]

In all studies, hand splints were used in combination with an additional intervention. Clinicians should therefore be aware that there is no evidence to support the use of

upper limb hand splints for children with CP in isolation. Findings from the trial by Elliott et al.[18,22] supported the use of upper limb hand splints in conjunction with goal-directed training. There is increasing evidence to support the use of treatments such as goal-directed training[9,38,39] and other motor training interventions such as bimanual therapy[1,9,10,40] and constraint-induced movement therapy.[1,9,16] Importantly, these motor training interventions have been shown to lead to improved goal achievement and functional outcomes and have also demonstrated a lasting effect beyond the treatment period.[9,10]

There exists a significant gap in the evidence regarding the use of functional hand splints for children with CP, designed with the primary purpose of improving performance in activities and participation tasks. Preliminary investigations support a small, immediate benefit of functional hand splints;[18,19,22,41–43] however, further research of high methodological quality is required. Given the theoretical basis of functional hand splints, which may be in contrast to that of motor training, future studies should investigate the relationship between these common treatments for children with CP and brain injury. Functional hand splints are based on biomechanical principles, i.e. they are designed to support a joint in a biomechanically advantageous position in order to improve functional activities performance.[14] This, in effect, may also produce the unwanted effect of inhibiting joint movement, and therefore muscle activity. By inhibiting muscle activity, a functional splint may limit the capacity of the child to maximize recovery by engaging neural pathways, one of the theoretical underpinnings of motor training. Motor training incorporates active use of the upper limb and is underpinned by principles of motor learning and neuroplasticity.[44] As suggested above, there is emerging evidence to support the use of motor training with the present population;[16,35,39] however, the relationship between upper limb motor training and functional splint use is not yet known.

Consistent with previous studies, we found that many upper limb interventions address deficits in the body function and structure domain of the ICF model;[35] however, it has been suggested that the emphasis of therapy is changing to focus on outcomes in activity and participation.[45] Recent studies question the direct correlation between changes at body function and structure to changes in activity and participation, suggesting that a higher-order improvement or effect should not be assumed.[46] Although therapeutic interventions targeted at body function and structure may indeed be warranted,[47,48] therapists need to consider the outcomes their interventions are targeting and develop a treatment plan to address these. Consistent with this model of service provision, there continues to be increasing support for the value of therapy that is directed by the goals and functional outcomes relevant to an individual, within the broader context of the child and family.[6,45,47]

The limitations of this review include the small number of studies that met inclusion criteria and the variable methodological quality of these studies. There was a high level of heterogeneity among included studies. This, combined with the risk of bias in included studies, makes it difficult to draw clear conclusions regarding the effectiveness of hand splints for this population. The findings of this review must, therefore, be interpreted with these limitations in mind.

Further research is needed to determine if the small clinical effect that may be gained through splint use is worthwhile to a child and family, in light of the commitment that splint use may require. Research investigating the use of functional hand splints is particularly lacking, and further methodologically sound studies investigating these commonly prescribed hand splints are needed. Future studies should use sound research methods, larger participant numbers, and measures that have been shown to be sensitive to meaningful change[30] and that represent client-centred outcomes. Whether age is a predictor of success should also be considered. Furthermore, the long-term effects of splint use for this population needs to be investigated, and may be better understood through the use of long-term diagnostic registers such as the Swedish population-based healthcare programme,[48] rather than research studies that are time limited.

CONCLUSION

This review found a small trend favouring splint plus therapy over therapy-alone, based on moderate-quality evidence. Importantly, the benefits were diminished and possibly not even maintained 2 to 3 months after the splint was no longer worn. Further methodologically sound research, particularly investigating the use of functional hand splints, is needed to determine whether this small clinical effect leads to meaningful improvements for children with CP. Clinicians should consider whether upper limb splint use is the most effective intervention for this population, within the context of the child and family, to lead to meaningful long-term outcomes.

SUPPORTING INFORMATION

The following additional material may be found online.

Table SI: Search terms.

REFERENCES

1. Sakzewski L, Ziviani J, Boyd R. Systematic review and meta-analysis of therapeutic management of upper-limb dysfunction in children with congenital hemiplegia. *Pediatrics* 2009; **123**: e1111–22.
2. Arner M, Eliasson AC, Nicklasson S, Sommerstein K, Hägglund G. Hand function in cerebral palsy. Report of 367 children in a population-based longitudinal health care program. *J Hand Surg Am* 2008; **33**: 1337–47.
3. Teplicky R, Law M, Russell D. The effectiveness of casts, orthoses, and splints for children with neurological disorders. *Infants Young Child* 2002; **15**: 42–50.
4. Autti-Rämö I, Suoranta J, Anttila H, Malmivaara A, Mäkelä M. Effectiveness of upper and lower limb casting and orthoses in children with cerebral palsy: an overview of review articles. *Am J Phys Med Rehabil* 2006; **85**: 89–103.
5. Morris C, Bowers R, Ross K, Stevens P, Phillips D. Orthotic management of cerebral palsy: recommendations from a consensus conference. *NeuroRehabilitation* 2011; **28**: 37–46.
6. Wilton J. Casting, splinting, and physical and occupational therapy of hand deformity and dysfunction in

cerebral palsy [corrected] [published erratum appears in *Hand Clin* 2004; **20:** 227]. *Hand Clin* 2003; **19**: 573–84.

7. Brown GT, Burns SA. The efficacy of neurodevelopmental treatment in paediatrics: a systematic review. *Br J Occup Ther* 2001; **64**: 235–44.
8. Butler C, Darrah J. Effects of neurodevelopmental treatment (NDT) for cerebral palsy: an AACPDM evidence report. *Dev Med Child Neurol* 2001; **43**: 778–90.
9. Sakzewski L, Ziviani J, Abbott DF, MacDonell RAL, Jackson GD, Boyd RN. Randomised trial of constraint-induced movement therapy and bimanual training on activity outcomes for children with congenital hemiplegia. *Dev Med Child Neurol* 2011; **53**: 313–20.
10. Gordon AM, Hung Y-C, Brandao M, et al. Bimanual training and constraint-induced movement therapy in children with hemiplegic cerebral palsy: a randomized trial. *Neurorehabil Neural Repair* 2011; **25**: 692–702.
11. Rosenbaum P, Stewart D. The World Health Organization International Classification of Functioning, Disability, and Health: a model to guide clinical thinking, practice and research in the field of cerebral palsy. *Semin Pediatr Neurol* 2004; **11**: 5–10.
12. Chevignard M, Toure H, Brugel DG, Poirier J, Laurent-Vannier A. A comprehensive model of care for rehabilitation of children with acquired brain injuries. *Child* 2010; **36**: 31–43.
13. Fess EE. A history of splinting: to understand the present, view the past. *J Hand Ther* 2002; **15**: 97–132.
14. Lannin N, Lannin NA, Ada L. Neurorehabilitation splinting: theory and principles of clinical use. *NeuroRehabilitation* 2011; **28**: 21–8.
15. Katalinic Owen M, Harvey Lisa A, Herbert Robert D, Moseley Anne M, Lannin Natasha A, Schurr K. Stretch for the treatment and prevention of contractures. *Cochrane Database Syst Rev* 2010; **9**: CD007455.
16. Hoare Brian J, Wasiak J, Imms C, Carey L. Constraint-induced movement therapy in the treatment of the upper limb in children with hemiplegic cerebral palsy. *Cochrane Database Syst Rev* 2007; **2**: CD004149.
17. Lannin Natasha A, Novak I. Occupational Therapy & Physical Dysfunction: Enabling Occupation. In: Curtin M, Molineaux M, Supyk J, editors. Orthotics for Occupational Outcomes, 6th edn. London: Elsevier, 2010: 507–26.
18. Elliott CM, Reid SL, Alderson JA, Elliott BC. Lycra arm splints in conjunction with goal-directed training can improve movement in children with cerebral palsy. *NeuroRehabilitation* 2011; **1**: 47–54.
19. Louwers A, Meester-Delver A, Folmer K, Nollet F, Beelen A. Immediate effect of a wrist and thumb brace on bimanual activities in children with hemiplegic cerebral palsy. *Dev Med Child Neurol* 2011; **53**: 321–6.
20. Moher D, Liberati A, Tetzlaff J, Altman DG. Reprint – Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Reprinted with permission from the Annals of Internal Medicine from Mother D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Phys Ther* 2009; **89**: 873–80.
21. Macedo LG, Elkins MR, Maher CG, Moseley AM, Herbert RD, Sherrington C. There was evidence of convergent and construct validity of Physiotherapy Evidence Database quality scale for physiotherapy trials. *J Clin Epidemiol* 2010; **63**: 920–5.
22. Elliott C, Reid S, Hamer P, Alderson J, Elliott B. Lycra (®) arm splints improve movement fluency in children with cerebral palsy. *Gait Posture* 2011; **2**: 214–9.
23. Kanellopoulos AD, Mavrogenis AF, Mitsiokapa EA, et al. Long lasting benefits following the combination of static night upper extremity splinting with botulinum toxin A injections in cerebral palsy children. *Eur J Phys Rehabil Med* 2009; **4**: 501–6.
24. Kitis A, Kayihan H. Comparison of EMG biofeedback and Johnstone pressure splints in children with hemiplegic cerebral palsy [in Turkish]. *Turk J Phys Med Rehabil* 2010; **56**: 116–23.
25. Law M, Cadman D, Rosenbaum P, Walter S, Russell D, de Matteo C. Neurodevelopmental therapy and upper-extremity inhibitive casting for children with cerebral palsy. *Dev Med Child Neurol* 1991; **33**: 379–87.
26. Law M, Russell D, Pollock N, Rosenbaum P, Walter S, King G. A comparison of intensive neurodevelopmental therapy plus casting and a regular occupational therapy program for children with cerebral palsy. *Dev Med Child Neurol* 1997; **10**: 664–70.
27. Ozer K, Chesher SP, Scheker LR. Neuromuscular electrical stimulation and dynamic bracing for the management of upper-extremity spasticity in children with cerebral palsy. *Dev Med Child Neurol* 2006; **7**: 559–63.
28. OCEBM. (2011) The Oxford 2011 Levels of Evidence. OCEMB Levels of Evidence Working Group. http://www.cebm.net/index.aspx?o = 5653 (accessed 27 May 2013).
29. Hoare B, Imms C, Randall M, Carey L. Linking cerebral palsy upper limb measures to the International Classification of Functioning. Disability and Health. *J Rehabil Med* 2011; **43**: 987–96.
30. Hoare BJ, Wallen MA, Imms C, Villanueva E, Rawicki HB, Carey L. Botulinum toxin A as an adjunct to treatment in the management of the upper limb in children with spastic cerebral palsy (UPDATE). *Cochrane Database Syst Rev* 2010; **1**: CD003469.
31. Guyatt G, Oxman AD, Sultan S, et al. GRADE guidelines: 11. Making an overall rating of confidence in effect estimates for a single outcome and for all outcomes. *J Clin Epidemiol* 2013; **66**: 151–7.
32. Schroder N, Crabtree MJ, Lyall-Watson S. The effectiveness of splinting as perceived by the parents of children with juvenile idiopathic arthritis. *Br J Occup Ther* 2002; **65**: 75–80.
33. Nicholson JH, Morton RE, Attfield S, Rennie D. Assessment of upper-limb function and movement in children with cerebral palsy wearing Lycra garments. *Dev Med Child Neurol* 2001; **6**: 384–91.
34. Lannin NA, Novak I, Cusick A. A systematic review of upper extremity casting for children and adults with central nervous system motor disorders. *Clin Rehabil* 2007; **21**: 963–76.
35. Boyd RN, Morris ME, Graham HK. Management of upper limb dysfunction in children with cerebral palsy: a systematic review. *Eur J Neurol* 2001; **8**(Suppl. 5): 150–66.
36. Wright PA, Durham S, Ewins DJ, Swain ID. Neuromuscular electrical stimulation for children with cerebral palsy: a review. *Arch Dis Child* 2012; **97**: 364–71.
37. Russo RN, Atkins R, Haan E, Crotty M. Upper limb orthoses and assistive technology utilization in children with hemiplegic cerebral palsy recruited from a population register. *Dev Neurorehabil* 2009; **12**: 92–9.
38. Novak I, Cusick A, Lannin N. Occupational therapy home programs for cerebral palsy: double-blind, randomized, controlled trial. *Pediatrics* 2009; **124**: e606–14.
39. Wallen M, Ziviani J, Naylor O, Evans R, Novak I, Herbert RD. Modified constraint-induced therapy for children with hemiplegic cerebral palsy: a randomized trial. *Dev Med Child Neurol* 2011; **53**: 1091–9.
40. Gordon AM, Schneider JA, Chinnan A, Charles JR. Efficacy of a hand-arm bimanual intensive therapy (HABIT) in children with hemiplegic cerebral palsy: a randomized control trial. *Dev Med Child Neurol* 2007; **49**: 830–8.
41. Mazzone S, Serafini A, Iosa M, et al. Functional taping applied to upper limb of children with hemiplegic cerebral palsy: a pilot study. *Neuropediatrics* 2011; **42**: 249–53.
42. Ten Berge SR, Boonstra AM, Dijkstra PU, Hadders-Algra M, Haga N, Maathuis CGB. A systematic evaluation of the effect of thumb opponens splints on hand function in children with unilateral spastic cerebral palsy. *Clin Rehabil* 2012; **26**: 362–71.
43. Barroso PN, Vecchio SD, Xavier YR, Sesselmann M, Araújo PA, Pinotti M. Improvement of hand function in children with cerebral palsy via an orthosis that provides wrist extension and thumb abduction. *Clin Biomech (Bristol, Avon)* 2011; **26**: 937–43.
44. Gauthier LV, Taub E, Perkins C, Ortmann M, Mark VW, Uswatte G. Remodelling the brain: plastic structural brain changes produced by different motor therapies after stroke. *Stroke* 2008; **39**: 1520–5.
45. Law MC, Darrah J, Pollock N, et al. Focus on function: a cluster, randomized controlled trial comparing child- versus context-focused intervention for young children with cerebral palsy. *Dev Med Child Neurol* 2011; **53**: 621–9.
46. Wright FV, Rosenbaum PL, Goldsmith CH, Law M, Fehlings DL. How do changes in body functions and structures, activity, and participation relate in children with cerebral palsy? *Dev Med Child Neurol* 2008; **50**: 283–9.
47. Chiarello LA, Palisano RJ, Bartlett DJ, McCoy SW. A Multivariate model of determinants of change in gross-motor abilities and engagement in self-care and play of young children with cerebral palsy. *Phys Occup Ther Pediatr* 2011; **31**: 150–68.
48. Hägglund G, Andersson S, Düppe H, Lauge-Pedersen H, Nordmark E, Westbom L. Prevention of severe contractures might replace multilevel surgery in cerebral palsy: results of a population-based health care programme and new techniques to reduce spasticity. *J Pediatr Orthop* 2005; **14**: 269–73.