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Responsiveness of Kinematic and Clinical Measures of Upper Limb Motor

Function after Stroke: A Systematic Review and Meta-Analysis

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Abbreviations¹

¹ ¹ ADLs, Activities of Daily Living; ARAT, Action Research Arm Test; BAT, Bilateral Arm Therapy; CAHAI, Chedoke Activity Hand and Arm Inventory, CIMT, Constraint Induced Movement Therapy; CLIO, Clinical Outcome Measures; FMA-UE, Fugl-Meyer Assessment - Upper Extremity; [ICF, International Classification of Functioning, Disability and Health](#); KINO, Kinematic Motion Analysis Outcome Measures; MAL, Motor Activity Log; [PICOS, Population-Interventions-Comparator-Outcomes-Study design\(s\)](#); ROM, Range of Motion; TRT, Trunk Restraint Therapy; UL, Upper Limb; WMFT, Wolf Motor Function Test.

ADLs, Activities of Daily Living; ARAT, Action Research Arm Test; BAT, Bilateral Arm Therapy; CAHAI, Chedoke Activity Hand and Arm Inventory, CIMT, Constraint Induced Movement Therapy; CLIO, Clinical Outcome Measures; FMA-UE, Fugl-Meyer Assessment - Upper Extremity; [ICF, International Classification of Functioning, Disability and Health](#); KINO, Kinematic Motion Analysis Outcome Measures; MAL, Motor Activity Log; [PICOS, Population-Interventions-Comparator-Outcomes-Study design\(s\)](#); ROM, Range of Motion; TRT, Trunk Restraint Therapy; UL, Upper Limb; WMFT, Wolf Motor Function Test.

Abstract

Background

Kinematic analysis and clinical outcome measures with established responsiveness contribute to the quantified assessment of post-stroke upper limb function, the selection of interventions and the differentiation of motor recovery patterns.

Objective

To report trends in use and compare responsiveness of kinematic and clinical measures in studies measuring the effectiveness of constraint-induced movement, trunk restraint and bilateral arm therapies for upper extremity function after stroke.

Methods

This systematic review was conducted in accordance with PRISMA guidelines and registered at PROSPERO (CRD42015023907). Randomised controlled trials implementing kinematic analysis and clinical outcome measures to evaluate the effects of therapies in post-stroke adults were eligible. Search strategies were adapted across eight electronic databases (MEDLINE, EMBASE, Web of Science, Scopus, CINAHL, CENTRAL, OTseeker and Pedro). Risk of bias was assessed in accordance with Cochrane's risk of bias domains. A meta-analysis was conducted for repeated design measures of pre and post-test data providing estimated standardised mean differences (SMD).

Results

Twelve studies, including 191 participants, reporting kinematic smoothness, movement duration and efficiency, trunk and shoulder range of motion, control strategy and velocity variables in conjunction with Motor Activity Log, Fugl-Meyer Assessment and Wolf Motor Function Test were analysed. The questionnaire Motor Activity Log (SMD of 1.0; 95%CI, 0.75 to 1.25; $p < 0.001$ for amount of use, and SMD of 0.96; 95%CI, 0.72 to 1.20; $p < 0.001$ for quality of movement) demonstrated significantly higher responsiveness (i.e. non-overlap of their 95% confidence intervals) than movement efficiency, trunk and shoulder range of motion, control strategy and peak velocity.

Conclusion

These results are consistent with current literature supporting the use of combined kinematic and clinical measures for comprehensive and accurate evaluation of post-stroke upper limb function. Future research should include other design trials and rehabilitation types to confirm these findings, focusing on subgroup analysis of type of rehabilitation intervention and functional levels.

Introduction

Upper limb (UL) impairment due to neurological loss post-stroke typically includes upper motor neuron syndrome, somatosensory deficit contralateral to brain lesion and cognitive disorders [1–3]. Studies estimate that 50 to 85 per cent of acute and 50 per cent of chronic stroke patients present UL impairment [4–6]. This influences functional ability in task accomplishment and independence impacting upon quality of life in individuals post-stroke [1,7–9].

Studies report a large number of measures used to evaluate UL function. Fifty-three measures have been identified contributing to a large diversity in the selection of measures across trials post-stroke [6,7,10,11]. Clinical guidelines recommend the use of valid, reliable and responsive measures contributing to evidence-based practice [10,12]. Studies show strong trends in the use of several measures to evaluate various International Classification of Functioning, Disability and Health (ICF) levels for UL function post-stroke [6,10,11,13,14]. The use of more than one measure for several ICF levels is reported in 72 per cent of trials [6]. Discrepancies in selection of measures exists, according to psychometric properties and/or intervention types [6,14]. Knowledge of psychometric properties of measures will contribute to potential comparison of treatment effects [10,15]. This will contribute to trial quality and allow comparison of practices of studies through meta-analyses contributing to evidence-based care [6,10,13].

The use of psychometrically sound outcome measures contributes to the identification of appropriate rehabilitation interventions [3,6,7,10,13,16,17]. Generally, the evaluation of treatment effects in stroke trials depend on the use of observational measures of timed standardised tasks [10,18,19]. Measures assessing ICF activity level function demonstrate limitations for the discrimination of motor recovery from motor compensation that is an important point to consider in constraint-induced movement therapy (CIMT), trunk restraint therapy (TRT) and bilateral arm therapy (BAT) [8,18,9]. Selection of appropriate interventions should consider whether outcomes are recovery or compensatory based for effects [8–10]. Recovery is defined as the return of physiological motor patterns with impaired structure, whereas compensatory movement refers to ability for accomplishment of a task through adaptation of motor patterns [8,9,20].

Discrete strategies of movement and motor impairment may not be detected with clinical measures [6,21], indicating a need for more precise measures of compensatory strategies or subtle impairments [8,19,22,20]. Furthermore, compensatory movement strategies, such as

lateral flexion and forward displacement of the trunk in reaching patterns are not explicitly measured by most activity level motor scales, with the exception of the Wolf Motor Function Test (WMFT) [8,22]. The use of kinematic measures combined with clinical measures aligned with ICF levels improves the ability to distinguish motor recovery from compensatory strategies [8,10,13,9].

The use of kinematic measures in UL evaluation is gaining increased recognition for the measurement of UL movement in stroke trials, supported by expert-based recommendations [6,13,22,23]. Combined use of kinematic motion analysis outcomes (KINO) with clinical outcome measures (CLIO) contributes to the differentiation of motor recovery and compensatory movement patterns, as well as prognostic accuracy [6,8,10,22,20,24]. KINO provide a quantitative and objective measure of UL body function level according to the ICF [10]. Furthermore, KINO have been found to correlate well with other clinical measures in stroke trials demonstrating high to moderate significant association with FMA-UE, ARAT and WMFT across reaching tasks [18,22,25]. The strength of correlations is dependent upon the specific actions that are being measured and the variable measured in the task [8,22].

They may present higher responsiveness to change compared to CLIO [22,26]. KINO for assessment of UL post-stroke was present in 21 of 41 trials from 2010 until 2014 [22]. Studies report an increasing use of KINO with CLIO, such as the FMA-UE [6], and with activity dexterity measures providing impairment level measurement of trunk movements in relation to UL tasks [10,27]. KINO variables demonstrate established validity and reliability in stroke populations [10,22,28]; however, responsiveness remains understudied, reported in only three trials for movement duration, smoothness, and trunk displacement variables [22,26,28]. In addition, kinematic analysis has been based on small sample sizes affecting generalizability of findings [22,23]. KINO variables may be more precise than clinical measures, with some studies demonstrating advantages of peak velocity and movement duration over timed performances of WMFT. However, it should be noted that these variables measured different aspects of UL movement [10,18]. Other studies demonstrated the ability of KINO to provide higher precision of quantitative measurement of specific movement aspects over global clinical scales assessing broad constructs of UL function [22,25].

Recent recommendations encourage standardisation of kinematic analysis measurement protocols according to ICF levels, tasks and conditions analysed, as well as psychometric properties [10,15,23]. However, evidence regarding KINO responsiveness remains limited

[22].

The aim of this systematic review was to establish and compare KINO and CLIO responsiveness for UL function following post-stroke interventions. Our review sought to firstly report the effect sizes of KINO and CLIO changes related to CIMT, TRT, and BAT rehabilitation interventions in order to conduct the comparison.

Methods

This protocol was registered on the PROSPERO database on 9 March, 2016 under registration number CRD42015023907.

Literature search

Studies were searched in electronic bibliographic databases, subject specific databases, unpublished grey literature and authors were contacted to identify additional studies and reference lists were manually scanned by two reviewers independently. The search was applied to MEDLINE, EMBASE, Web of Science, Scopus, CINAHL, Central Register of Controlled Trials (CENTRAL), OTSeeker and PEDro. No date limit was imposed in accordance with recent developments of KINO [22]. Language limits were applied to articles in English and French. The last search was performed on 1 May 2016, and an update of the literature search was conducted from 1 May 2016 to 28 October 2019.

Specific strategies were developed for each database. The MEDLINE strategy is illustrated in Appendix A, supplementary method. Index terms used were stroke, upper limb, kinematic and outcome measure. Methodological filters were used for RCT designs contributing to a sensitivity and precision maximising based search [29].

Selection criteria

Studies were selected according to predetermined eligibility criteria based on Population-Interventions-Comparator-Outcomes-Study design(s) (PICOS) components [29,30].

Type of participants: Adults with UL impairment post-stroke having undergone CIMT, TRT and/or BAT interventions were considered. Participants having received other therapies, such as functional electric stimulation, robot and/or virtual reality therapy were excluded to ensure the homogeneity of groups for meta-analysis [29]. Neurological conditions other than stroke

1 were excluded. Participants were aged 18 years and above. No exclusion regarding [time-point](#)
2 [post-stroke](#) was applied [20].
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5 *Types of intervention:* Only studies implementing KINO of UL movement with 3-dimensional
6 optoelectronics motion capture systems were considered due to high measurement accuracy
7 of free movements, [congruent with recommendations in stroke rehabilitation](#) [22,23,31].
8 Trials with KINO from virtual, robotic or haptic devices were excluded due to difficulty of
9 comparison of data [and/or](#) restriction of UE movements [22,31]. Studies reporting KINO
10 according to established classifications were selected including: trunk range of motion
11 (ROM), shoulder ROM, elbow ROM, movement duration, peak velocity, movement
12 efficiency (index of curvature in distal trajectory expressed as a path ratio), smoothness of
13 movement (number of movement units or peaks on the velocity curve in distal, the score
14 being inversely proportional to smoothness), and control strategy (time of peak velocity
15 expressed as a percentage of the movement duration) [22,31]. Studies were excluded if they
16 did not report at least one of these measurement variables.
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29 *Types of comparators:* Only studies implementing KINO in conjunction with CLIO for UL
30 function post-stroke were included. CLIO selected were the most frequently used with high
31 level psychometric properties and established clinical utility: FMA-UE, WMFT, ARAT,
32 Chedoke Activity Hand and Arm Inventory (CAHAI), MAL and Box and Block Test (BBT)
33 [6,7,10,11]. Studies not reporting at least one of these measures were excluded.
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40 *Types of outcome measures:* Responsiveness of KINO and CLIO ([described in the previous](#)
41 [two paragraphs](#)) was computed from pre- and post-test means and standard deviation values, as
42 a standardised mean difference appropriate for continuous outcomes [29,32].
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45 *Study design and setting:* Randomised clinical trials reporting at least two measurement points
46 (i.e. pre/post) were included. Studies conducted within clinical, hospital, rehabilitative-based
47 and/or community settings were included contributing to external validity, hence
48 generalisability of the results [29].
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Study selection and data extraction

Selection of studies was performed independently by two reviewers (CV and DG) upon screening of title and abstracts, according to eligibility criteria. Inclusion of studies was made after agreement by reviewers with discrepancies resolved by a third author (AV). Duplicate publications were removed after contact with authors and application of a decision tree [30]. The study selection process is demonstrated in Figure 1. The collection and management of studies was conducted with Zotero (<https://www.zotero.org/>) referencing storage and spreadsheet software (Microsoft Office Excel) [33].

The data extraction form was pre-piloted [29] and used independently by two reviewers (CV and DG). Information extracted in accordance with PICOS included characteristics of participants, type of intervention, modalities of rehabilitation (Table 1), technical aspects of the kinematic evaluation (Table 2), KINO and CLIO (Table 3).

Risk of bias

Risk of bias of studies was determined independently by two reviewers (CV and DG) according to the Cochrane Collaboration's Risk of Bias tool [29,30]. Judgement of bias according to the extracted information was determined as high (red), low (green) or unclear risk (yellow) due to lack of information [29]. Data was extracted using RevMan 5.3 software. Disagreement between reviewers was resolved by the arbitrary decision of a third author (AV).

Data Analysis

Meta-analyses were performed for continuous summary measures from individual studies with the standardised mean difference calculated by Hedges' g with 95% confidence intervals (95CI), p values and z scores [29,34]. This was appropriate for different measurement units for comparison between studies [29,30]. Hedges' g was computed for all outcomes as proposed by Borenstein [34] for paired continuous outcomes, considering the variance of pre- and post-test data. An inversion of the sign of the post-pre differences was made for outcomes in which improvement is represented as a decrease in score (WMFT Time subscale; movement smoothness, duration and efficiency; and trunk ROM) in order to consistently obtain a positive effect size related to the interventions. Due to the lack of availability of correlation (r) data between pre- and post-test from studies, the pooled effect size values for $r = 0.5$ were selected as proposed in the literature [34]. A sensitivity analysis using a range of plausible correlations (0, 0.25, 0.5, 0.75 and 0.9) was performed for imputation of r values for

all outcomes, allowing analysis of effect of association strength between pre- and post-test data on between-studies effect size and between-outcomes responsiveness [29,34,35].

Meta-analysis of Hedges' g was done for each KINO and CLIO across the studies, independently of the intervention (i.e. CIMT and/or TRT or BAT). Effect size values were classified as small (<0.2), moderate ($0.2-0.8$) or large (>0.8) [30,34]. Heterogeneity or between-study variation of studies was determined by I^2 test statistics (low if $I^2 < 50\%$ [29,36]) and visual assessment of forest plots [29]. A random effect model was systematically applied given the heterogeneous nature of the data collection, and the large variance of the I^2 values obtained [37,38]. Forest plots were examined for similarities of direction of treatment effects [39]. Meta-analysis was performed using the package *Metafor* for R Statistical software [40,41].

Comparison of responsiveness between outcomes was done through classification according to the decreasing value of the pooled Hedges' g values. With a conservative hypothesis, we considered that a difference in effect size between two outcomes was significant in cases of no overlap of their 95% confidence interval.

Results

Study selection

A total of 479 articles were identified through the selection procedure presented in Figure 1. After adjusting for duplicates, 347 studies remained for which titles and abstracts were screened, among which 332 studies were discarded as they did not meet the eligibility criteria. Full-text of 15 studies were assessed in further detail for eligibility: two studies did not meet the inclusion criteria in terms of participants [19,25]; one study was found to be a synthesis of three RCTs lacking individual results [43]; and a final study was a duplicate study [25,44]. An additional article was identified for inclusion from the manual search of reference lists [45]; no relevant unpublished studies were retained [30]. Authors of identified studies were contacted; however, this did not generate any additional trials. Finally, a total of 12 studies from 2006 to 2015 were identified for inclusion, some studies including two distinct groups in terms of rehabilitation (CIMT and/or TR or BAT).

Characteristics of the participants

Characteristics of participants in included studies are shown in Table 1. The mean age of participants was 56.6 years and the mean time since stroke onset was predominately chronic (>6 months) [20] across all trials except one [46], with an average of 25.7 months ranging from 11.9 weeks to 21.5 months. Most studies included participants with mild (57 to 66) to moderate (28 to 57) UE impairment severity with an average FMA-UE of 46.9/66 [47]. Included studies involved 247 participants having undergone UL rehabilitation including 128 for CIMT in eight studies [5,46,48–53], 30 for TRT across three studies [45,54,55], 38 for BAT over two studies [51,56], and 51 for CIMT combined with TRT in four studies [5,49,52,53].

Intervention characteristics

Technical aspects of kinematic evaluation are presented in Table 2. Movement was recorded at spontaneous velocity across all studies except for one measuring maximal velocity [53], while two studies recorded both (data were analysed at spontaneous velocity) [51,56] (Table 2). UL evaluation was assessed across unimanual functional tasks including reaching, point-to-point or reach-to-grasp with objects (either a bell or can) [5,45,46,48–56], while three trials analysed bimanual tasks in both reaching and ADL (opening a box or drawer and retrieving a note; not retained for data analysis) [50,51,56]. The evaluations retained for data analysis were systematically performed at the end of the rehabilitation programme.

Kinematic outcomes

KINO are shown in Table 3. Trunk ROM was assessed in seven trials but reported in six trials reporting TRT with or without additional CIMT [5,45,49,52–54] (data not usable from the study by Michaelsen et al., 2006). Values were calculated from sagittal trunk displacement and often standardised by hand movement indicating the trunk to UE movement ratio. Data from one study was not included [53] because of calculation according to three phases of the reaching movement. Five studies measured shoulder ROM, two after TRT [54,57] and three in CIMT+TRT studies [49,52,53] with a predominance of shoulder flexion. Seven studies assessed elbow ROM after TRT, CIMT and CIMT+TRT, including one where the data was not usable [55]. Four trials were found to report both metrics from two TRT [45,54], one CIMT [46], and one CIMT/BAT [51] subgroups. Movement efficiency, movement duration and control strategy were the most reported, in seven trials [5,46,49,54–56]. Smoothness was measured in six studies [46,48,49,51,54,55] among all intervention subgroups.

Clinical outcomes

CLIO are shown in Table 3. Three studies reported the use of only one CLIO [48,50,54] either FMA-UE or MAL. Use of more than one ICF level measure was reported in remaining studies. FMA-UE impairment measure, for all intervention subgroups, was used in seven studies, but the data was reported in only six, for which five reported combined use with activity level measure including MAL, WMFT and/or BBT. MAL activity measure was present in all nine studies reporting CIMT [5,46,48–52,56] and used in combination with other impairment and activity level measures in seven studies. Activity measure WMFT was used in three studies [5,49,51] across all interventions. ARAT and BBT were the least reported measures in CIMT+TRT and TRT respectively. No studies reported use of CAHAI.

Risk of bias within studies

Risk of bias for included studies is shown in Figure 2. Detailed description of risk of bias for individual studies is provided in Appendix A, supplementary results – risk of bias.

Results of individual studies

Raw values and results of meta-analyses for KINO and CLIO summary measures from individual studies (standardised mean difference calculated by Hedges' g with 95% confidence intervals, p values, z scores, heterogeneity and forest plots) are presented in Appendix A, supplementary results – individual studies meta-analyses.

Primary outcomes: Kinematic measures

All KINO demonstrated statistically significant responsiveness, except for Trunk ROM. Statistically significant moderate pooled effect estimates demonstrating improvement in post-test scores overall were found for smoothness (Fig. A.1), movement duration (Fig. A.2; improvement expressed as reduction in time scores), peak velocity (Fig A.3), shoulder ROM (Fig A.4), control strategy (Fig A.5) and movement efficiency (Fig. A.6; expressed as a reduction in the measure, hence negative value). Elbow ROM (Fig A.7) demonstrated statistically significant small to moderate improvement in pooled effect estimate post-test scores, and trunk ROM (Fig. A.8) not demonstrated statistically significant improvement in pooled effect estimate post-test scores.

Clinical outcomes measures

All CLIO demonstrated statistically significant responsiveness. Amount of Use (AOU; Fig. A.9) and Quality of Movement (QOM; Fig. A.10) subscales of the questionnaire MAL demonstrated large statistically significant effect sizes of post-test measures. FMA-UE (Fig. A.11), WMFT Time subscale (Fig. A.12; expressed as a reduction to indicating improvement) and WMFT Quality (Fig. A.13) score variables demonstrated statistically significant moderate improvement of pooled effect estimate.

ARAT and BBT were reported in only one trial, each making meta-analysis inappropriate. BBT reported in TRT subgroup [57] (n=15) demonstrated significant improvement ($p<0.01$), however no confidence interval was provided. Improvements of activity measure ARAT was reported [53] in CIMT+TRT (n=20) and CIMT (n=19) groups ($p<0.05$), however no confidence interval was provided. No studies reported the use of the CAHAI to measure UE functional capacity in conjunction with KINO analysis post-stroke.

Comparison of responsiveness of KINO and CLIO

Comparison of pooled effect estimates of standardised mean difference calculated by Hedges' g (95CI) of individual KINO and CLIO are shown in Figure 3. Comparison of pooled effect estimates enabled identification of the strength of change following interventions.

No statistical difference of responsiveness can be assumed between measures, except for MAL AOU and QOM over KINO movement efficiency, trunk ROM, shoulder ROM, control strategy and peak velocity due to absence of overlapping confidence intervals.

Smoothness was the most responsive KINO with the highest moderate estimated effect size, while FMA-UE clinical measure of UE structure and function demonstrated similar responsiveness. In descending order of responsiveness effect sizes, moderate effect sizes were demonstrated across WMFT Time measure, movement duration, WMFT Quality, peak velocity, shoulder ROM, followed by movement efficiency, control strategy and elbow ROM. Finally, trunk ROM did not demonstrate significant responsiveness.

Sensitivity analysis

The sensitivity analysis conducted with different correlation values of pre-post measures for calculation of the between-outcomes summative effect size (i.e. responsiveness for KINO and CLIO) revealed that the analyses done with $r = 0.5$ were robust. Changing the correlations had a negligible impact on the results (Table A.1 in Appendix A, supplementary results – sensitivity analysis).

Discussion

The main finding of this review was the reporting and comparison of responsiveness of UL stroke outcome measures, as determined by treatment effect sizes of pre-test/post-test measurements, following CIMT, TR, CIMT+TR and BAT rehabilitation. Thirteen KINO (n=8) and CLIO (n=5) outcome measures were identified allowing a comparative overview of meta-analysis results. All measures demonstrated significant statistical improvements with the exception of trunk ROM. Responsiveness of kinematic variables were identified for use in clinical trials and practice filling a gap identified within the literature [22]. Information regarding psychometric properties of KINO measures will assist in the selection of clinically relevant kinematic variables appropriate to intervention studies and practice [22].

Comparison of responsiveness between outcomes measures

MAL activity measure was present among all nine studies reporting CIMT [5,46,48–52,56]. Our meta-analysis highlighted that the responsiveness of MAL AOU and QOM was greater than peak velocity, shoulder ROM, movement efficiency, control strategy, elbow ROM and trunk ROM. Comparison of effect sizes of kinematic and clinical outcomes measures between them demonstrated homogenous responsiveness as demonstrated by overlap of 95% confidence intervals [42]. Contrary to previous studies in similar populations, responsiveness of KINO was not found to be greater than CLIO following CIMT, TR, CIMT+TR and BAT in chronic stroke patients [13,22,26] and no advantage of peak velocity and movement duration was demonstrated over WMFT time [10,18]. This discrepancy can be explained by the greater statistical power of the meta-analysis compared to individual studies.

Consideration of subjective measures

The subjective dimension of the MAL questionnaire should be highlighted on its influence of treatment effects leading to effect sizes larger than the more objective measures, based on actual performance [7,58,59]. This finding illustrates potential overestimation by subjective measures on treatment effects contributing to the risk of bias in outcome assessment [6,11,29]. The benefit of interventions judged by a subjective questionnaire (i.e. MAL scores) appeared greater than that judged by objective outcomes measures (i.e. kinematic data or scales with standardized rating by a therapist). This raises questions for future research to compare MAL to quantitative ecological observational measures [1,6], highlighting the importance of using MAL in combination with outcome measures of various ICF levels ensuring objective and comprehensive evaluation of UL impairment on ADLs [6,7,10,11].

Trends and combination of measure selection

CLIO: FMA-UE was the most reported measure in combination with kinematic analysis, consistent with findings supporting its use for the assessment of body function and structure in conjunction with activity ICF measures, as a predominant consensus post-stroke [6,10,13]. Trends of ICF activity measure use across trials varied. Despite emerging international consensus supporting its use [13], the ARAT was reported in only one study [52]. Trends of WMFT and BBT use, reported in two and one studies respectively, is consistent with reviews identifying the highest frequency of use among these measures with ARAT and MAL [6,10]. Despite well-established psychometric properties in post-stroke rehabilitation [10], CAHAI was not reported in conjunction with KINO.

KINO: Movement duration, efficiency and control strategy were the most reported kinematic variables, followed by smoothness, elbow ROM, peak velocity, shoulder ROM and trunk displacement. KINO selection was consistent with findings among stroke populations across 93 intervention, comparative and longitudinal trials [22]. Our findings are consistent with recommendations for the use of measures in conjunction with ICF levels [6,7,10].

Although the literature recommends measure [classification according to](#) ICF levels, time since stroke, measurement type and psychometric properties, [the responsiveness of KINO variables remains understudied](#) [6,13,22]. [Increased use of kinematic analysis in](#) UL evaluation [highlights a need to standardise analyses methods and the identification of](#) best-fit variables for specific interventions [and prediction of recovery](#), encouraging potential use across clinical practice [10,15,19,22].

Limitations

The lack of availability of data from studies, despite contact with authors, did not provide sufficient information for potential imputation of correlation values appropriate to repeated measures analysis methodology. Restriction of study selection in English and French may have contributed to a language bias [29,30]. Despite application of a duplicate publication decision tree [30], multiple publication bias may have influenced results. Even if predefined inclusion criteria and RCT design selection contributed to comparability and synthesis of results [29], evidence can only be generalised to CIMT, TRT and BAT interventions using 3D optoelectronic movement analysis systems [22]. [Variation of data acquisition conditions across studies, such as number of trials, task analysed \(e.g. reaching with or without grasping\)](#)

and/or sampling rate, may have influenced comparability of effect sizes [9,22,23]. Studies were found to have low or unclear bias, with the exception of two studies presenting high risk in conjunction with small sample sizes. The conclusions of this work cannot be extrapolated to kinematic data obtained from virtual, robotic or haptic devices that were not retained in our analysis in order to limit the heterogeneity of the data.

Conclusions

This study has highlighted current trends of measure selection for evaluation of UL function post-stroke following CIMT, BAT and TRT.

Findings support combined use of kinematic analysis and clinical outcome measures aligned with ICF levels for assessment. The use of FMA-UE measure for assessment of ICF body function level was identified by our findings supporting international consensus. Variations in the use of ICF activity level measures indicate further consensus is needed regarding their use across trials. Furthermore, the influence of objective (i.e. kinematic data or scales with standardized rating by a therapist) or subjective (i.e. self-report questionnaire) nature of outcomes measures on treatment effects should be considered in trials, as findings confirm subjective measures demonstrated greater perceived benefits. Kinematic variables were not found to have higher levels of responsiveness over objective clinical outcome measures in adults with chronic stroke. However, unlike the CLIO, they have the advantage of characterizing the quality and the structure of the movement, leading to a better understanding of the underlying neural mechanisms of functional improvements [9].

Further research should include various study designs, rehabilitation techniques and time-points post-stroke to enable further investigation for use of standardised kinematic variables. The development of the use of wearable, inexpensive and easy to use kinematic analysis devices could promote their dissemination [23]. Consensus will contribute to the identification of clinically significant change contributing to evidence-based practice. Future research of kinematic variable responsiveness for stroke rehabilitation should highlight the potential use of combined evaluative methods, demonstrating psychometric qualities for composite scores of UL function in conjunction with ICF components.

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Figures legend

Figure 1: PRISMA flow diagram of study selection process.

Figure 2: Risk of bias of studies assessed with the Cochrane Collaboration's Risk of Bias tool.

Figure 3: Responsiveness assessed by comparison of meta-analysis pooled effect estimates of standardised mean difference obtained with a coefficient of correlation of 0.5 between pre and post-test paired data, for individual KINO and CLIO (Abbreviations: CI, Confidence interval; CLIO, clinical outcome measures; FMA-UE, Fugl-Meyer Assessment - Upper Extremity; KINO, kinematic outcome measures; MAL, Motor Activity Log; AOU, amount of use; QOM, quality of movement; ROM, range of motion; WMFT, Wolf Motor Function Test).

Table 1. Characteristics of participants, type of intervention and modalities of rehabilitation.

Study (Year)	Type of intervention	N	Age, y, mean (SD)	Time-point	Baseline	Rehabilitation Modalities	
				post-stroke, months, mean (SD)	FMA-UE score (/66), mean (SD)	Duration and frequency	Setting (number of centres)
Michaelsen (2006)	TRT	15	68.9 (10.7)	16.7 (9.1)	47.9 (8.5)	1h, 3days/week, 5 weeks	Home
Lin, Wu, Wei (2007)	CIMT	17	57.1 (18.3)	16.3 (N/A)	N/A	2h, 5 days/week, 3 weeks	Rehab (4)
Wu, Chen, Tang (2007)	CIMT	24	53.9 (11.2)	12.5 (9.6)	46.8 (11.6)	2h, 5 days/week, 3 weeks	Rehab (2)
Wu, Lin, Chen (2007)	CIMT	15	54.7 (8.6)	18.5 (6.9)	N/A	2h, 5 days/week, 3 weeks	Rehab (2)
Thielman (2008)	TRT	5	62.4 (8.9)	13.6 (11.0)	29.8 (2.5)	45min, 3days/week, 12 sessions	Rehab (1)
Woodbury (2009)	CIMT+TRT	6	60.0 (8.6)	36.3 (35.3)	38 (10.3)	6h, 5 days/week, 2 weeks	Rehab (1)
	CIMT	5	64.8 (2.7)	32.4 (33.7)	42.0 (6.8)	6h, 5 days/week, 2 weeks	
Lin (2010)	BAT	16	52.1 (9.6)	13.9 (12.7)	48.0 (12.4)	2h, 5 days/week, 3 weeks	Rehab (3)
Wu (2011)	CIMT	22	51.9 (11.9)	14.9 (12.0)	N/A	2h, 5 days/week, 3 weeks	Rehab (4)
	BAT	22	52.2 (10.7)	15.9 (13.7)	N/A	2h, 5 days/week, 3 weeks	
Wu, Chen, Chen (2012)	CIMT+TRT	15	52.3 (11.3)	14.9 (13.6)	46.9 (5.9)	2h, 5 days/week, 3 weeks	Rehab (4)
	CIMT	15	54.9 (10.2)	15.0 (10.2)	46.6 (9.0)	2h, 5 days/week, 3 weeks	
Wu, Chen, Lin (2012)	CIMT+TRT	20	54.0 (9.7)	15.7 (13.5)	43.0 (9.6)	2h, 5 days/week, 3 weeks	Rehab (4)
	CIMT	19	56.3 (12.2)	13.7 (7.3)	39.1 (11.3)	2h, 5 days/week, 3 weeks	
Lima (2014)	CIMT+TRT	10	61.6 (9.5)	86.0 (64.3)	46.9 (10.1)	3h, 5 days/week, 2 weeks	Home
	CIMT	11	56.7 (7.2)	75.6 (29.4)	48.6 (5.7)	3h, 5 days/week, 2 weeks	
de Oliveira Cacho (2015)	TRT	10	47.4 (11.5)	51.84 (48.36)	32.8 (18.6)	45min, 2/week, 20 sessions	Rehab (1)

Abbreviations: BAT, bilateral arm therapy; CIMT, constraint induced movement therapy; CIMT+TRT, constraint induced movement therapy associated with trunk restraint therapy; FMA-UE, Fugl-Meyer Assessment for upper extremity; Home, home-based rehabilitation; N/A, not available; Rehab, rehabilitation units; TRT, trunk restraint therapy.

Table2

Table 2. Technical aspects of the kinematic evaluation.

Study (year)	Movement capture system	Sampling frequency (LPF), Hz	Number of markers	Position analysed	Distance of object	Mov. velocity	Number of trials	Task analysed	Onset / Offset of movement
Michaelсен (2006)	IREД, Optotrack	120	8	Seated, trunk unrestrained	80% AL	SV	10	Palmar grasp (cylinder)	> 5% PV / < 5% PV
Lin, Wu, Wei (2007)	IMAS, Vicon	60 (5)	4	Seated, trunk restrained	AL	SV	5	Reaching to grasp a can	Pressure sensor / Movement of can
Wu, Chen, Tang (2007)	IMAS, Vicon	60 (5)	1	Seated, trunk restrained	AL	SV	5	Reaching to press a bell	Hand pressure sensor / Desk bell pressure sensor
Wu, Lin, Chen (2007)	IMAS, Vicon	60 (5)	1	Seated, trunk restrained	AL	SV	3	Reaching to press a bell	Hand pressure sensor / Desk bell pressure sensor
Thielman (2008)	IMAS, Motion Analysis System	60 (6)	5	Seated, trunk unrestrained	75% AL	SV	5	Reaching to touch a target	Wrist velocity > 0.06 m/s / < 0.06 m/s
Woodbury (2009)	IMAS, Vicon	100 (12)	12	Seated, trunk unrestrained	80% AL	SV	3	Reaching to touch a target	> 10% PV / < 10% PV

Lin (2010)	IMAS, Vicon	120 (5)	1	Seated, trunk restrained	AL	MV	3	Reaching to press a bell with index	> 5% PV / Desk bell pressure sensor
Wu (2011)	IMAS, Vicon	120	1	Seated, trunk restrained	AL	MV	3	Reaching to press a bell with index	> 5% PV / Desk bell pressure sensor
Wu, Chen, Chen (2012)	IMAS, Vicon	120 (5)	12	Seated, trunk unrestrained	90% AL	SV	3	Reaching to grasp a can	> 5% PV / < 5% PV
Wu, Chen, Lin (2012)	IMAS, Vicon	120 (5)	12	Seated, trunk unrestrained	90% AL	MV	3	Reaching to press a bell with index	> 5% PV / Desk bell pressure sensor
Lima (2014)	IMAS, Qualisys	120 (7)	27	Seated, trunk unrestrained	90% AL	SV	N/A	Reaching to grasp a can	N/A / N/A
de Oliveira Cacho (2015)	IMAS, Qualisys	240 (6)	5	Seated, trunk restrained	AL	N/A	3	Reaching a target	> 5% PV / < 5% PV

Abbreviations: AL, arm length; Hz, Hertz; IMAS, infrared motion analysis system (passive markers); IRED, infrared-emitting diodes; LPF, low pass filter; MV, maximal velocity; N/A, not available; SV, spontaneous velocity; **PV**, peak velocity.

Table 3. Kinematic and clinical outcome measures.

Kinematic outcome measures								Clinical outcome measures
Study (Year)	Trunk ROM	Shoulder ROM	Elbow ROM	Movement duration	Movement peak velocity	Movement efficiency (index of curvature)	Smoothness (number of velocity peaks)	Control strategy*
Michaelsen (2006)		Active ROM (degrees)			At the wrist (mm/s)	At the wrist	At the wrist	FMA-UE, BBT
Lin, Wu, Wei (2007)				Normalised (s/cm)			At the wrist, normalized per distance	At the wrist (%) MAL
Wu, Chen, Tang (2007)				Normalised (s/m)	At the wrist (cm/s)	At the wrist	At the wrist, normalized per distance	FMA-UE, MAL
Wu, Lin, Chen (2007)				Normalised (s/m)		At the wrist		At the wrist (%) MAL
Thielman (2008)	Flexion in % of wrist motion		Extension (degrees)	Movement Time (s)				At the wrist (%) FMA-UE

Woodbury (2009)	3D motion in % of actual hand path length	Active ROM (degrees)	Active ROM (degrees)		At the hand	At the hand		FMA-UE, WMFT, MAL
Lin (2010)			Normalised (s/cm)		At the wrist		At the wrist (%)	FMA-UE, MAL
Wu (2011)			Normalised (s/m)	At the wrist (cm/s)		At the wrist, normalised per distance	At the wrist (%)	WMFT, MAL
Wu, Chen, Chen (2012)	ROM in % of wrist ROM	Normalised active ROM (degrees / mm)	Normalised active ROM (degrees / mm)					FMA-UE, MAL
Wu, Chen, Lin (2012)		Normalised active ROM (degrees / mm)	Normalised active ROM (degrees / mm)					ARAT, MAL
Lima (2014)	Anterior displacement (mm)		Active ROM (degrees)	At the wrist (mm/s)	At the wrist		At the wrist (%)	WMFT, MAL

de Oliveira Cacho (2015)	Sagittal displacement (mm)	Flex/Ext (degrees) Add/Abd (degrees)	Horizontal Flex / Ext (degrees)	Movement Time (s)	At the wrist (mm/s)	At the wrist	At the wrist	At the wrist (%)	FMA-UE
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Abbreviations: Abd/Add, Abduction/Adduction; ARAT, Action Research Arm Test; BBT, Box and Block Test; Flex/Ext, Flexion/Extension; FMA-UE, Fugl-Meyer Assessment-Upper Extremity; MAL, Motor Activity Log; ROM, range of motion; WMFT, Wolf Motor Function Test.

* Percentage of movement time where peak velocity occurs.

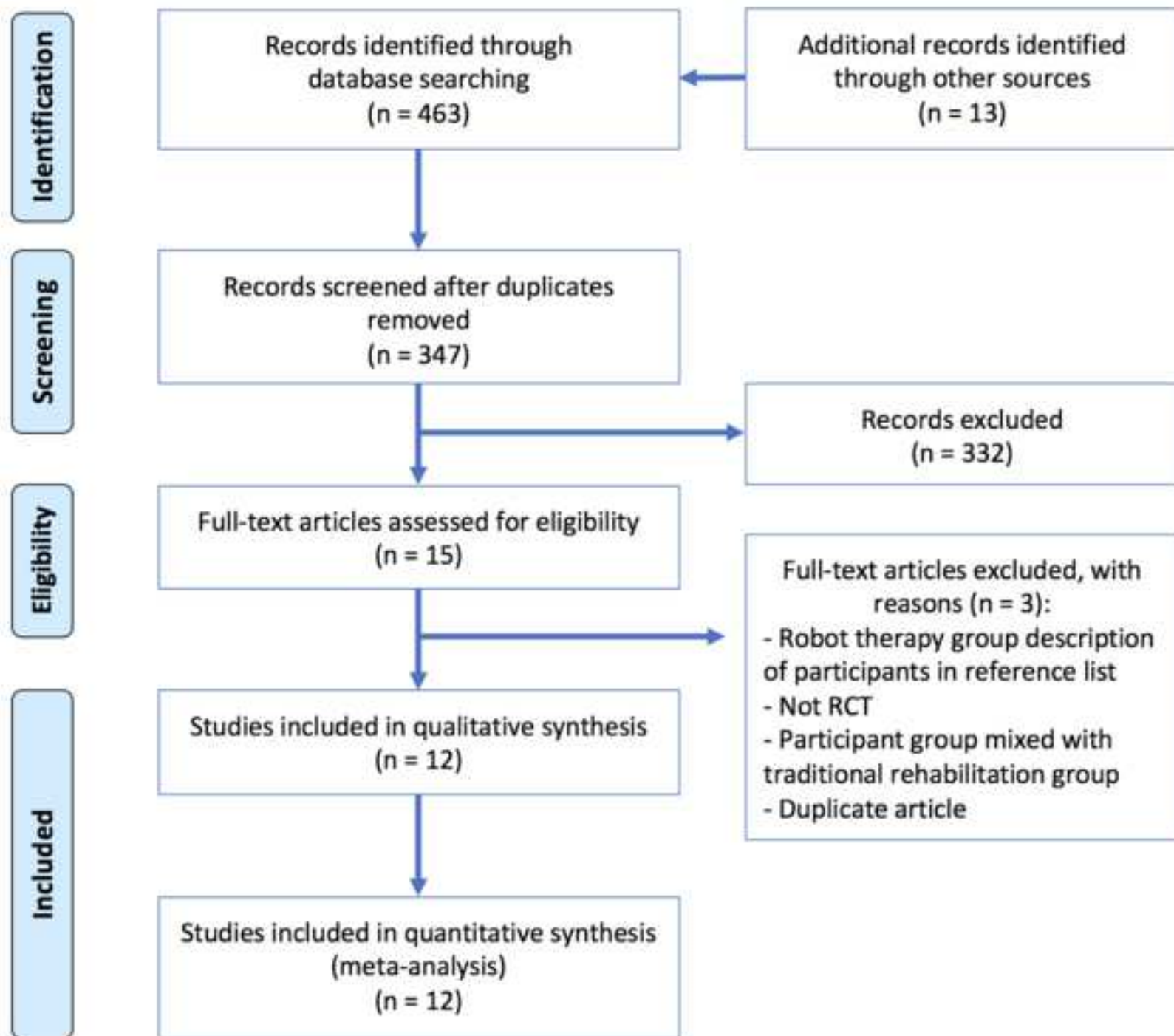
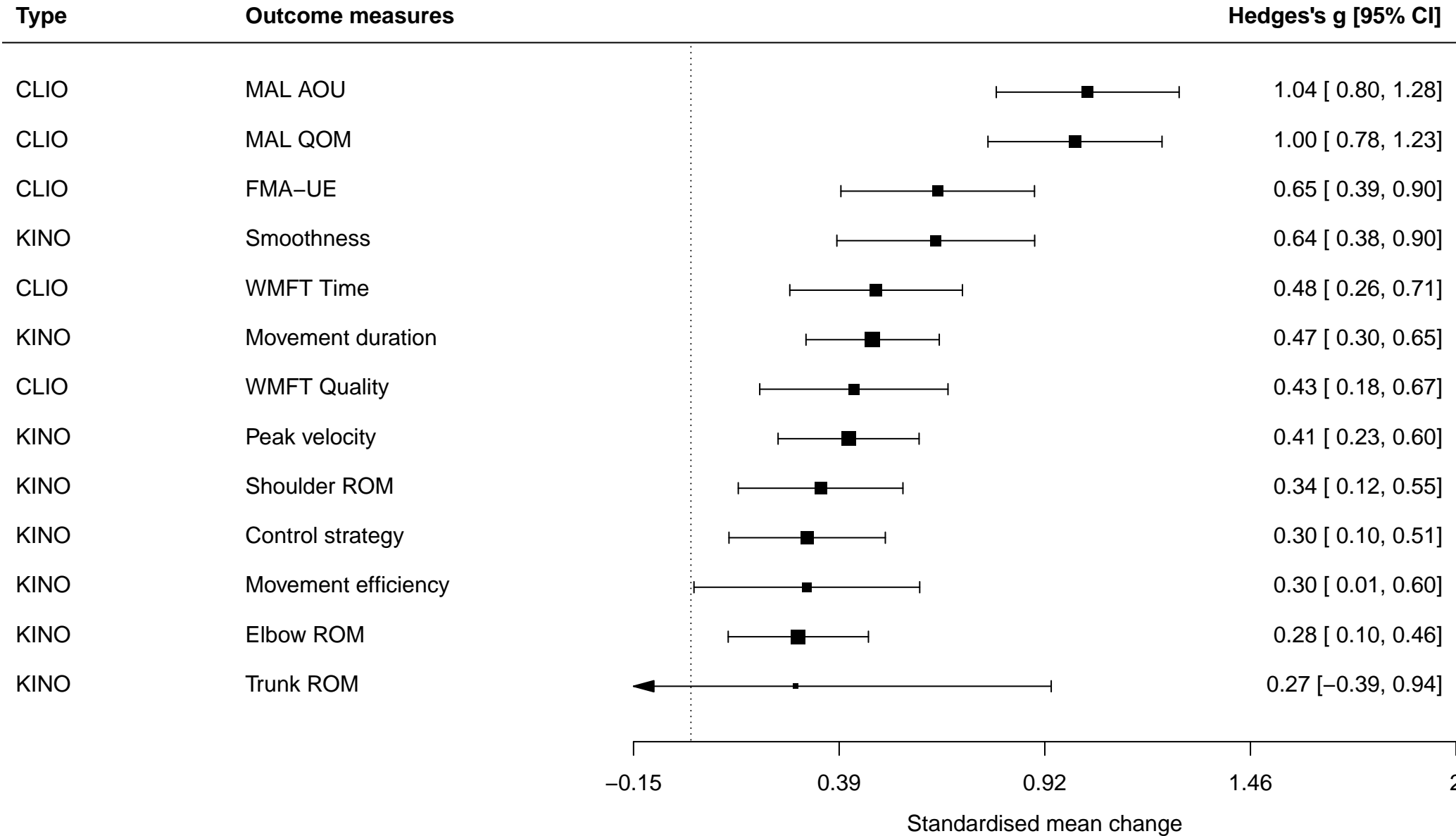


Figure 2

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
de Oliveria Cacho 2015	+	+	-	+	+	+	+
Lima 2014	+	+	-	+	+	+	+
Lin 2007	+	+	-	+	+	+	+
Lin 2010	?	?	-	?	+	+	+
Michaelсен 2006	?	?	-	+	+	-	+
Thielman 2008	?	?	-	-	+	-	?
Woodbury 2009	?	?	-	?	+	+	?
Wu, Chen, Chen 2012	+	+	-	+	+	+	+
Wu, Chen, Lin 2012	+	+	-	+	+	+	+
Wu, Chen, Tang 2007	+	?	-	+	+	+	+
Wu, Lin, Chen 2007	?	?	-	+	+	+	+
Wu 2011	+	+	-	+	+	+	+

Figure3





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