Archives of Rehabilitation Research and Clinical Translation (2024) 6, 100384

ACRM AMERICAN CONGRESS OF REHABILITATION MEDICINE

**Archives of Rehabilitation Research and Clinical Translation**

Archives of Rehabilitation Research and Clinical Translation 2024;6:100384

Available online at www.sciencedirect.com

Review Article

# Psychometrics of Wearable Devices Measuring Physical Activity in Ambulant Children With Gait Abnormalities: A Systematic Review and Meta-analysis

**Huib van Moorsel, MSc [a,*], Barbara Engels, MSc [b,c,*], Jacek Buczny, PhD [d], Jan Willem Gorter, MD [e,f], Kelly Arbour-Nicitopoulos, PhD [g], Tim Takken, PhD [h], Raoul H.H. Engelbert, PhD [i,j,**], Manon A.T. Bloemen, PhD [b,**]**

[a] *Institute for Human Movement Studies, University of Applied Sciences, Utrecht, The Netherlands*
[b] *Research Centre Healthy and Sustainable Living, Research group Lifestyle and Health, Utrecht University of Applied Sciences, Utrecht, The Netherlands*
[c] *University Medical Center Utrecht Brain Center and Center of Excellence for Rehabilitation Medicine, Utrecht University, Utrecht, The Netherlands*
[d] *Faculty of Behavioral and Movement Sciences, Department of Experimental and Applied Psychology, Amsterdam University Medical Center, Amsterdam, The Netherlands*
[e] *Department of Rehabilitation, Physical Therapy Science and Sports, University Medical Center Utrecht Brain Center, Utrecht, The Netherlands*
[f] *CanChild, Department of Pediatrics, McMaster University, Hamilton, Ontario, Canada*
[g] *Faculty of Kinesiology and Physical Education, University of Toronto, Toronto, Ontario, Canada*
[h] *Child Development & Exercise Center, Wilhelmina Children's Hospital, University Medical Center Utrecht, Utrecht, The Netherlands*
[i] *Centre of Expertise Urban Vitality, Faculty of Health, Amsterdam University of Applied Sciences, Amsterdam, The Netherlands*
[j] *Department of Rehabilitation Medicine, Amsterdam University Medical Center, University of Amsterdam, Amsterdam, The Netherlands*

*List of abbreviations:* ABI, acquired brain injury; CI, confidence interval; COSMIN, Consensus-Based Standards for the Selection of Health Measurement Instruments; CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; ICC, intraclass correlation coefficient; MVPA, moderate-to-vigorous physical activity; OSF, Open Science Framework; PA, physical activity; SB, spina bifida; WHO, World Health Organization.

Supported by Foundation Innovation Alliance—Regional Attention and Action for Knowledge Circulation (SIA Raak. MKB12.OO2).
Cite this article as: Arch Rehabil Res Clin Transl. 2024;6:100384

* van Moorsel and Engels contributed equally as first authors.
** Engelbert and Bloemen contributed equally as last authors.

https://doi.org/10.1016/j.arrct.2024.100384
2590-1095/© 2024 The Authors. Published by Elsevier Inc. on behalf of American Congress of Rehabilitation Medicine. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

**KEYWORDS**
Accelerometry;
Gait abnormality;
Meta-analysis;
Physical activity;
Psychometric properties;
Rehabilitation;
Systematic review

**Abstract** *Objective:* To evaluate psychometrics of wearable devices measuring physical activity (PA) in ambulant children with gait abnormalities due to neuromuscular conditions.
*Data Sources:* We searched PubMed, Embase, PsycINFO, CINAHL, and SPORTDiscus in March 2023.
*Study Selection:* We included studies if (1) participants were ambulatory children (2-19y) with gait abnormalities, (2) reliability and validity were analyzed, and (3) peer-reviewed studies in the English language and full-text were available. We excluded studies of children with primarily visual conditions, behavioral diagnoses, or primarily cognitive disability. We performed independent screening and inclusion, data extraction, assessment of the data, and grading of results with 2 researchers.
*Data Extraction:* Our report follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. We assessed methodological quality with Consensus-based Standards for the selection of health measurement instruments. We extracted data on reported reliability, measurement error, and validity. We performed meta-analyses for reliability and validity coefficient values.
*Data Synthesis:* Of 6911 studies, we included 26 with 1064 participants for meta-analysis. Results showed that wearables measuring PA in children with abnormal gait have high to very high reliability (intraclass correlation coefficient $[ICC]_{+,\ \text{test-retest reliability}}$=0.81; 95% confidence interval [CI], 0.74-0.89; $I^2$=88.57%; $ICC_{+,\ \text{interdevice reliability}}$=0.99; 95% CI, 0.98-0.99; $I^2$=71.01%) and moderate to high validity in a standardized setting ($r_{+,\ \text{construct validity}}$=0.63; 95% CI, 0.36-0.89; $I^2$=99.97%; $r_{+,\ \text{criterion validity}}$=0.68; 95% CI, 0.57-0.79; $I^2$=98.70%; $r_{+,\ \text{criterion validity cutoff point based}}$=0.69; 95% CI, 0.58-0.80; $I^2$=87.02%). The methodological quality of all studies included in the meta-analysis was moderate.
*Conclusions:* There was high to very high reliability and moderate to high validity for wearables measuring PA in children with abnormal gait, primarily due to neurological conditions. Clinicians should be aware that several moderating factors can influence an assessment.
© 2024 The Authors. Published by Elsevier Inc. on behalf of American Congress of Rehabilitation Medicine. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Promoting physical activity (PA) in children to stimulate beneficial health effects, such as physical and psychological development, well-being, and socialization, is an important international target.[1-4] Promoting PA is advised for typically developing children, as well as for those with chronic diseases and disorders with consequent disability. In 2022, the World Health Organization (WHO) reported that more than 80% of children do not meet the recommended levels of PA for optimum health.[5]

There is a lack of reports on levels of PA among children of all ages living with disability.[5] Children living with disability are less likely to be physically active compared with those without a disability.[5-7] PA guidelines report that children from 5 to 17 years of age with and without disabilities should be active for an average of at least 60 minutes per day in moderate-to-vigorous activity (MVPA), as well as engaged in activities designed to strengthen muscle and bone at least 3 days a week and should limit sedentary time.[5,8] The WHO defines the age range of 2-19 years old as encompassing childhood and adolescence.[9] Accordingly, this study will refer to this population as children.

Health care professionals can use different instruments to assess and inform children and their caretakers about reaching recommended levels of PA. Clinicians can use these instruments and data to propose individual monitoring of PA to enhance or maintain a physically active lifestyle. The availability of instruments with demonstrated psychometric properties for children with and without disabilities is essential. Self-report instruments, such as questionnaires and activity diaries, are cost-effective and feasible for users but subject to social desirability and recall bias and tend to have low reliability and weak to moderate validity.[5,10-12] Wearables such as accelerometers or pedometers seem more reliable and valid for measuring PA in children without disabilities.[13,14] Among children with disabilities, there are several patient groups that may show gait abnormalities due to neurological conditions, including cerebral palsy (CP), spina bifida (SB), or muscular dystrophy.[15-17] Variability in movement, asymmetrical walking pattern, and slow walking pace influence psychometric properties of wearables, resulting in overestimation or underestimation of PA outcomes.[18-21]

"Normal gait" relates to neuromotor development and movement parameters.[22] The International Classification of Diseases and Related Health Problems (version 2019) defines "gait with abnormalities" as ataxic and paralytic gait or difficulty in walking.[23] Individual studies of wearable devices measuring PA in children with gait abnormalities are inconclusive about their psychometric properties and clinical implications because of variations within assessed patient populations, placement of the devices, suitability of existing cutoff points related to PA metrics in specific populations, and different measurement protocols.[10,16,24-26] A systematic review or meta-analysis of the psychometric properties of existing studies reporting on wearable devices measuring PA in children with gait abnormalities is lacking.

Therefore, we aim to critically appraise, compare, summarize, and generalize psychometric properties of studies reporting on wearables assessing PA in ambulant children (2-19y of age) with gait abnormalities associated with neuromuscular conditions. Based on these findings, clinicians can be informed about wearable devices measuring PA using existing wearables as guidance for tailored treatment in clinical practice for children with disabilities and consequent gait abnormalities.

## Methods

We registered our review protocol at the International Prospective Register for Systematic Reviews, registration number CRD42022313297. We conducted this review according to the quality assessment of patient-reported outcome measurements, the Consensus-based Standards for the Selection of Health Measurement Instruments (COSMIN),[27,28] and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[29] All appendices and supplemental appendices are available on the Open Science Framework (OSF, https://osf.io/kgse9/).

We performed study screening, data extraction data assessment and grading of the results, with 2 independent researchers and, if indicated, with a third researcher for consensus. We performed the meta-analysis with 2 independent researchers using *R* version 4.3.2 (Peter Dalgaard) (2024).[30]

### Search strategy

We systematically conducted a literature search in March 2023 (supplemental appendix S1, available online only at http://www.archives-pmr.org/, OSF) in the following electronic databases: PubMed (MEDLINE), Embase (Elsevier), PsycINFO, CINAHL, and SPORTDiscus (EBSCOhost). We divided key search words into 3 blocks: (1) words related to the population (children with gait abnormalities), (2) measuring methods (wearable devices to measure PA), and (3) measurement properties (reliability, measurement error, validity). We used previously published search filters[31-33] and we consulted a panel of clinicians to check for completeness. Also, we hand-searched the reference lists of the included studies for the inclusion of relevant additional studies. We conducted the search without any restrictions regarding the publication date.

### Eligibility criteria

Inclusion criteria were: (1) ambulatory children between 2 and 19 years of age with gait abnormalities; (2) examination of measurement properties: reliability, measurement error, and validity of instruments for wearable devices measuring PA as defined by Mokkink et al[28]; and (3) peer-reviewed studies published in English and with full-text available. We included studies with mixed populations (eg, children with normal and abnormal gait) if we were able to extract data on children with abnormal gait patterns. We excluded studies of children with primarily visual conditions, behavioral diagnoses, or primarily cognitive disability.

### Screening process and study selection

We imported all identified studies into Covidence systematic review software[a] and removed duplicates. We screened all titles/abstracts and full texts for eligibility using the systematic review software Rayyan.[b]

### Data extraction

We used a data extraction form based on COSMIN.[27,28] The extracted information included details regarding the PA setting (whether laboratory, free-living), frequency, intensity, and duration (PA dimension), as well as the classification of physical behavior (sedentary, low PA, MVPA). Moreover, we documented the types of physical behavior, including individual categories (such as lying, sitting, standing, walking, running), and combined categories observed during activities such as free play or structured protocols. We collected information on the name of the author(s), year of publication, study characteristics, population, type of measurement instrument, comparator instrument, measurement protocol and properties, details of units of measure, statistical and psychometrical information, and results.

### Evaluation of the measurement properties

#### Methodological quality

We assessed the methodological quality of included studies with the COSMIN Risk of Bias tool for outcome measurement instruments, following the standards for reliability, measurement error, and validity studies.[34,35] We scored each item following the COSMIN with a 4-point scale: very good (V), adequate (A), doubtful (D), and inadequate (I). To determine the overall rating of the methodological quality of each single study, we used the worst-score-counts principle.[36]

#### Evaluation of results and grading of the quality of evidence

We categorized the results of each measurement property: reliability (test-retest reliability, inter-device reliability), measurement error, and validity (construct, criterion, criterion cutoff point based). As our analytical approach is of a quantitative nature, we only rated the pooled results of the meta-analysis.[34,37]

### Meta-analysis

We employed a multilevel random-effects meta-analysis using *metafor*, version 4.4-0 (Wolfgang Viechtbauer).[38,39] This analysis considered sampling variance (level 1), within-study variance (level 2), and between-study variance (level 3), and reported concordance between standard reference and wearables measuring PA with pooled effect sizes.[40,41] For reliability studies, we considered the intraclass correlation coefficient (ICC) as the effect size with generalizability coefficients and Pearson *r* coefficient as equivalents.[42] For validity studies, Pearson *r* served as the effect size, with the concordance correlation coefficient, ICC and Spearman $\rho$ considered equivalents.[43] The materials of the meta-analysis (appendices 1 and 2) and calculation of effect sizes

(supplemental appendix S2, available online only at http://www.archives-pmr.org/) are available at OSF.

We assessed heterogeneity levels for each level to explain the within and between-study variance with R packages *clubSandwich*,[44] *dmetar*,[45] *meta*,[40] *orchaRd*,[46] and, for cross-validating, we used *robumeta*.[47] We evaluated the level of heterogeneity with Q, $\tau^2$, and $I^2$ statistics. $I^2$ indicates how much variance of true effects is reflected in the observed variance of the effect sizes,[48] for simplification we assumed that a value of $I^2$ greater than 75% suggests high heterogeneity in the effect sizes.[49] The scripts of the meta-analyses are available (supplemental appendices S3 and S4, available online only at http://www.archives-pmr.org/, OSF).

### Moderator coding and analytical strategy

Through the multilevel meta-analysis, we could show relationships between moderators and effect sizes. Moderator analysis was used to investigate variation in the evidence and heterogeneity. It could further lead to the understanding of findings and help produce practical insights that guide further decision-making.[48] We performed moderator analyses to assess both reliability and validity. Table 1 presents the moderator coding for each psychometric property. Specific moderators were coded for test-retest reliability, inter-device reliability, construct validity, criterion validity, and cutoff point criterion validity, as per our data extraction (supplemental appendices S5 and S6, available online only at http://www.archives-pmr.org/, OSF).

Sensitivity analysis and publication bias were evaluated using a funnel plot, a *p*-curve analysis,[50] and the *R* package *PublicationBias*.[51] Furthermore, we conducted moderator analysis by examining the relationship between year of publication and effect sizes.[52] By means of *R* package *metaplus*,[41] we ran analysis to identify possible outliers. Lastly, as the number of effect sizes for all the meta-analyses could be considered low, a post hoc power analysis was conducted using *POMADE*.[53]

For interpretation of pooled correlation coefficients with 95% confidence interval (CI), we interpreted 0-0.3 as negligible correlation; 0.3-0.5 as low correlation; 0.5-0.7 as moderate correlation; 0.7-0.9 as high correlation; 0.9-1.0 as very high correlation.[54] We chose different interpretations than COSMIN based "sufficient," "indeterminate," and "insufficient" because we wanted to be able to differentiate, if necessary, borderline values with more detail, as we included negative as well as positive results in our meta-analysis.

## Grading the pooled evidence

Finally, we evaluated the quality of evidence for the pooled results of all studies using the modified Grading of Recommendations Assessment, Development, and Evaluation, as proposed in the COSMIN guideline and rated the quality of evidence as "high," "moderate," "low," or "very low."[28]

# Results

## Description of studies

We identified 8777 studies resulting in 6911 unique studies after duplicate removal, of which we included 47 for full text screening. Through reference search we included 5 additional ones.[24,55-58] Eventually, for data extraction we included 30 studies with 1145 children with gait abnormalities between the lowest mean age of 2.3 years[56] and the highest mean age of 18.7 years.[59] Figure 1 presents a flow diagram of the full selection process.

Eight studies focused on test-retest reliability,[59-66] and 3 examined inter-device reliability.[67-69] Two examined test-retest reliability as well as inter-device reliability.[20,57] Seven studies reported measurement error,[57,59,62-66] whereas 8 assessed reliability and validity.[20,57,59,60,66-69]

For reliability, a total of 670 children were included (with the lowest mean age of 6.3y[60] and the highest mean age of 18.7y[59]). Eleven studies described wearables measuring PA in children with CP,[20,57,59,60,63-69] whereas the others investigated children with amyoplasia, distal arthrogryposis,[62] or acquired brain injury (ABI).[61] Six studies were conducted in a laboratory setting,[20,60,66-69] 5 in free-living settings,[57,59,62-64] and 2 in both settings.[61,65] One study assessed test-retest reliability with 1 device on the thigh and inter-device reliability with 2 devices in different locations.[57] Twice, the device was placed on the ankle,[62,64] and once on the thigh.[59] In 4 studies, the device was placed on the trunk,[20,61,65,67] or multiple devices were placed in different locations.[60,63,66,69]

Measurement error was assessed in 440 children with the lowest mean age of 8.3 years[64] and the highest mean age of 18.7 years.[59] A detailed description of reliability and measurement error studies is presented in table 2.

Validity was assessed in 25 studies.[16,18,20,21,24,26,55-60,66-78] Three evaluated construct validity,[21,66,74] 13 evaluated criterion validity,[16,20,57-60,67-69,72,75,76,78] 4 focused on criterion validity based on cutoff points,[24,56,70,71] and 4 described criterion validity and criterion validity based on cutoff points.[18,26,73,77] One study described criterion validity and construct validity.[55]

Validity was assessed in 661 children with the lowest mean age of 2.3 years[56] and the highest mean age of 18.7 years.[59] Eighteen studies described wearables measuring PA in children with CP,[18,20,24,55-57,59,60,67-75,78] and 2 in children with SB.[16,76] Three studies included children with ABI,[77] juvenile arthritis and inherited muscle disease,[26] or congenital muscular dystrophy, respectively.[21] In 24 out of 30 studies, a laboratory setting was used.[16,18,20,21,24,26,55,56,58-60,66-78] In 10 studies the wearable device was placed on the trunk,[20,21,24,26,56,70,71,73,75,77] in 7 on the thigh,[16,57-59,67,72,78] and in 1 on the arm.[68] Seven studies placed multiple devices in different locations.[18,55,60,66,69,74,76] Tables 3A and B summarize a detailed description of the studies' validity.

## Quality of studies

### Reliability and measurement error

We rated 2 test-retest reliability studies[64,65] as adequate, 6 as doubtful,[59-63,66] and 1 was inadequate.[57] For inter-device reliability studies, 1 achieved adequate methodological quality,[67] whereas 3 were rated as doubtful,[20,68,69] and 1 was rated as inadequate (table 2).[57] Insufficient description of population characteristics, missing data, or test-retest

**Table 1** Moderator coding for reliability and validity.

| Moderators | Aggregation | Reliability | | Validity | | |
|---|---|---|---|---|---|---|
| | | Test-Retest | Interdevice | Construct Validity | Criterion Validity | Criterion Validity Cutoff Point Based |
| PA setting | Laboratory | • | • | | | |
| | Free-living | • | • | | | |
| PA dimension | Frequency | • | • | | • | • |
| | Intensity | • | • | | • | • |
| | Duration | • | • | | • | • |
| Physical behavior type | Single category | • | | • | • | |
| | Combined categories | • | | • | • | |
| Physical behavior type specified | Walking | • | • | | • | |
| | Lying and sitting | • | • | | • | |
| | Standing | • | | | • | |
| | Running | | • | | • | |
| Physical behavior class | SED | | | | | • |
| | LPA | | | | | • |
| | MVPA | | | | | • |
| %GMFCS level I | | • | • | • | • | • |
| Placement | Leg | • | • | • | • | |
| | Trunk | • | • | | • | |
| | Arm | • | • | • | • | |
| | Multi | • | | | • | |
| Age | >6 y | | | | | • |
| | <6 y | | | | | • |
| | >13 y | • | • | | • | • |
| | <13 y | • | • | | • | • |
| Interval test-retest | >2 wk | • | | | | |
| | <2 wk | • | | | | |
| Placement body side | Same | | • | | | |
| | Opposite | | • | | | |
| Cutoff points | Population specific | | | | | • |
| | General | | | | | • |

NOTE. A dot (•) corresponds to the examined moderators; GMFCS was used in studies with CP and ABI; when GMFCS levels were not specified, the average percentage GMFCS level across all studies was used.
Abbreviations: LPA, low physical activity; SED, sedentary.

duration intervals longer than 2 weeks influenced methodological quality.

Two measurement error studies demonstrated adequate methodological quality,[64,65] whereas 4 were rated doubtful,[59,62,63,69] and 1 showed inadequate methodological quality (table 2).[57]

### Validity

We rated 5 criterion validity studies as very good,[20,67,69,75,76] 6 as doubtful,[55,57,59,60,68,78] and 3 as inadequate.[16,58,72] For criterion validity based on cutoff points, we rated 5 studies as very good,[18,24,26,70,77] and 3 as doubtful.[71,73,79] All studies examining construct validity achieved doubtful methodological quality.[21,55,66,74] Not reporting the length of the epoch, missing a description of the population, or inadequate statistical calculations resulted in lower levels of methodological quality (tables 4A and B).

## Meta-analysis

From 30 studies, we excluded 4 that did not present absolute values, therefore we were not able to convert results into ICC or Pearson *r*.[16,58,66,75] We conducted separate meta-analyses for 26 studies, deriving from test-retest reliability, inter-device reliability, criterion validity, criterion validity of cutoff point based methods and construct validity.[18,20,21,24,26,55-57,59-65,67-74,76-78] Two studies presented partial data: one described newly developed cutoff points but no comparator cutoff points,[26] whereas another described newly developed cutoff points but no absolute values regarding the validity of those.[73] We used reported partial data for analyses.

We excluded all the studies analyzing measurement error because of the impossibility to convert to a standard effect size and because of heterogeneity in outcome measures evaluating measurement error, for example, levels of agreement,[57,59] coefficient of variation,[62] standard error of the mean with or without the smallest detectable change,[63,65] and within-subject SD.[66]

For meta-analysis, we included a total of 1064 children with the lowest mean age of 2.3 years[56] and the highest mean age of 18.7 years.[59] In the studies, children were diagnosed with CP (n=22)[18,20,24,55-57,59,60,63-65,67-75,78]; ABI (n=2)[61,77]; amyoplasia and distal arthrogryposis (n=1)[62];

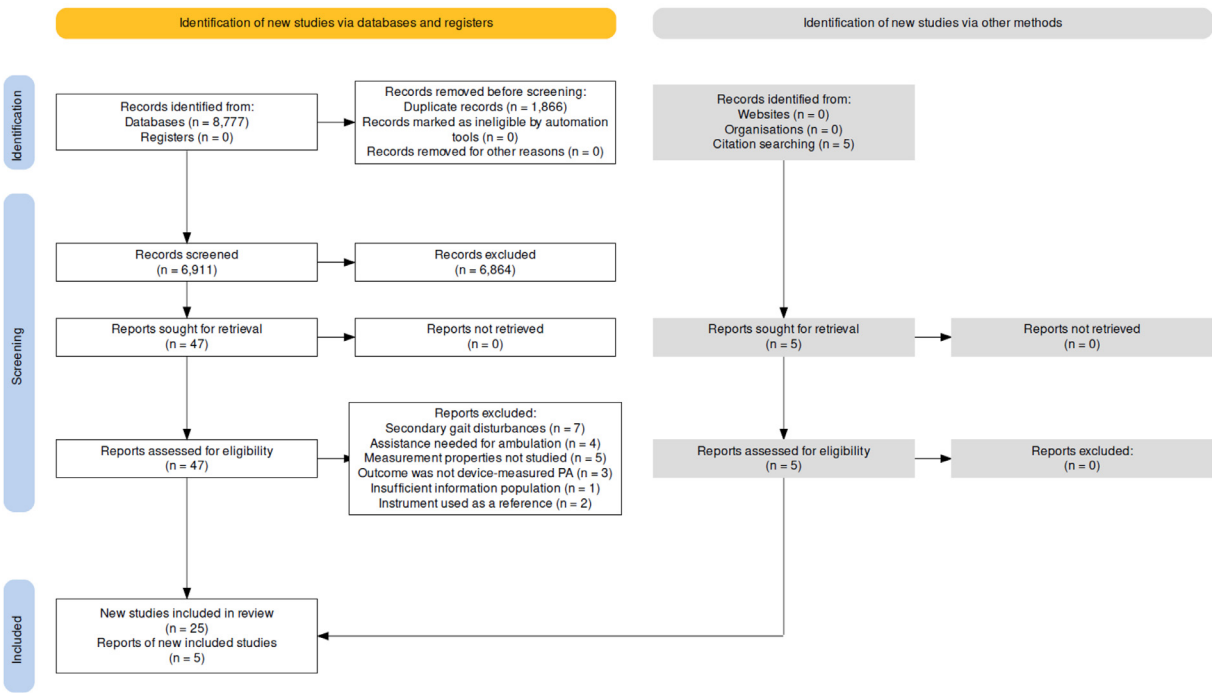


**Fig 1** Preferred Reporting Items for Systematic Reviews and Meta-analyses flow diagram of study inclusion. For the quantitative analysis, we included 26 studies.

juvenile arthritis and inherited muscle disease (n=1)[26]; SB (n=1)[76]; and congenital muscular atrophy (n=1).[21]

### Meta-analysis: Test-retest reliability

The overall effect size of test-retest reliability was high with $ICC_+$=0.81 (95% CI, 0.74-0.89; $I^2$=88.57%; see appendix 1; fig 2).

### Meta-analysis: Interdevice reliability

The overall effect size of inter-device reliability in wearables measuring PA was very high with an $ICC_+$=0.99 (95% CI, 0.98-1.00; $I^2$=71.01%; see appendix 1; fig 3).

### Meta-analysis: Construct validity

The overall effect size of construct validity to measure PA was moderate with $r_+$=0.63 (95% CI, 0.36-0.89; $I^2$=99.97%; see appendix 1; fig 4).

### Meta-analysis: Criterion validity

The overall effect size of criterion validity was high with $r_+$=0.70 (95% CI, 0.59-0.82; $I^2$=98.70%; see appendix 1; fig 5).

### Meta-analysis: Criterion validity of cutoff point based methods

The overall effect size of criterion validity of cutoff point based methods was moderate with $r_+$=0.69 (95% CI, 0.58-0.80; $I^2$=87.02%; see appendix 1; fig 6).

### Meta-analysis: Moderator analyses

For test-retest reliability, PA setting was a statistically significant moderator with a very high correlation for laboratory settings with $ICC_+$=0.91 (95% CI, 0.81-1.00) and a high correlation for free-living settings with $ICC_+$=0.77 (95% CI, 0.69-0.84). Frequency (steps, PA counts) showed a very high correlation with $ICC_+$=1 (95% CI, 0.77-1.00), and intensity (energy expenditure rate) and duration (seconds, minutes of PA) showed a high correlation with $ICC_+$=0.88 (95% CI, 0.78-0.97) and $ICC_+$=0.71 (95% CI, 0.60-0.81), respectively. Specified physical behavior type showed a high correlation for walking with $ICC_+$=0.87 (95% CI, 0.76-0.98), lying and sitting with $ICC_+$=0.73 (95% CI, 0.56-0.89), and standing with $ICC_+$=0.70 (95% CI, 0.53-0.87). Percentage Gross Motor Function Classification System (GMFCS) level, placement of the device, difference in age, physical behavior type, and duration interval between test and retest were statistically nonsignificant moderators (see appendix 2).

For inter-device reliability, PA dimensions showed a very high correlation for intensity (energy expenditure rate; $ICC_+$=1; 95% CI, 1.00-1.00), frequency (steps, PA counts; $ICC_+$=0.98; 95% CI, 0.98-0.99), and duration (seconds, minutes of PA; $ICC_+$=0.99; 95% CI, 0.98-0.99). Regarding age, a very high correlation was found for children younger than 13 years ($ICC_+$=0.99; 95% CI, 0.98-0.99) and children older than 13 years ($ICC_+$=1; 95% CI, 0.99-1.00). PA setting, specified and unspecified physical behavior type, placement of the device and placement on the same or opposite body side were nonsignificant moderators (see appendix 2).

We did not find any statistically significant moderators (percentage GMFCS level I, physical behavior type, placement of the device) related to construct validity (see appendix 2).

For criterion validity, moderator analysis showed that only the specified physical behavior type was a significant moderator with a high correlation for walking and running with $r_+$=0.73 (95% CI, 0.56-0.90) and $r_+$=0.76 (95% CI, 0.56-0.95), respectively. Lying and sitting and standing showed a moderate correlation with $r_+$=0.46 (95% CI, 0.23-0.70) and $r_+$=0.64 (95% CI, 0.43-0.86). PA dimensions, percentage

**Table 2** Results reliability and measurement error of device-measured physical activity.

| Study Author(s) YoP | Devices | | Population | | | Device-Measured PA | Reliability | Measurement Error | Quality | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Name Device<br>Epoch Length<br>Placement Body | PB Domain<br>Activity Duration | Condition<br>GMFCS Level (n) | Sample<br>Age<br>Gender | Group Specs | | | | Risk of Bias | GRADE Reliability |
| Test-retest reliability | | | | | | | | | | ⊕⊕⊕ |
| Aviram et al[60]<br>2011 | IDEEA<br>ND<br>Chest, thigh (2), foot (2) | Laboratory<br>2 × 4 min | Cerebral palsy<br>I=4<br>II=5<br>III=3 | n=12<br>Age=6.3±1.3 y<br>6 girls | | EE rate (Kcal/min) slow walking | $r$=0.998, $P \leq .001$ | | D | |
| Bania[59]<br>2014 | activPAL<br>ND<br>Thigh | Free living<br>7 × 24 h | Cerebral palsy<br>II=15<br>III=9 | n=21<br>Age=18.7±2.9 y<br>13 girls | n=21<br>Meas>2 d<br><br>n=17<br>Meas>2 d | Duration (h/d) standing<br>Duration (h/d) lying+sitting<br>Steps (ND) walking<br>Duration (h/d) standing<br>Duration (h/d) lying+sitting<br>Steps (ND) walking | ICC (2,1)=0.60<br>ICC (2,1)=0.66<br>ICC (2,1)=0.87<br>ICC (2,1)=0.56<br>ICC (2,1)=0.63<br>ICC (2,1)=0.89 | MD=−0.31 h/d, 95% LoA (−2.6 to 1.98)<br>MD=0.37 h/d, 95% LoA (−2.30 to 3.04)<br>MD=−411 steps/d, 95% LoA (−3125 to 2303)<br>MD=−0.40 h/d, 95% LoA (−2.9 to 2.1)<br>MD=0.48 h/d, 95% LoA (−2.4 to 3.3)<br>MD=−516 steps/d, 95% LoA (−3191 to 2159) | D | |
| Baque et al[61]<br>2016 | ActiGraph GT3X+<br>5 s<br>Waist (LNI) | Laboratory<br>4 × 5 min | ABI<br>I=17<br>II=15 | n=32<br>Age=12.1±2.3 y<br>ND | | AC−VM (n/min) slow walking<br>AC−VM (n/min) moderate walking<br>AC−VM (n/min) fast walking<br>AC−VM (n/min) stepping | ICC (2,1)=0.90; 95% CI, 0.79-0.95<br>ICC (2,1)=0.83; 95% CI, 0.66-0.92<br>ICC (2,1)=0.91; 95% CI, 0.82-0.96<br>ICC (2,1)=0.89; 95% CI, 0.77-0.95 | | D | |
| Baque et al[61]<br>2016 | ActiGraph GT3X+<br>60 s<br>Waist (LNI) | Free living<br>4 × >7 h<br>(2 wk+2 we) | Acquired brain injury<br>I=26<br>II=25 | n=51<br>Age=12.1±2.4 y<br>ND | Total (n=51)<br>Meas 2-3-4 d<br><br>Children (<13 y; n=33)<br>Meas 2-3-4 d<br><br>Adoles (≥13 y; n=18)<br>Meas 2-3-4 d | Duration (h) unstructured activities (MVI)*<br><br>Duration (h) unstructured activities (MVI)*<br><br>Duration (h) unstructured activities (MVI)*<br><br>Duration (h) unstructured activities (MVI)* | ICC=0.72; 95% CI, 0.52-0.84<br>ICC=0.78; 95% CI, 0.66-0.87<br>ICC=0.79; 95% CI, 0.67-0.87<br>ICC=0.57; 95% CI, 0.13-0.79<br>ICC=0.73; 95% CI, 0.52-0.86<br>ICC=0.70; 95% CI, 0.48-0.84<br>ICC=0.81; 95% CI, 0.49-0.93<br>ICC=0.76; 95% CI, 0.48-0.90<br>ICC=0.79; 95% CI, 0.56-0.91 | | D | |
| Braun et al[62]<br>2016 | StepWatch<br>ND<br>Ankle (l) | Free living<br>7 d × walking h | Amyoplasia, distal arthrogryposis<br>ND | 14<br>Age=10.9±3.8 y<br>4 girls | n=13 | Steps (n) unstructured activities | G coeff=0.67; 95% CI, 0.56-0.78 | CV=0.36 steps | D | |
| Gerber et al[63]<br>2021 | Physilog4<br>ND<br><br>Trunk, thigh (2), shank (2) | Free living<br>2 d × 8 h (walking h) | Cerebral palsy<br>I=6<br><br>II=3<br><br>III=4 | n=15<br>Age=13.7±3.4 y<br><br>9 girls | n=13 wk-wk d<br><br>n=12 wk-we d | Duration (% total duration) lying +sitting<br>Duration (% total duration) standing<br>Duration (% total duration) walking<br>Duration (% total duration) lying +sitting<br>Duration (% total duration) standing<br>Duration (% total duration) walking | ICC (3,1)=0.47; 95% CI, 0.00-0.80<br>ICC (3,1)=0.18; 95% CI, 0.00-0.64<br>ICC (3,1)=0.76; 95% CI, 0.39-0.92<br>ICC (3,1)=0.30; 95% CI, 0.00-0.73<br>ICC (3,1)=0.31; 95% CI, 0.00-0.72<br>ICC (3,1)=0.00; 95% CI, 0.00-0.42 | SEM/SDC=7.88/21.8% total duration<br>SEM/SDC=8.22/21.8% total duration<br>SEM/SDC=1.89/5.24% total duration<br>SEM=10.73% total duration<br>SEM=8.06% total duration<br>SEM=4.12% total duration | D | |
| Gerber et al[63]<br>2021 | | | Cerebral palsy<br>I=3<br><br>II=2<br><br>III=5 | n=10<br>Age=13.1±3.7 y<br><br>6 girls | Same wk d, 2-4 wk apart | Duration (% total duration) lying +sitting<br>Duration (% total duration) standing<br>Duration (% total duration) walking | ICC (3,1)=0.90; 95% CI, 0.64-0.97<br>ICC (3,1)=0.90; 95% CI, 0.65-0.97<br>ICC (3,1)=0.91; 95% CI, 0.67-0.98 | SEM/SDC=4.77/13.22% total duration<br>SEM/SDC=3.64/10.10% total duration<br>SEM/SDC=1.39/3.86% total duration | | |
| Ishikawa et al[64]<br>2013 | StepWatch<br>ND<br>Ankle (l) | Free living<br>7 d × walking h | Cerebral palsy<br>I=75<br>II=78<br>II=48 | n=209<br>Age=8.3±3.3 y<br>91 girls | Total (n=201)<br>2-5 y (n=56)<br><br>6-14 y (n=145) | Steps (n) unstructured activities | G coeff=0.77; 95% CI, 0.74-0.81<br>G coeff=0.77; 95% CI, 0.71-0.83<br><br>G coeff=0.78; 95% CI, 0.74-0.82 | <br>CV=28% (GMFCS I)<br>CV=40% (GMFCS II)<br>CV=70% (GMFCS III)<br>CV=38% (GMFCS I)<br>CV=40% (GMFCS II)<br>CV=63% (GMFCS III) | A | |

(*continued*)

**Table 2** (*Continued*)

| Study Author(s) YoP | Devices | | Population | | | Device-Measured PA | Reliability | Measurement Error | Quality | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Name Device Epoch Length Placement Body | PB Domain Activity Duration | Condition GMFCS Level (n) | Sample Age Gender | Group Specs | | | | Risk of Bias | GRADE Reliability |
| Mackey et al[66] 2009 | IDEEA<br>ND<br>Chest, thigh (2), foot (2) | Laboratory<br>5 × 30 s | Cerebral palsy<br>I+II=16<br>III=9 | n=25<br>Age 14.1; range=8-12<br>17 girls | | Duration (min) lying<br>Duration (min) standing<br>Duration (min) sitting<br>Duration (min) walking (overground and stairs) | | sw=15% sensitivity; 2% specificity<br>sw=21% sensitivity; 6% specificity<br>sw=21% sensitivity; 13% specificity<br>sw=6% sensitivity; 2% specificity | D | |
| Mitchell et al[65] 2014 | ActiGraph GT3X+<br>5 s<br>Waist (LNI) | Laboratory<br>4 × 5 min | Cerebral palsy<br>I=16<br>II=14 | n=30<br>Age=11.9±2.6 y<br>14 girls | | AC-VA (n/min) slow walking<br>AC-VA (n/min) moderate walking (MW)<br>AC-VA (n/min) fast walking (FW)<br>AC-VA (n/min) stepping (STEP)<br>AC-VA (n/min) MW+FW+STEP (MVi) | ICC=0.80; 95% CI, 0.76-0.83<br>ICC=0.80; 95% CI, 0.77-0.83<br>ICC=0.70; 95% CI, 0.66-0.74<br>ICC=0.66; 95% CI, 0.60-0.72<br>ICC=0.80; 95% CI, 0.77-0.83 | SEM/SDC=333.6/926 counts/min<br>SEM/SDC=438/1214 counts/min<br>SEM/SDC=702/1945 counts/min<br>SEM/SDC=771.6/2139 counts/min<br>SEM/SDC=510/1412 counts/min | A | |
| Mitchell et al[65] 2014 | ActiGraph GT3X+<br>5 s<br>Waist (LNI) | Free living<br>4 d × >8 h | Cerebral palsy<br>I=44<br>II=58 | n=102<br>Age=11.3±2.3 y<br>50 girls | Total (n=81)<br>Meas 2-3-4 d<br>Children (<13 y; n=58)<br>Meas 2-3-4 d<br>Adoles (≥13 y; n=23)<br>Meas 2-3-4 d | Duration (h) unstructured activities (MVI)[†]<br>Duration (h) unstructured activities (MVI)[†]<br>Duration (h) unstructured activities (MVI)[†] | ICC=0.63; 95% CI, 0.44-0.76<br>ICC=0.57; 95% CI, 0.28-0.74<br>ICC=0.72; 95% CI, 0.48-0.87<br>ICC=0.69; 95% CI, 0.56-0.79<br>ICC=0.63; 95% CI, 0.43-0.77<br>ICC=0.74; 95% CI, 0.44-0.88<br>ICC=0.73; 95% CI, 0.61-0.82<br>ICC=0.73; 95% CI, 0.58-0.83<br>ICC=0.78; 95% CI, 0.58-0.88 | | D | |
| O'Neil et al[20] 2014 | ActiGraph GT3X<br>1 s<br>Waist (l+r) | Laboratory<br>3 × 6 min | Cerebral palsy<br>I=4<br>II=1<br>III=3 | n=8<br>Age=11.9±3.2 y<br>2 girls | Meas left BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS<br>Meas right BS | AC (n) slow walking<br>AC (n) moderate walking<br>AC (n) fast walking<br>Steps (n) slow walking<br>Steps (n) moderate walking<br>Steps (n) fast walking | ICC=0.75; 95% CI, 0.02-0.95<br>ICC=0.86; 95% CI, 0.48-0.97<br>ICC=0.88; 95% CI, 0.52-0.98<br>ICC=0.95; 95% CI, 0.59-0.99<br>ICC=0.89; 95% CI, 0.47-0.98<br>ICC=0.95; 95% CI, 0.81-0.99<br>ICC=0.88; 95% CI, 0.49-0.98<br>ICC=0.96; 95% CI, 0.82-0.99<br>ICC=0.88; 95% CI, 0.47-0.98<br>ICC=0.98; 95% CI, 0.92-0.99<br>ICC=0.88; 95% CI, 0.48-0.98<br>ICC=0.97; 95% CI, 0.88-0.99 | | D | |
| Pirpiris and Graham[57] 2004 | PAL 1<br>5 s<br>Thigh (l) | Free living<br>6 × 24 h | Cerebral palsy<br>ND | n=300<br>Age=11±3.9 y<br>151 girls | 1 × 1 wk-wk d; (n=50)<br>1 × 1 wk-we d; (n=50)<br>2 × 2 wk-wk d; (n=50) | Duration (s) upright during ADL | ICC=0.83; 95% CI, 0.76-0.89<br>ICC=0.80; 95% CI, 0.74-0.87<br>ICC=0.87; 95% CI, 0.80-0.96 | MD=−133.13 s, LoA (-973.1 to 969.0)<br>MD=70.6013 s, LoA (-682.5 to 668.5) | I | |
| | | | | | 2 × 2 wk-we d; (n=50) | | ICC=0.83; 95% CI, 0.78-0.93 | MD=65.2313 s, LoA (-778.3 to 753.0) | | |
| Inter-device reliability | | | | | | | | | | ⊕⊕⊕ |
| Koehler et al[68] 2015 | SenseWear<br>ND<br>Upper portion of the arm | Laboratory<br>5 × 5 min | Cerebral palsy<br>II=10 | n=10<br>13.4±1.6 y<br>3 girls | n=10<br>n=9<br>n=10<br>n=6 | EE sitting<br>EE slow walking<br>EE moderate walking<br>EE fast walking | | MD=0.0 Kcal/min, SD=0.2<br>MD=−0.1 Kcal/min, SD=0.6<br>MD=−0.2 Kcal/min, SD=0.5<br>MD=0.0 Kcal/min, SD=1.1 | | |
| Maher et al[67] 2013 | NL−1000<br>ND<br>Waist (l+r) | Laboratory<br>3 × 6 min | Cerebral palsy<br>I=8<br>II=9 | n=17<br>Age=12.3±3.2 y<br>9 girls | Dominant BS<br>Nondominant BS | AC (n) walking<br>AC (n) running<br>AC (n) walking<br>AC (n) running | ICC=0.88; 95% CI, 0.71-0.96<br>ICC=0.98; 95% CI, 0.94-0.99<br>ICC=0.94; 95% CI, 0.84-0.98<br>ICC=0.99; 95% CI, 0.96-1.00 | | A | |
| O'Neil et al[20] 2014 | ActiGraph GT3X<br>1 s<br>Waist (l+r) | Laboratory<br>3 × 6 min | Cerebral palsy<br>I=4<br>II=1<br>III=3 | n=8<br>Age=11.9±3.2 y<br>2 girls | Left vs right | AC (n) slow walking<br>AC (n) moderate walking<br>AC (n) fast walking<br>Steps (n) slow walking<br>Steps (n) moderate walking<br>Steps (n) fast walking | ICC=0.98; 95% CI, 0.92-0.99<br>ICC=0.99; 95% CI, 0.98-1.00<br>ICC=0.98; 95% CI, 0.87-0.99<br>ICC=0.99; 95% CI, 0.98-1.00<br>ICC=0.96; 95% CI, 0.81-0.99<br>ICC=0.99; 95% CI, 0.99-1.00 | | D | |

(*continued*)

**Table 2** (*Continued*)

| Study Author(s) YoP | Devices | | Population | | | Device-Measured PA | Reliability | Measurement Error | Quality | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Name Device<br>Epoch Length<br>Placement Body | PB Domain<br>Activity Duration | Condition<br>GMFCS Level (n) | Sample<br>Age<br>Gender | Group Specs | | | | Risk of Bias | GRADE Reliability |
| O'Neil et al[69]<br>2016 | StepWatch<br>3 s<br>Ankle (l+r) | Laboratory<br>6 × 5 min+3 × 6 min | Cerebral palsy<br>I=28<br>II=16<br>III=13 | n=57<br>Age=12.5±3.3 y<br>29 girls | StepWatch | Steps (n/min) during activity protocol | ICC=0.977; 95% CI, 0.969-0.982<br>ICC=0.940; 95% CI, 0.929-0.950<br>ICC=0.986; 95% CI, 0.983-0.989 | | D | |
| | SenseWear<br>60 s<br>Upper portion of the arm (l+r) | | | | SenseWear | AC_VA (n/min) structured activities (II) | ICC=0.985; 95% CI, 0.982-0.987 | | | |
| | ActiGraph GT3X<br>1 s<br>Waist (l+r) | | | | ActiGraph GT3X | AC_VM (n/min) structured activities (II) | ICC=0.981; 95% CI, 0.978-0.984 | | | |
| Pirpiris and Graham[57]<br>2004 | PAL 1<br>5 s<br>Trunk, thigh (l+r) | Free living<br>6 × 24 h | Cerebral palsy<br>GMFCS<br>ND | n=300<br>Age=11±3.9 y<br>151 girls | Same limb (n=20)<br>Opposite limb, n=20<br>Limb-trunk (n=20) | Duration (s) upright unstructured Activities | ICC=0.99; 95% CI, 0.89-0.99<br>ICC=0.99; 95% CI, 0.88-0.99<br>ICC=0.52; 95% CI, 0.45-0.67 | MD=1 s, LoA (-120 to 131)<br>MD=2 s, LoA (-118 to 125)<br>MD=−27196 steps/d, LoA (-32,500 to -2189) | I | |

Abbreviations: "?", indeterminate; "-", insufficient; "+", sufficient; "⊕⊕⊕", moderate; A, adequate; AC, activity counts; ADL, activities of daily living; adoles, adolescent; BS, body side; CV, coefficient of variation; coeff, coefficient; D, doubtful; EE, energy expenditure; G, generalizability; GRADE, Grading of Recommendations Assessment, Development and Evaluation; I, inadequate; IDEEA, Intelligent Device for Energy Expenditure and Activity; II, increased intensity; l, left; LNI, least neurologic impaired; LoA, levels of agreement; MD, mean difference; ME, measurement error; meas, measured; min, minute(s); MVI, moderate-to-vigorous intensity; n, number; ND, not described; PAL 1, Positional Activity Logger version 1; PB, physical behavior; R, reliability; r, Pearson correlation coefficient; r, right; SB, Spearman-Brown; SDC, smallest detectable change; stat, statistics; sw, within-subject SD; VA, vertical axis; VM, vector magnitude; we, weekend; YoP, year of publication;

* Baque (2015)[87] cutoff points were used.

† Evenson (2008)[88] cutoff points were used.

**Table 3A** Results validity of device-measured physical activity.

| Study | Device | | | Population | |
|---|---|---|---|---|---|
| Author(s)<br>YoP | Name Device<br>Epoch Length<br>Placement Body | Comparison Measure<br>Specs<br>Outcome | PB Domain<br>Activity Duration | Condition<br>GMFCS level (n) | Sample<br>Age<br>Gender |
| Criterion validity | | | | | |
| Aviram et al[60]<br>2011 | IDEEA<br>ND<br>Chest, thigh (2),<br>foot (2) | PIC<br>Cosmed K4b2 | Laboratory<br>1 × ±7 min+3 × 4 min<br>II=6 | Cerebral palsy<br>I=8<br>ND<br>III=7 | n=21<br>6.4±1.9 y |
| Bania[59]<br>2014 | activPAL<br>ND<br>Thigh | Video DO<br>ND | Laboratory<br>2 × 3 min+6 min | Cerebral palsy<br>II=5<br>III=5 | n=10<br>18.6±2.7 y<br>4 girls |
| Baque et al[77]<br>2017 | ActiGraph GTX3+<br>15 s<br>Waist (LNI) | PIC<br>Cortex Metamax | Laboratory<br>1 × 5 min+3 ×<br>6 min+1 × 3 min | Acquired brain injury<br>I=16<br>II=11 | n=27<br>13.6±2.4 y<br>12 girls |
| Capio et al[75]<br>2010 | MTI (ActiGraph)<br>15 s<br>Waist (r) | SOFIT<br>ND | Laboratory<br>6 × 2 min (structured)<br>10 min (free play) | Cerebral palsy<br>I=14<br>II=9<br>III=8 | n=31<br>9.7±2.5 y<br>17 girls |
| de Groot et al[76]<br>2013 | Actical<br>60 s<br>Waist (l)<br>Actiheart<br>15 s<br>Trunk (front) | PIC<br>Cortex Metamax | Laboratory<br>6 min | Spina bifida<br>Hoffer normal=7<br>Hoffer community=19 | n=39<br>10.6±2.8 y<br>11 girls |
| Koehler et al[68]<br>2015 | SenseWear<br>ND<br>Upper portion of the arm (l+r) | PIC<br>ZAN 600 | Laboratory<br>5 × 5 min | Cerebral palsy<br>II=10<br>3 girls | n=10<br>13.4±1.6 y |
| Kuo et al[55]<br>2009 | AMP 331<br>ND<br>Ankle (r)<br>DynaPort Minimod<br>ND<br>Trunk (back) | Video DO<br>ND | Laboratory<br>ND<br><br>III=3 | Cerebral palsy<br>I=5<br>II=12 | n=20<br>10.5±3.0 y<br>7 girls |
| Lankhorst et al[16]<br>2019 | Activ8<br>5 s<br>Thigh (DBS) | Video DO<br>ND | Free living<br>45 min (1:30 min)<br>Hoffer household=2 | Spina bifida<br>Hoffer community=2<br>1 girl | n=10<br>12.9±2.1 y |
| Maher et al[67]<br>2013 | NL-1000 pedometer<br>ND<br>Thigh (nDBS, DBS) | Video DO<br>FlipVideo UltraHD<br>Camcorder | Laboratory<br>2 × 3 min | Cerebral palsy<br>I=8<br>II=9 | n=17<br>12.3±3.2 y<br>9 girls |
| McAloon et al[72]<br>2014 | activPAL<br>ND<br>Thigh (NI) | Video DO<br>ND | Laboratory<br>ND | Cerebral palsy<br>I=4<br>II=5<br>III=1 | n=10<br>4-18 y<br>ND |
| O'Donoghue and Kennedy[78]<br>2014 | activPAL<br>ND<br>Thigh (NI, LNI) | Video DO<br>2D Sony mini digital<br>Video camera | Laboratory<br>ND | Cerebral palsy<br>I=17 | n=17<br>9.4±3.9 y<br>8 girls |
| O'Neil et al[20]<br>2014 | ActiGraph GT3X<br>1 s<br>Waist (r) | PIC<br>Cosmed K4b2 | Laboratory<br>3 × 6 min | Cerebral palsy<br>I=4<br>II=1<br>III=3 | n=8<br>11.9±3.2 y<br>2 girls |
| O'Neil et al[69]<br>2016 | ActiGraph GT3X<br>1 s<br>Waist (l+r)<br>StepWatch<br>3 s<br>Ankle (l+r)<br>SenseWear<br>60 s<br>Upper portion of the arm (l+r) | PIC<br>Cosmed K4b2 | Laboratory<br>2-2.5 h | Cerebral palsy<br>I=28<br>II=16<br>III=13 | n=57<br>12.5±3.3 y<br>29 girls |
| Pirpiris and Graham[57]<br>2004 | PAL 1<br>1 s<br>Thigh (l) | Video DO<br>ND | Free living<br>1 h | Cerebral palsy | n=50<br>11.0±3.2 y<br>24 girls |
| Pirpiris and Graham[57]<br>2004 | PAL 1<br>1 s<br>Thigh (l) | PIC<br>Cosmed K4b2 | ND<br>ND | Cerebral palsy | n=35<br>ND<br>ND |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Waist (r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Juvenile arthritis | n=31<br>12.7±2.6 y<br>23 girls |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Waist (r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Inherited muscle disease | n=30<br>12.0±3.4 y<br>8 girls |

(*continued*)

**Table 3A** (*Continued*)

| Study | Device | | | Population | |
|---|---|---|---|---|---|
| Author(s)<br>YoP | Name Device<br>Epoch Length<br>Placement Body | Comparison Measure<br>Specs<br>Outcome | PB Domain<br>Activity Duration | Condition<br>GMFCS level (n) | Sample<br>Age<br>Gender |
| Tang et al[58]<br>2013 | activPAL<br>ND<br>Thigh (nDBS) | Video DO<br>ND | Laboratory<br>71±49 min<br>II=4 | Cerebral palsy<br>I=9<br>4 girls<br>III=2 | n=15<br>10.9±4.3 y |
| Xing et al[18]<br>2021 | ActiGraph GT3X<br>15 s<br>Waist (r)<br>activPAL3C<br>15 s<br>Thigh (front) | PIC<br>Sensor Medics | Laboratory<br>7 × 5 min | Cerebral palsy<br>I=3<br>II=6<br>III=1 | n=10<br>6 girls |
| Criterion validity of cutoff point based methods | | | | | |
| Baque et al[77]<br>2017 | ActiGraph GTX3+<br>15 s<br>Waist (LNI) | DO<br>ND | Laboratory<br>1 × 5 min+3 × 6 min+<br>1 × 3 min | | |
| Clanchy et al[70]<br>2011 | ActiGraph 7164<br>1 s<br>Waist (LNI or DBS) | PIC<br>Cosmed K4b2<br>3 min | Laboratory<br>10 min+2 × 6 min+<br>II=15 | Cerebral palsy<br>I=11<br>13 girls<br>III=13 | n=29<br>12.5±2.0 y |
| Keawutan et al[71]<br>2016 | Actigraph GT3X(+)<br>5 s<br>Trunk (back) | Video DO<br>ND | Laboratory<br>17.4 min<br>II=13 | Cerebral palsy<br>I=17<br>ND<br>III=10 | n=40<br>4.7 y |
| Keawutan et al[71]<br>2016 | Actigraph GT3X(+)<br>5 s<br>Trunk (back) | Laboratory | Cerebral palsy<br>19.7 min<br>II=7 | n=21<br>I=9<br>ND<br>III=5 | 4.6 y |
| Oftedal et al[56]<br>2014 | ActiGraph GT1M<br>5 s<br>Trunk (back)<br>ActiGraph GT3X and GT3X+<br>5 s<br>Trunk (back) | Video DO<br>ND | Laboratory<br>20 à 30 min | Cerebral palsy<br>I-III<br>26 girls | n=39<br>2.3±0.5 y |
| Oftedal et al[56]<br>2014 | ActiGraph GT1M<br>5 s<br>Trunk (back)<br>ActiGraph GT3X and GT3X+<br>5 s<br>Trunk (back) | Laboratory | 20 à 30 min | n=23<br>15 girls | 2.5±0.6 y |
| Ryan et al[73]<br>2014 | RT3<br>1 Hz<br>ND | PIC<br>Oxycon | Laboratory<br>6 min | Cerebral palsy<br>I=10<br>II=4 | n=18<br>11.4±3.2 y<br>8 girls |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Hip (mid-line, r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Juvenile arthritis | n=31<br>12.7±2.6 y<br>23 girls |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Hip (mid-line, r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Inherited muscle disease | n=30<br>12.0±3.4 y<br>8 girls |
| Trost et al[24]<br>2016 | ActiGraph GT3X<br>1 s<br>Waist (r) | PIC<br>Cosmed K4b2 | Laboratory<br>4 × 5 min+3 × 6 min | Cerebral palsy<br>I=27<br>II=12 | n=51<br>age=12.5<br>24 girls |
| Xing et al[18]<br>2021 | ActiGraph GT3X<br>15 s<br>Waist (r)<br>activPAL3C<br>15 s<br>Thigh | PIC<br>Sensor Medics | Laboratory<br>7 × 5 min | Cerebral palsy<br>I=3<br>II=6<br>III=1 | n=10<br>6 girls |
| Convergent validity | | | | | |
| Kuo et al[55]<br>2009 | AMP 331<br>ND<br>Ankle (r)<br>DynaPort Minimod<br>ND<br>Trunk (back) | Measuring wheel<br>ND | Laboratory<br>ND<br>III=3 | Cerebral palsy<br>I=5<br>II=12 | n=20<br>Age=10.5±3.0 y<br>7 girls |
| Lawal et al[21]<br>2020 | ActiGraph GT3X<br>60 s<br>Waist | Observation<br>Tally counter | Laboratory<br>6 min | Congenital muscular<br>Dystrophy<br>ND | n=9<br>Age=ND<br>6 girls |

(*continued*)

**Table 3A** (*Continued*)

| Study | Device | | | Population | |
|---|---|---|---|---|---|
| Author(s)<br>YoP | Name Device<br>Epoch Length<br>Placement Body | Comparison Measure<br>Specs<br>Outcome | PB Domain<br>Activity Duration | Condition<br>GMFCS level (n) | Sample<br>Age<br>Gender |
| Mackey et al[66]<br>2009 | IDEEA<br>ND<br>Chest, thigh (2), foot (2) | Time recording | Laboratory<br>5 × 30 s<br>III=9 | Cerebral palsy<br>I or II=16 | n=25<br>Age=14.1 y<br><br>17 girls |
| Sala et al[74]<br>2019 | Fitbit One<br>ND<br>Waist<br>Fitbit Flex<br>ND<br>Wrist (DBS) | Observation<br>Tally counter | Laboratory<br>3 × ±3 min | Cerebral palsy<br>I=22<br>II=5<br>III=11 | n=39<br>Age=9.6 y<br>Range 4-15 y<br>16 girls |

Abbreviations: DBS: dominant bodyside; DO, direct observation; IDEEA: Intelligent Device for Energy Expenditure and Activity; l: left; LNI: least neurological impaired; n: number; ND: not described; nDBS: nondominant bodyside; NI: neurological impaired; PAL 1: Positional Activity Logger version 1; PB: physical behavior; PIC: portable indirect calorimetry; r: right; SOFIT: System for Observing Fitness Instruction Time; YoP: year of publication.

**Table 3B** Results validity of device-measured physical activity.

| Study<br>Author(s)<br>YoP | Population<br>Group Specs | Cutoff points/pred.eq. | Device-Measured PA | Validity | | Quality<br>Risk of Bias | GRADE |
|---|---|---|---|---|---|---|---|
| Criterion validity | | | | | | | ⊕⊕⊕ |
| Aviram et al[60]<br>2011 | n=13 | | EE rate (Kcal/min) slow walking<br>EE rate (Kcal/min) moderate walking<br>EE rate (Kcal/min) stepping<br>total EE (Kcal) structured activities (II) | $r$=0.7<br>$r$=0.88<br>$r$=0.75<br>$r$=0.72 | | D | |
| Bania[59]<br>2014 | | | Duration sitting<br>Duration standing<br>Steps walking | MD=0.5 min, 95% LoA (−0.6 to 1.5)<br>MD=−0.06 min, 95% LoA (−0.4 to 0.3)<br>MD=−13.8 steps, 95% LoA (−36.9 to 9.4) | | D | |
| Baque et al[77]<br>2017 | | | AC-VM (n) structured activities (II) | $r$=0.89 | | V | |
| Capio et al[75]<br>2010 | | | AC (n) structured activities (II)<br>AC (n) unstructured activities (RI) | $R^2$=0.56<br>$R^2$=0.45 | | V | |
| de Groot et al[76]<br>2013 | Actical<br>Actiheart | Corder (AC)<br>Corder (AC)<br>Corder (HRAR)<br>Corder (AC+HRAR)<br>Corder (AC+predHRAS)<br>Corder (AC+trueHRAS)<br>Takken (predHRAS)<br>Takken (trueHRAS)<br>Current study (AC)<br>Current study (HRAR) | EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking | ICC=0.6; 95% CI, 0.28-0.80<br>ICC=0.49 (0.12-0.74)<br>ICC=0.74 (0.49-0.88)<br>ICC=0.8; 95% CI, 0.59-0.91<br>ICC=0.12 (−0.28 to 0.48)<br>ICC=0.71 (0.45-0.86)<br>ICC=0.018; 95% CI, −0.37 to 0.40<br>ICC=0.73 (0.48-0.87)<br>$R^2$=0.68<br>$R^2$=0.72 | | V | |
| Koehler et al[68]<br>2015 | n=10 (NHS)<br>n=9<br>n=10<br>n=6<br>n=2<br>n=10 (HS)<br>n=9<br>n=10<br>n=6<br>n=2 | | EE sitting (rest)<br>EE walking (0.85 m/s)<br>EE walking (1.35 m/s)<br>EE walking (1.85 m/s)<br>EE (Kcal/min) running (2.35 m/s)<br>EE sitting (rest)<br>EE walking (0.85 m/s)<br>EE walking (1.35 m/s)<br>EE walking (1.85 m/s)<br>EE running (2.35 m/s) | MD=0.3 Kcal/min, 95% LoA (−0.7 to 1.3)<br>MD=−0.6 Kcal/min, 95% LoA (−3.2 to 2.0)<br>MD=−0.3 Kcal/min, 95% LoA (−3.7 to 3.1)<br>MD=0.8 Kcal/min, 95% LoA (−4.1 to 5.7)<br>NA<br>MD=0.4 Kcal/min, 95% LoA (−0.7 to 1.5)<br>MD=−0.6 Kcal/min, 95% LoA (−2.7 to 1.4)<br>MD=−0.1 Kcal/min, 95% LoA (−2.9 to 2.6)<br>MD=0.7 Kcal/min, 95% LoA (−5.9 to 7.2)<br>MD=−0.6 Kcal/min, 95% LoA (−9.4 to 8.3) | | D | |
| Kuo et al[55]<br>2009 | AMP<br>Minimod<br>AMP<br>Minimod<br>AMP<br>Minimod<br>AMP<br>Minimod | | Steps continuous walking<br>Steps continuous walking<br>Steps intermittent walking<br>Steps intermittent walking<br>Steps downstair climbing<br>Steps downstair climbing<br>Steps upstair climbing<br>Steps upstair climbing | MD=−3.5 steps, 95% LoA (−16.9 to 10.0)<br>MD=−11.2 steps, 95% LoA (−40.0 to 17.7)<br>MD=−0.4 step, 95% LoA (−4.1 to 3.3)<br>MD=−38.7 steps, 95% LoA (−87.8 to 104)<br>MD=−10.1 steps, SD=9.5<br>MD=−1 step, SD=1<br>MD=−8.1 steps, SD=9.2<br>MD=−1 step, SD=1.7 | | D | |
| Lankhorst et al[16]<br>2019 | n=8 (slow pace); n=7 (fast pace)<br>n=8<br><br><br>n=8 | | Duration basic sitting<br>Duration basic standing<br>Duration basic walking<br>Duration basic bicycling<br>Duration basic running<br>Duration complex sitting<br>Duration complex standing<br>Duration complex walking<br>Duration complex bicycling<br>Duration complex running | MD=83 s<br>MD−70 s<br>MD=−385 s<br>MD=357 s<br>MD=15 s<br>MD=−106 s<br>MD=−296 s<br>MD=−372 s<br>MD=713 s<br>MD=61 s | Error=6.9%<br>Error=−11.6%<br>Error=−21%<br>Error=39.7%<br>Error=3.4%<br>Error=−8.1%<br>Error=−84.6%<br>Error=−12.4%<br>NA<br>Error=265.2% | I | |

(*continued*)

**Table 3B** (*Continued*)

| Study Author(s) YoP | Population Group Specs | Cutoff points/pred.eq. | Device-Measured PA | Validity | Quality | |
|---|---|---|---|---|---|---|
| | | | | | Risk of Bias | GRADE |
| Maher et al[67] 2013 | Dominant body side | | Steps (n) walking | ICC=0.94; 95% CI, 0.83-0.98 | V | |
| | | | Steps (n) running | ICC=0.94; 95% CI, 0.84-0.98 | | |
| | Non-dominant body side | | Steps (n) walking | ICC=0.78; 95% CI, 0.49-0.92 | | |
| | | | Steps (n) running | ICC=0.95; 95% CI, 0.87-0.98 | | |
| McAloon et al[72] 2014 | | | Duration sitting | MD=−6.8 s, 95% LoA (18.5 to −32.1) | I | |
| | | | Duration standing | MD=5.9 s, 95% LoA (19.1 to −7.3) | | |
| | | | Duration walking | MD=−2.2 s, 95% LoA (7.8 to −12.3) | | |
| | | | Steps steps | MD=−3.2 steps, 95% LoA (4.5 to −10.9) | | |
| | | | Duration (s) structured activities (RI) | Agreement=86.5% | | |
| O'Donoghue and Kennedy[78] 2014 | NI | | Duration (s) sitting | ICC (3.1)=0.49 | D | |
| | | | Duration (s) standing | ICC (3.1)=0.59 | | |
| | | | Duration (s) walking | ICC (3.1)=0.99 | | |
| | | | Steps (n) walking | ICC (3.1)=0.96 | | |
| | LNI | | Duration (s) sitting | ICC (3.1)=0.95 | | |
| | | | Duration (s) standing | ICC (3.1)=0.98 | | |
| | | | Duration (s) walking | ICC (3.1)=0.94 | | |
| | | | Steps (n) walking | ICC (3.1)=0.95 | | |
| O'Neil et al[20] 2014 | | | AC (n) walking (slow, brisk, fast) | *rs*=0.67 | V | |
| | | | Steps (n) walking (slow, brisk, fast) | *rs*=0.29 | | |
| O'Neil et al[69] 2016 | ActiGraph | | Steps (n) structured activities | *rs*=0.82 | V | |
| | | | AC-VA (n) structured activities | *rs*=0.835 | | |
| | | | AC-VM (n) structured activities | *rs*=0.84 | | |
| | StepWatch | | Steps (n) structured activities | *rs*=0.78 | | |
| | SenseWear | | Steps (n) structured activities | *rs*=0.74 | | |
| Pirpiris and Graham[57] 2004 | | | Duration upright (s) unstructured activities | MD=5 s, 95% LoA (−37 to 47) | D | |
| Pirpiris and Graham[57] 2004 | | | Duration upright (s) | *rs*=0.61 | | |
| Stephens et al[26] 2016 | Actical | Puyau | EE (METs) structured activities (II) | ICC (2,1)=0.41; 95% CI, 0.30-0.52 | V | |
| | ActiGraph | Corder | EE (METs) | ICC (2,1)=0.28; 95% CI, 0.14-0.40 | | |
| | | Freedson | EE (METs) | ICC (2,1)=0.35; 95% CI, 0.22-0.47 | | |
| | | Puyau | EE (METs) | ICC (2,1)=0.22; 95% CI, 0.09-0.35 | | |
| | Actical | Current study | EE (METs) | ICC (2,1)=0.75; 95% CI, 0.74-0.76 | | |
| | | Current study (HR) | EE (METs) | ICC (2,1)=0.85; 95% CI, 0.84-0.86 | | |
| | ActiGraph | Current study | EE (METs) | ICC (2,1)=0.7; 95% CI, 0.69-0.71 | | |
| | | Current study (HR) | EE (METs) | ICC (2,1)=0.84; 95% CI, 0.83-0.85 | | |
| Stephens et al[26] 2016 | Actical | Puyau | EE (METs) structured activities (II) | ICC (2,1)=0.38; 95% CI, 0.25-0.50 | | |
| | ActiGraph | Corder | EE (METs) | ICC (2,1)=0.31; 95% CI, 0.17-0.45 | | |
| | | Freedson | EE (METs) | ICC (2,1)=0.36; 95% CI, 0.21-0.49 | | |
| | | Puyau | EE (METs) | ICC (2,1)=0.25; 95% CI, 0.10-0.39 | | |
| | Actical | Current study | EE (METs) | ICC (2,1)=0.74; 95% CI, 0.73-0.75 | | |
| | | Current study (HR) | EE (METs) | ICC (2,1)=0.78; 95% CI, 0.77-0.79 | | |
| | ActiGraph | Current study | EE (METs) | ICC (2,1)=0.71; 95% CI, 0.70-0.72 | | |
| | | Current study | EE (METs) | ICC (2,1)=0.68; 95% CI, 0.66-0.70 | | |
| Tang et al[58] 2013 | | | Duration (min) sitting/lying | Error=−2.6% | I | |
| | | | Duration (min) upright | Error=1.1% | | |
| | | | Duration (min) standing | Error=−0.5% | | |
| | | | Duration (min) stepping | Error=5.6% | | |
| | | | Steps (n) walking | Error=3.8% | | |
| Xing et al[18] 2021 | ActiGraph | Freedman (VA) | EE sitting | MD=−0.58 METs; 95% CI, −0.64 to −0.44 | V | |
| | | Trost (VA) | EE sitting | MD=−0.24 Kcal/min; 95% CI, −0.46 to −0.02 | | |
| | | Treuth (VA) | EE sitting | MD=−1.13 METs; 95% CI, −1.18 to −1.07 | | |
| | activPAL | | EE sitting | MD=−0.37 METs; 95% CI, −0.42 to −0.31 | | |
| | ActiGraph | Freedman | EE standing | MD=−0.13 METs; 95% CI, −0.27 to 0.02 | | |
| | | Trost | EE standing | MD=0.13 Kcal/min; 95% CI, −0.09 to 0.33 | | |
| | | Treuth | EE standing | MD=−0.71 METs; 95% CI, −0.81 to −0.62 | | |
| | activPAL | | EE standing | MD=−0.16 METs; 95% CI, −0.28 to −0.05 | | |
| | ActiGraph | Freedman | EE slow walking | MD=0.46 METs; 95% CI, 0.21-0.70 | | |
| | | Trost | EE slow walking | MD=0.75 Kcal/min; 95% CI, 0.59-0.91 | | |
| | | Treuth | EE slow walking | MD=0.02 METs; 95% CI −0.14 to 0.19 | | |
| | activPAL | | EE slow walking | MD=−0.44 METs; 95% CI −0.60 to −0.27] | | |
| | ActiGraph | Freedman | EE moderate walking | MD=−0.17 METs; 95% CI, −0.50 to 0.17 | | |
| | | Trost | EE moderate walking | MD=0.51 Kcal/min, 95% CI, 0.28-0.75 | | |
| | | Treuth | EE moderate walking | MD=−0.29 METs, 95% CI, −0.47 to −0.10 | | |
| | activPAL | | EE moderate walking | MD=0.39 METs, 95% CI, 0.09, 0.68 | | |
| | ActiGraph | Freedman | EE fast walking | MD=1.84 METs, 95% CI, 1.26, 2.43 | | |
| | | Trost | EE fast walking | MD=2.17 Kcal/min, 95% CI, 1.33, 3.01 | | |
| | | Treuth | EE fast walking | MD=1.48 METs, 95% CI, 0.94, 2.02 | | |
| | activPAL | | EE fast walking | MD=3.54 METs, 95% CI, 2.60, 4.48 | | |

(*continued*)

**Table 3B** (*Continued*)

| Study Author(s) YoP | Population Group Specs | Cutoff points/pred.eq. | Device-Measured PA | Validity | | | Quality Risk of Bias | Quality GRADE |
|---|---|---|---|---|---|---|---|---|
| Criterion validity for cutoff point based methods | | | | | | | | ⊕⊕⊕ |
| Baque et al[77] 2017 | | Baque | AC-VM (n/15 s) structured activities (SED) | AUC=1 | Se=100% | Sp=100% | V | |
| | | | AC-VM (n/15 s) structured activities (MI) | AUC=0.98 | Se=90.7% | Sp=92.6% | | |
| | | | AC-VM (n/15 s) structured activities (VI) | AUC=0.99 | Se=93.8% | Sp=96.3% | | |
| | | Clanchy | PA intensity levels (SED, LPA, MPA, VPA) (METs) structured activities (II) | $\kappa$=0.73 (SE=−0.08) | | | | |
| | | Evenson | PA intensity levels (SED, LPA, MPA, VPA) (METs) structured activities (II) | $\kappa$=0.77 (SE=−0.07) | | | | |
| | | Baque | PA intensity levels (SED, LPA, MPA, VPA) (METs) structured activities (II) | $\kappa$=0.92 (SE=−0.07) | | | | |
| Clanchy et al[70] 2011 | | Freedson | SED≤1.5 (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | V | |
| | | Puyau | SED (METs) structured activities (II) | AUC=0.90, 95% CI, 0.84-0.96 | Se=90.3% | Sp=89.4% | | |
| | | Treuth | SED (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | | |
| | | Evenson | SED (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | | |
| | | Clanchy | SED (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | | |
| | | Freedson | LPA=[1.5, 4] (METs) structured activities (II) | AUC=0.66, 95% CI, 0.58-0.74 | Se=45.3% | Sp=85.7% | | |
| | | Puyau | LPA (METs) structured activities (II) | AUC=0.68, 95% CI, 0.59-0.77 | Se=63.2% | Sp=73.1% | | |
| | | Treuth | LPA (METs) structured activities (II) | AUC=0.68, 95% CI, 0.60-0.75 | Se=60.4% | Sp=76.2% | | |
| | | Evenson | LPA (METs) structured activities (II) | AUC=0.67, 95% CI, 0.58-0.75 | Se=49.1% | Sp=84.1% | | |
| | | Clanchy | LPA (METs) structured activities (II) | AUC=0.63, 95% CI, 0.56-0.71 | Se=35.9% | Sp=90.5% | | |
| | | Freedson | MVPA=≥4 (METs) structured activities (II) | AUC=0.75, 95% CI, 0.66-0.83 | Se=81.8% | Sp=67.5% | | |
| | | Puyau | MVPA (METs) structured activities (II) | AUC=0.75, 95% CI, 0.68-0.83 | Se=59.6% | Sp=91.3% | | |
| | | Treuth | MVPA (METs) structured activities (II) | AUC=0.73, 95% CI, 0.63-0.82 | Se=66.7% | Sp=78.3% | | |
| | | Evenson | MVPA (METs) structured activities (II) | AUC=0.91, 95% CI, 0.84-0.97 | Se=81.8% | Sp=100% | | |
| | | Clanchy | MVPA (METs) structured activities (II) | AUC=0.94, 95% CI, 0.88-0.98 | Se=91.4% | Sp=86.2% | | |
| Keawutan et al[71] 2016 | GMFCS I | Keawutan | AC-VM (n) structured activities (SED) | AUC=0.79, 95% CI, 0.77-081 | Se=74% | Sp=73% | D | |
| | GMFCS II | | AC-VM (n) structured activities (SED) | AUC=0.78, 95% CI, 0.76-0.80 | Se=72% | Sp=73% | | |
| | GMFCS III | | AC-VM (n) structured activities (SED) | AUC=0.81, 95% CI, 0.79-0.82 | Se=74% | Sp=74% | | |
| Keawutan et al[71] 2016 | GMFCS I | Keawutan | Duration SED (min) structured activities (II) | MD=−13.3%, 95% LoA [−34.0 to 7.4] | Se=78.6% | Sp=84% | | |
| | | Butte | Duration SED (min) structured activities (II) | MD=−6.2%, 95% LoA [−22.8 to 10.4] | Se=84.1% | Sp=79.6% | | |
| | GMFCS II | Keawutan | Duration SED (min) structured activities (II) | MD=−15.6%, 95% LoA [−33.5 to 2.3] | Se=78.2% | Sp=86.7% | | |
| | | Butte | Duration SED (min) structured activities (II) | MD=−10.4%, 95% LoA [−27.2 to 6.4] | Se=81.7% | Sp=83.2% | | |
| | GMFCS III | Keawutan | Duration SED (min) structured activities (II) | MD=−1%, 95% LoA [−25.6 to 23.7] | Se=72.5% | Sp=76.2% | | |
| | | Butte | Duration SED (min) structured activities (II) | MD=−2.4%, 95% LoA [−26.8 to 21.9] | Se=71.8% | Sp=77% | | |
| Oftedal et al[56] 2014 | n=39 | Oftedal (VM) | AC-VA (n) structured activities (SED) | AUC=0.77, 95% CI, 0.76-0.78 | Se=71% | Sp=77% | D | |
| | n=18 | | AC-VM (n) structured activities (SED) | AUC=0.81, 95% CI, 0.80-0.82 | Se=75% | Sp=76% | | |
| Oftedal et al[56] 2014 | n=23 | Oftedal (VA) | Duration SED (min) structured activities (II) | MD=−10.5%, 95% LoA [−30.2 to 9.1] | Se=74% | Sp=80% | D | |
| | n=18 | | Duration SED (min) structured activities (II) | MD=−1.5%, 95% LoA [−20.0 to 16.8] | Se=79% | Sp=72% | | |
| Ryan et al[73] 2014 | | Ryan | AC (n) structured activities (LI) | AUC=0.965, 95% CI, 84.6-99.8 | | | D | |
| | | | AC (n) structured activities (MVI) | AUC=0.896, 95% CI, 77.4-96.6 | | | | |
| | | VanHelst | SED (<2) (METs) structured activities (II) | $\kappa$=0.92, 95% CI, 0.82-1.00 | Se=89.5% | Sp=100% | | |
| | | Ryan | SED (<2) (METs) structured activities (II) | $\kappa$=0.96, 95% CI, 0.89-1.00 | Se=94.7% | Sp=100% | | |
| | | VanHelst | LPA ([2, 3]) (METs) structured activities (II) | $\kappa$=0.57, 95% CI, 0.38-0.77 | Se=88.9% | Sp=79.6% | | |
| | | Ryan | LPA (METs) structured activities (II) | $\kappa$=0.71, 95% CI, 0.52-0.90 | Se=83.3% | Sp=89.8% | | |
| | | Rowlands | MVPA (≥3) (METs) structured activities (II) | $\kappa$=0.69, 95% CI, 0.52-0.86 | Se=70% | Sp=97.3% | | |
| | | VanHelst | MVPA (METs) structured activities (II) | $\kappa$=0.66, 95% CI, 0.48-0.84 | Se=70% | Sp=94.6% | | |
| | | Ryan | MVPA (METs) structured activities (II) | $\kappa$=0.79, 95% CI, 0.64-0.94 | Se=86.7% | Sp=91.9% | | |
| Stephens et al[26] 2016 | Actical | Stephens | AC-VM (n) structured activities (SED) | AUC=0.84, 95% CI, 0.78-0.90 | Se=78% | Sp=88% | V | |
| | | | AC-VM (n) structured activities (MI) | AUC=0.82, 95% CI, 0.77-0.88 | Se=72% | Sp=75% | | |
| | | | AC-VM (n) structured activities (VI) | AUC=0.98, 95% CI, 0.96-1.0 | Se=100% | Sp=94% | | |
| | ActiGraph | Stephens | AC-VA (n) structured activities (SED) | AUC=0.82, 95% CI, 0.74-0.90 | Se=75% | Sp=91% | | |
| | | | AC-VA (n) structured activities (MI) | AUC=0.78, 95% CI, 0.71-0.86 | Se=86% | Sp=63% | | |
| | | | AC-VA (n) structured activities (VI) | AUC=0.78, 95% CI, 0.52-1.0 | Se=83% | Sp=79% | | |
| | Actical | Evenson | SED (n) structured activities (RI) | | Se=72% | Sp=92% | | |
| | | | MPA (n) structured activities (RI) | | Se=49% | Sp=94% | | |
| | | | VPA (n) structured activities (RI) | | Se=100% | Sp=92% | | |
| | ActiGraph | Evenson | SED (n) structured activities (RI) | | Se=75% | Sp=90% | | |
| | | | MPA (n) structured activities (RI) | | Se=41% | Sp=90% | | |
| | | | VPA (n) structured activities (RI) | | Se=50% | Sp=95% | | |
| Stephens et al[26] 2016 | Actical | Stephens | AC-VM (n) structured activities (SED) | AUC=0.96, 95% CI, 0.93-0.98 | Se=82% | Sp=97% | V | |
| | | | AC-VM (n) structured activities (MI) | AUC=0.89, 95% CI, 0.83-0.94 | Se=82% | Sp=81% | | |
| | | | AC-VM (n) structured activities (VI) | AUC=0.91, 95% CI, 0.87-0.95 | Se=100% | Sp=90% | | |
| | ActiGraph | Stephens | AC-VA (n) structured activities (SED) | AUC=0.9, 95% CI, 0.86-0.95 | Se=78% | Sp=91% | | |
| | | | AC-VA (n) structured activities (MI) | AUC=0.91, 95% CI, 0.85-0.97 | Se=81% | Sp=94% | | |
| | | | AC-VA (n) structured activities (VI) | AUC=0.92, 95% CI, 0.88-0.96 | Se=100% | Sp=92% | | |
| | Actical | Evenson | SED (n) structured activities (RI) | | Se=80% | Sp=97% | | |
| | | | MPA (n) structured activities (RI) | | Se=47% | Sp=96% | | |
| | | | VPA (n) structured activities (RI) | | Se=0% | Sp=96% | | |

(*continued*)

**Table 3B** (*Continued*)

| Study Author(s) YoP | Population Group Specs | Cutoff points/pred.eq. | Device-Measured PA | Validity | | | Quality | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Risk of Bias | GRADE |
| | ActiGraph | Evenson | SED (n) structured activities (RI) | | Se=75% | Sp=91% | | |
| | | | MPA (n) structured activities (RI) | | Se=81% | Sp=90% | | |
| | | | VPA (n) structured activities (RI) | | Se=0% | Sp=92% | | |
| Trost et al[24] | | Evenson | SED (<1.5) (METs) structured activities (II) | AUC=0.93, 95% CI, 0.91-0.96 | Se=98.9% | Sp=87.6% | V | |
| 2016 | | Clanchy | SED (METs) structured activities (II) | AUC=0.93, 95% CI, 0.91-0.96 | Se=98.9% | Sp=87.6% | | |
| | | Trost (VA) | SED (METs) structured activities (II) | AUC=0.97, 95% CI, 0.95-0.99 | Se=97.9% | Sp=96.1% | | |
| | | Trost (VM) | SED (METs) structured activities (II) | AUC=0.96, 95% CI, 0.94-0.99 | Se=96.9% | Sp=96.1% | | |
| | | Evenson | LPA ([1.5, 3]) (METs) structured activities (II) | AUC=0.68, 95% CI, 0.63-0.73 | Se=61.5% | Sp=74.6% | | |
| | | Clanchy | LPA (METs) structured activities (II) | AUC=0.68, 95% CI, 0.62-0.73 | Se=58.1% | Sp=77.1% | | |
| | | Trost (VA) | LPA (METs) structured activities (II) | AUC=0.82, 95% CI, 0.77-0.86 | Se=77.8% | Sp=86.4% | | |
| | | Trost (VM) | LPA (METs) structured activities (II) | AUC=0.8, 95% CI, 0.76-0.85 | Se=72.7% | Sp=87.8% | | |
| | | Evenson | MVPA (≥3) (METs) structured activities (II) | AUC=0.75, 95% CI, 0.71-0.80 | Se=57.1% | Sp=93.4% | | |
| | | Clanchy | MVPA (METs) structured activities (II) | AUC=0.76, 95% CI, 0.72-0.81 | Se=61.4% | Sp=91.6% | | |
| | | Trost (VA) | MVPA (METs) structured activities (II) | AUC=0.86, 95% CI, 0.82-0.89 | Se=78.6% | Sp=92.5% | | |
| | | Trost (VM) | MVPA (METs) structured activities (II) | AUC=0.86, 95% CI, 0.82-0.89 | Se=81.4% | Sp=89.7% | | |
| Xing et al[18] | | Puyau (VA) | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *r*s=0.84 | $\kappa$=0.458 | | V | |
| 2021 | | Evenson | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *r*s=0.888 | $\kappa$=0.585 | | | |
| | | Romanzini (VA) | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *r*s=0.886 | $\kappa$=0.56 | | | |
| | | Romanzini (VM) | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *r*s=0.886 | $\kappa$=0.675 | | | |
| | | Clanchy | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *r*s=0.935 | $\kappa$=0.721 | | | |
| | | Baque | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *r*s=0.896 | $\kappa$=0.773 | | | |
| Convergent validity | | | | | | | | ⊕⊕⊕ |
| Kuo et al[55] | AMP | | Distance continuous walking | MD=−4.8 m, 95% LoA (-20.1 to 10.5) | | | D | |
| 2009 | Minimod | | Distance continuous walking | MD=−0.4 m, 95% LoA (-4.7 to 4.0) | | | | |
| | AMP | | Distance intermittent walking | MD=−3.6 m, 95% LoA (-19.2 to 12.0) | | | | |
| | Minimod | | Distance intermittent walking | MD=−2.3 m, 95% LoA (-27.9 to 23.3) | | | | |
| | AMP | | Distance downstair climbing | MD=−1.3 m, SD -2.5 | | | | |
| | Minimod | | Distance downstair climbing | MD=8.9 m, SD -2.5 | | | | |
| | AMP | | Distance upstair climbing | MD=−2 m, SD -2.5 | | | | |
| | Minimod | | Distance upstair climbing | MD=3.3 m, SD -2.2 | | | | |
| Lawal et al[21] | ActiGraph GT3X | | Steps (n) walking | ICC=0.29, 95% CI, −0.42 to 0.78 | | | D | |
| 2020 | LFE-ActiGraph GT3X | | Steps (n) walking | ICC=0.52, 95% CI, −0.16 to 0.87 | | | | |
| Mackey et al[66] | | | Duration (min) lying | | Se=100% | Sp=100% | D | |
| 2009 | | | Duration (min) sitting | | Se=100% | Sp=100% | | |
| | | | Duration (min) standing | | Se=100% | Sp=97% | | |
| | n=12 for stair climbing | | Duration (min) walking (overground and stairs) | | Se=78.5% | Sp=100% | | |
| Sala et al[74] 2019 | Hip (n=38) | | Steps walking | MAE=7 steps, range=−52 to 6 | *r*=0.991 | | D | |
| | | | Distance walking | MAE=0.07 miles, range=0.01 to 0.16 | | | | |
| | GMFCS I+II (n=27) | | Steps walking | MAE=6 steps, range=−20 to 6 | *r*=0.998 | | | |
| | | | Distance walking | MAE=0.07 miles, range=0.01 to 0.16 | | | | |
| | GMFCS III (n=11) | | Steps walking | MAE=12 steps, range=−52 to 1 | *r*=0.981 | | | |
| | | | Distance walking | MAE=0.07 miles, range=0.02 to 0.14 | | | | |
| | Wrist (n=38) | | Steps walking | MAE=88 steps, range=−484 to 35 | *r*=−0.033 | | | |
| | | | Distance walking | MAE=0.06 miles, range=−0.13 to 0.16 | | | | |
| | GMFCS I+II (n=27) | | Steps walking | MAE=27 steps, range=−177 to 23 | *r*=0.837 | | | |
| | | | Distance walking | MAE=0.04 miles, range=−0.02 to 0.16 | | | | |
| | GMFCS III (n=11) | | Steps walking | MAE=238 steps, range=−484 to 35 | *r*=−0.242 | | | |
| | | | Distance walking | MAE=0.08 miles, range=−0.13 to 0.11 | | | | |

Abbreviations: "?", indeterminate; "-", insufficient; "+", sufficient; "⊕⊕⊕", moderate; AC, activity counts; AUC, area under the curve; D, doubtful; EE, energy expenditure; GRADE, Grading of Recommendations Assessment, Development and Evaluation; HR, heart rate; HRAR, heart rate above rest; HRAS, heart rate above sleep; HS, hemiparetic side; I, inadequate; II, increased intensity; LNI, least neurological impaired; LoA, levels of agreement; LPA, low physical activity; MAE, mean absolute error; MD, mean difference; MET, metabolic equivalent of task; MI, moderate intensity; MPA, moderate physical activity; MVI, moderate-to-vigorous; n, number; NA, not applicable; NHS, nonhemiparetic side; NI, neurological impaired; pred, prediction; r, Pearson correlation coefficient; $R^2$, coefficient of determination; RI, random intensity; rs, Spearman rank correlation coefficient; Se, sensitivity; SED, sedentary; Sp, specificity; V, very good; VA, vertical axis; VI, vigorous intensity; VM, vector magnitude; VPA, vigorous physical activity; YoP, year of publication; $\kappa$, Cohen's kappa.

**Table 4A** Validity of device-measured physical activity.

| Study | Instrument | | | Population | |
|---|---|---|---|---|---|
| Author(s)<br>YoP | Name<br>Epoch<br>Placement | Comparison Measure<br>Specs<br>Outcome | PB Domain<br>Activity Duration | Condition<br>GMFCS level (n) | Sample<br>Age<br>Gender |
| Criterion validity | | | | | |
| Aviram et al[60]<br>2011 | IDEEA<br>ND<br>Chest, thigh (2),<br>Foot (2) | PIC<br>Cosmed K4b2 | Laboratory<br>1 × ±7 min+3 × 4 min<br>II=6 | Cerebral palsy<br>I=8<br>ND<br>III=7 | n=21<br>6.4±1.9 y |
| Bania[59]<br>2014 | activPAL<br>ND<br>Thigh | Video DO<br>ND | Laboratory<br>2 × 3 min+6 min | Cerebral palsy<br>II=5<br>III=5 | n=10<br>18.6±2.7 y<br>4 girls |
| Baque et al[77]<br>2017 | ActiGraph GTX3+<br>15 s<br>Waist (LNI) | PIC<br>Cortex Metamax | Laboratory<br>1 × 5 min+3 ×<br>6 min+1 × 3 min | Acquired brain injury<br>I=16<br>II=11 | n=27<br>13.6±2.4 y<br>12 girls |
| Capio et al[75]<br>2010 | MTI (ActiGraph)<br>15 s<br>Waist (r) | SOFIT<br>ND | Laboratory<br>6 × 2 min (structured)<br>10 min (free play) | Cerebral palsy<br>I=14<br>II=9<br>III=8 | n=31<br>9.7±2.5 y<br>17 girls |
| de Groot et al[76]<br>2013 | Actical<br>60 s<br>Waist (l)<br>Actiheart<br>15 s<br>Trunk (front) | PIC<br>Cortex Metamax | Laboratory<br>6 min | Spina bifida<br>Hoffer normal=7<br>Hoffer community=19 | n=39<br>10.6±2.8 y<br>11 girls |
| Koehler et al[68]<br>2015 | SenseWear<br>ND<br>Upper portion of the arm (l+r) | PIC<br>ZAN 600 | Laboratory<br>5 × 5 min | Cerebral palsy<br>II=10<br>3 girls | n=10<br>13.4±1.6 y |
| Kuo et al[55]<br>2009 | AMP 331<br>ND<br>Ankle (r)<br>DynaPort Minimod<br>ND<br>Trunk (back) | Video DO<br>ND | Laboratory<br>ND<br><br>III=3 | Cerebral palsy<br>I=5<br>II=12 | n=20<br>10.5±3.0 y<br>7 girls |
| Lankhorst et al[16]<br>2019 | Activ8<br>5 s<br>Thigh (DBS) | Video DO<br>ND | Free living<br>45 min (1:30 min)<br>Hoffer household=2 | Spina bifida<br>Hoffer community=2<br>1 girl | n=10<br>12.9±2.1 y |
| Maher et al[67]<br>2013 | NL-1000 pedometer<br>ND<br>Thigh (nDBS, DBS) | Video DO<br>FlipVideo UltraHD<br>Camcorder | Laboratory<br>2 × 3 min | Cerebral palsy<br>I=8<br>II=9 | n=17<br>12.3±3.2 y<br>9 girls |
| McAloon et al[72]<br>2014 | activPAL<br>ND<br>Thigh (NI) | Video DO<br>ND | Laboratory<br>ND | Cerebral palsy<br>I=4<br>II=5<br>III=1 | n=10<br>4-18 y<br>ND |
| O'Donoghue and Kennedy[78]<br>2014 | activPAL<br>ND<br>Thigh (NI, LNI) | Video DO<br>2D Sony mini digital<br>Video camera | Laboratory<br>ND | Cerebral palsy<br>I=17 | n=17<br>9.4±3.9 y<br>8 girls |
| O'Neil et al[20]<br>2014 | ActiGraph GT3X<br>1 s<br>Waist (r) | PIC<br>Cosmed K4b2 | Laboratory<br>3 × 6 min | Cerebral palsy<br>I=4<br>II=1<br>III=3 | n=8<br>11.9±3.2 y<br>2 girls |
| O'Neil et al[69]<br>2016 | ActiGraph GT3X<br>1 s<br>Waist (l+r)<br>StepWatch<br>3 s<br>Ankle (l+r)<br>SenseWear<br>60 s<br>Upper portion of the arm (l+r) | PIC<br>Cosmed K4b2 | Laboratory<br>2-2.5 h | Cerebral palsy<br>I=28<br>II=16<br>III=13 | n=57<br>12.5±3.3 y<br>29 girls |
| Pirpiris and Graham[57]<br>2004 | PAL 1<br>1 s<br>Thigh (l) | Video DO<br>ND | Free living<br>1 h | Cerebral palsy | n=50<br>11.0±3.2 y<br>24 girls |
| Pirpiris and Graham[57]<br>2004 | PAL 1<br>1 s<br>Thigh (l) | PIC<br>Cosmed K4b2 | ND<br>ND | Cerebral palsy | n=35<br>ND<br>ND |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Waist (r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Juvenile arthritis | n=31<br>12.7±2.6 y<br>23 girls |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Waist (r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Inherited muscle disease | n=30<br>12.0±3.4 y<br>8 girls |

*(continued)*

**Table 4A** (*Continued*)

| Study | Instrument | | | Population | |
|---|---|---|---|---|---|
| Author(s)<br>YoP | Name<br>Epoch<br>Placement | Comparison Measure<br>Specs<br>Outcome | PB Domain<br>Activity Duration | Condition<br>GMFCS level (n) | Sample<br>Age<br>Gender |
| Tang et al[58]<br>2013 | activPAL<br>ND<br>Thigh (nDBS) | Video DO<br>ND | Laboratory<br>71±49 min<br>II=4 | Cerebral palsy<br>I=9<br>4 girls<br>III=2 | n=15<br>10.9±4.3 y |
| Xing et al[18]<br>2021 | ActiGraph GT3X<br>15 s<br>Waist (r)<br>activPAL3C<br>15 s<br>Thigh (front) | PIC<br>Sensor Medics | Laboratory<br>7 × 5 min | Cerebral palsy<br>I=3<br>II=6<br>III=1 | n=10<br>6 girls |
| Criterion validity of cutoff point based methods | | | | | |
| Baque et al[77]<br>2017 | ActiGraph GTX3+<br>15 s<br>Waist (LNI) | DO<br>ND | Laboratory<br>1 × 5 min+3 × 6 min+<br>1 × 3 min | | |
| Clanchy et al[70]<br>2011 | ActiGraph 7164<br>1 s<br>Waist (LNI or DBS) | PIC<br>Cosmed K4b2<br>3 min | Laboratory<br>10 min+2 × 6 min+<br>II=15 | Cerebral palsy<br>I=11<br>13 girls<br>III=13 | n=29<br>12.5±2.0 y |
| Keawutan et al[71]<br>2016 | Actigraph GT3X(+)<br>5 s<br>Trunk (back) | Video DO<br>ND | Laboratory<br>17.4 min<br>II=13 | Cerebral palsy<br>I=17<br>ND<br>III=10 | n=40<br>4.7 y |
| Keawutan et al[71]<br>2016 | Actigraph GT3X(+)<br>5 s<br>Trunk (back) | Laboratory | Cerebral palsy<br>19.7 min<br>II=7 | n=21<br>I=9<br>ND<br>III=5 | 4.6 y |
| Oftedal et al[56]<br>2014 | ActiGraph GT1M<br>5 s<br>Trunk (back)<br>ActiGraph GT3X and GT3X+<br>5 s<br>Trunk (back) | Video DO<br>ND | Laboratory<br>20 à 30 min | Cerebral palsy<br>I-III<br>26 girls | n=39<br>2.3±0.5 y |
| Oftedal et al[56]<br>2014 | ActiGraph GT1M<br>5 s<br>Trunk (back)<br>ActiGraph GT3X and GT3X+<br>5 s<br>Trunk (back) | Laboratory | 20 à 30 min | n=23<br>15 girls | 2.5±0.6 y |
| Ryan et al[73]<br>2014 | RT3<br>1 Hz<br>ND | PIC<br>Oxycon | Laboratory<br>6 min | Cerebral palsy<br>I=10<br>II=4 | n=18<br>11.4±3.2 y<br>8 girls |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Hip (mid-line, r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Juvenile arthritis | n=31<br>12.7±2.6 y<br>23 girls |
| Stephens et al[26]<br>2016 | Actical<br>15 s<br>Hip (mid-line, r)<br>ActiGraph<br>15 s<br>Waist (r) | PIC<br>Cosmed K4b2/<br>Cortex Metamax | Laboratory<br>7 × 6 min | Inherited muscle disease | n=30<br>12.0±3.4 y<br>8 girls |
| Trost et al[24]<br>2016 | ActiGraph GT3X<br>1 s<br>Waist (r) | PIC<br>Cosmed K4b2 | Laboratory<br>4 × 5 min+3 × 6 min | Cerebral palsy<br>I=27<br>II=12 | n=51<br>Age=12.5<br>24 girls |
| Xing et al[18]<br>2021 | ActiGraph GT3X<br>15 s<br>Waist (r)<br>activPAL3C<br>15 s<br>Thigh | PIC<br>Sensor Medics | Laboratory<br>7 × 5 min | Cerebral palsy<br>I=3<br>II=6<br>III=1 | n=10<br>6 girls |
| Convergent validity | | | | | |
| Kuo et al[55]<br>2009 | AMP 331<br>ND<br>Ankle (r)<br>DynaPort Minimod<br>ND<br>Trunk (back) | Measuring wheel<br>ND | Laboratory<br>ND<br>III=3 | Cerebral palsy<br>I=5<br>II=12 | n=20<br>Age=10.5±3.0 y<br>7 girls |
| Lawal et al[21]<br>2020 | ActiGraph GT3X<br>60 s<br>Waist | Observation<br>Tally counter | Laboratory<br>6 min | Congenital muscular<br>Dystrophy<br>ND | n=9<br>Age=ND<br>6 girls |

(*continued*)

**Table 4A** (*Continued*)

| Study | Instrument | | | Population | |
|---|---|---|---|---|---|
| Author(s)<br>YoP | Name<br>Epoch<br>Placement | Comparison Measure<br>Specs<br>Outcome | PB Domain<br>Activity Duration | Condition<br>GMFCS level (n) | Sample<br>Age<br>Gender |
| Mackey et al[66]<br>2009 | IDEEA<br>ND<br>Chest, thigh (2), foot (2) | Time recording | Laboratory<br>5 × 30 s<br>III=9 | Cerebral palsy<br>I or II=16 | n=25<br>Age=14.1 y<br><br>17 girls |
| Sala et al[74]<br>2019 | Fitbit One<br>ND<br>Waist<br>Fitbit Flex<br>ND<br>Wrist (DBS) | Observation<br>Tally counter | Laboratory<br>3 × ±3 min | Cerebral palsy<br>I=22<br>II=5<br>III=11 | n=39<br>Age=9.6 y<br>Range 4-15 y<br>16 girls |

Abbreviations: DBS, dominant bodyside; DO, direct observation; IDEEA, Intelligent Device for Energy Expenditure and Activity; l, left; LNI, least neurological impaired; n, number; ND, not described; nDBS, nondominant bodyside; NI, neurological impaired; PAL 1, Positional Activity Logger version 1; PB, physical behavior; PIC, portable indirect calorimetry; r, right; SOFIT, System for Observing Fitness Instruction Time; YoP, year of publication.

**Table 4B** Validity of device-measured physical activity.

| Study | Population | | Device-Measured PA | Validity | | Quality | | |
|---|---|---|---|---|---|---|---|---|
| Author(s)<br>YoP | Group specs | Cutoff points/<br>pred.eq. | | | | Overall Rating | Risk of Bias | GRADE |
| **Criterion validity** | | | | | | | | ⊕⊕⊕ |
| Aviram et al[60]<br>2011 | n=13 | | EE rate (Kcal/min) slow walking<br>EE rate (Kcal/min) moderate walking<br>EE rate (Kcal/min) stepping<br>Total EE (Kcal) structured activities (II) | $r$=0.7<br>$r$=0.88<br>$r$=0.75<br>$r$=0.72 | | + | D | |
| Bania[59]<br>2014 | | | Duration sitting<br>Duration standing<br>Steps walking | MD=0.5 min, 95% LoA (-0.6 to 1.5)<br>MD=−0.06 min, 95% LoA (-0.4 to 0.3)<br>MD=−13.8 steps, 95% LoA (-36.9 to 9.4) | | ? | D | |
| Baque et al[77]<br>2017 | | | AC-VM (n) structured activities (II) | $r$=0.89 | | + | V | |
| Capio et al[75]<br>2010 | | | AC (n) structured activities (II)<br>AC (n) unstructured activities (RI) | $R^2$=0.56<br>$R^2$=0.45 | | ? | V | |
| de Groot et al[76]<br>2013 | Actical<br>Actiheart | Corder (AC)<br>Corder (AC)<br>Corder (HRAR)<br>Corder (AC+HRAR)<br>Corder (AC+predHRAS)<br>Corder (AC+trueHRAS)<br>Takken (predHRAS)<br>Takken (trueHRAS)<br>Current study (AC)<br>Current study (HRAR) | EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking<br>EE (J/kg/min) walking | ICC=0.6, 95% CI, 0.28-0.80<br>ICC=0.49 (0.12-0.74)<br>ICC=0.74 (0.49-0.88)<br>ICC=0.8, 95% CI, 0.59-0.91<br>ICC=0.12 (-0.28 to 0.48)<br>ICC=0.71 (0.45-0.86)<br>ICC=0.018, 95% CI, −0.37 to 0.40<br>ICC=0.73 (0.48-0.87)<br>$R^2$=0.68<br>$R^2$=0.72 | | -/?/+ | V | |
| Koehler et al[68]<br>2015 | n=10 (NHS)<br>n=9<br>n=10<br>n=6<br>n=2<br>n=10 (HS)<br>n=9<br>n=10<br>n=6<br>n=2 | | EE sitting (rest)<br>EE walking (0.85 m/s)<br>EE walking (1.35 m/s)<br>EE walking (1.85 m/s)<br>EE (Kcal/min) running (2.35 m/s)<br>EE sitting (rest)<br>EE walking (0.85 m/s)<br>EE walking (1.35 m/s)<br>EE walking (1.85 m/s)<br>EE running (2.35 m/s) | MD=0.3 Kcal/min, 95% LoA (-0.7 to 1.3)<br>MD=−0.6 Kcal/min, 95% LoA (-3.2 to 2.0)<br>MD=−0.3 Kcal/min, 95% LoA (-3.7 to 3.1)<br>MD=0.8 Kcal/min, 95% LoA (-4.1 to 5.7)<br>NA<br>MD=0.4 Kcal/min, 95% LoA (-0.7 to 1.5)<br>MD=−0.6 Kcal/min, 95% LoA (-2.7 to 1.4)<br>MD=−0.1 Kcal/min, 95% LoA (-2.9 to 2.6)<br>MD=0.7 Kcal/min, 95% LoA (-5.9 to 7.2)<br>MD=−0.6 Kcal/min, 95% LoA (-9.4 to 8.3) | | ? | D | |
| Kuo et al[55]<br>2009 | AMP<br>Minimod<br>AMP<br>Minimod<br>AMP<br>Minimod<br>AMP<br>Minimod | | Steps continuous walking<br>Steps continuous walking<br>Steps intermittent walking<br>Steps intermittent walking<br>Steps downstair climbing<br>Steps downstair climbing<br>Steps upstair climbing<br>Steps upstair climbing | MD=−3.5 steps, 95% LoA (-16.9 to 10.0)<br>MD=−11.2 steps, 95% LoA (-40.0 to 17.7)<br>MD=−0.4 step, 95% LoA (-4.1 to 3.3)<br>MD=−38.7 steps, 95% LoA (-87.8 to 104)<br>MD=−10.1 steps, SD=9.5<br>MD=−1 step, SD=1<br>MD=−8.1 steps, SD=9.2<br>MD=−1 step, SD=1.7 | | ? | D | |
| Lankhorst et al[16]<br>2019 | n=8 (slow pace); n=7 (fast pace)<br>n=8<br><br><br><br>n=8 | | Duration basic sitting<br>Duration basic standing<br>Duration basic walking<br>Duration basic bicycling<br>Duration basic running<br>Duration complex sitting<br>Duration complex standing<br>Duration complex walking<br>Duration complex bicycling<br>Duration complex running | MD=83 s<br>MD=−70 s<br>MD=−385 s<br>MD=357 s<br>MD=15 s<br>MD=−106 s<br>MD=−296 s<br>MD=−372 s<br>MD=713 s<br>MD=61 s | Error=6.9%<br>Error=−11.6%<br>Error=−21%<br>Error=39.7%<br>Error=3.4%<br>Error=−8.1%<br>Error=−84.6%<br>Error=−12.4%<br>NA<br>Error=265.2% | ? | I | |
| Maher et al[67]<br>2013 | Dominant body side<br><br>Nondominant body side | | Steps (n) walking<br>Steps (n) running<br>Steps (n) walking<br>Steps (n) running | ICC=0.94, 95% CI, 0.83-0.98<br>ICC=0.94, 95% CI, 0.84-0.98<br>ICC=0.78, 95% CI, 0.49-0.92<br>ICC=0.95, 95% CI, 0.87-0.98 | | + | V | |

(*continued*)

**Table 4B** (*Continued*)

| Study | Population | | Device-Measured PA | Validity | | | Quality | | |
|---|---|---|---|---|---|---|---|---|---|
| Author(s) YoP | Group specs | Cutoff points/ pred.eq. | | | | | Overall Rating | Risk of Bias | GRADE |
| McAloon et al[72] 2014 | | | Duration sitting | MD=−6.8 s, 95% LoA (18.5 to -32.1) | | | ? | I | |
| | | | Duration standing | MD=5.9 s, 95% LoA (19.1 to -7.3) | | | | | |
| | | | Duration walking | MD=−2.2 s, 95% LoA (7.8 to -12.3) | | | | | |
| | | | Steps steps | MD=−3.2 steps, 95% LoA (4.5 to -10.9) | | | | | |
| | | | Duration (s) structured activities (RI) | | Agreement=86.5% | | | | |
| O'Donoghue and Kennedy[78] 2014 | NI | | Duration (s) sitting | ICC (3.1)=0.49 | | | -/+ | D | |
| | | | Duration (s) standing | ICC (3.1)=0.59 | | | | | |
| | | | Duration (s) walking | ICC (3.1)=0.99 | | | | | |
| | | | Steps (n) walking | ICC (3.1)=0.96 | | | | | |
| | LNI | | Duration (s) sitting | ICC (3.1)=0.95 | | | | | |
| | | | Duration (s) standing | ICC (3.1)=0.98 | | | | | |
| | | | Duration (s) walking | ICC (3.1)=0.94 | | | | | |
| | | | Steps (n) walking | ICC (3.1)=0.95 | | | | | |
| O'Neil et al[20] 2014 | | | AC (n) walking (slow, brisk, fast) | *rs*=0.67 | | | - | V | |
| | | | Steps (n) walking (slow, brisk, fast) | *rs*=0.29 | | | | | |
| O'Neil et al[69] 2016 | ActiGraph | | Steps (n) structured activities | *rs*=0.82 | | | + | V | |
| | | | AC-VA (n) structured activities | *rs*=0.835 | | | | | |
| | | | AC-VM (n) structured activities | *rs*=0.84 | | | | | |
| | StepWatch | | Steps (n) structured activities | *rs*=0.78 | | | | | |
| | SenseWear | | Steps (n) structured activities | *rs*=0.74 | | | | | |
| Pirpiris and Graham[57] 2004 | | | Duration upright (s) unstructured activities | MD=5 s, 95% LoA (-37 to 47) | | | ? | D | |
| Pirpiris and Graham[57] 2004 | | | Duration upright (s) | *rs*=0.61 | | | - | | |
| Stephens et al[26] 2016 | Actical | Puyau | EE (METs) structured activities (II) | ICC (2,1)=0.41, 95% CI, 0.30-0.52 | | | -/+ | V | |
| | ActiGraph | Corder | EE (METs) | ICC (2,1)=0.28, 95% CI, 0.14-0.40 | | | | | |
| | | Freedson | EE (METs) | ICC (2,1)=0.35, 95% CI, 0.22-0.47 | | | | | |
| | | Puyau | EE (METs) | ICC (2,1)=0.22, 95% CI, 0.09-0.35 | | | | | |
| | Actical | Current study | EE (METs) | ICC (2,1)=0.75, 95% CI, 0.74-0.76 | | | | | |
| | | Current study (HR) | EE (METs) | ICC (2,1)=0.85, 95% CI, 0.84-0.86 | | | | | |
| | ActiGraph | Current study | EE (METs) | ICC (2,1)=0.7, 95% CI, 0.69-0.71 | | | | | |
| | | Current study (HR) | EE (METs) | ICC (2,1)=0.84, 95% CI, 0.83-0.85 | | | | | |
| Stephens et al[26] 2016 | Actical | Puyau | EE (METs) structured activities (II) | ICC (2,1)=0.38, 95% CI, 0.25-0.50 | | | -/+ | | |
| | ActiGraph | Corder | EE (METs) | ICC (2,1)=0.31, 95% CI, 0.17-0.45 | | | | | |
| | | Freedson | EE (METs) | ICC (2,1)=0.36, 95% CI, 0.21-0.49 | | | | | |
| | | Puyau | EE (METs) | ICC (2,1)=0.25, 95% CI, 0.10-0.39 | | | | | |
| | Actical | Current study | EE (METs) | ICC (2,1)=0.74, 95% CI, 0.73-0.75 | | | | | |
| | | Current study (HR) | EE (METs) | ICC (2,1)=0.78, 95% CI, 0.77-0.79 | | | | | |
| | ActiGraph | Current study | EE (METs) | ICC (2,1)=0.71, 95% CI, 0.70-0.72 | | | | | |
| | | Current study | EE (METs) | ICC (2,1)=0.68, 95% CI, 0.66-0.70 | | | | | |
| Tang et al[58] 2013 | | | Duration (min) sitting/lying | | Error=−2.6% | | ? | I | |
| | | | Duration (min) upright | | Error=1.1% | | | | |
| | | | Duration (min) standing | | Error=−0.5% | | | | |
| | | | Duration (min) stepping | | Error=5.6% | | | | |
| | | | Steps (n) walking | | Error=3.8% | | | | |
| Xing et al[18] 2021 | ActiGraph | Freedman (VA) | EE sitting | MD=−0.58 METs, 95% CI, −0.64 to −0.44 | | | ? | V | |
| | | Trost (VA) | EE sitting | MD=−0.24 Kcal/min, 95% CI, −0.46 to −0.02 | | | | | |
| | | Treuth (VA) | EE sitting | MD=−1.13 METs, 95% CI, −1.18 to −1.07] | | | | | |
| | activPAL | | EE sitting | MD=−0.37 METs, 95% CI, −0.42 to −0.31] | | | | | |
| | ActiGraph | Freedman | EE standing | MD=−0.13 METs, 95% CI, −0.27 to 0.02 | | | | | |
| | | Trost | EE standing | MD=0.13 Kcal/min, 95% CI, −0.09 to 0.33 | | | | | |
| | | Treuth | EE standing | MD=−0.71 METs, 95% CI, −0.81 to −0.62 | | | | | |
| | activPAL | | EE standing | MD=−0.16 METs, 95% CI, −0.28 to −0.05 | | | | | |
| | ActiGraph | Freedman | EE slow walking | MD=0.46 METs, 95% CI, 0.21 to 0.70 | | | | | |
| | | Trost | EE slow walking | MD=0.75 Kcal/min, 95% CI, 0.59 to 0.91 | | | | | |
| | | Treuth | EE slow walking | MD=0.02 METs, 95% CI, −0.14 to 0.19 | | | | | |
| | activPAL | | EE slow walking | MD=−0.44 METs, 95% CI, −0.60 to −0.27 | | | | | |
| | ActiGraph | Freedman | EE moderate walking | MD=−0.17 METs, 95% CI, −0.50 to 0.17 | | | | | |
| | | Trost | EE moderate walking | MD=0.51 Kcal/min, 95% CI, 0.28 to 0.75 | | | | | |
| | | Treuth | EE moderate walking | MD=−0.29 METs, 95% CI, −0.47 to −0.10 | | | | | |
| | activPAL | | EE moderate walking | MD=0.39 METs, 95% CI, 0.09 to 0.68 | | | | | |
| | ActiGraph | Freedman | EE fast walking | MD=1.84 METs, 95% CI, 1.26 to 2.43 | | | | | |
| | | Trost | EE fast walking | MD=2.17 Kcal/min, 95% CI, 1.33 to 3.01 | | | | | |
| | | Treuth | EE fast walking | MD=1.48 METs, 95% CI, 0.94 to 2.02 | | | | | |
| | activPAL | | EE fast walking | MD=3.54 METs, 95% CI, 2.60 to 4.48 | | | | | |
| Criterion validity for cutoff point based methods | | | | | | | | | ⊕⊕⊕ |
| Baque et al[77] 2017 | | Baque | AC-VM (n/15 s) structured activities (SED) | AUC=1 | Se=100% | Sp=100% | + | V | |
| | | | AC-VM (n/15 s) structured activities (MI) | AUC=0.98 | Se=90.7% | Sp=92.6% | | | |
| | | | AC-VM (n/15 s) structured activities (VI) | AUC=0.99 | Se=93.8% | Sp=96.3% | | | |
| | | Clanchy | PA intensity levels (SED, LPA, MPA, VPA) (METs) structured activities (II) | $\kappa$=0.73 (SE=−0.08) | | | | | |
| | | Evenson | PA intensity levels (SED, LPA, MPA, VPA) (METs) structured activities (II) | $\kappa$=0.77 (SE=−0.07) | | | | | |
| | | Baque | PA intensity levels (SED, LPA, MPA, VPA) (METs) structured activities (II) | $\kappa$=0.92 (SE=−0.07) | | | | | |

(*continued*)

**Table 4B** (*Continued*)

| Study | Population | | Device-Measured PA | Validity | | | Quality | | |
|---|---|---|---|---|---|---|---|---|---|
| Author(s) YoP | Group specs | Cutoff points/ pred.eq. | | | | | Overall Rating | Risk of Bias | GRADE |
| Clanchy et al[70] | | Freedson | SED≤1.5 (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | -/+ | V | |
| 2011 | | Puyau | SED (METs) structured activities (II) | AUC=0.90, 95% CI, 0.84-0.96 | Se=90.3% | Sp=89.4% | | | |
| | | Treuth | SED (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | | | |
| | | Evenson | SED (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | | | |
| | | Clanchy | SED (METs) structured activities (II) | AUC=0.92, 95% CI, 0.85-0.98 | Se=86.7% | Sp=96.5% | | | |
| | | Freedson | LPA=[1.5, 4] (METs) structured activities (II) | AUC=0.66, 95% CI, 0.58-0.74 | Se=45.3% | Sp=85.7% | | | |
| | | Puyau | LPA (METs) structured activities (II) | AUC=0.68, 95% CI, 0.59-0.77 | Se=63.2% | Sp=73.1% | | | |
| | | Treuth | LPA (METs) structured activities (II) | AUC=0.68, 95% CI, 0.60-0.75 | Se=60.4% | Sp=76.2% | | | |
| | | Evenson | LPA (METs) structured activities (II) | AUC=0.67, 95% CI, 0.58-0.75 | Se=49.1% | Sp=84.1% | | | |
| | | Clanchy | LPA (METs) structured activities (II) | AUC=0.63, 95% CI, 0.56-0.71 | Se=35.9% | Sp=90.5% | | | |
| | | Freedson | MVPA=≥4 (METs) structured activities (II) | AUC=0.75, 95% CI, 0.66-0.83 | Se=81.8% | Sp=67.5% | | | |
| | | Puyau | MVPA (METs) structured activities (II) | AUC=0.75, 95% CI, 0.68-0.83 | Se=59.6% | Sp=91.3% | | | |
| | | Treuth | MVPA (METs) structured activities (II) | AUC=0.73, 95% CI, 0.63-0.82 | Se=66.7% | Sp=78.3% | | | |
| | | Evenson | MVPA (METs) structured activities (II) | AUC=0.91, 95% CI, 0.84-0.97 | Se=81.8% | Sp=100% | | | |
| | | Clanchy | MVPA (METs) structured activities (II) | AUC=0.94, 95% CI, 0.88-0.98 | Se=91.4% | Sp=86.2% | | | |
| Keawutan et al[71] | GMFCS I | Keawutan | AC-VM (n) structured activities (SED) | AUC=0.79, 95% CI, 0.77-081 | Se=74% | Sp=73% | + | D | |
| 2016 | GMFCS II | | AC-VM (n) structured activities (SED) | AUC=0.78, 95% CI, 0.76-0.80 | Se=72% | Sp=73% | | | |
| | GMFCS III | | AC-VM (n) structured activities (SED) | AUC=0.81, 95% CI, 0.79-0.82 | Se=74% | Sp=74% | | | |
| Keawutan et al[71] | GMFCS I | Keawutan | Duration SED (min) structured activities (II) | MD=−13.3%, 95% LoA [−34.0 to 7.4] | Se=78.6% | Sp=84% | ? | | |
| 2016 | | Butte | Duration SED (min) structured activities (II) | MD=−6.2%, 95% LoA [−22.8 to 10.4] | Se=84.1% | Sp=79.6% | | | |
| | GMFCS II | Keawutan | Duration SED (min) structured activities (II) | MD=−15.6%, 95% LoA [−33.5 to 2.3] | Se=78.2% | Sp=86.7% | | | |
| | | Butte | Duration SED (min) structured activities (II) | MD=−10.4%, 95% LoA [−27.2 to 6.4] | Se=81.7% | Sp=83.2% | | | |
| | GMFCS III | Keawutan | Duration SED (min) structured activities (II) | MD=−1%, 95% LoA [−25.6 to 23.7] | Se=72.5% | Sp=76.2% | | | |
| | | Butte | Duration SED (min) structured activities (II) | MD=−2.4%, 95% LoA [−26.8 to 21.9] | Se=71.8% | Sp=77% | | | |
| Oftedal et al[56] | n=39 | Oftedal (VM) | AC-VA (n) structured activities (SED) | AUC=0.77, 95% CI, 0.76-0.78 | Se=71% | Sp=77% | + | D | |
| 2014 | n=18 | | AC-VM (n) structured activities (SED) | AUC=0.81, 95% CI, 0.80-0.82 | Se=75% | Sp=76% | | | |
| Oftedal et al[56] | n=23 | Oftedal (VA) | Duration SED (min) structured activities (II) | MD=−10.5%, 95% LoA [−30.2 to 9.1] | Se=74% | Sp=80% | ? | D | |
| 2014 | n=18 | | Duration SED (min) structured activities (II) | MD=−1.5%, 95% LoA [−20.0 to 16.8 | Se=79% | Sp=72% | | | |
| Ryan et al[73] | | Ryan | AC (n) structured activities (LI) | AUC=0.965, 95% CI, 84.6-99.8 | | | ?/+ | D | |
| 2014 | | | AC (n) structured activities (MVI) | AUC=0.896, 95% CI, 77.4-96.6 | | | | | |
| | | VanHelst | SED (<2) (METs) structured activities (II) | $\kappa$=0.92, 95% CI, 0.82-1.00 | Se=89.5% | Sp=100% | | | |
| | | Ryan | SED (<2) (METs) structured activities (II) | $\kappa$=0.96, 95% CI, 0.89-1.00 | Se=94.7% | Sp=100% | | | |
| | | VanHelst | LPA ([2, 3]) (METs) structured activities (II) | $\kappa$=0.57, 95% CI, 0.38-0.77 | Se=88.9% | Sp=79.6% | | | |
| | | Ryan | LPA (METs) structured activities (II) | $\kappa$=0.71, 95% CI, 0.52-0.90 | Se=83.3% | Sp=89.8% | | | |
| | | Rowlands | MVPA (≥3) (METs) structured activities (II) | $\kappa$=0.69, 95% CI, 0.52-0.86 | Se=70% | Sp=97.3% | | | |
| | | VanHelst | MVPA (METs) structured activities (II) | $\kappa$=0.66, 95% CI, 0.48-0.84 | Se=70% | Sp=94.6% | | | |
| | | Ryan | MVPA (METs) structured activities (II) | $\kappa$=0.79, 95% CI, 0.64-0.94 | Se=86.7% | Sp=91.9% | | | |
| Stephens et al[26] | Actical | Stephens | AC-VM (n) structured activities (SED) | AUC=0.84, 95% CI, 0.78-0.90 | Se=78% | Sp=88% | -/?/+ | V | |
| 2016 | | | AC-VM (n) structured activities (MI) | AUC=0.82, 95% CI, 0.77-0.88 | Se=72% | Sp=75% | | | |
| | | | AC-VM (n) structured activities (VI) | AUC=0.98, 95% CI, 0.96-1.0 | Se=100% | Sp=94% | | | |
| | ActiGraph | Stephens | AC-VA (n) structured activities (SED) | AUC=0.82, 95% CI, 0.74-0.90 | Se=75% | Sp=91% | | | |
| | | | AC-VA (n) structured activities (MI) | AUC=0.78, 95% CI, 0.71-0.86 | Se=86% | Sp=63% | | | |
| | | | AC-VA (n) structured activities (VI) | AUC=0.78, 95% CI, 0.52-1.0 | Se=83% | Sp=79% | | | |
| | Actical | Evenson | SED (n) structured activities (RI) | | Se=72% | Sp=92% | | | |
| | | | MPA (n) structured activities (RI) | | Se=49% | Sp=94% | | | |
| | | | VPA (n) structured activities (RI) | | Se=100% | Sp=92% | | | |
| | ActiGraph | Evenson | SED (n) structured activities (RI) | | Se=75% | Sp=90% | | | |
| | | | MPA (n) structured activities (RI) | | Se=41% | Sp=90% | | | |
| | | | VPA (n) structured activities (RI) | | Se=50% | Sp=95% | | | |
| Stephens et al[26] | Actical | Stephens | AC-VM (n) structured activities (SED) | AUC=0.96, 95% CI, 0.93-0.98 | Se=82% | Sp=97% | -/?/+ | V | |
| 2016 | | | AC-VM (n) structured activities (MI) | AUC=0.89, 95% CI, 0.83-0.94 | Se=82% | Sp=81% | | | |
| | | | AC-VM (n) structured activities (VI) | AUC=0.91, 95% CI, 0.87-0.95 | Se=100% | Sp=90% | | | |
| | ActiGraph | Stephens | AC-VA (n) structured activities (SED) | AUC=0.9, 95% CI, 0.86-0.95 | Se=78% | Sp=91% | | | |
| | | | AC-VA (n) structured activities (MI) | AUC=0.91, 95% CI, 0.85-0.97 | Se=81% | Sp=94% | | | |
| | | | AC-VA (n) structured activities (VI) | AUC=0.92, 95% CI, 0.88-0.96 | Se=100% | Sp=92% | | | |
| | Actical | Evenson | SED (n) structured activities (RI) | | Se=80% | Sp=97% | | | |
| | | | MPA (n) structured activities (RI) | | Se=47% | Sp=96% | | | |
| | | | VPA (n) structured activities (RI) | | Se=0% | Sp=96% | | | |
| | ActiGraph | Evenson | SED (n) structured activities (RI) | | Se=75% | Sp=91% | | | |
| | | | MPA (n) structured activities (RI) | | Se=81% | Sp=90% | | | |
| | | | VPA (n) structured activities (RI) | | Se=0% | Sp=92% | | | |
| Trost et al[24] | | Evenson | SED (<1.5) (METs) structured activities (II) | AUC=0.93, 95% CI, 0.91-0.96 | Se=98.9% | Sp=87.6% | -/+ | V | |
| 2016 | | Clanchy | SED (METs) structured activities (II) | AUC=0.93, 95% CI, 0.91-0.96 | Se=98.9% | Sp=87.6% | | | |
| | | Trost (VA) | SED (METs) structured activities (II) | AUC=0.97, 95% CI, 0.95-0.99 | Se=97.9% | Sp=96.1% | | | |
| | | Trost (VM) | SED (METs) structured activities (II) | AUC=0.96, 95% CI, 0.94-0.99 | Se=96.9% | Sp=96.1% | | | |
| | | Evenson | LPA ([1.5, 3]) (METs) structured activities (II) | AUC=0.68, 95% CI, 0.63-0.73 | Se=61.5% | Sp=74.6% | | | |
| | | Clanchy | LPA (METs) structured activities (II) | AUC=0.68, 95% CI, 0.62-0.73 | Se=58.1% | Sp=77.1% | | | |
| | | Trost (VA) | LPA (METs) structured activities (II) | AUC=0.82, 95% CI, 0.77-0.86 | Se=77.8% | Sp=86.4% | | | |
| | | Trost (VM) | LPA (METs) structured activities (II) | AUC=0.8, 95% CI, 0.76-0.85 | Se=72.7% | Sp=87.8% | | | |
| | | Evenson | MVPA (≥3) (METs) structured activities (II) | AUC=0.75, 95% CI, 0.71-0.80 | Se=57.1% | Sp=93.4% | | | |
| | | Clanchy | MVPA (METs) structured activities (II) | AUC=0.76, 95% CI, 0.72-0.81 | Se=61.4% | Sp=91.6% | | | |
| | | Trost (VA) | MVPA (METs) structured activities (II) | AUC=0.86, 95% CI, 0.82-0.89 | Se=78.6% | Sp=92.5% | | | |
| | | Trost (VM) | MVPA (METs) structured activities (II) | AUC=0.86, 95% CI, 0.82-0.89 | Se=81.4% | Sp=89.7% | | | |

(*continued*)

**Table 4B** (*Continued*)

| Study | Population | | Device-Measured PA | Validity | | | Quality | | |
|---|---|---|---|---|---|---|---|---|---|
| Author(s) YoP | Group specs | Cutoff points/ pred.eq. | | | | | Overall Rating | Risk of Bias | GRADE |
| Xing et al[18] | | Puyau (VA) | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *rs*=0.84 | $\kappa$=0.458 | | + | V | |
| 2021 | | Evenson | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *rs*=0.888 | $\kappa$=0.585 | | | | |
| | | Romanzini (VA) | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *rs*=0.886 | $\kappa$=0.56 | | | | |
| | | Romanzini (VM) | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *rs*=0.886 | $\kappa$=0.675 | | | | |
| | | Clanchy | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *rs*=0.935 | $\kappa$=0.721 | | | | |
| | | Baque | PA intensity levels (SED, LPA, MVPA) (METs) structured activities (II) | *rs*=0.896 | $\kappa$=0.773 | | | | |
| Convergent validity | | | | | | | | | ⊕⊕⊕ |
| Kuo et al[55] | AMP | | Distance continuous walking | MD=−4.8 m, 95% LoA (-20.1 to 10.5) | | | ? | D | |
| 2009 | Minimod | | Distance continuous walking | MD=−0.4 m, 95% LoA (-4.7 to 4.0) | | | | | |
| | AMP | | Distance intermittent walking | MD=−3.6 m, 95% LoA (-19.2 to 12.0) | | | | | |
| | Minimod | | Distance intermittent walking | MD=−2.3 m, 95% LoA (-27.9 to 23.3) | | | | | |
| | AMP | | Distance downstair climbing | MD=−1.3 m, SD -2.5 | | | | | |
| | Minimod | | Distance downstair climbing | MD=8.9 m, SD -2.5 | | | | | |
| | AMP | | Distance upstair climbing | MD=−2 m, SD -2.5 | | | | | |
| | Minimod | | Distance upstair climbing | MD=3.3 m, SD −2.2 | | | | | |
| Lawal et al[21] | ActiGraph GT3X | | Steps (n) walking | ICC=0.29, 95% CI, −0.42 to 0.78 | | | - | D | |
| 2020 | LFE-ActiGraph GT3X | | Steps (n) walking | ICC=0.52, 95% CI, −0.16 to 0.87 | | | | | |
| Mackey et al[66] | | | Duration (min) lying | | Se=100% | Sp=100% | ? | D | |
| 2009 | | | Duration (min) sitting | | Se=100% | Sp=100% | | | |
| | | | Duration (min) standing | | Se=100% | Sp=97% | | | |
| | n=12 for stair climbing | | Duration (min) walking (overground and stairs) | | Se=78.5% | Sp=100% | | | |
| Sala et al[74] | Hip (n=38) | | Steps walking | MAE=7 steps, range=−52 to 6 | *r*=0.991 | | -/+ | D | |
| 2019 | | | Distance walking | MAE=0.07 miles, range=0.01 to 0.16 | | | | | |
| | GMFCS I+II (n=27) | | Steps walking | MAE=6 steps, range=−20 to 6 | *r*=0.998 | | | | |
| | | | Distance walking | MAE=0.07 miles, range=0.01 to 0.16 | | | | | |
| | GMFCS III (n=11) | | Steps walking | MAE=12 steps, range=−52 to 1 | *r*=0.981 | | | | |
| | | | Distance walking | MAE=0.07 miles, range=0.02 to 0.14 | | | | | |
| | Wrist (n=38) | | Steps walking | MAE=88 steps, range=−484 to 35 | r=−0.033 | | | | |
| | | | Distance walking | MAE=0.06 miles, range=−0.13 to 0.16 | | | | | |
| | GMFCS I+II (n=27) | | Steps walking | MAE=27 steps, range=−177 to 23 | *r*=0.837 | | | | |
| | | | Distance walking | MAE=0.04 miles, range=−0.02 to 0.16 | | | | | |
| | GMFCS III (n=11) | | Steps walking | MAE=238 steps, range=−484 to 35 | r=−0.242 | | | | |
| | | | Distance walking | MAE=0.08 miles, range=−0.13 to 0.11 | | | | | |

Abbreviations: "?", indeterminate; "-", insufficient; "+", sufficient; "⊕⊕⊕", moderate; AC, activity counts; AUC, area under the curve; D, doubtful; EE, energy expenditure; GRADE, Grading of Recommendations Assessment, Development and Evaluation; HR, heart rate; HRAR, heart rate above rest; HRAS, heart rate above sleep; HS, hemiparetic side; I, inadequate; II, increased intensity; LNI, least neurological impaired; LoA, levels of agreement; LPA, low physical activity; MAE, mean absolute error; MD, mean difference; MET, metabolic equivalent of task; MI, moderate intensity; MPA, moderate physical activity; MVI, moderate-to-vigorous; n, number; NA, not applicable; NHS, nonhemiparetic side; NI, neurological impaired; pred, prediction; *r*, Pearson correlation coefficient; $R^2$, coefficient of determination; RI, random intensity; *rs*, Spearman rank correlation coefficient; Se, sensitivity; SED, sedentary; Sp, specificity; V, very good; VA, vertical axis; VI, vigorous intensity; VM, vector magnitude; VPA, vigorous physical activity; YoP, year of publication; $\kappa$, Cohen's kappa.

GMFCS level, age difference, physical behavior type, and placement were non-significant moderators (see appendix 2).

For criterion validity based on cutoff points, moderator analysis showed that physical behavior class and age were statistically significant in cutoff point based methods with a high correlation with $r_+$=0.76 (95% CI, 0.62-0.89) for sedentary behavior, $r_+$=0.47 (95% CI, 0.29-0.65) for light PA, and $r_+$=0.61 (95% CI, 0.47-0.76) for MVPA. Children ≥13 years old showed a very high correlation with $r_+$=0.91 (95% CI, 0.79-1.00), compared with children <13 years of age with a moderate correlation of $r_+$=0.61 (95% CI, 0.54-0.68). PA dimensions, percentage GMFCS level, age <6 years or >6 years, and cutoff points based on a specific population or general were nonsignificant moderators (see appendix 2).

## Grading the pooled evidence

The quality of evidence of all psychometric properties was moderate.

## Publication bias

Funnel plots, *p*-curve analysis, year of publication as analysis as a moderator, and outlier identification reveal no substantial evidence of publication bias. Notably, recent studies on cutoff point based criterion validity exhibit a larger effect size (slope, 0.03; 95% CI, 0.01-0.07; $F[1,22]$ =4.56; $P$<.04). Simulation detected outliers for interdevice reliability (observed simulation outliers, 0.50). However, there was no significant difference between the observed and simulated data ($P$=.14), indicating no anticipated impact on the overall effect size. Additionally, corrected effect sizes were computed ($ICC_{test\text{-}retest\ reliability}$=0.76; 95% CI, 0.61-0.91; $ICC_{interdevice\ reliability}$=analysis not possible; $r_{construct\ validity}$=0.34; 95% CI, −0.09 to 0.78; $r_{criterion\ validity}$=0.49; 95% CI, 0.27-0.72; $r_{criterion\ validity\ cutoff\ point\ based\ methods}$=0.59; 95% CI, 0.18-0.99), considering the assumption that confirmatory findings are 5 times more likely to be published than nonconfirmatory findings.

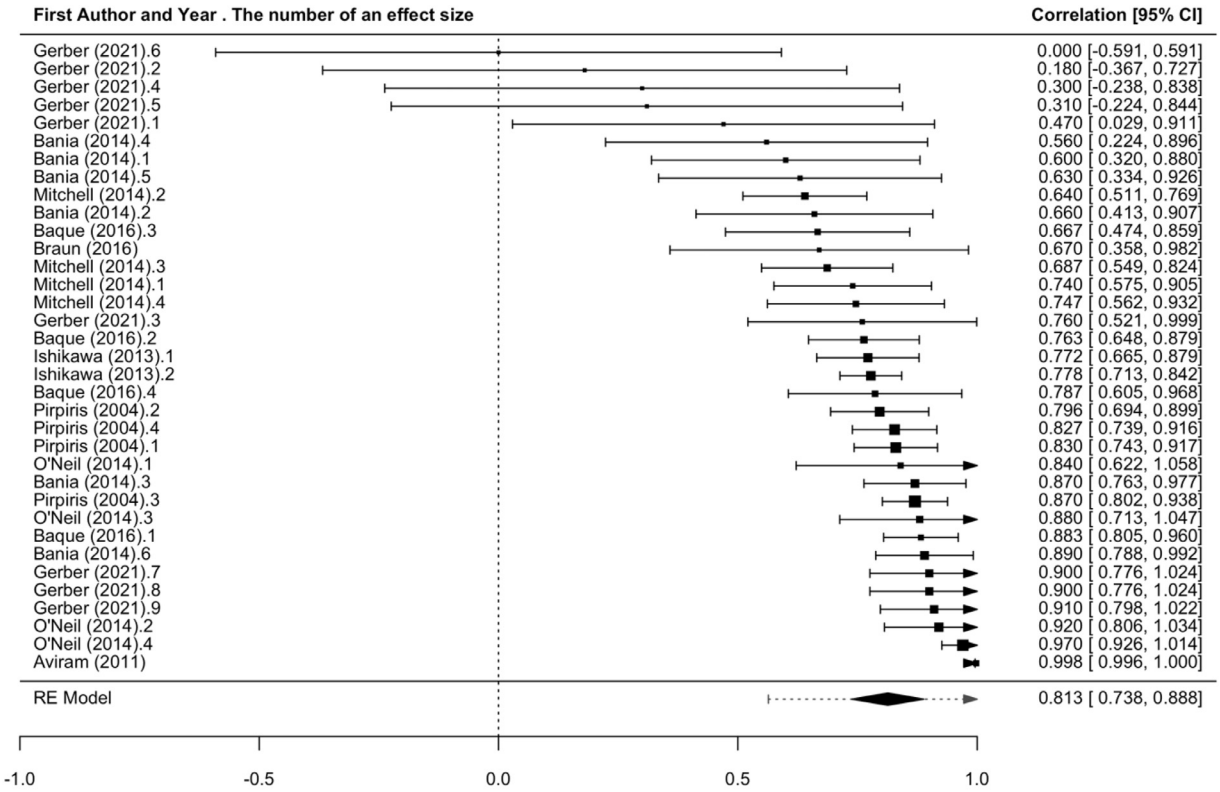


**Fig 2** Forest plot for test-retest reliability. RE, Random Effects Model.

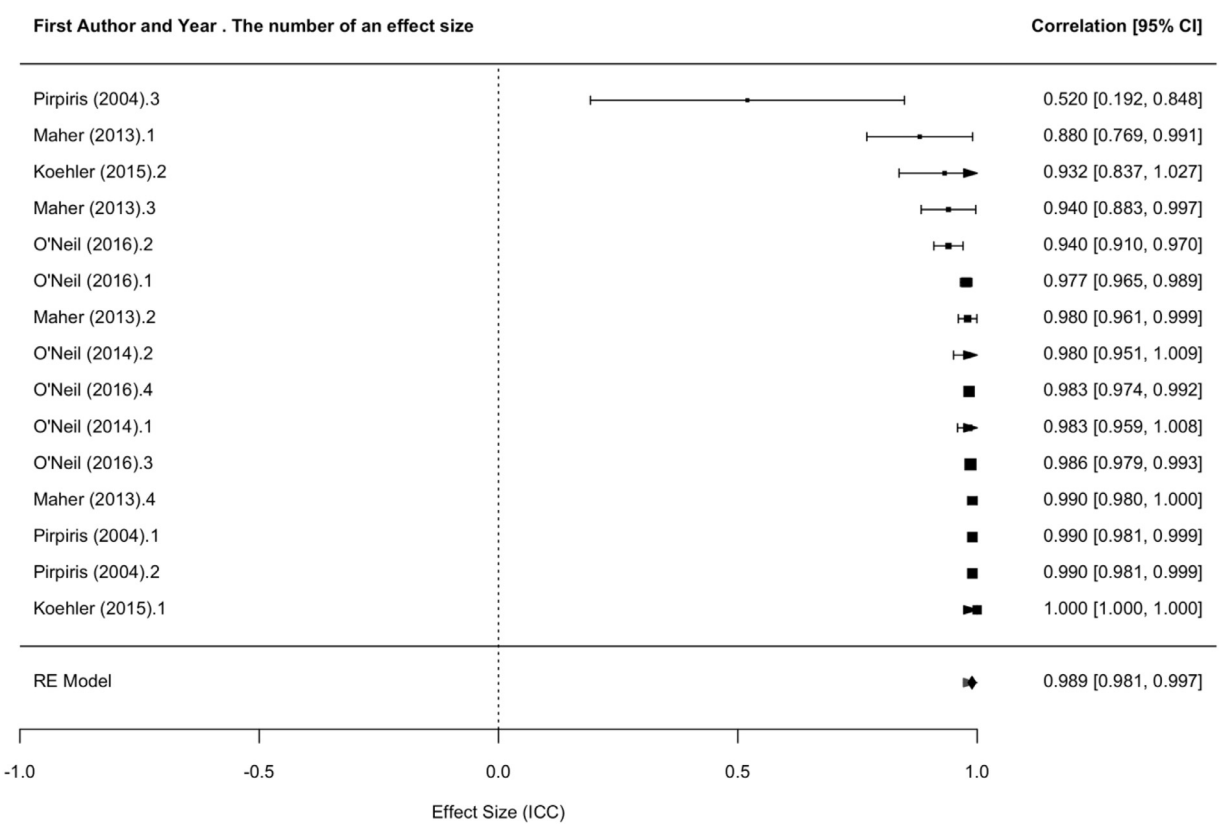


**Fig 3** Forest plot for inter-device reliability. RE, Random Effects Model.

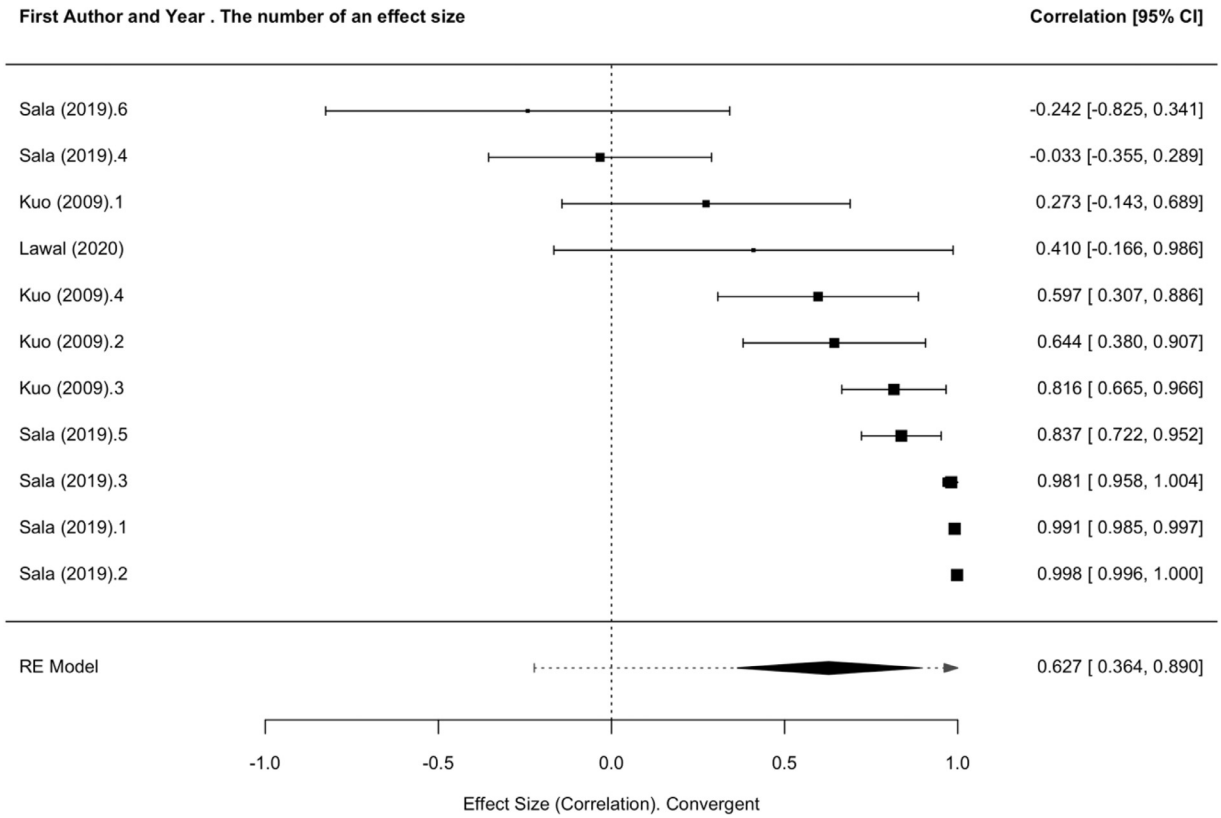


**Fig 4** Forest plot for construct validity. RE, Random Effects Model.

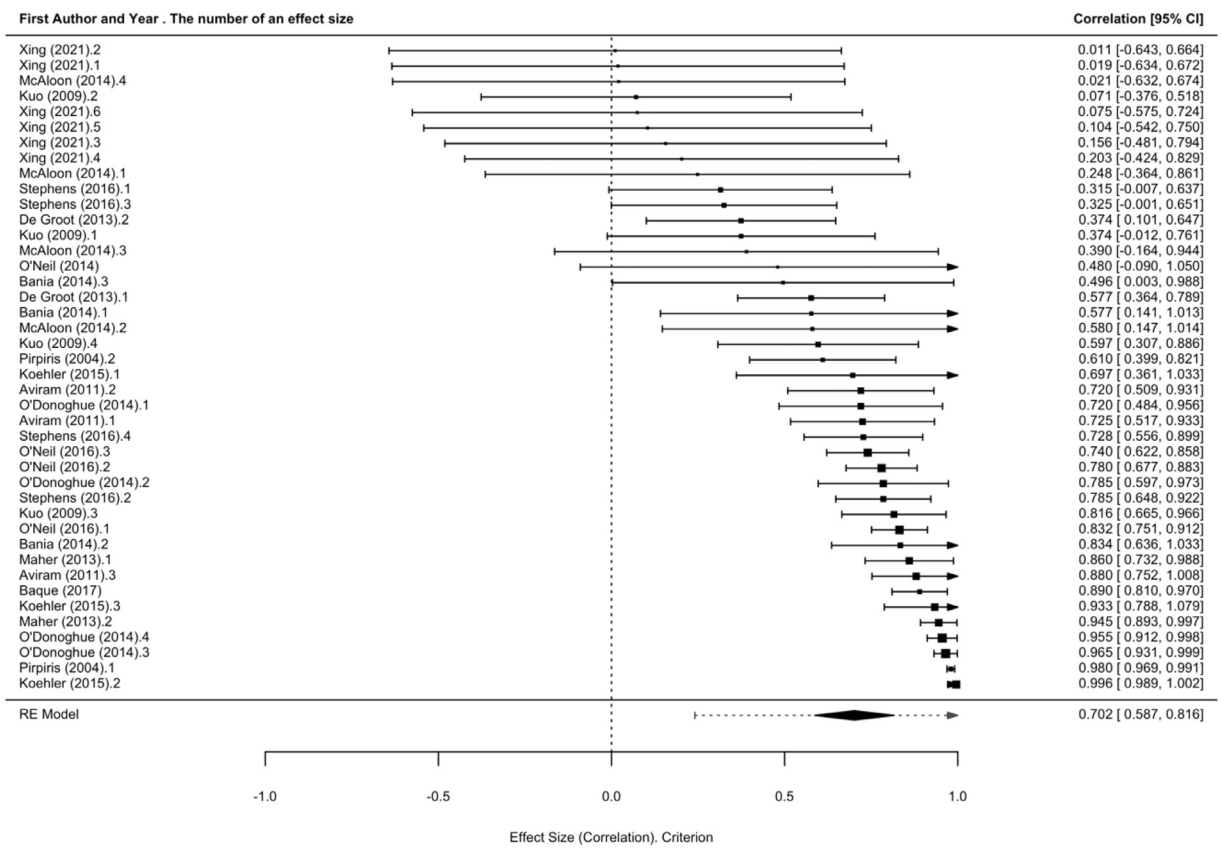


**Fig 5** Forest plot for criterion validity. RE, Random Effects Model.

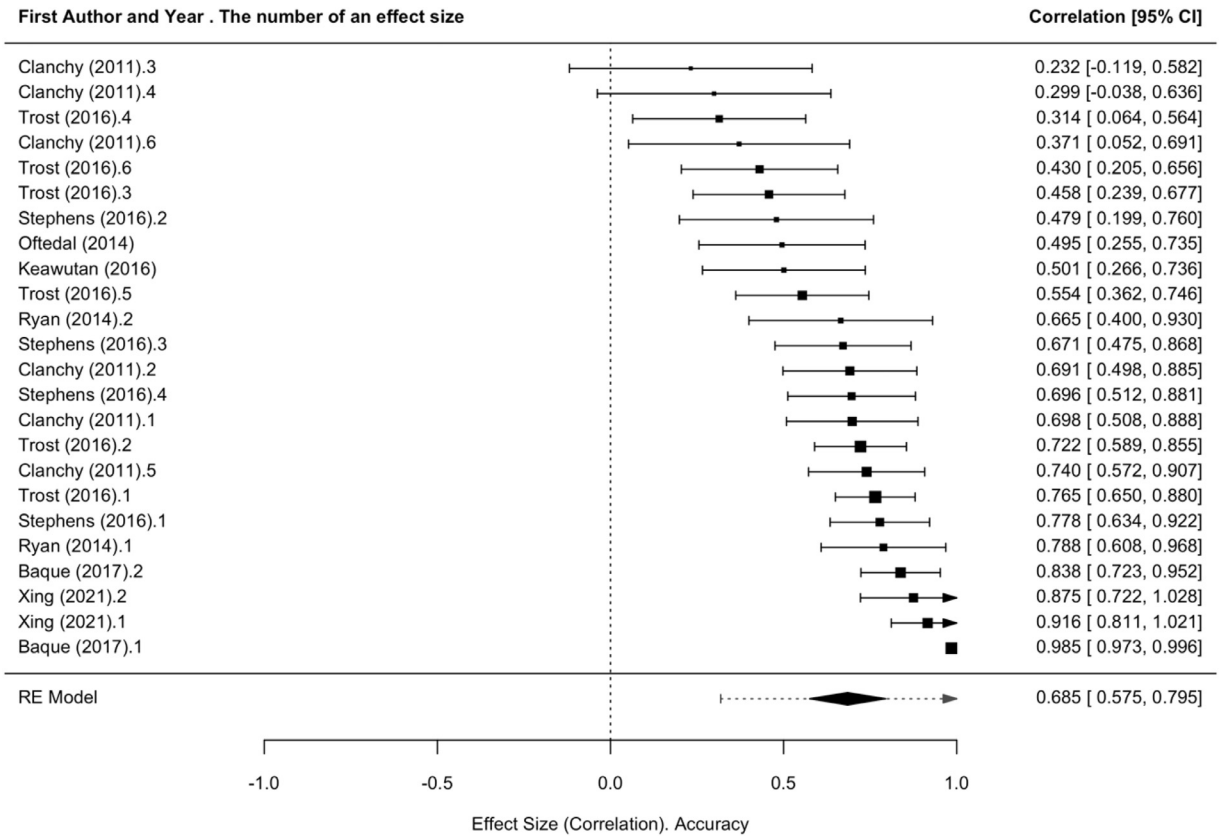


**Fig 6** Forest plot for criterion validity based on cutoff points. RE, Random Effects Model.

## Discussion

Our systematic review represents a multilevel meta-analysis appraising, comparing, summarizing, and generalizing levels of reliability and validity of instruments for wearables measuring PA in ambulatory children with gait abnormalities due to neuromuscular conditions. The meta-analysis of 26 studies showed high to very high reliability and moderate to high validity of wearables measuring PA. Despite the heterogeneous quality of the studies (risk of bias), the overall quality of evidence (Grading of Recommendations Assessment, Development and Evaluation) of reliability studies, and the quality of validity studies, was moderate. Significant moderators for test-retest reliability were PA setting (laboratory vs free-living setting), PA dimensions (frequency, intensity, duration), and specified physical behavior type (walking, lying and sitting, standing). For inter-device reliability, PA dimensions (frequency, intensity, duration), and age (<13y, >13y) were statistically significant moderators. Specified physical behavior type (running, lying and sitting, standing, walking) was a significant moderator for criterion validity, whereas criterion validity based on cutoff points was affected by physical behavior class (sedentary, low PA, MVPA), as well as age (<13y, >13y). Levels of measurement error could not be compared or summarized because of heterogeneity in outcome measures.

### Practical implications

Most studies were conducted in laboratory settings. For test-retest reliability, we differentiated between laboratory and free-living settings. Studies conducted in laboratories showed higher test-retest reliability than those conducted in free-living settings. Similar findings from other reviews on wearables in children without disabilities highlight a lack of free-living validations with child-specific movements in their protocols.[13,80] Future research should prioritize validating wearables in free-living settings, incorporating child-specific movements to improve clinical relevance. This will enable clinicians to analyze better and interpret results in daily practice.

Interestingly, correlation for free-living setting for reliability is still high, indicating that wearables measuring PA in children with gait abnormalities shows consistent scores over time. We understand that the measurement error in free-living settings is higher than in laboratory settings because children are more prone to factors of physical environment, social environment and personal factors, influencing their level of PA.[81] To estimate the true change of a patient when assessed in repeated measurements, a clinician also needs to know information about the measurement error. Unfortunately, we were not able to comprehensively summarize the measurement error reported in the studies found, as there was a broad variability in calculating and reporting measurement error.[28] Consequently, the interpretation of the individual study findings regarding measurement error must be situated within the context of each individual study and cannot be generalized for children with abnormal walking patterns.

In our study, we did not find a moderating effect of the percentage of GMFCS level I on the psychometric properties,

and therefore, we cannot draw conclusions about the accuracy of wearable devices measuring PA related to increasing gait abnormalities, based on the pooled results of our study. We defined the moderator as percentage of GMFCS level I, as many studies did not report the contrast between levels I, II, and III. In individual studies, there is evidence that SDs in step counts are higher in children with GMFCS III compared with GMFCS I because of higher energy cost and variability in increasing abnormal gait.[17,64] A reason for higher misclassification in children with a GMFCS level III may be that they use functional walking aids such as crutches or walkers, which can influence the accuracy of a device.[74]

The moderator of age (>13y of age or younger) was only significant in cutoff point based validity: older children reached higher correlations than younger children. This finding has consequences for clinical assessment and treatment as accuracy drops to a moderate level in children younger than 13 years, which induces more uncertainty about the actual level of PA. Given that children younger than 13 years tend to be more physically active, both age and higher activity levels serve as moderators that adversely affect cutoff point based criterion validity. More research in younger children is needed for a better understanding of their levels of PA.[5] This is especially true since the age-related decrease in PA and increased sedentary time seems to become apparent at 6-7 years of age.[4] We are aware that walking may be delayed in children with disabilities, and therefore, the age of 2 is the first age of inclusion with possible PA measurements of gait pattern.

For test-retest reliability, steps and PA counts (frequency) showed very high correlations and energy expenditure rate (intensity) and duration were correlated highly. Among physical behavior types, duration has a negative impact on test-retest reliability compared with frequency and intensity. Duration differs statistically from frequency and intensity, implying that clinicians might have the most optimal assessment when measuring frequency (PA counts) or intensity (energy expenditure rate). The high to very high values of test-retest reliability imply that the clinician should use devices to measure PA in children with abnormal gait as robust tools when repeating an assessment.

When comparing the same devices worn at the same time on different locations, for example, right and left hip, correlations were very high for intensity (energy expenditure rate). This trend was consistent across measures of intensity (energy expenditure rate), frequency (steps, PA counts), as well as duration (seconds, minutes of PA). Those findings show that the devices are suitable for repeated measures and robust in construct.

The specified physical behavior type (running, lying and sitting, standing, walking) was a significant moderator. When interested in step counts and supporting children to increase their daily walking time, clinicians can use devices that are validated well for step counts. If clinicians are more interested in intensity levels of PA, they have to get familiar with devices that can distinguish between physical behavior classes as sedentary, low PA, or MVPA. Cutoff point based methods try to shed light into the best algorithms to provide valid assessments. Physical behavior class was a statistically significant moderator for cutoff point based methods with a low correlation for sedentary activities. Sedentary behavior, as measured by lying or sitting, shows statistical differences from walking and running. This indicates that cutoff point based criterion validity is higher during activities as walking or running, indicating that cutoff points may positively impact the validity for sedentary behavior. Our finding is contrary to Lynch et al,[82] who assessed the accuracy of accelerometers for measuring PA and levels of sedentary behavior in children in 11 studies: accuracy appeared to be highest when detecting sedentary activities and least with low PA. Based on our findings we believe that cutoff point based values can be used best to distinguish between sedentary and active behavior in children with abnormal gait.

To the best of our knowledge, this systematic review represents the first multilevel meta-analysis appraising, comparing, summarizing, and generalizing the levels of reliability and validity of instruments for wearable devices measuring PA in children with gait abnormalities due to neuromuscular conditions. A notable strength of our research is the predetermined and Prospective Register for Systematic Reviews—registered methodology, which aligns with COSMIN guidelines. Through this meta-analysis, we overcame the influence of small samples (n<100) in determining the evidence of effect size, a common limitation in systematic literature reviews on the measurement properties of wearable PA instruments. In addition, our meta-analysis enabled us to analyze the effects of publication bias, for which we found no substantial evidence. We suppose that the analysis techniques used will be future solutions for pooling and analyzing data. When grading the level of evidence with COSMIN guidelines, publication bias is not taken into account because it is difficult to assess studies on measurement properties because of a lack of registries for these types of studies.[28]

As there is a literature gap about wearables measuring PA and surveys of parents in children under 5 years of age,[5] this review makes an important contribution given its inclusion of studies of children with a mean age of 2.3 years and could not find a moderating effect of children younger than 6 years on wearable devices measuring PA.

## Study limitations

A limitation is the generalizability of the results to all children with abnormal gait. Our research question was narrow, targeting children with gait abnormality due to neuromuscular conditions and therefore excluding children who use a wheelchair and children with conditions other than neuromuscular etiology. Most studies (71%) focused on children with CP, similar to a previous review about activity instruments in children with physical disabilities, which also found 64% of studies focusing on CP.[10] This aligns with the higher global prevalence of CP[83] compared with, for example, muscular dystrophies[84] or neural tube defects,[85] and therefore reflects a realistic proportion in pediatric rehabilitation.

In our study, we analyzed reliability and validity and did not assess responsiveness ("longitudinal validity"), which is important as it refers to the ability of a measurement instrument to detect change over time in the construct to be measured.[28,86] Responsiveness was included in the search strategy and screening, but we did not find studies assessing responsiveness in children with abnormal gait. We assume that research is still concentrating on reliability and validity

studies in this group of children before focusing on responsiveness.

For construct validity, results should be interpreted cautiously because of the low number of studies (n=3) included. Measuring PA in children with gait abnormalities with other than criterion standard reference methods is prone to errors. Therefore, better instruments should be developed to catch the construct they are supposed to assess. Nonetheless, Sala et al[74] provide the clinician with important knowledge: they assessed children with CP with a wrist-based and hip-based activity monitor (AM) to investigate the number of steps and distance walked. The number of steps detected by a wearable device showed a very low correlation with steps registered with a tally counter ($r$=−0.03). This correlation is based on the placement of the device (wrist), while 11 of 13 children walked with crutches and posterior walkers, which affected the natural sway of the arm.[74] Although wrist-worn wearables may be better accepted among children, they seem to be unable to detect steps when using walking aids. With this important finding, we urge clinicians to consider the intended outcome and target population of interest when choosing suitable wearables. Unfortunately, based on this systematic review, the best placement of a device remains unclear, as moderator analyses were statistically nonsignificant.

The WHO recently stated that there is insufficient device-measured data assessing PA in children with a disability,[5] which may result in insufficient action from policymakers because there is no factual problem.[3] Wearables used by clinicians to measure PA are essential in diagnostics and individually tailored treatment of functional (dis)ability in children with neuromuscular conditions with consequent abnormal gait. With more evidence that children with a developmental disability show lower levels of PA than typically developing peers, we can elucidate the problem and apply for structural support from policymakers.

## Conclusions

There is high to very high reliability for wearable devices measuring instruments in children with abnormal gait, and moderate to high validity in children with primarily neurological conditions. The use of wearables in clinical practice can support a clinician's clinical reasoning process and help assess tailored PA interventions. Clinicians should be aware that several moderators, for example, setting of measurement (laboratory, free-living), dimensions (frequency, intensity, duration), specified physical behavior type (walking, lying and sitting, running, standing), physical behavior class (sedentary, low PA, MVPA), or age can influence an assessment. As we found barely any studies that were conducted in free-living settings, we encourage researchers to conduct psychometric studies of devices measuring PA in more functional, free-living environments and include child-specific variability of movements. We advise researchers to report their methodology clearly and provide access to raw data, which can be used for pooling.

## Suppliers

a. Covidence systematic review software, Veritas Health Innovation.
b. Rayyan software for systematic reviews, Rayyan.

## Corresponding author

Manon A.T. Bloemen, PhD, HU University of Applied Sciences Utrecht, Heidelberglaan 7, 3584 CJ Utrecht, The Netherlands. *E-mail address:* manon.bloemen@hu.nl.

## Disclosure

Supported by Foundation Innovation Alliance-Regional Attention and Action for Knowledge Circulation (SIA Raak. MKB12.002).

## Acknowledgments

We thank data stewards Jurgen Mollema (passed away) and Tale Evenhuis for their enthusiastic support setting up and conducting the search strategy.

## Appendix 1 Meta-analysis Results

Tables 1–5

**Table 1** Meta-analysis results for test-retest reliability.

| Model (k) | ICC (SE) | 95% CI LB | 95% CI UB | $t$ ($df$) | $P$ | $Q$ | $P$ | $I^2$ |
|---|---|---|---|---|---|---|---|---|
| Random-effects (35)* | 0.813 (0.037) | 0.738 | 0.888 | 22.010 (34) | <.001 | 320.262 | <.001 | 88.574 |
| Random-effects (35)† | 0.807 (0.021) | 0.765 | 0.849 | 38.902 (34) | <.001 | | | 0.001 |
| Random-effects (35)‡ | 0.813 (0.037) | 0.738 | 0.888 | 22.010 (34) | <.001 | | | 88.573 |

Abbreviations: LB, lower bound; UB, upper bound.
* The multilevel model that accounted for the within and between-study variance.
† A model that accounted for the within-study variance only (level 2 only).
‡ A model that accounted for the between-study variance (level 3 only).

**Table 2** Meta-analysis results for interdevice reliability.

| Model (k) | ICC (SE) | 95% CI LB | 95% CI UB | *t* (*df*) | *P* | i | *P* | $I^2$ |
|---|---|---|---|---|---|---|---|---|
| Random-effects (15)* | 0.989 (0.004) | 0.981 | 0.997 | 261.809 (14) | <.001 | 96.876 | <.001 | 71.014 |
| Random-effects (13)† | 0.985 (0.003) | 0.978 | 0.992 | 307.124 (14) | <.001 | | | 0.001 |
| Random-effects (13)‡ | 0.989 (0.004) | 0.981 | 0.997 | 261.809 (14) | <.001 | | | 71.013 |

Abbreviations: LB, lower bound; UB, upper bound.
* The multilevel model that accounted for the within and between-study variance.
† A model that accounted for the within-study variance only (level 2 only).
‡ A model that accounted for the between-study variance (level 3 only).

**Table 3** Meta-analysis results for construct validity.

| Model (k) | *r* (SE) | 95% CI LB | 95% CI UB | *t* (*df*) | *P* | *Q* | *P* | $I^2$ |
|---|---|---|---|---|---|---|---|---|
| Random-effects (11)* | 0.627 (0.118) | 0.364 | 0.890 | 5.311 (10) | <.001 | 106.882 | <.001 | 99.967 |
| Random-effects (11)† | 0.627 (0.118) | 0.364 | 0.890 | 5.331 (10) | <.001 | | | 99.966 |
| Random-effects (11)‡ | 0.788 (0.144) | 0.467 | 1.110 | 5.463 (10) | <.001 | | | 0.001 |

Abbreviations: LB, lower bound; UB, upper bound.
* The multilevel model that accounted for the within and between-study variance.
† A model that accounted for the within-study variance only (level 2 only).
‡ A model that accounted for the between-study variance (level 3 only)

**Table 4** Meta-analysis results for criterion validity.

| Model (k) | *r* (SE) | 95% CI LB | 95% CI UB | *t* (*df*) | *P* | *Q* | *P* | $I^2$ |
|---|---|---|---|---|---|---|---|---|
| Random-effects (42)* | 0.702 (0.057) | 0.587 | 0.816 | 12.373 (41) | <.001 | 308.638 | <.001 | 98.703 |
| Random-effects (42)† | 0.689 (0.038) | 0.612 | 0.766 | 18.084 (41) | <.001 | | | 19.443 |
| Random-effects (42)‡ | 0.732 (0.057) | 0.617 | 0.848 | 12.805 (41) | <.001 | | | 79.261 |

Abbreviations: LB, lower bound; UB, upper bound.
* The multilevel model that accounted for the within and between-study variance.
† A model that accounted for the within-study variance only (level 2 only).
‡ A model that accounted for the between-study variance (level 3 only).

**Table 5** Meta-analysis results for criterion validity of cutoff point based methods.

| Model (k) | *r* (SE) | 95% CI LB | 95% CI UB | *t* (*df*) | *P* | *Q* | *P* | $I^2$ |
|---|---|---|---|---|---|---|---|---|
| Random-effects (24)* | 0.685 (0.053) | 0.575 | 0.795 | 12.905 (23) | <.001 | 266.948 | <.001 | 87.021 |
| Random-effects (24)† | 0.657 (0.041) | 0.573 | 0.741 | 16.215 (23) | <.001 | | | 44.629 |
| Random-effects (24)‡ | 0.717 (0.055) | 0.603 | 0.831 | 12.973 (23) | <.001 | | | 42.392 |

Abbreviations: LB, lower bound; UB, upper bound.
* The multilevel model that accounted for the within and between-study variance.
† A model that accounted for the within-study variance only (level 2 only).
‡ A model that accounted for the between-study variance (level 3 only).

## Appendix 2: Moderator Analysis

Tables 1–5

**Table 1** Moderator analysis test-retest reliability.

| Test-Retest Reliability | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | |
| Moderator (k) | ICC (SE)/ Slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ |
| PA domain (33) | | | | 19.739 | <.001 | 5.630 (1, 33) | .024 | 0.302 | 82.39%/0.01%/82.38% |
| Laboratory | 0.915 (0.050) | 0.814 | 1.016 | 18.359 | <.001 | | | | |
| Community | 0.767 (0.037) | 0.692 | 0.843 | 20.690 | <.001 | | | | |
| PA dimension (35) | | | | | | 5.922 (2, 32) | .007 | 0.388 | 86.72%/0.01%/86.71% |
| Frequency* | 0.998 (0.108) | 0.779 | 1.217 | 9.284 | <.001 | | | | |
| Intensity† | 0.876 (0.045) | 0.783 | 0.968 | 19.268 | <.001 | | | | |
| Duration*,† | 0.713 (0.046) | 0.620 | 0.806 | 15.632 | <.001 | | | | |
| PB type specified (22) | | | | | | 3.934 (2, 19) | .004 | 0.270 | 89.44%/6.83%/82.61% |
| Lying and sitting‡ | 0.727 (0.079) | 0.562 | 0.893 | 9.217 | <.001 | | | | |
| Standing§ | 0.704 (0.081) | 0.533 | 0.874 | 8.645 | <.001 | | | | |
| Walking‡,§ | 0.872 (0.053) | 0.760 | 0.984 | 16.318 | <.001 | | | | |
| PB type (41) | | | | | | 0.492 (1, 27) | .489 | 0.053 | 89.87%/0.01%/89.86% |
| Single | 0.852 (0.049) | 0.751 | 0.952 | 17.412 | <.001 | | | | |
| Multi | 0.786 (0.080) | 0.622 | 0.950 | 9.858 | <.001 | | | | |
| % GMFCS level I (35) | −0.001 (0.003) | −0.007 | 0.004 | −0.526 | .602 | 0.277 (1, 33) | .602 | 0.039 | 89.57%/0.01%/89.56% |
| Placement (33) | | | | | | 0.072 (2, 32) | .930 | 0.016 | 90.61%/0.01%/90.60% |
| Leg | 0.796 (0.072) | 0.649 | 0.943 | 11.016 | <.001 | | | | |
| Trunk | 0.807 (0.062) | 0.680 | 0.934 | 12.951 | <.001 | | | | |
| Multi | 0.836 (0.081) | 0.672 | 1.000 | 10.382 | <.001 | | | | |
| Age (35) | | | | | | 0.599 (1, 31) | .445 | 0.059 | 88.83%/0.01%/88.82% |
| <13 y | 0.811 (0.038) | 0.734 | 0.888 | 21.410 | <.001 | | | | |
| >13 y | 0.880 (0.081) | 0.714 | 1.047 | 10.810 | <.001 | | | | |
| Time interval test-retest (33) | | | | | | 0.410 (1, 33) | .527 | 0.050 | 89.55%/0.01%/89.54% |
| <2 wk | 0.801 (0.042) | 0.714 | 0.887 | 18.742 | <.001 | | | | |
| >2 wk | 0.864 (0.090) | 0.681 | 1.048 | 9.564 | <.001 | | | | |

Abbreviations: LB, lower bound; PB, physical behavior; $R^2$, coefficient of determination; UB, upper bound.
*,†,‡,§ Differences between effect sizes are statistically significant.

**Table 2** Moderator analyses and publication bias for inter reliability.

| Inter-Device Reliability | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | |
| Moderator (k) | ICC (SE)/slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ |
| PA domain (15) | | | | | | 0.010 (1, 13) | .921 | 0.003 | 76.97%/0.01%/76.96% |
| Laboratory | 0.989 (0.005) | 0.978 | 0.999 | 203.151 | <.001 | | | | |
| Community | 0.990 (0.009) | 0.970 | 1.010 | 203.151 | <.001 | | | | |
| PA dimensions (15) | | | | | | 35.070 (2, 12) | .001 | — | —/—/— |
| Frequency* | 0.983 (0.002) | 0.979 | 0.988 | 456.832 | <.001 | | | | |
| Intensity*,† | 1.000 (0.000) | 1.000 | 1.000 | 14998.97 | <.001 | | | | |
| Duration† | 0.990 (0.003) | 0.983 | 0.997 | 306.675 | <.001 | | | | |
| PB type specified (8) | | | | | | 3.003 (2, 5) | .139 | 0.435 | 93.51%/0.01%/93.50% |
| Lying and sitting | 1.000 (0.025) | 0.942 | 1.071 | 40.256 | <.001 | | | | |
| Walking | 0.957 (0.022) | 0.901 | 1.013 | 44.132 | <.001 | | | | |
| Running | 1.000 (0.023) | 0.945 | 1.063 | 43.948 | <.001 | | | | |

(*continued*)

**Table 2** (*Continued*)

| Inter-Device Reliability | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | |
| Moderator (k) | ICC (SE)/slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ |
| Placement (14) | | | | | | 2.207 (2, 11) | .156 | 0.197 | 93.73%/0.01%/93.72% |
| Leg | 0.989 (0.009) | 0.969 | 1.010 | 108.275 | <.001 | | | | |
| Trunk | 0.997 (0.009) | 0.977 | 1.017 | 108.032 | <.001 | | | | |
| Arm | 0.973 (0.013) | 0.945 | 1.001 | 76.573 | <.001 | | | | |
| Age (15) | | | | | | 15.709 (1, 13) | .002 | 0.828 | 24.28%/0.01%/24.27% |
| <13 y | 0.986 (0.002) | 0.981 | 0.991 | 415.326 | <.001 | | | | |
| ≥13 y | 1.000 (0.003) | 0.994 | 1.006 | 372.703 | <.001 | | | | |
| Placement body side (15) | | | | | | 0.018 (1, 13) | .897 | 0.002 | 73.63%/8.42%/65.21% |
| Same | 0.988 (0.006) | 0.976 | 1.000 | 173.089 | <.001 | | | | |
| Opposite | 0.989 (0.004) | 0.980 | 0.998 | 228.930 | <.001 | | | | |

Abbreviations: LB, lower bound; PB, physical behavior; $R^2$, coefficient of determination; UB, upper bound.
[*,†] Differences between effect sizes are statistically significant.

**Table 3** Moderator analysis for construct validity.

| Construct Validity | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | |
| Moderator (k) | *r* (SE)/Slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ |
| % GMFCS level 1 (11) | 0.004 (0.004) | −0.006 | 0.014 | 0.914 | .385 | 0.835 (1, 9) | .385 | 0.085 | 99.97%/99.96%/0.01% |
| PA type (11) | | | | | | 0.000 (1, 9) | .997 | 0.001 | 99.97%/99.96%/0.01% |
| Single | 0.621 (0.139) | 0.307 | 0.936 | 4.468 | .002 | | | | |
| Multi | 0.620 (0.293) | −0.042 | 1.282 | 2.120 | .063 | | | | |
| Placement (11) | | | | | | 0.147 (2, 8) | .866 | 0.033 | 99.97%/99.96%/0.01% |
| Leg | 0.471 (0.314) | −0.253 | 1.000 | 1.500 | <.100 | | | | |
| Trunk | 0.630 (0.180) | 0.215 | 1.000 | 3.501 | <.010 | | | | |
| Arm | 0.682 (0.241) | 0.125 | 1.000 | 2.826 | <.050 | | | | |

Abbreviations: LB, lower bound; PB, physical behavior; *r*, Pearson correlation coefficient; $R^2$, coefficient of determination; UB, upper bound.

**Table 4** Moderator analysis for criterion validity.

| Criterion Validity | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | |
| Moderator (k) | *r* (SE)/Slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ |
| PA dimensions (41) | | | | | | 1.250 (2, 38) | .298 | 0.137 | 98.67%/30.74%/67.92% |
| Frequency | 0.784 (0.088) | 0.605 | 0.963 | 8.863 | <.001 | | | | |
| Intensity | 0.602 (0.080) | 0.441 | 0.764 | 7.540 | <.001 | | | | |
| Duration | 0.759 (0.090) | 0.576 | 0.942 | 8.405 | <.001 | | | | |
| % GMFCS level 1 (42) | 0.002 (0.003) | −0.003 | 0.007 | 0.703 | .486 | 0.494 (1, 40) | .486 | 0.037 | 98.77%/18.97%/79.80% |
| PB type specified (29) | | | | | | 3.582 (3, 25) | .028 | 0.177 | 96.95%/0.01%/96.94% |
| Lying and sitting[*,†] | 0.463 (0.113) | 0.230 | 0.696 | 4.095 | <.001 | | | | |
| Standing | 0.643 (0.105) | 0.427 | 0.859 | 6.123 | <.001 | | | | |
| Walking[*] | 0.733 (0.082) | 0.564 | 0.903 | 8.913 | <.001 | | | | |
| Running[†] | 0.756 (0.094) | 0.563 | 0.949 | 8.064 | <.001 | | | | |
| Age (37) | | | | | | 0.142 (1, 35) | .709 | 0.012 | 98.92%/18.82%/80.10% |
| <13 yo | 0.740 (0.073) | 0.593 | 0.888 | 10.170 | <.001 | | | | |
| ≥13 yo | 0.689 (0.116) | 0.454 | 0.924 | 5.955 | <.001 | | | | |

(*continued*)

**Table 4** (*Continued*)

| Criterion Validity | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | | |
| Moderator (k) | *r* (SE)/Slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ | |
| PB type (41) | | | | | | 0.265 (1, 39) | .610 | 0.008 | 98.90%/16.26%/82.64% | |
| Single | 0.723 (0.073) | 0.577 | 0.870 | 9.977 | <.001 | | | | | |
| Multi | 0.676 (0.084) | 0.507 | 0.845 | 8.076 | <.001 | | | | | |
| Placement (42) | | | | | | 0.307 (3, 38) | .820 | 0.033 | 98.97%/17.60%/81.36% | |
| Leg | 0.650 (0.079) | 0.489 | 0.810 | 8.207 | <.001 | | | | | |
| Trunk | 0.727 (0.083) | 0.559 | 0.895 | 8.761 | <.001 | | | | | |
| Arm | 0.715 (0.130) | 0.452 | 0.978 | 5.507 | <.001 | | | | | |
| Multi | 0.789 (0.239) | 0.306 | 1.000 | 3.305 | .002 | | | | | |

Abbreviations: LB, lower bound; PB, physical behavior; *r*, Pearson correlation coefficient; $R^2$, coefficient of determination; UB, upper bound; yo, years old.
[*,†] Differences between effect sizes are statistically significant.

**Table 5** Moderator analysis for criterion validity of cutoff point based methods.

| Criterion Validity of Cutoff Point Based Methods | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary Effect and 95% CI | | | | | Test of Moderation | | | |
| Moderator (k) | *r* (SE)/Slope (SE) | 95% CI LB | 95% CI UB | *t* | *P* | F (*df*1, *df*2) | *P* | $R^2$ | Total $I^2$/Level 2 $I^2$/Level 3 $I^2$ |
| PA dimensions (24) | | | | | | 0.098 (1, 22) | .757 | 0.010 | 88.02%/42.82%/45.20% |
| Frequency | 0.699 (0.073) | 0.547 | 0.850 | 9.559 | <.001 | | | | |
| Intensity | 0.663 (0.086) | 0.485 | 0.842 | 7.716 | <.001 | | | | |
| Duration | | | | | | | | | |
| % GMFCS level 1 (24) | 0.001 (0.006) | −0.012 | 0.014 | 0.188 | .853 | 0.035 (1, 22) | .853 | 0.003 | 88.30%/40.68%/47.62% |
| PB class (22) | | | | | | 9.388 (2,19) | .002 | 0.340 | 84.26%/6.18%/78.08% |
| Sedentary[*,†] | 0.755 (0.063) | 0.623 | 0.888 | 11.907 | <.001 | | | | |
| Light[*] | 0.469 (0.087) | 0.288 | 0.651 | 5.406 | <.001 | | | | |
| Moderate-to-vigorous[†] | 0.610 (0.070) | 0.465 | 0.756 | 8.773 | <.001 | | | | |
| Age (24) | | | | | | 2.009 (1, 22) | .170 | 0.126 | 86.00%/42.31%/43.69% |
| <6 yo | 0.498 (0.143) | 0.202 | 0.795 | 3.483 | .002 | | | | |
| ≥6 yo | 0.715 (0.055) | 0.601 | 0.830 | 12.952 | <.001 | | | | |
| Age (24) | | | | | | 21.364 (1, 22) | .001 | 0.406 | 78.31%/78.30%/0.01% |
| <13 yo | 0.610 (0.033) | 0.542 | 0.678 | 18.629 | <.001 | | | | |
| ≥13 yo | 0.911 (0.056) | 0.795 | 1.000 | 16.204 | <.001 | | | | |
| Cutoff points (24) | | | | | | 1.293 (1, 22) | .268 | 0.061 | 86.73%/47.18%/39.56% |
| Population specific | 0.703 (0.054) | 0.590 | 0.815 | 12.930 | <.001 | | | | |
| General | 0.611 (0.083) | 0.439 | 0.783 | 7.380 | <.001 | | | | |

Abbreviations: LB, lower bound; PB, physical behavior; *r*, Pearson correlation coefficient; $R^2$, coefficient of determination; UB, upper bound; yo, years old.
[*,†] Differences between effect sizes are statistically significant.

## References


1. The Lancet Child Adolescent Health. Enabling participation in physical activity. Lancet Child Adolesc Health 2022;6:71.
2. Carbone PS, Smith PJ, Lewis C, LeBlanc C. Promoting the participation of children and adolescents with disabilities in sports, recreation, and physical activity. Pediatrics 2021;148:e2021054664.
3. Olusanya BO, Davis AC, Hadders-Algra M, Wright SM. Global investments to optimise the health and wellbeing of children with disabilities: a call to action. Lancet 2023;401:175–7.
4. Steene-Johannessen J, Hansen BH, Dalene KE, et al. Variations in accelerometry measured physical activity and sedentary time across Europe - harmonized analyses of 47,497 children and adolescents. Int J Behav Nutr Phys Act 2020;17:38.
5. World Health Organization. Global status report on physical activity 2022. Available at: https://www.who.int/teams/health-promotion/physical-activity/global-status-report-on-physical-activity-2022. Accessed November 25, 2023.
6. Bloemen MAT, van den Berg-Emons RJG, Tuijt M, et al. Physical activity in wheelchair-using youth with spina bifida: an observational study. J Neuroeng Rehabil 2019;16:9.
7. Verschuren O, Peterson MD, Balemans AC, Hurvitz EA. Exercise and physical activity recommendations for people with cerebral palsy. Dev Med Child Neurol 2016;58:798–808.
8. World Health Organization. Physical activity fact sheet. Available at: https://www.who.int/publications/i/item/WHO-HEP-HPR-RUN-2021.2. Accessed October 13, 2022.
9. World Health Organization. Adolescent health. Available at: https://www.who.int/health-topics/adolescent-health/#tab=tab_1. Accessed March 05, 2024.
10. White L, Volfson Z, Faulkner G. Arbour-Nicitopoulos K. Reliability and validity of physical activity instruments used in children

and youth with physical disabilities: a systematic review. Pediatr Exerc Sci 2016;28:240–63.
11. Trost SG, O'Neil M. Clinical use of objective measures of physical activity. Br J Sports Med 2014;48:178–81.
12. Prince SA, Cardilli L, Reed JL, et al. A comparison of self-reported and device measured sedentary behaviour in adults: a systematic review and meta-analysis. Int J Behav Nutr Phys Act 2020;17:31.
13. Lettink A, Altenburg TM, Arts J, van Hees VT, Chinapaw MJM. Systematic review of accelerometer-based methods for 24-h physical behavior assessment in young children (0-5 years old). Int J Behav Nutr Phys Act 2022;19:116.
14. Ahmadi MN, Pfeiffer KA, Trost SG. Physical activity classification in youth using raw accelerometer data from the hip. Meas Phys Educ Exerc Sci 2020;24:129–36.
15. Downs J, Leonard H, Hill K. Initial assessment of the StepWatch Activity Monitor™ to measure walking activity in Rett syndrome. Disabil Rehabil 2012;34:1010–5.
16. Lankhorst K, van den Berg-Emons RJ, Bussmann JBJ, Horemans HLD, de Groot JF. A novel tool for quantifying and promoting physical activity in youths with typical development and youths who are ambulatory and have motor disability. Phys Ther 2019;99:354–63.
17. Paraschiv-Ionescu A, Newman CJ, Carcreff L, Gerber CN, Armand S, Aminian K. Locomotion and cadence detection using a single trunk-fixed accelerometer: validity for children with cerebral palsy in daily life-like conditions. J Neuroeng Rehabil 2019;16:24.
18. Xing R, Huang WY, Sit CH. Validity of accelerometry for predicting physical activity and sedentary time in ambulatory children and young adults with cerebral palsy. J Exerc Sci Fit 2021;19:19–24.
19. Ryan JM, Forde C, Hussey JM, Gormley J. Comparison of patterns of physical activity and sedentary behavior between children with cerebral palsy and children with typical development. Phys Ther 2015;95:1609–16.
20. O'Neil ME, Fragala-Pinkham MA, Forman JL, Trost SG. Measuring reliability and validity of the ActiGraph GT3X accelerometer for children with cerebral palsy: a feasibility study. J Pediatr Rehabil Med 2014;7:233–40.
21. Lawal TA, Todd JJ, Elliott JS, et al. Assessing motor function in congenital muscular dystrophy patients using accelerometry. J Neurosci Nurs 2020;52:172–8.
22. Bonnefoy-Mazure A, Armand S. Normal gait. In: Canavese F, Deslandes J, eds. Orthopedic management of children with cerebral palsy, Hauppauge: Nova Science Publishers, Inc; 2015. p. 211.
23. World Health Organization. ICD-10: international statistical classification of diseases and related health problems: tenth revision, 2nd ed. Available at: https://apps.who.int/iris/handle/10665/42980. Accessed May 30, 2023.
24. Trost SG, Fragala-Pinkham M, Lennon N, O'Neil ME. Decision trees for detection of activity intensity in youth with cerebral palsy. Med Sci Sports Exerc 2016;48:958–66.
25. Nooijen CF, de Groot JF, Stam HJ, van den Berg-Emons RJ, Bussmann HB. Fit for the Future Consortium. Validation of an activity monitor for children who are partly or completely wheelchair-dependent. J Neuroeng Rehabil 2015;12:11.
26. Stephens S, Takken T, Esliger DW, et al. Validation of accelerometer prediction equations in children with chronic disease. Pediatr Exerc Sci 2016;28:117–32.
27. Prinsen CAC, Mokkink LB, Bouter LM, et al. COSMIN guideline for systematic reviews of patient-reported outcome measures. Qual Life Res 2018;27:1147–57.
28. Mokkink LB, Prinsen CAC, Patrick DL, et al. COSMIN methodology for systematic reviews of patient-reported outcome measures (PROMs). Version 1.0. Available at: https://cosmin.nl/wp-content/uploads/COSMIN-syst-review-for-PROMs-manual_version-1_feb-2018.pdf. Accessed May 30, 2021.
29. Moher D, Liberati A, Tetzlaff J, Altman DG. PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-analyses: the PRISMA statement. BMJ 2009;339:b2535.
30. R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available at: https://www.r-project.org/ Accessed September 10, 2023.
31. Novak-Pavlic M, Abdel Malek S, Rosenbaum P, Macedo LG, Di Rezze B. A scoping review of the literature on grandparents of children with disabilities. Disabil Rehabil 2022;44:3326–48.
32. Terwee CB, Jansma EP, Riphagen II, de Vet HC. Development of a methodological PubMed search filter for finding studies on measurement properties of measurement instruments. Qual Life Res 2009;18:1115–23.
33. Bloemen MA, Backx FJ, Takken T, et al. Factors associated with physical activity in children and adolescents with a physical disability: a systematic review. Dev Med Child Neurol 2015;57:137–48.
34. Mokkink LB, de Vet HCW, Prinsen CAC, et al. COSMIN risk of bias checklist for systematic reviews of patient-reported outcome measures. Qual Life Res 2018;27:1171–9.
35. Mokkink LB, Boers M, van der Vleuten CPM, et al. COSMIN risk of bias tool to assess the quality of studies on reliability or measurement error of outcome measurement instruments: a Delphi study. BMC Med Res Methodol 2020;20:293.
36. Terwee CB, Mokkink LB, Knol DL, Ostelo RW, Bouter LM, de Vet HC. Rating the methodological quality in systematic reviews of studies on measurement properties: a scoring system for the COSMIN checklist. Qual Life Res 2012;21:651–7.
37. Mokkink LB, Elsman EBM, Terwee CB. COSMIN guideline for systematic reviews of patient-reported outcome measures version 2.0. Qual Life Res 2024;33(11):2929–39.
38. Viechtbauer W. Conducting meta-analyses in R with the metafor package. J Stat Softw 2010;36:1–48.
39. Pastor DA, Lazowski RA. On the multilevel nature of meta-analysis: a tutorial, comparison of software programs, and discussion of analytic choices. Multivariate Behav Res 2018;53:74–89.
40. Balduzzi S, Rücker G, Schwarzer G. How to perform a meta-analysis with R: a practical tutorial. Evid Based Ment Health 2019;22:153–60.
41. Beath KJ. Metaplus: an R package for the analysis of robust meta-analysis and meta-regression. R Journal 2016;8:5–16.
42. Fan X, Sun S. Generalizability theory as a unifying framework of measurement reliability in adolescent research. J Early Adolesc 2014;34:38–65.
43. Friedman L, Nixon MS, Komogortsev OV. Method to assess the temporal persistence of potential biometric features: application to oculomotor, gait, face and brain structure databases. PLoS One 2017;12:e0178501.
44. Pustejovsky JE. clubSandwich: cluster-robust (sandwich) variance estimators with small-sample corrections. R package version 0.5.6. 2022. Available at: https://github.com/jepusto/clubSandwich. Accessed September 10, 2023.
45. Harrer M, Cuijpers P, Furukawa T, Ebert DD. Companion R package for the guide "Doing Meta-Analysis in R." 2019. http://dmetar.protectlab.org/. Accessed July 31, 2023.
46. Nakagawa S, Lagisz M, O'Dea RE, et al. The orchard plot: cultivating a forest plot for use in ecology, evolution, and beyond. Res Synth Methods 2021;12:4–12.
47. Fisher Z, Tipton E, Hou Z. Robumeta: robust variance meta-regression. 2017. Available at: https://cran.r-project.org/. Accessed September 10, 2023.
48. Borenstein M. In a meta-analysis, the I-squared statistic does not tell us how much the effect size varies. J Clin Epidemiol 2022;152:281–4.
49. Higgins J, Thomas J, Chandler J, et al. Cochrane handbook for systematic reviews of interventions. Version 6.4. 2023. Available at: https://training.cochrane.org/handbook/current. Accessed December 11, 2023.

50. Simonsohn U, Simmons JP, Nelson LD. Better P-curves: making P-curve analysis more robust to errors, fraud, and ambitious P-hacking, a reply to Ulrich and Miller (2015). J Exp Psychol Gen 2015;144:1146–52.
51. Mathur MB, VanderWeele TJ. Sensitivity analysis for publication bias in meta-analyses. J R Stat Soc Ser C Appl Stat 2020;69:1091–119.
52. Körner R, Röseler L, Schütz A, Bushman BJ. Dominance and prestige: meta-analytic review of experimentally induced body position effects on behavioral, self-report, and physiological dependent variables. Psychol Bull 2022;148:67–85.
53. Vembye MH, Pustejovsky JE. POMADE: power for meta-analysis of dependent effects. R package version 0.1.0. 2022. Available at: https://mikkelvembye.github.io/POMADE/. Accessed September 10, 2023.
54. Cabot M, Daviet JC, Duclos N, Bernikier D, Salle JY, Compagnat M. First systematic review and meta-analysis of the validity and test-retest reliability of physical activity monitors for estimating energy expenditure during walking in individuals with stroke. Arch Phys Med Rehabil 2022;103:2245–55.
55. Kuo YL, Culhane KM, Thomason P, Tirosh O, Baker R. Measuring distance walked and step count in children with cerebral palsy: an evaluation of two portable activity monitors. Gait Posture 2009;29:304–10.
56. Oftedal S, Bell KL, Davies PS, Ware RS, Boyd RN. Validation of accelerometer cut points in toddlers with and without cerebral palsy. Med Sci Sports Exerc 2014;46:1808–15.
57. Pirpiris M, Graham HK. Uptime in children with cerebral palsy. J Pediatr Orthop 2004;24:521–8.
58. Tang KT, Richardson AM, Maxwell D, Spence WD, Stansfield BW. Evaluation of an activity monitor for the objective measurement of free-living physical activity in children with cerebral palsy. Arch Phys Med Rehabil 2013;94:2549–58.
59. Bania T. Measuring physical activity in young people with cerebral palsy: validity and reliability of the activPAL™ monitor. Physiother Res Int 2014;19:186–92.
60. Aviram R, Belokopytov M, Ben-Chaim S, Rotstein A. Evaluation of energy expenditure in children with cerebral palsy using a multi-sensor accelerometer. J Sports Med Phys Fitness 2011;51:506–14.
61. Baque E, Barber L, Sakzewski L, Boyd RN. Reproducibility in measuring physical activity in children and adolescents with an acquired brain injury. Brain Inj 2016;30:1692–8.
62. Braun S, Dillon E, Sheiko M, Kang M, Bjornson K, Song K. Reliably estimating ambulatory activity in youth with arthrogryposis. Disabil Rehabil 2016;38:749–53.
63. Gerber CN, Carcreff L, Paraschiv-Ionescu A, Armand S, Newman CJ. Reliability of single-day walking performance and physical activity measures using inertial sensors in children with cerebral palsy. Ann Phys Rehabil Med 2021;64:101250.
64. Ishikawa S, Kang M, Bjornson KF, Song K. Reliably measuring ambulatory activity levels of children and adolescents with cerebral palsy. Arch Phys Med Rehabil 2013;94:132–7.
65. Mitchell LE, Ziviani J, Boyd RN. Variability in measuring physical activity in children with cerebral palsy. Med Sci Sports Exerc 2015;47:194–200.
66. Mackey AH, Hewart P, Walt SE, Stott NS. The sensitivity and specificity of an activity monitor in detecting functional activities in young people with cerebral palsy. Arch Phys Med Rehabil 2009;90:1396–401.
67. Maher C, Kenyon A, McEvoy M, Sprod J. The reliability and validity of a research-grade pedometer for children and adolescents with cerebral palsy. Dev Med Child Neurol 2013;55:827–33.
68. Koehler K, Abel T, Wallmann-Sperlich B, Dreuscher A, Anneken V. Energy expenditure in adolescents with cerebral palsy: comparison of the sensewear armband and indirect calorimetry. J Phys Act Health 2015;12:540–5.
69. O'Neil ME, Fragala-Pinkham M, Lennon N, George A, Forman J, Trost SG. Reliability and validity of objective measures of physical activity in youth with cerebral palsy who are ambulatory. Phys Ther 2016;96:37–45.
70. Clanchy KM, Tweedy SM, Boyd RN, Trost SG. Validity of accelerometry in ambulatory children and adolescents with cerebral palsy. Eur J Appl Physiol 2011;111:2951–9.
71. Keawutan P, Bell KL, Oftedal S, Davies PS, Boyd RN. Validation of accelerometer cut-points in children with cerebral palsy aged 4 to 5 years. Pediatr Phys Ther 2016;28:427–34.
72. McAloon MT, Hutchins S, Twiste M, Jones R, Forchtner S. Validation of the activPAL activity monitor in children with hemiplegic gait patterns resultant from cerebral palsy. Prosthet Orthot Int 2014;38:393–9.
73. Ryan J, Walsh M, Gormley J. Ability of RT3 accelerometer cut points to detect physical activity intensity in ambulatory children with cerebral palsy. Adapt Phys Activ Q 2014;31:310–24.
74. Sala DA, Grissom HE, Delsole EM, et al. Measuring ambulation with wrist-based and hip-based activity trackers for children with cerebral palsy. Dev Med Child Neurol 2019;61:1309–13.
75. Capio CM, Sit CH, Abernethy B. Physical activity measurement using MTI (actigraph) among children with cerebral palsy. Arch Phys Med Rehabil 2010;91:1283–90.
76. de Groot JF, de Jong AS, Visser T, Takken T. Validation of the actical and actiheart monitor in ambulatory children with spina bifida. J Pediatr Rehabil Med 2013;6:103–11.
77. Baque E, Sakzewski L, Trost SG, Boyd RN, Barber L. Validity of accelerometry to measure physical activity intensity in children with an acquired brain injury. Pediatr Phys Ther 2017;29:322–9.
78. O'Donoghue D, Kennedy N. Validity of an activity monitor in young people with cerebral palsy gross motor function classification system level I. Physiol Meas 2014;35:2307–18.
79. Oftedal S, Bell KL, Davies PS, Ware RS, Boyd RN. Sedentary and active time in toddlers with and without cerebral palsy. Med Sci Sports Exerc 2015;47:2076–83.
80. Hendry D, Rohl AL, Rasmussen CL, et al. Objective measurement of posture and movement in young children using wearable sensors and customised mathematical approaches: a systematic review. Sensors (Basel) 2023;23:9661.
81. Holsbeeke L, Ketelaar M, Schoemaker MM, Gorter JW. Capacity, capability, and performance: different constructs or three of a kind? Arch Phys Med Rehabil 2009;90:849–55.
82. Lynch BA, Kaufman TK, Rajjo TI, et al. Accuracy of accelerometers for measuring physical activity and levels of sedentary behavior in children: a systematic review. J Prim Care Community Health 2019;10:2150132719874252.
83. McIntyre S, Goldsmith S, Webb A, et al. Global prevalence of cerebral palsy: a systematic analysis. Dev Med Child Neurol 2022;64:1494–506.
84. Salari N, Fatahi B, Valipour E, et al. Global prevalence of Duchenne and Becker muscular dystrophy: a systematic review and meta-analysis. J Orthop Surg Res 2022;17:96.
85. Blencowe H, Kancherla V, Moorthie S, Darlison MW, Modell B. Estimates of global and regional prevalence of neural tube defects for 2015: a systematic analysis. Ann N Y Acad Sci 2018;1414:31–46.
86. Mokkink L, Terwee C, de Vet H. Key concepts in clinical epidemiology: responsiveness, the longitudinal aspect of validity. J Clin Epidemiol 2021;140:159–62.
87. Baque E, Barber L, Sakzewski L, Boyd R. Validity of accelerometry to measure physical activity in children and adolescents with an acquired brain injury. Dev Med Child Neurol 2015;57 (S5):77–8.
88. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. J Sports Sci 2008;26(14):1557–65.