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Review

Measuring Outcomes for Children with Cerebral Palsy Who Use Gait Trainers

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Abstract: Gait trainers are walking devices that provide additional trunk and pelvic support. The primary population of children using gait trainers includes children with cerebral palsy (CP) functioning at Gross Motor Function Classification System (GMFCS) levels IV and V. A recent systematic review found that evidence supporting the effectiveness of gait trainer interventions for children was primarily descriptive and insufficient to draw firm conclusions. A major limitation identified was the lack of valid, sensitive and reliable tools for measuring change in body structure and function, activity and participation outcomes. Twelve different clinical tools were identified in the systematic review and in this paper we review and discuss the evidence supporting their reliability, validity and clinical utility for use with children using gait trainers. We also describe seven additional clinical measurement tools that may be useful with this intervention and population. The Pediatric Evaluation of Disability Inventory (PEDI) rated highest across all areas at this time. Individualized outcome measures, such as the Canadian Occupational Performance Measure (COPM) and Goal Attainment Scaling and measuring user satisfaction with tools, such as the Quebec User Evaluation of Satisfaction with assistive Technology, show potential for gait trainer outcomes research. Spatiotemporal measures appear to be less useful than functional measures with this intervention and population. All tools would benefit from further development for use with children with CP functioning at GMFCS levels IV and V.

Keywords: gait trainer; outcome measure; cerebral palsy; support walker; body weight support; overground training; GMFCS levels IV and V

1. Introduction

Cerebral Palsy (CP) is the most prevalent diagnosis for children with significant motor impairments who are followed by physical and occupational therapists [1]. This diagnosis results in lifelong progressive deforming secondary sequellae, most likely as a direct result of immobility. One of the newest revealed pressing issues is that change in muscle physiology including the loss of stem (satellite) cells and increase in collagen and muscle stiffness may be a result of non-use [2].

The Gross Motor Function Classification System (GMFCS) [3] classifies children with CP according to their mobility level and need for assistive devices. Children classified as GMFCS levels IV and V are unable to walk with hand-held walkers due to lack of trunk/postural control, strength, range of motion (ROM) and balance. These children require more supportive walkers that provide additional trunk and pelvic support, as well as unweighting. These types of walkers are often referred to as gait trainers, but the term support walker is also found in the literature [4]. Following onset of independent ambulation, children at GMFCS levels I–III are unlikely to use gait trainers except for activities that are enhanced by a device that is hands-free and/or offers increased postural support with or without body weight support. The use of a gait trainer may be one methodology to increase activity and muscle use and thus decrease contracture and disuse weakness for children at GMFCS levels IV and V.

A recent systematic review of outcomes of gait trainer use in children [5] identified mainly descriptive evidence supporting a positive impact on walking distance, mobility level and ability to take steps. Some studies suggested a positive impact on bone mineral density and bowel function along with a variety of activity and participation outcomes, but overall the evidence was low level and strong conclusions could not be reached. This review identified a limited number of clinical measurement tools that have been used to evaluate impact of gait trainer interventions for children. The review suggests that lack of reliable sensitive outcome measures may be a factor contributing to lack of stronger intervention research in this area. However, outcome measurement was not the focus of this previous paper and no critical appraisal of the tools was conducted.

The purpose of this review is to summarize the clinical measurement tools available to assess outcomes relevant to children with CP who are functioning at GMFCS IV and V as these are primarily the population of children who are using gait trainers; to critically appraise the psychometric properties of these tools and to identify which International Classification of Functioning, Disability and Health (ICF) [6,7] domains they address. We defined a gait trainer as a walker that provides additional trunk and pelvic support and is designed to be used in typical home or school settings. Our specific clinical question was "For children aged 18 years or younger, with CP, what clinical measurement tools have been used to assess gait trainer outcomes; what additional clinical measurement tools may be appropriate for this intervention and population; what are their psychometric properties; and which ICF domains do they address?"

2. Materials and Methods

We built on the search that was completed for the systematic review [5] and updated it in January 2016. Databases included CINAHL; Medline; EMBASE; and EBM Reviews. Search terms included "gait trainer", "supported walking", "support walker", "walking device", "body weight support gait trainer", "walker", "supported ambulation" and "David Hart Walker". Articles from the systematic review [5] were included if they provided a description of the clinical tools used and information on reliability, validity and/or clinical utility. We defined a clinical tool as one that could be used by a physical or occupational therapist in a family home or community, school or typical therapeutic setting. We specifically searched for tools that could be used for evaluative purposes rather than those designed to classify level of disability or discriminate between children with and without disabilities or delays. Outcome measures that require specialized medical or hospital-based equipment and are not able to be completed in a typical clinical environment were excluded, e.g., X-ray, bone mineral density scans, specialized gait analysis, etc. We included questionnaire-type assessments describing typical performance and designed to be completed by child or parent-proxy report. Capacity assessments completed by professional observation could include observation of physical abilities in real time or reviewing later via video-taping. Tempero-spatial measures could include use of a measuring tape or wheel, and stop-watch or video-camera, but would exclude specialized gait analysis that would require a gait lab setting or specialized camera or computer technology to complete. We excluded studies that did not provide detail on the clinical measurement tools or information on their psychometric properties.

In order to identify additional tools that might be appropriate for use with children with CP who use gait trainers, the search was expanded to include non-peer reviewed articles and conference proceeding submissions regarding children using gait trainers. We also searched for intervention studies involving other types of mobility interventions for children classified as GMFCS level IV and/or V and clinical tool development articles including children classified as GMFCS level IV and/or V. Search terms included "cerebral palsy" and "gait" or "walk* (* includes other word endings e.g. walker, walking, etc.)" in combination with terms such as "measure", "tool" or "assess* (* includes other word endings such as assessment or assessed)". We also hand searched for further articles including each of the tools identified in the electronic search by searching for them by name. We contacted known researchers and presenters on this topic in case there were other studies on these tools.

Knowing that a limited number of clinical tools have been used with gait trainer interventions, we also hand searched the reference lists of several systematic reviews of mobility and other motor interventions for children classified as GMFCS IV and V for potentially relevant tools. We purposely selected reviews of interventions that we considered to be commonly used by community-based therapists with our selected population, and that had some characteristics related to use of gait trainers. These included power mobility, adaptive seating, as well as supported walking and movement interventions that did not meet the inclusion criteria for the gait trainer systematic review [5], such as treadmill training or larger institutional or powered walking devices. We did not include reviews of general therapy interventions (e.g., Neurodevelopmental Therapy, Constraint induced movement therapy, Intensive motor therapies, etc.) or reviews of hippotherapy or aquatic therapy.

Reviews selected for hand-searching of reference lists were identified through the electronic search process using the search terms "cerebral palsy", "power mobility", "motor intervention", "treadmill training", "adaptive seating", "participation" and "review". All electronic searches were completed using the databases listed above. Any reviews identified in the electronic search were read full text to determine if they provided information on the clinical tools used in their included studies. If the studies included additional tools that had not previously been identified as having been used with gait trainer interventions, the individual articles were then read full-text.

The reviews selected from this process included seating interventions [8], power mobility interventions [9], motor interventions [10], and treadmill training [11], as well as reviews of measurement tools suitable for children with CP [12], children using seating interventions [13], and children using power mobility [14]. The additional tools were only included based on agreement of the two reviewers if at least one study evidencing psychometric properties of these clinical tools and their use in measuring intervention outcomes with children with CP classified as GMFCS level IV or V was identified.

Data on included tools were extracted independently from identified articles by reviewers using the McMaster Outcome Measures Rating Form [15]. This tool was used to rate reliability and validity results as well as to provide information on clinical utility of the tools and to provide an overall utility rating. The McMaster Outcome Measures Rating Form provides a standardized form for recording the reliability, validity, responsiveness and clinical utility of tools. It also provides a means of recording ICF domains. Ratings of excellent, adequate and poor take into account the conduct of the studies as well as the psychometric results. Individual reliability coefficients are considered excellent if above 0.8, adequate at 0.6–0.79 and poor if less than 0.6.

Tools are considered to have excellent reliability if supported by more than 2 well-designed studies with adequate to excellent reliability values; adequate reliability if supported by 1–2 well-designed studies with adequate to excellent reliability ratings; and poor reliability if only supported by poorly designed studies or poor reliability ratings. Similarly, validity would be rated excellent if supported by more than two well-designed studies supporting the measure's validity, adequate if supported by 1–2 well-designed studies and poor if the studies were poorly completed or did not support the measure's validity. Responsiveness would be rated as excellent if more than two well-designed studies showed strong hypothesized relationships between changes on the measure and other measures of change on the same attribute; adequate if supported by 1–2 well-designed studies and poor if the studies were poorly completed or did not support the measures responsiveness. Clinical tools were rated adequate or excellent if these psychometric properties had been demonstrated with children functioning at GMFCS levels IV and/or V. Overall ratings also take into account clinical utility with this population.

3. Results

Eleven of the original 17 articles identified in the previous systematic review of gait trainer outcomes [5] were included in this new review specific to outcome measurement [16–25]. These articles described 12 different clinical measurement tools that have been used in gait trainer outcomes research with children functioning at GMFCS levels IV and V and provided information on the tools psychometric properties and clinical utility.

The tools include the 10-meter (10-m) walk test [26,27], 10-minute (10-min) walk test [27], Directional Mobility Assessment (DMA) [24,25], Gross Motor Function Measure (GMFM) [28], Pediatric Evaluation of Disability Inventory (PEDI) [29], Physical Abilities and Mobility Scale (PAMS) [30], School Function Assessment (SFA)—Travel subscale [31], Step/leg movement count [16,20,21,32], Step length and velocity footprint analysis [24,25], Top Down Motor Milestone Test (TDMMT) [33], Videoing indices of happiness [19,21], and the Functional Independence Measure for children (Wee FIM) [34,35].

In the expanded search, methodological studies providing further information on the Top Down Motor Milestone Test [33,36], use of the 10-m walk test with children with CP GMFCS levels I–III [37,38], and the PAMS [39] were identified. Only one gait trainer intervention study not included in the systematic review was identified [40]. It used the WeeFIM mobility scale [34,35] to discriminate between mobility function with and without a specialized gait trainer and orthotic device.

In the expanded search seven other clinical tools that have been used in mobility-related interventions with children with CP and appeared relevant to review regarding potential for use in gait trainer outcomes research were identified and agreed by two reviewers. All articles and tools were identified through the expanded electronic search and the hand search of the reference lists in the previously identified systematic reviews. These include: 6-min walk test [41]; Canadian Occupational Performance Measure (COPM) [42]; Early Activity Scale for Endurance (EASE) [43]; Goal Attainment Scaling (GAS) [44]; Matching Assistive Technology and Child (MATCH) [45]; Quebec User Evaluation of Satisfaction with assistive Technology 2.0 (QUEST 2.0) [46]; and the Supported Walker Ambulation Performance Scale (SWAPS) [47]. Figure 1 shows a flow diagram of the search.

3.1. Tool Identification

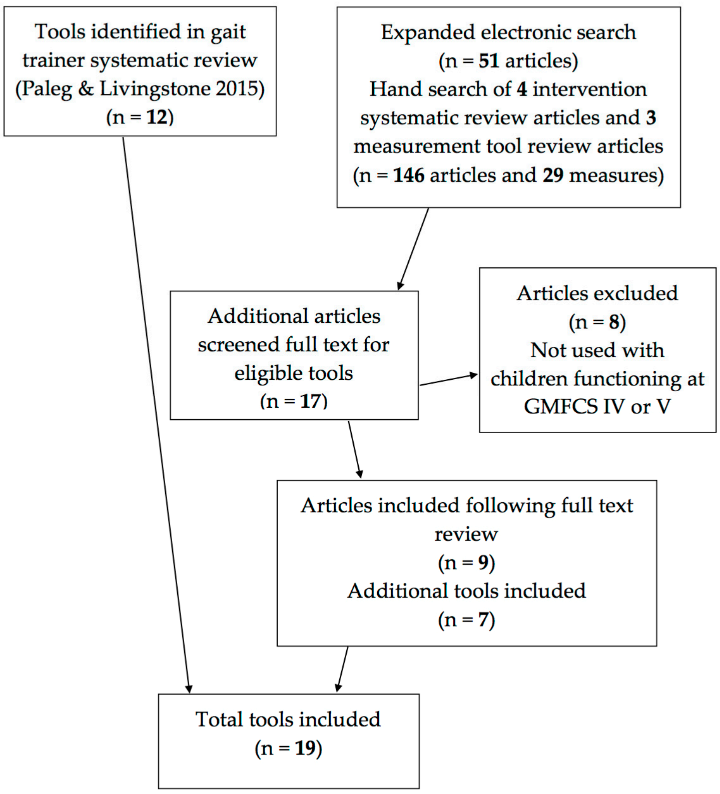

Figure 1. Flow chart of the search.

3.2. Tool Characteristics

Table 1 provides a summary of the measurement properties of the clinical tools included in this review. Readers are directed to the published systematic review [5] for evaluation of the evidence provided in the gait trainer intervention studies. A number of the included tools merited poor McMaster Outcome Measure [15] ratings, as psychometric properties have not been established for children with CP functioning at GMFCS levels IV and V.

Table 1. Psychometric properties.

Description	Reliability	Validity	Sensitivity and Responsiveness
Clinical Tools Used in Gait Trainer Intervention Studies			
10-m walk test [26,27] Participant observation capacity measure. Time taken to walk the middle 10 m of a 14-m walkway measured with a stopwatch. Walking speed calculated by dividing time by distance.	Adequate *test-retest reliability* GMFCS III—ICC 0.78 (95% CI 45–93), SEM 6.4 s [37] Excellent *test-retest reliability* at preferred speed GMFCS II and III: ICC 0.90 (95% CI 0.8–0.95) SEM 3.61 s [38] **Poor for GMFCS IV and V**	*Face and Content Validity:* More appropriate for evaluating gait kinematics than speed with GMFCS I–III [27] Used to measure self-selected walking speed in children with GMFCS IV and V [23] **Poor for GMFCS IV and V**	MDC^{95} in children functioning at GMFCS III 17.7 s [37] SRD in children functioning at GMFCS II and III—10 s [38] **Poor for GMFCS IV and V**
10 min walk test [27] Participant observation capacity measure. Distance walked in 10 min is recorded. Studies including children with CP used a 20-m oval track marked at 1-m intervals [23,27,48].	Good *test-retest reliability* in children with neuromuscular conditions including CP GMFCS III ICC > 0.91 95% CI [27] **Poor for GMFCS IV and V**	*Face and Content Validity:* Measure of community walking ability for children with CP [27] Feasible for some children GMFCS IV and V using walkers and gait trainers [23] **Poor for GMFCS IV and V**	**Not established**
DMA [24,25] Participant observation capacity measure. Measures ability to maneuver gait trainer. 11 items on 5 point scale indicating full, partial or inability to complete.	**Not established**	*Convergent Validity:* moderate correlation between DMA and GMFM dimension E. $r = 0.59$ $p = 0.007$ [25] **Adequate**	**Not established**
GMFM-88 [28] Participant observation capacity measure. Criterion-referenced, evaluative measure for children with CP. 5 dimensions: A lying and rolling; B crawling and kneeling; C sitting; D standing; and E walking, running and jumping.	*Intra-rater* and *inter-rater reliability* reported to be excellent in multiple studies. ICC > 0.95 at all GMFCS levels [49] **Excellent**	Reported to have excellent *face, content* and *construct validity* in multiple studies. **Excellent**	Responsive to change in children with CP [28]. Regardless of GMFCS level [49] **Excellent**
Indices of happiness/affect [19,21] Participant observation capacity measure. Count incidences of alertness, smiling or positive affect within a set time period from video recording	Mean agreement of 92% [21] and 94% [19] between two raters 20% of sessions. **Adequate**	**Not established**	**Not established**
PAMS [30] Participant observation capacity measure. Evaluative measure of gross motor function. Each item rated on a 5 point scale 1 = no tolerance—5 = complete tolerance of an activity.	High *inter-rater reliability*—ICC 0.99 for children with BI [39] **Poor for CP**	*Internal consistency*—0.97 [30] Validated for children with Acquired BI. *Criterion validity* with WeeFIM mobility scale [39] **Poor for CP**	**Not established**
PEDI [29] Performance measure involving structured parent interview. Measures functional abilities and caregiver assistance in self-care, mobility and social function.	Good reliability in CP [50,51] **Excellent**	Good validity in children with CP reported in multiple studies. **Excellent**	MCID—between 6 and 15 points or an 11% change on all scales [52] **Adequate**
SFA Travel subscale [31] Performance measure involving parent or caregiver report. Criterion referenced judgment-based questionnaire with 3 domains. The travel subscale is part of the Activity domain. Rated on 4-point scale: 1 (does not perform) to 4 (consistently performs).	Good *test-retest reliability* for Activity domain 0.8–0.99 [23]. *Inter-rater reliability* ICC 0.73 for Activity performance subscale [12]. **Adequate**	*Content validity* from expert panel and factor analysis. *Discriminative validity:* Detects differences between children with/without CP [12]. Activity domain difficult for children with CP [53]. **Adequate**	**Not established**
Step/leg movement counting [16,20,21,32] Participant observation capacity measure. Involves counting number of independent steps or leg movements within a set time period.	*Inter-rater reliability* checks completed at least twice with each child—100% agreement [16]. Mean agreement of 96% [20] or >90% [32] between two raters 20% trials. **Adequate**	**Not established**	**Not established**

Table 1. *Cont.*

Description	Reliability	Validity	Sensitivity and Responsiveness
Step length and velocity footprint analysis [24,25] Participant observation capacity measure. Step length is analyzed from footprint analysis taken from pressure sensitive paper.	Good *inter-rater reliability* in school-aged children with CP (ICC > 70) [54] Excellent *test-retest reliability* for children GMFCS I-III ICC = 0.86 SEM 0.14 m/s [54] **Poor**	*Face validity:* Used with children using hands-free gait trainers in two studies [24,25] **Poor**	**Not established**
Top Down Motor Milestone Test (TDMMT) [33] Performance measure completed by school and therapy team. Assesses sitting, standing and walking skills in individuals with severe and profound multiple disabilities.	*Test-retest reliability* mean 0.8 range—0.54 to 0.9. Item test reliability 0.97 range—0.58–1.0. Strong *internal consistency* —cronbach's alpha 0.95 [33] *Test-retest reliability* individual subtests—kappa 0.74–0.96 Pooled kappa—0.88 SEM 0.06 $p < 0.01$ [36] **Adequate**	*Construct validity:* Factor analysis did not confirm the three underlying factors of standing, sitting and walking but only one or two factors. Suggests a uni-dimensional theoretical construct **Poor**	**Not established**
WeeFIM [34,35] Performance Measure—structured interview with parents. 18-item assessment used to determine level of assistance needed in self-care and mobility tasks. Items rated on 7 point scale from 1 (total dependence) to 7 (independent).	Reported to be reliable (0.94) in the pediatric inpatient population [34] **Poor for GMFCS IV and V**	*Face and Content Validity:* Valid for inpatient population [34] *Discriminative Validity:* Detects significant change in mobility level with/without gait trainer and previous aid [40] **Poor for GMFCS IV and V**	Not sensitive to changes in non-ambulatory children [18] **Not established**
Tools used with children at GMFCS IV and V with other interventions			
6-min walk test [41] Participant observation capacity measure. Measures distance walked at preferred or fastest speed over 6-min time period. Assistive devices can be used. Time measured with stopwatch. Measuring wheel used to record distance. Walking back and forth on short straight track not recommended due to negative impact of direction changes.	Excellent *test-retest reliability* in GMFCS III ICC = 0.98 (95% CI 95–99), SEM 17.1 [37] Excellent *test-retest reliability* in GMFCS I and II ICC = 0.89 (95% CI 77–95) SEM 58.02 [38] Excellent *test-retest reliability* in GMFCS I–III ICC 0.98 [41] MDC^{95} 47.4m GMFCS III [37] SRD 160.82m [38] **Poor for GMFCS IV and V**	*Construct Validity*—Valid measure of cardiovascular fitness for children with CP GMFCS levels I and II [55] **Poor for GMFCS IV and V**	**Not established**
COPM [42] Performance level individualized outcome measure—completed by child or parent proxy in semi-structured interview. Clients identify and rate importance of up to five goals in the areas of self-care, productivity and leisure. Performance and satisfaction of these goals are rated from 1–10 and difference from baseline to follow-up (change score) is used as an outcome. The manual recommends parent-proxy rating for children below 8 years of age.	*Internal consistency* Acceptable reliability when completed by parent proxy [56] Performance—Cronbach's alpha 0.73 Satisfaction—Cronbach's alpha 0.83 *Inter-rater reliability* 80 parents of children with disabilities including 14 with CP. Limits of agreement −2.4 to +2.3 mean performance and −2.3 to +2.6 mean satisfaction scores [57] *Test-retest reliability* No significant difference blinded or unblinded to previous rating of parents of 50 children hemiplegic CP [58] **Adequate for GMFCS IV and V**	*Content validity:* adapted for pediatrics and valid for use by parent proxy for children with hemiplegic CP [56,59] *Construct and criterion validity:* Valid for use with parents of children with a wide range of disabilities [57] 6 children with CP aged 8–12 years rated with caregivers present [60] Significant change in level of independence rated by parents of children with CP GMFCS IV and V following use of a power wheelchair [61] **Adequate for GMFCS IV and V**	A change of 2 points is thought to represent a clinically significant change in adult studies [62] *Sensitivity to change* —able to detect medium effect size in children with hemiplegic CP Performance—ES 0.78 Satisfaction—ES 0.69 [59] **Poor for GMFCS IV and V**
EASE [43] Performance level parent report measure. Estimates endurance for physical activity for children with CP aged 2–6 years of age. Frequency, intensity and duration of physical activity in typical environments rated on 5-point scale. Maximum score 50-higher scores = higher levels of endurance for physical activity.	*Test-retest reliability* Excellent-ICC (2,1) = 0.95 95%CI (0.90–0.98) *Internal Consistency* Good—Cronbach's alpha 0.93 *Absolute reliability* SEM 2.9—at 68% CI *Minimal Detectable Difference* 8.0—at 95% CI—a difference of 8 points could be within measurement error **Adequate for GMFCS IV and V**	*Discriminative Validity* Scores differed significantly between all GMFCS levels except children at GMFCS II and III *Convergent Validity* Moderate correlation ($r_s = 0.57$) between EASE and 6 min walk test for children at GMFCS I and II **Adequate for GMFCS IV and V**	**Not established**
MATCH [45] Personal and environmental factors parent-report measure. Parents rate statements on a 4 point likert scale from strongly agree to strongly disagree or on a 5 point likert scale from very satisfied to not satisfied at all. Statements range from satisfaction with child's ability to use the device, go where desired, sleep-wake cycle, communication, play and social skills as well as the parent's feelings of stress or frustration.	No reliability testing found with parents of children with CP GMFCS levels IV and V **Poor**	No validity testing found with parents of children with CP GMFCS levels IV and V **Poor**	**Not established**

Table 1. *Cont.*

Description	Reliability	Validity	Sensitivity and Responsiveness
GAS [44] Performance level individualized outcome measure completed by child and/or parent proxy. Clients select goals and rate these on a 5 point scale where 0 = expected level of achievement; +1 = somewhat more than expected; +2 = much more than expected; −1 = somewhat less than expected; −2 = much less than expected. Overall score calculated by incorporating goal outcome scores into a single aggregated T score.	*Inter-rater reliability* Good to excellent ICC 0.82 (95% CI 73–91) Children with CP GMFCS I–V [63] Excellent *inter* and *intra-rater reliability* in children with CP at a range of GMFCS levels ICC = 0.96 (95% CI 93–97 and 94–98, respectively) [64] **Excellent for GMFCS IV and V**	*Content validity* established for use with children with CP at a range of GMFCS levels [64] *Convergent validity* with COPM for children with hemiplegic CP [59] **Adequate for GMFCS IV and V**	Responsive to change in activity goals in children CP at all GMFCS levels [65] Likert scale GAS more sensitive than weighted GAS goals or COPM in hemiplegic CP [59]. Responsive to change in gross motor goals at a range of GMFCS levels [64] **Adequate for GMFCS IV and V**
QUEST 2.0 [46] Measure evaluating environmental factors completed by child and/or parent proxy. Evaluates client satisfaction with assistive technology. 8 item device scale and a 4 item services scale can be scored separately. Each item rated on 5-point scale from not satisfied at all to very satisfied.	Excellent and adequate *inter-rater and intra-rater reliability* with adults using mobility devices Device = 0.80 Service = 0.76 Total = 0.82 [66] Excellent *test-retest reliability* with adults ICC: Device = 0.82 Service = 0.82 Total = 0.91 [67] **Poor for CP**	No validity testing completed with children with CP. **Poor for CP**	**Not established**
SWAPS [47] Participant observation capacity measure. Measures locomotor changes in non-independent walkers. Four dimensions: level of support; posture; quality of steps; quantity of steps. Each rated on 4 point likert scale. Support is weighted at 40% and the other dimensions at 20% each with 100% score representing independent walking.	Excellent *Inter-rater reliability* ICC 2.1 0.95 with lower 95% CI of 0.89 [47] **Adequate for GMFCS IV and V**	*Convergent validity* Moderate correlation with GMFM Spearman rho 0.68 [47] **Adequate for GMFCS IV and V**	Did not detect significant change in children at GMFCS II or III despite increased overground walking speed [68] Only marginal change in total score following overground gait training in children, four with CP GMFCS levels unclear [69] **Not established**

Abbreviations in Table 1: BI = Brain Injury; COPM = Canadian Occupational Performance Measure; DMA = Directional Mobility Assessment; CI = Confidence Interval; CP = cerebral palsy; EASE = Early Activity Scale for Endurance; ES = Effect Size; GAS = Goal Attainment Scaling; GMFCS = Gross Motor Function Classification System; GMFM = Gross Motor Function Measure; ICC = Intra-class Correlation; m/s = meters per second; MATCH = Matching Assistive Technology and Child; MDC^{95} = Minimum Detectible Change at 95% confidence level; MCID = Minimal Clinically Important Difference; r = correlation coefficient; PAMS = Physical Abilities and Mobility Scale; PEDI = Pediatric Evaluation of Disability Inventory; QUEST 2.0 = Quebec User Evaluation of Satisfaction with assistive Technology; SFA = School Function Assessment; SEM = Standard Error of Measurement; SRD = smallest real difference; SWAPS = Supported Walker Ambulation Performance Scale; WeeFIM = Functional Independence Measure for Children.

See Appendix A for a brief summary of the six intervention and three methodological or tool development studies providing information on additional clinical tools that have been used with children functioning at GMFCS levels IV and/or V and may have utility for evaluating outcomes of gait trainer interventions.

3.3. Reliability

Studies that measured step or leg movement counts, or indices of happiness [16,19–21,32] all reported excellent inter-rater reliability with % agreement ranging from 90%–100%. Timed walking tests such as the 10-m walk test have excellent test-retest reliability [26,70] and acceptable inter-rater reliability [70] in adults with neurological impairments. However, the reliability of the three included spatiotemporal tests (10-m walk test [26,27]; 10 min-walk test [27]; 6-min walk test [41]) has not been confirmed for children functioning at GMFCS levels IV or V.

Functional measures, such as the PEDI [29] and GMFM [28], are reported to have excellent inter, intra and test-retest reliability with children with CP, but evaluation of all the articles published on these widely known measures is beyond the scope of this paper. The COPM [42] was rated as having adequate reliability due to the limited number of studies relevant to the specific population being considered in this paper whereas GAS [44] is reported to have excellent reliability with children at all GMFCS levels.

3.4. Validity

Face and content validity is evident for most of the included measures but only the most relevant examples are listed in the table in the interests of space. Some measures used factor analysis (e.g., SFA [31]) while others (e.g., SWAPS [47]) were developed through expert consensus. The SWAPS [47] and DMA [24,25] demonstrate construct (convergent) validity with a moderate correlation with the GMFM [28]. The PAMS [30,39] demonstrates moderate to strong correlation with the WeeFIM [34,35]. Discriminative validity is demonstrated by some measures (e.g., EASE [43]) being able to discriminate between GMFCS levels [43] and others (e.g., WeeFIM [34,35]) being able to discriminate between mobility levels with and without a specific mobility device [40]. However, this does not indicate that a measure is suitable for evaluative purposes with this population.

3.5. Responsiveness and Sensitivity to Change

Limited information was available for the majority of tools identified. Responsiveness indicates that a measure is able to detect clinically meaningful change and sensitivity or the ability to detect any change is an important first step. Although the GMFM [28] is reported to have good responsiveness to change in children with CP regardless of GMFCS level, many of the items cannot be completed by children using gait trainers and therefore it is limited in its utility for assessing change related to gait trainer interventions. The PEDI [29] has been found to be sensitive to change in children with CP and a scaled score change of 11 points is thought to represent a clinically important change in an inpatient population [71]. The COPM [42] has been shown to be sensitive to change in children with mild CP (GMFCS I and II equivalent) although parents have rated a significant increase in independence in children with severe CP (GMFCS IV and V equivalent) using power mobility [61].

The 10-m walk test [26,27] has been heavily studied with adult populations and a change of more than 0.5 s is thought to be greater than measurement error [70]. However, studies with children with CP suggest much greater variability between assessments with differences as great as 17 s [37] and 10 s [38] being measured in children functioning at GMFCS level III. Since no studies have compared measurement properties of the 10-m walk test [26,27] with children at GMFCS level IV and V, it is unclear whether or not greater variability between performances would be present in this population.

3.6. Clinical Utility

Table 2 provides a summary of the clinical utility of all the measures identified in this review. Clinical utility was rated using the McMaster Outcome Measures rating form and includes consideration of the clarity of the instructions, format, time needed to complete, need for specialized training or equipment, availability of the measure and instruction manual as well as cost. Consideration of usefulness for children using gait trainers would also include whether or not the measure can be used with the child in the gait trainer or not. Excellent overall utility indicates that the tool has adequate to excellent clinical utility, is easily available and has excellent reliability and validity. Adequate overall utility indicates that the tool has adequate to excellent clinical utility, is easily available and has adequate to excellent reliability and validity. Poor overall utility indicates that the tool has poor clinical utility for this population or intervention, is not easily available or has poor reliability and validity. A poor score in any of these factors would result in an overall score of poor overall utility.

Several outcome measures identified are freely available and require little specialized equipment other than a tape measure or stop watch. Counting steps or positive affect instances from video or at the time are easily accomplished in clinical practice and ways to increase reliability are included in the relevant articles [16,19–21,32]. Detailed instructions for administration of the 10-m [26,27] and 10-min [27] walk tests are provided in the citing article [23]. In addition, detailed instructions for use with adult patients with stroke or spinal cord injury and video support materials are available online [72].

The GMFM [28] and PEDI [29] are commonly available in pediatric therapy settings, but the SFA [31] is costly and its purchase in order to use only one subscale may be prohibitive. The PAMS [30,39] appears to be a useful measure for tracking smaller changes in positioning and mobility function and tolerance in an inpatient population, but is not freely available. The DMA [24,25] was developed specifically for children with CP using gait trainers but has had limited development on its psychometric properties and is also not freely available for use. In contrast, the SWAPS scoring and administration detail, is provided in an appendix to the article [47].

The GMFM-88 [28] is most sensitive to change for children at GMFCS levels IV and V because of the increased number of test items in domains A and B. If clinicians choose to use the GMFM-66 [73] they should note that orthotics and assistive devices cannot be used during testing. The updated Gross Motor Ability Estimator (GMAE-2) software must be used (available for free, download at www.canchild.ca) and the GMFM-66 and percentiles can never be "hand-scored". However, the usefulness of the GMFM [28] for gait trainer outcomes is questionable given that function in the gait trainer cannot be directly assessed.

Table 2. Clinical Utility and Usefulness of all included tools.

Measure *(ICF)*	Clinical Utility and Usefulness for Children Using Gait Trainers	Overall Utility
	Tools suitable for use in clinical practice or research	
PEDI [29] *(A & P)*	Appears sensitive to changes in mobility level in short-term intervention studies. Sensitivity to changes in caregiver assistance and impact on self-care and social domains require further exploration.	Excellent
	Tools that need further development but show potential for use in clinical practice/research	
COPM [42] *(A & P)*	Manual available for purchase. Time efficient and easy to use in OT practice. Responsiveness with children at GMFCS IV and V needs further development.	Adequate
GAS [44] *(A & P)*	Freely available. Can be time consuming and difficult to score. Training is strongly recommended prior to use in effect studies with children [74]. Reliability, validity and responsiveness for children functioning at GMFCS IV and V need further development.	Adequate
SWAPS [47] *(A)*	Freely available with scale and scoring descriptions available as an appendix to the original article [47]. Designed to measure changes in gait in children transitioning from dependent to independent walking. Limited documentation of use to measure gait changes in children at GMFCS levels IV or V. May need adaptation for use with gait trainers (Francine Malouin, personal communication 18, April 2016).	Adequate
TDMMT [33] *(A)*	Can administer a shortened set of items increasing clinical utility. Designed to be used with the Rifton gait trainer. However not all skills included can be accomplished with a gait trainer e.g., sitting skills, or higher level walking skills such as stairs. Validity and responsiveness need further development.	Adequate
	Further development of psychometric properties needed	
DMA [24,25] *(A)*	Not available. Not included as an appendix to the articles. Only two sample items are included in the follow-up study [25]. Reliability, validity and responsiveness for children using gait trainers need further development.	Poor
EASE [43] *(A)*	Feasible and low burden indirect measure of a child's endurance for physical activity. Reliability, validity and responsiveness with children at GMFCS IV and V need further development.	Poor
Indices of happiness [19,21] *(BSF)*	Simple to carry out in clinical practice.	Poor
QUEST 2.0 [46] *(EF)*	Freely available. Low administrative and time burden. Reliability, validity and responsiveness for children at GMVCS levels IV and V need further development.	Poor
Step/leg movement counting [16,20,21,32] *(A)*	Simple to carry out in clinical practice. Demands full attention of assessor unless videotaped for later analysis	Poor

Table 2. *Cont.*

Measure *(ICF)*	Clinical Utility and Usefulness for Children Using Gait Trainers	Overall Utility
May be useful for children who are more active walkers or require less body weight support		
6-min walk test [41] *(A)*	Free and easy to use in clinical practice. Younger children and children with reduced cognitive abilities can be difficult to motivate to complete the test reliably [38] as can young children who use walking aids [43].	Poor
10-m walk test [26,27] *(A)*	Testing protocol freely available and utility with children who use gait trainers documented. Simple to set up in a school or community setting. However, reliability, validity and responsiveness not yet established for children with CP functioning at GMFCS IV and V.	Poor
10 min walk test [27] *(A)*	Testing protocol described in Willoughby [23]. Able to be used by children who use gait trainers. Relatively simple to conduct in a school or community setting. Reliability, validity and responsiveness not yet established for children functioning at GMFCS IV and V.	Poor
Utility for children using gait trainers questionable		
GMFM-88 [28] *(A)*	Only 6/14 items in domain D and 8/14 items in domain E can be completed by a child using a gait trainer [24]. May show secondary changes due to increased activity in gait trainer but does not directly assess gait trainer function.	Poor
MATCH [45] *(EF & PF)*	The entire questionnaire is extensive and too lengthy for routine use in clinical practice. Impact on the reliability and validity from non standard use e.g., administration of selected items only [75] unclear.	Poor
PAMS [30] *(A)*	Developed for an inpatient rehabilitation setting. Not validated for children with CP. Not freely available.	Poor
SFA [31] Travel subscale *(A)*	Reflects typical performance rather than based on a single trial therefore not suitable for blinded assessment. Reliability, validity and responsiveness with children at GMFCS IV and V need further development.	Poor
Step length and velocity footprint analysis [24,25] *(A)*	May be challenging to complete in the clinical settingrequires pressure sensitive paper or some type of gait recognition mat. Reliability, validity and responsiveness with children at GMFCS levels IV and V who use gait trainers need further development.	Poor
WeeFIM [34,35] *(A)*	Able to discriminate mobility function in children with and without functional mobility aids, but may not be useful for detecting change over time in children at GMFCS levels IV and V.	Poor

Abbreviations for Table 2: A = Activity domain; BSF = Body Structure and Function domain; COPM = Canadian Occupational Performance Measure; DMA = Directional Mobility Scale; EASE = Early Activity Scale for Endurance; GAS = Goal Attainment Scaling; GMFCS = Gross Motor Function Classification System; GMFM = Gross Motor Function Measure; ICF = International Classification of Functioning, Disability and Health; MATCH = Matching Assistive Technology and Child; P = Participation Domain; PF = Personal Factors; PEDI = Pediatric Evaluation of Disability Inventory; QUEST 2.0 = Quebec User Evaluation of Satisfaction with assistive Technology; SFA = School Function Assessment; SWAPS = Supported Walker Ambulation Performance Scale; TDMMT = Top Down Motor Milestone Test; WeeFIM = Functional Independence Measure for Children.

4. Discussion

This review has identified 12 different clinical measures that have been used to measure outcomes with children diagnosed with CP functioning at GMFCS levels IV and V who use gait trainers. An additional seven measures have been used in assessment of mobility interventions with children functioning at GMFCS levels IV and V and have been evaluated regarding their potential for use in future gait trainer intervention research. The majority of tools identified address the ICF domain of activity despite the recent emphasis on maximizing participation for children with motor impairments [76].

Only one measure (PEDI [29]) has demonstrated reliability, validity and responsiveness to change in children with CP at GMFCS levels IV and V and appears to have utility for use with gait trainer outcomes research. While the GMFM [28] has excellent psychometric properties, its usefulness in gait trainer outcome research is limited. In the short term, significant change in PEDI [29] mobility level was demonstrated from use of the Hart walker in two studies [17,24]. However, it was only over the longer-term [25] that reduced need for caregiver assistance in social function and self-care skills were measured. Similarly, one study investigating effects of 12 sessions of treadmill training in children aged 2.5–3.9 years at GMFCS levels I–IV [77] also measured change in mobility level and need for caregiver assistance in mobility activities, but not in self-care skills. However, Jones and colleagues [78] measured significant change in mobility skills and reduced need for caregiver assistance in mobility and self-care tasks in subjects versus controls following 12 months power mobility intervention in children at GMFCS levels IV and V aged 14–30 months. This suggests that the PEDI [29] may be more useful as a measure of change in mobility level in shorter-term intervention studies. Impact on participation or environmental factors may only be measured in more longitudinal research and requires further exploration.

Walking (and supported/assisted stepping) remains a primary long-term goal for parents of children with CP, despite the fact that their children often see walking as exercise rather than functional mobility [79]. Many of the outcomes measured in gait trainer research focus on increasing number of steps, increasing walking speed or endurance, or quality of stepping. Most methodological articles exploring psychometric properties of gait and walking assessment tools are focused on children functioning at GMFCS levels I–III. Walking endurance tests, such as the 10-min walk test [27], have not established validity, reliability or responsiveness for children functioning at GMFCS levels IV and V.

Clinical experience suggests that many children who use gait trainers would not be able to complete this task, and perhaps the 6-min walk test [41] maybe a more appropriate length of time. However, this measure has not been used in gait trainer research and use with only a few children at GMFCS level IV has been demonstrated in studies investigating body-weight support treadmill training [77] and robotic step training [80]. One study [43] states that the 6-min walk test [41] is not valid for young children who walk with walking aids following pilot testing with children at GMFCS III. For children who are just learning to walk with assistive device, their movements are slow and labored in comparison with floor mobility and therefore may not be a valid representation of tolerance for physical activity.

This same study described the development of the Early Activity Scale for Endurance (EASE) [43], a parent-report measure of endurance for physical activity developed for use with children at all GMFCS levels. The study measured a moderate correlation with the 6-min walk test [41] for children at GMFCS I and II. They state that walking tests such as the 6-min walk test [41] are not appropriate for children under three years of age due to difficulties in following the directions. However, Mattern-Baxter [77] used the 6-min walk test [41] and the 10-m walk test [26,27] with children aged 2.5–3.9 years and report children with gait trainers being able to complete both tests at follow-up. Children needed directional locks on gait trainers as they were unable to steer, but could step forward. The EASE [43] was found to have construct validity and test-retest reliability for children at all GMFCS levels and to be a feasible and low burden method of assessing tolerance of and endurance for physical activity. However, responsiveness has not been established so it is unknown if it could be used to measure increase in endurance for physical activity following an intervention. In addition, it has a wide minimal detectible change of eight points, due to wide variability in scores.

The DMA [24,25] directly assesses functional use of the gait trainer and has initial documentation of face, content and construct validity, however it is unfortunately not available for use in practice. The SWAPS [47] can be adapted to assess level of support and stepping in a gait trainer, although in the initial development studies children were supported by an adult. Other studies [68,69] have used this measure to assess function of children with CP at GMFCS III or possibly IV using a walker or gait trainer. Inter-rater reliability testing has been completed and it is freely available for use in clinical practice. For children whose gait velocity is less than 50% of typical, clinical measures are more appropriate and sensitive to change than spatiotemporal gait measures [81,82]. There are no published gait lab studies including children at GMFCS IV and V although gait lab studies, with EMG and 3D motion analysis are considered to be the gold standard in gait analysis [83].

Improving participation in meaningful life activities is being stressed as a major focus in current pediatric rehabilitation [76]. For many children functioning at GMFCS levels IV and V, gait trainers are primarily a means of increasing activity and participation rather than as a means of training gait or progression towards independent walking. A lack of measures sensitive to measure change in functional activity and participation goals has been identified for children using gait trainers [5]. In a review of appropriate participation measures for children with CP, Sakzewski [12] suggests that the COPM [42] and GAS [44] are worth considering. The COPM [42] has been successfully used to measure significant improvement in self-selected participation goals following robot-assisted gait training [84] in a study that included one child at GMFCS IV. The COPM [42] has also been used to measure increase in independence or progress in self-selected activity goals in effectiveness research for adaptive seating [60] and power mobility [61].

Environmental and personal factors are other important influences on use of assistive technology [85]. The QUEST 2.0 [46] has been widely used to measure user satisfaction with a variety of different assistive technologies in many different populations. Although it does not have reliability, validity or responsiveness established for children with CP functioning at GMFCS IV or V, it has been previously used with parents of children with CP whose children were using a power mobility intervention [75,86]. Device acceptability is thought to be an important factor influencing device adoption and abandonment. Parents generally rated a high level of acceptability of power mobility device features other than size, weight and transportability [75]. When considering acceptability of gait trainers environmental factors, such as location of use may be influential. If the device is primarily being used in a therapeutic or educational setting, impressions of care staff may be more influential, but parent views may be more important to collect if the device is primarily going to be used in the home setting.

There are a number of limitations to be considered in this review. Although we expanded beyond peer-reviewed journals to grey literature, it was challenging to search conference proceedings and studies may have been missed. Although the term gait trainer is widely used and known particularly in the United States, other terms are used in other countries and this made the electronic search challenging. Using more generic terms such as "walker" generates a wide range of citations and was difficult to narrow down.

Since the number of tools that have been used in gait trainer interventions is limited, we attempted to identify other measures that might be useful in future gait trainer intervention research. However, searching for all potential measures that could be used with this population, would have made the search unmanageable. Instead, we chose to limit our search to an electronic search for systematic reviews of interventions that we considered likely to include children with CP, GMFCS IV and V. We have identified the specific reviews that we used as a source to hand search for additional measures and studies in order to increase replicability of our methods, but recognize that some studies or measures may have been missed.

However, a large-scale comprehensive review of interventions for children with CP [87] that did not meet our inclusion criteria also identified the same reviews on treadmill training [11] and adaptive seating [8] as providing the highest level of evidence published on these interventions. In addition, another review of gait related outcomes [88] and a review of walking ability measures published since our search took place [89], failed to suggest any additional measures that had been used in intervention studies with children functioning at GMFCS IV and V.

Some of the clinical tools identified in this review (e.g., GMFM, PEDI, COPM, GAS) have been widely used with other populations and interventions and it was not within the scope of this paper to evaluate all the studies published on these tools. As a result some of the table results are listed as a summary of ratings based on the data retrieved from the articles we included. We attempted to retrieve the studies relevant to children with CP GMFCS levels IV and V but had to rely on evidence related to children classified as GMFCS I–III, other disabilities or adult research in some instances.

The McMaster Outcome Measures Rating Form [15] was used with all studies but ratings take into account whether the studies had included our identified population or an alternate population. Reliability, validity and responsiveness can only be established in regard to a specific population or setting [90,91] and therefore only studies including children functioning at GMFCS levels IV and V were considered when rating properties as excellent, adequate or poor. Tools may have demonstrated good psychometric properties with another population but could be rated as poor for CP, or poor for GMFCS IV and V.

We considered using an additional quality rating such as the Consensus-based Standards for the selection of health status Measurement Instruments (COSMIN) [92,93], but the sample size requirement for this tool means that almost all the studies included in this review would automatically receive a poor or fair rating, regardless of the conduct of the study. As a result, we determined that this rating would not provide any additional information to assist readers in discriminating between measures. Instead, we chose to divide Table 2 into sections to clarify the tools most useful for gait trainer research, for which specific populations, and which tools required further development, but recognize that this is a qualitative rating based on the consensus of the two reviewers.

5. Conclusions

Lack of sensitive outcomes measures has been identified as a factor in low evidence quality ratings in gait trainer outcomes research. In this study we identified 17 potential tools with the PEDI [29] attaining the highest ratings in all categories. The COPM [42] and GAS [44] show potential for measuring progress on individually selected activity and participation goals while the SWAPS [47] may be adapted to measure progress in mobility or gait function within the gait trainer. The QUEST 2.0 [46] may be beneficial for exploring user satisfaction in comparing different gait trainer features and function with different children. Gait trainer interventions have a multi-dimensional impact while, at this point, most tools have been used to measure activity level outcomes. A more comprehensive outcomes framework [94] should be used to assist in measuring and understanding contextual and functional factors, as well as including activity and participation outcomes that are meaningful to families and children. Further development of all potential tools used with children functioning at GMFCS levels IV and V is warranted.

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Abbreviations

COPM	Canadian Occupational Performance Measure
CP	Cerebral Palsy
DMA	Directional Mobility Assessment
EASE	Early Activity Scale for Endurance
GAS	Goal Attainment Scaling
GMFCS	Gross Motor Function Classification System
GMFM	Gross Motor Function Measure
ICF	International Classification of Functioning, Disability and Health
MATCH	Matching Assistive Technology and Child
PAMS	Physical Abilities Mobility Scale
PEDI	Pediatric Evaluation of Disability Inventory
QUEST 2.0	Quebec User Evaluation of Satisfaction with Technology
SFA	School Function Assessment
SWAPS	Supported Walker Ambulation Scale
TDMMT	Top Down Motor Milestone Test
Wee FIM	Functional Independence Measure for Children

Appendix A. Studies Providing Evidence for Use of Additional Tools to Measure Outcomes of Motor Interventions with Children at GMFCS IV and V

Study	Design	Intervention	Participants & Sample	Clinical Tools
Benedict et al., 1999 [86]	Cross-sectional	Assistive Technology	21 families; 19 CP, 2 metabolic; 2–4 years; 1 PWC user (GMFCS IV)	PEDI [29] QUEST 2.0 [46]
Bottos et al., 2001 [61]	Case series	Power Mobility	25 children with CP, (GMFCS IV or V) 3–8 years	COPM [42]
Malouin et al., 1997 [47]	Tool development	NA	3 expert PT's 9 children with CP 1.3–2.3 years. GMFCS levels unclear—4 quadriplegic	SWAPS [47]
Mattern-Baxter et al., 2009 [77]	Cohort without control	Treadmill training	6 children with CP 2.5–3.9 years Including 2 at GMFCS IV	6-min walk test [41] 10-m walk test [26,27] PEDI [29] GMFM-66 [73]
Meyer-Heim et al., 2009 [80]	Single Subject Research Design	Robot-assisted treadmill training	22 children with CP mean 8.6 years (4.6–11.7 years). Including 4 at GMFCS IV	6 min walk test [41] 10 m walk test [26,27] GMFM-66 [73]
Reid et al., 1999 [60]	Single Subject Research Design	Rigid pelvic stabilizer	6 children with CP GMFCS IV; 8–12 years. Rated with caregiver	COPM [42]
Steenbeek et al., 2011 [65]	Methodological	Multi-disciplinary rehabilitation	23 children with CP GMFCS I–V 2–13 years. Included 5 at GMFCS V and 4 at GMFCS IV	GAS [44] PEDI [29] GMFM-66 [73]
Tefft et al., 2011 [75]	Cohort without control	Power Mobility	Parents of 23 children; 18–72 mos. 13 CP (GMFCS IV or V), 10 other	MATCH [45] QUEST 2.0 [46]
Westcott-McCoy et al., 2012 [43]	Tool development	Not Appropriate	69 children GMFCS IV and 92 GMFCS V—Construct validity 8 children GMFCS V—Test-retest reliability study 13 children GMFCS I and 1 GMFCS II—convergent reliability with 6 min walk test	EASE [43] 6-min walk test [41]

References

1. Hanna, S.E.; Bartlett, D.J.; Rivard, L.M.; Russell, D.J. Reference curves for the Gross Motor Function Measure: Percentiles for clinical description and tracking over time among children with cerebral palsy. *Phys. Ther.* **2008**, *88*, 596–607. [CrossRef] [PubMed]
2. Dayanidhi, S.; Dykstra, P.B.; Lyubasyuk, V.; McKay, B.R.; Chambers, H.G.; Lieber, R.L. Reduced satellite cell number in situ in muscular contractures from children with cerebral palsy. *J. Orthop. Res.* **2015**, *33*, 1039–1045. [CrossRef] [PubMed]
3. Palisano, R.; Rosenbaum, P.; Walter, S.; Russell, D.; Wood, E.; Galuppi, B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev. Med. Child Neurol.* **1997**, *39*, 214–223. [CrossRef] [PubMed]
4. Low, S.A.; McCoy, S.W.; Beling, J.; Adams, J. Pediatric physical therapists' use of support walkers for children with disabilities: A nationwide survey. *Pediatr. Phys. Ther.* **2011**, *23*, 381–389. [CrossRef] [PubMed]
5. Paleg, G.; Livingstone, R. Outcomes of gait trainer use in home and school settings for children with motor impairments: A systematic review. *Clin. Rehabil.* **2015**, *28*, 1077–1091. [CrossRef] [PubMed]
6. World Health Organization. *International Classification of Functioning, Disability & Health (ICF)*; World Health Organization: Geneva, Switzerland, 2001.
7. World Health Organization. *International Classification of Functioning, Disability and Health—Children and Youth*; World Health Organization: Geneva, Switzerland, 2007.
8. Chung, J.; Evans, J.; Lee, C.; Rabbani, Y.; Roxborough, L.; Harris, S.R. Effectiveness of adaptive seating on sitting posture and postural control in children with cerebral palsy. *Pediatr. Phys. Ther.* **2008**, *20*, 303–317. [CrossRef] [PubMed]

9. Livingstone, R.; Field, D. Systematic review of power mobility outcomes for infants, children and adolescents with mobility limitations. *Clin. Rehabil.* **2014**, *28*, 954–964. [CrossRef] [PubMed]
10. Houwen, S.; Van der Putten, A.; Vlaskamp, C. A systematic review of the effects of motor interventions to improve motor, cognitive, and/or social functioning in people with severe or profound intellectual disabilities. *Res. Dev. Disabil.* **2014**, *35*, 2093–2116. [CrossRef] [PubMed]
11. Zwicker, J.G.; Mayson, T.A. Effectiveness of treadmill training in children with motor impairments: An overview of systematic reviews. *Pediatr. Phys. Ther.* **2010**, *22*, 361–377. [CrossRef] [PubMed]
12. Sakzewski, L.; Boyd, R.; Ziviani, J. Clinimetric properties of participation measures for 5 to 13 year old children with cerebral palsy: A systematic review. *Dev. Med. Child Neurol.* **2007**, *49*, 232–240. [CrossRef] [PubMed]
13. Field, D.; Livingstone, R. Clinical tools that measure sitting posture, seated postural control or functional abilities in children with motor impairments: A systematic review. *Clin. Rehabil.* **2013**, *27*, 994–1004. [CrossRef] [PubMed]
14. Field, D.A.; Miller, W.C.; Ryan, S.E.; Jarus, T.; Abundo, A. Measuring participation for children and youth with power mobility needs: A systematic review of potential health measurement tools. *Arch. Phys. Med. Rehabil.* **2015**, *97*, 462–477. [CrossRef] [PubMed]
15. Law, M. Outcome Measures Rating Form Guidelines. Available online: http://www.canchild.ca/en/canchildresources.resources.measguid.pdf (accessed on 7 May 2016).
16. Barnes, S.B.; Whinnery, K.W. Effects of Functional Mobility Skills Training for Young Students with Physical Disabilities. *Except. Child.* **2002**, *68*, 313–324. [CrossRef]
17. Eisenberg, S.; Zuk, L.; Carmeli, E.; Katz-Leurer, M. Contribution of stepping while standing to function and secondary conditions among children with cerebral palsy. *Pediatr. Phys. Ther.* **2009**, *21*, 79–85. [CrossRef] [PubMed]
18. Farrell, E.; Naber, E.; Geigle, P. Description of a multifaceted rehabilitation program including overground gait training for a child with cerebral palsy: A case report. *Physiother. Theory Pract.* **2010**, *26*, 56–61. [CrossRef] [PubMed]
19. Lancioni, G.; Nirbhay, N.; O'Reilly, F.; Campodonico, F.; Oliva, O.; Vigo, C. Promoting walker-assisted step responses by an adolescent with multiple disabilities through automatically delivered stimulation. *J. Vis. Impair. Blind* **2005**, *99*, 109–113.
20. Lancioni, G.E.; Singh, N.N.; O'Reilly, M.F.; Sigafoos, J.; Oliva, D.; Scalini, L.; Castagnaro, F.; Di Bari, M. Promoting foot-leg movements in children with multiple disabilities through the use of support devices and technology for regulating contingent stimulation. *Cogn. Process.* **2007**, *8*, 279–283. [CrossRef] [PubMed]
21. Lancioni, G.E.; Singh, N.N.; O'Reilly, M.F.; Sigafoos, J.; Oliva, D.; Piazzolla, G.; Pidala, S.; Smaldone, A.; Manfredi, F. Automatically Delivered Stimulation for Walker-Assisted Step Responses: Measuring its Effects in Persons with Multiple Disabilities. *J. Dev. Phys. Disabil.* **2007**, *19*, 1–13. [CrossRef]
22. Van der Putten, A.; Vlaskamp, C.; Reynders, K.; Nakken, H. Children with profound intellectual and multiple disabilities: The effects of functional movement activities. *Clin. Rehabil.* **2005**, *19*, 613–620. [CrossRef] [PubMed]
23. Willoughby, K.L.; Dodd, K.J.; Shields, N.; Foley, S. Efficacy of partial body weight-supported treadmill training compared with overground walking practice for children with cerebral palsy: A randomized controlled trial. *Arch. Phys. Med. Rehabil.* **2010**, *91*, 333–339. [CrossRef] [PubMed]
24. Wright, F.V.; Belbin, G.; Slack, M.; Jutai, J. An evaluation of the David Hart Walker Orthosis: A new assistive device for children with Cerebral Palsy. *Physiother. Can.* **1999**, *51*, 280–291.
25. Wright, F.V.; Jutai, J.W. Evaluation of the longer-term use of the David Hart Walker Orthosis by children with cerebral palsy: A 3-year prospective evaluation. *Disabil. Rehabil. Assist. Technol.* **2006**, *1*, 155–166. [CrossRef] [PubMed]
26. Evans, M.D.; Goldie, P.A.; Hill, K.D. Systematic and random error in repeated measurements of temporal and distance parameters of gait after stroke. *Arch. Phys. Med. Rehabil.* **1997**, *78*, 725–729. [CrossRef]
27. Pirpiris, M.; Wilkinson, A.J.; Rodda, J.; Nguyen, T.C.; Baker, R.J.; Nattrass, G.R.; Graham, H.K. Walking speed in children and young adults with neuromuscular disease: Comparison between two assessment methods. *J. Pediatr. Orthop.* **2003**, *23*, 302–307. [CrossRef] [PubMed]

28. Russell, D.; Rosenbaum, P.; Cadman, D.; Gowland, C.; Hardy, S.; Jarvis, S. The Gross Motor Function Measure: A means to evaluate the effects of physical therapy. *Dev. Med. Child Neurol.* **1989**, *31*, 341–352. [CrossRef] [PubMed]
29. Haley, S.; Coster, W.; Ludlow, L. *Pediatric Evaluation of Disability Inventory: Development, Standardization and Administration Manual*; New England Medical Center Publications: Boston, MA, USA, 1992.
30. Suskauer, S.; Slomine, B.; Salorio, C.; Bradley, E.; Madigan, L.; Sesma, H.; Christensen, J. The physical abilities and mobility scale. *J. Head Trauma Rehabil.* **2006**, *21*, 420–420. [CrossRef]
31. Coster, W.; Deeney, T.; Haltiwanger, J.; Haley, S. *School Function Assessment (SFA) User's Manual*; PsychCorp: San Antonio, TX, USA, 1998.
32. Lancioni, G.E.; Singh, N.N.; O'Reilly, M.F.; Sigafoos, J.; Oliva, D.; Campodonico, F.; Buono, S. Walker devices and microswitch technology to enhance assisted indoor ambulation by persons with multiple disabilities: Three single-case studies. *Res. Dev. Disabil.* **2013**, *34*, 2191–2199. [CrossRef] [PubMed]
33. Van der Putten, A.; Vlaskamp, C.; Reynders, K.; Nakken, H. Movement skill assessment in children with profound multiple disabilities: A psychometric analysis of the Top Down Motor Milestone Test. *Clin. Rehabil.* **2005**, *19*, 635–643. [CrossRef] [PubMed]
34. Chen, C.C.; Bode, R.K.; Granger, C.V.; Heinemann, A.W. Psychometric Properties and Developmental Differences in Children's ADL Item Hierarchy. *Am. J. Phys. Med. Rehabil.* **2005**, *84*, 671–679. [CrossRef] [PubMed]
35. *Uniform Data System for Medical Rehabilitation: WeeFIM System Clinical Guide*, 5th ed.; University of Buffalo: New York, NY, USA, 1998.
36. Tedla, J.S.; Ganesan, S.; Katragadda, S. Inter-rater reliability of the Top Down Motor Milestone Test: A cross-sectional study. *Clin. Rehabil.* **2009**, *23*, 725–729. [CrossRef] [PubMed]
37. Thompson, P.; Beath, T.; Bell, J.; Jacobson, G.; Phair, T.; Salbach, N.M.; Wright, F.V. Test-retest reliability of the 10-metre fast walk test and 6-minute walk test in ambulatory school-aged children with cerebral palsy. *Dev. Med. Child Neurol.* **2008**, *50*, 370–376. [CrossRef] [PubMed]
38. Graser, J.V.; Letsch, C.; Van Hedel, H.J.A. Reliability of timed walking tests and temporo-spatial gait parameters in youths with neurological gait disorders. *BMC Neurol.* **2016**, *16*, 15. [CrossRef] [PubMed]
39. Trovato, M.K.; Bradley, E.; Slomine, B.S.; Salorio, C.F.; Christensen, J.R.; Suskauer, S.J. Physical abilities and mobility scale: Reliability and validity in children receiving inpatient rehabilitation for acquired brain injury. *Arch. Phys. Med. Rehabil.* **2013**, *94*, 1335–1341. [CrossRef] [PubMed]
40. Kuenzle, C.; Brunner, R. The effects of the Norsk Funktion-walking orthosis on the walking ability of children with cerebal palsy and severe gait impairment. *J. Prosthet. Orthot.* **2009**, *21*, 138–144. [CrossRef]
41. Maher, C.; Williams, L.; Olds, T. The six-minute walk test for children with cerebral palsy. *Int. J. Rehabil. Res.* **2008**, *31*, 185–188. [CrossRef] [PubMed]
42. Law, M.; Baptiste, S.; Carswell, A.; McColl, M.; Polatajko, H.; Pollock, N. *Canadian Occupational Performance Measure*, 2nd ed.; Canadian Association of Occupational Therapists: Toronto, ON, Canada, 1994.
43. Westcott McCoy, S.; Yocum, A.; Bartlett, D.J.; Mendoza, J.; Jeffries, L.; Chiarello, L.; Palisano, R.J. Development of the Early Activity Scale for Endurance for children with cerebral palsy. *Pediatr. Phys. Ther.* **2012**, *24*, 232–240. [CrossRef] [PubMed]
44. Kiresuk, T.; Smith, A.; Cardillo, J. *Goal Attainment Scaling: Application, Theory and Measurement*; Lawrence Erlbaum Associates: Hillscale, NJ, USA, 1994.
45. Scherer, M. *Matching Assistive Technology & Child (MATCH. A Process and Series of Assessments for Selecting and Evaluating Technologies Used by Infants and Young Children*; The Institute for Matching Person & Technology: Webster, NY, USA, 1998.
46. Demers, L.; Weiss-Lambrou, R.; Ska, B. The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST Version 2.0), 2000. Available online: http://www.midss.ie/sites/default/files/questmanual_final_electronic20version_0.pdf (accessed on 7 May 2016).
47. Malouin, F.; Richards, C.; Menier, C.; Dumas, F.; Marcoux, S. Supported walker ambulation performance scale (SWAPS): Development of an outcome measure of locomotor status in children with cerebral palsy. *Pediatr. Phys. Ther.* **1997**, *9*, 48–53. [CrossRef]
48. Dodd, K.J. Partial body-weight-supported treadmill training can improve walking in children with cerebral palsy: A clinical controlled trial. *Dev. Med. Child Neurol.* **2007**, *49*, 101–105. [CrossRef] [PubMed]

49. Ko, J.; Kim, M. Reliability and responsiveness of the gross motor function measure-88 in children with cerebral palsy. *Phys. Ther.* **2013**, *93*, 393–400. [CrossRef] [PubMed]
50. Wright, F.; Boschen, K. Use of the Pediatric Evaluation of Disability Inventory to detect change in functional status in children with cerebral palsy. *Physiother. Can.* **1996**, *48* (Suppl. 2), 1–6.
51. Nichols, D.; Case-Smith, J. Reliability and Validity of the Pediatric Evaluation of Disability Inventory. *Pediatr. Phys. Ther.* **1996**, *8*, 15–24. [CrossRef]
52. Iyer, L.V.; Haley, S.M.; Watkins, M.P.; Dumas, H.M. Establishing minimal clinically important differences for scores on the pediatric evaluation of disability inventory for inpatient rehabilitation. *Phys. Ther.* **2003**, *83*, 888–898. [PubMed]
53. Wright, F.V.; Boschen, K.; Jutai, J. Exploring the comparative responsiveness of a core set of outcome measures in a school-based conductive education programme. *Child Care Health Dev.* **2005**, *31*, 291–302. [CrossRef] [PubMed]
54. Wright, F.; Liu, G.; Milne, F. Reliability of the measurement of time-distance parameters of gait: A comparison in children with juvenile rheumatoid arthritis and children with cerebral palsy. *Physiother. Can.* **1999**, *15*, 191–200.
55. Nsenga Leunkeu, A.; Shephard, R.J.; Ahmaidi, S. Six-minute walk test in children with cerebral palsy gross motor function classification system levels I and II: Reproducibility, validity, and training effects. *Arch. Phys. Med. Rehabil.* **2012**, *93*, 2333–2339. [CrossRef] [PubMed]
56. Cusick, A.; Lannin, N.A.; Lowe, K. Adapting the Canadian Occupational Performance Measure for use in a paediatric clinical trial. *Disabil. Rehabil.* **2007**, *29*, 761–766. [CrossRef] [PubMed]
57. Verkerk, G.J.Q.; Wolf, M.J.M.; Louwers, A.M.; Meester-Delver, A.; Nollet, F. The reproducibility and validity of the Canadian Occupational Performance Measure in parents of children with disabilities. *Clin. Rehabil.* **2006**, *20*, 980–988. [CrossRef] [PubMed]
58. Wallen, M.A.; Ziviani, J.M. Canadian Occupational Performance Measure: Impact of blinded parent-proxy ratings on outcome. *Can. J. Occup. Ther.* **2012**, *79*, 7–14. [CrossRef] [PubMed]
59. Cusick, A.; McIntyre, S.; Novak, I.; Lannin, N.; Lowe, K. A comparison of goal attainment scaling and the Canadian Occupational Performance Measure for paediatric rehabilitation research. *Pediatr. Rehabil.* **2006**, *9*, 149–157. [CrossRef] [PubMed]
60. Reid, D.; Rigby, P.; Ryan, S. Functional impact of a rigid pelvic stabilizer on children with cerebral palsy who use wheelchairs: users' and caregivers' perceptions. *Pediatr. Rehabil.* **1999**, *3*, 101–118. [PubMed]
61. Bottos, M.; Bolcati, C.; Sciuto, L.; Ruggeri, C.; Feliciangeli, A. Powered wheelchairs and independence in young children with tetraplegia. *Dev. Med. Child Neurol.* **2001**, *43*, 769–777. [CrossRef] [PubMed]
62. Carswell, A.; McColl, M.A.; Baptiste, S.; Law, M.; Polatajko, H.; Pollock, N. The Canadian Occupational Performance Measure: A research and clinical literature review. *Can. J. Occup. Ther.* **2004**, *71*, 210–222. [CrossRef] [PubMed]
63. Steenbeek, D.; Ketelaar, M.; Lindeman, E.; Galama, K.; Gorter, J.W. Interrater Reliability of Goal Attainment Scaling in Rehabilitation of Children With Cerebral Palsy. *Arch. Phys. Med. Rehabil.* **2010**, *91*, 429–435. [CrossRef] [PubMed]
64. Law, L.S.H.; Dai, M.O.; Siu, A. Applicability of goal attainment scaling in the evaluation of gross motor changes in children with cerebral palsy. *Hong Kong Physiother. J.* **2004**, *22*, 22–28. [CrossRef]
65. Steenbeek, D.; Gorter, J.W.; Ketelaar, M.; Galama, K.; Lindeman, E. Responsiveness of Goal Attainment Scaling in comparison to two standardized measures in outcome evaluation of children with cerebral palsy. *Clin. Rehabil.* **2011**, *25*, 1128–1139. [CrossRef] [PubMed]
66. Demers, L.; Weiss-Lambrou, R.; Ska, B. Item analysis of the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST). *Assist. Technol.* **2000**, *12*, 96–105. [CrossRef] [PubMed]
67. Demers, L.; Weiss-lambrou, R.; Ska, B. The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0): An overview and recent progress. *Technol. Disabil.* **2002**, *14*, 101–105.
68. Kurz, M.J.; Stuberg, W.; Dejong, S.; Arpin, D.J. Overground body-weight-supported gait training for children and youth with neuromuscular impairments. *Phys. Occup. Ther. Pediatr.* **2013**, *33*, 353–365. [CrossRef] [PubMed]
69. Stuberg, W.; DeJong, S.; Kelly, M. Gait training using partial body weight support during over ground walking in individuals with developmental disabilities. *Pediatr. Phys. Ther.* **2004**, *16*, 65–66.

70. Watson, M.J. Refining the ten-metre walking test for use with neurologically impaired people. *Physiother* **2002**, *88*, 386–397. [CrossRef]
71. Haley, S.M.; Coster, W.I.; Kao, Y.C.; Dumas, H.M.; Fragala-Pinkham, M.A.; Kramer, J.M.; Ludlow, L.H.; Moed, R. Lessons from use of the Pediatric Evaluation of Disability Inventory: Where do we go from here? *Pediatr. Phys. Ther.* **2010**, *22*, 69–75. [CrossRef] [PubMed]
72. SCIRE Project. Available online: http://www.scireproject.com/outcome-measures-new/10-m-walking-test-10-mwt# (accessed on 26 July 2016).
73. Russell, D.; Rosenbaum, P.; Avery, L.; Lane, M. *The Gross Motor Function Measure (GMFM-66 and GMFM-88) User's Manual*; Cambridge University Press: Cambridege, UK, 2002.
74. Steenbeek, D.; Ketelaar, M.; Galama, K.; Gorter, J.W. Goal attainment scaling in paediatric rehabilitation: A report on the clinical training of an interdisciplinary team. *Child Care Health Dev.* **2008**, *34*, 521–529. [CrossRef] [PubMed]
75. Tefft, D.; Guerette, P.; Furumasu, J. The impact of early powered mobility on parental stress, negative emotions, and family social interactions. *Phys. Occup. Ther. Pediatr.* **2011**, *31*, 4–15. [CrossRef] [PubMed]
76. Palisano, R.J.; Chiarello, L.A.; King, G.A.; Novak, I.; Stoner, T.; Fiss, A. Participation-based therapy for children with physical disabilities. *Disabil. Rehabil.* **2012**, *34*, 1041–1052. [CrossRef] [PubMed]
77. Mattern-Baxter, K.; Bellamy, S.; Mansoor, J.K. Effects of intensive locomotor treadmill training on young children with cerebral palsy. *Pediatr. Phys. Ther.* **2009**, *21*, 308–318. [CrossRef] [PubMed]
78. Jones, M.; McEwen, I.; Neas, B. Effects of power wheelchairs on the development and function of young children with severe motor impairments. *Pediatr. Phys. Ther.* **2012**, *24*, 131–140. [CrossRef] [PubMed]
79. Gibson, B.E.; Teachman, G.; Wright, V.; Fehlings, D.; Young, N.L.; McKeever, P. Children's and parents' beliefs regarding the value of walking: Rehabilitation implications for children with cerebral palsy. *Child Care Health Dev.* **2012**, *38*, 61–69. [CrossRef] [PubMed]
80. Meyer-Heim, A.; Ammann-Reiffer, C.; Schmartz, A.; Schaefer, J.; Sennhauser, F.H.; Heinen, F.; Knecht, B.; Dabrowski, E.; Borggraefe, I. Improvement of walking abilities after robotic-assisted locomotion training in children with cerebral palsy. *Arch. Dis. Child* **2009**, *94*, 615–620. [CrossRef] [PubMed]
81. Richards, C.L.; Malouin, F.; Dumas, F.; Marcoux, S.; Lepage, C.; Menier, C. Early and intensive treadmill locomotor training for young children with cerebral palsy: A feasibility study. *Pediatr. Phys. Ther.* **1997**, *9*, 158–165. [CrossRef]
82. Drouin, L.M.; Malouin, F.; Richards, C.L.; Marcoux, S. Correlation between the gross motor function measure scores and gait spatiotemporal measures in children with neurological impairments. *Dev. Med. Child Neurol.* **1996**, *38*, 1007–1019. [CrossRef] [PubMed]
83. Carty, C.P.; Walsh, H.P.J.; Gillett, J.G.; Phillips, T.; Edwards, J.M.; Boyd, R.N. The effect of femoral derotation osteotomy on transverse plane hip and pelvic kinematics in children with cerebral palsy: A systematic review and meta-analysis. *Gait Posture* **2014**, *40*, 333–340. [CrossRef] [PubMed]
84. Schroeder, A.S.; Homburg, M.; Warken, B.; Auffermann, H.; Koerte, I.; Berweck, S.; Jahn, K.; Heinen, F.; Borggraefe, I. Prospective controlled cohort study to evaluate changes of function, activity and participation in patients with bilateral spastic cerebral palsy after Robot-enhanced repetitive treadmill therapy. *Eur. J. Paediatr. Neurol.* **2014**, *18*, 502–510. [CrossRef] [PubMed]
85. Scherer, M.J.; Craddock, G. Matching Person & Technology ({MPT}) assessment process. *Technol. Disabil.* **2002**, *14*, 125–132.
86. Benedict, R.; Lee, J.; Marrujo, S.; Farel, A. Assistive devices as an early childhood intervention: Evaluating outcomes. *Technol. Disabil.* **1999**, *11*, 79–90.
87. Novak, I.; McIntyre, S.; Morgan, C.; Campbell, L.; Dark, L.; Morton, N.; Stumbles, E.; Wilson, S.; Goldsmith, S. A systematic review of interventions for children with cerebral palsy: state of the evidence. *Dev. Med. Child Neurol.* **2002**, *55*, 885–910. [CrossRef] [PubMed]
88. Amman-Reiffer, C.; Bastiaenen, C.H.G.; De Bie, R.A.; Van Hedel, H.J.A. Measurement properties of gait-related outcomes in youth with neuromuscular diagnoses: A systematic review. *Phys. Ther.* **2014**, *94*, 1067–1082. [CrossRef] [PubMed]
89. Himoru, N.; Hirokazu, A.; Nishibu, H.; Seino, T.; Mori, M. Easy to use clinical measures of walking ability in children and adolescents with cerebral palsy: A systematic review. *Disabil. Rehabil.* **2016**. [CrossRef] [PubMed]

90. Streiner, D.L.; Norman, G.R.; Cairney, J. *Health Measurement Scales: A Practical Guide to Their Development and Use*; Oxford University Press: Oxford, UK, 2014.
91. Andresen, E.M. Criteria for assessing the tools of disability outcomes research. *Arch. Phys. Med. Rehabil.* **2000**, *81*, S15–S20. [CrossRef] [PubMed]
92. Terwee, C.B.; Prinsen, C.A.C.; Ricci Garotti, M.G.; Suman, A.; De Vet, H.C.W.; Mokkink, L.B. The quality of systematic reviews of health-related outcome measurement instruments. *Qual. Life Res.* **2016**, *25*, 767–779. [CrossRef] [PubMed]
93. Mokkink, L.B.; Terwee, C.B.; Stratford, P.W.; Alonso, J.; Patrick, D.L.; Riphagen, I.; Knol, D.L.; Bouter, L.M.; DeVet, H.C.W. Evaluation of the methodological quality of systematic reviews of health status measurement instruments. *Qual. Life Res.* **2009**, *18*, 313–333. [CrossRef] [PubMed]
94. Fuhrer, M.J.; Jutai, J.W.; DeRuyter, F.A. A framework for the conceptual modelling of assistive technology device outcomes. *Disabil. Rehabil.* **2003**, *25*, 1243–1251. [CrossRef] [PubMed]