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Clin Rehabil 2009; 23; 1018 originally published online Sep 28, 2009;
DOI: 10.1177/0269215509339004

The online version of this article can be found at:
http://cre.sagepub.com/cgi/content/abstract/23/11/1018

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Clinical Rehabilitation 2009; **23:** 1018–1033

The psychometric properties and clinical utility of measures of walking and mobility in neurological conditions: a systematic review

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Received 5th December 2008; returned for revisions 14th April 2009; revised manuscript accepted 26th April 2009.

Objective: To identify psychometrically robust and clinically feasible measures of walking and mobility in people with neurological conditions
Data sources: MEDLINE, CINAHL, EMBASE, PEDro and AMED.
Review methods: Independent reviewers selected and extracted data from articles that assessed the reliability, validity, sensitivity to change or clinical utility of measures of walking and mobility in adult neurological conditions. Measures with 'good' psychometrics and 9/10 clinical utility scores were recommended.
Results: Seventeen measures were selected. Of these, the 5-m and 10-m walk tests, six-minute walk test, High Level Mobility Assessment Tool (HiMAT) and the Rivermead Mobility Index (RMI) reached the required standards and are usable in clinical practice. None of the recommended measures assessed wheelchair mobility. The least frequently assessed property was sensitivity to change. Further measures could be recommended if the minimal detectable change were demonstrated.
Conclusion: The 5-m, 10-m and six-minute walk test, High Level Mobility Assessment Tool and the Rivermead Mobility Index are psychometrically robust measures of walking and mobility and are feasible for use in clinical practice.

Introduction

Patients with neurological conditions frequently have difficulty walking, which limits their activity and participation in everyday life.[1] The restoration of walking and functional mobility is therefore a priority in rehabilitation; for patients and health care professionals alike.[2,3] To plan rehabilitation effectively an understanding of the nature and severity of the patients' problems is needed, which requires effective, consistent, accurate measurement tools and assessment processes. This is often problematic in the clinical setting. Although there are many tools that measure walking and mobility, nearly all have been developed for use in research and are impractical or inadequately developed for clinical use.[4–8] Consequently, the adoption of standardized, objective measures in clinical practice has been inconsistent and is limited by health care professionals' lack of time, information and expertise.[4–6,8]

This paper reports part of a project to identify and recommend the best measures to use with

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10.1177/0269215509339004

neurological and stroke patients in the clinical setting. Previous work has identified the domains that need to be measured[9] and systematically reviewed the psychometric properties and clinical utility (or usefulness) of the tools that measure each of the domains to identify the 'best of the bunch'. This paper reports the results of the systematic review of measures of walking and mobility.

Mobility was defined as 'a means of moving from one position to another'. It included moving around the bed, from one chair to another (transfers), using a wheelchair and all aspects of walking. Using the World Health Organization's International Classification of Functioning (ICF),[10] mobility is defined as an activity limitation, but walking can be defined as both an activity limitation or an impairment. In this review, parameters which measured the 'walking system', such as speed, step or stride length, joint kinematics or kinetics (weight-bearing or weight transfers) were defined as walking impairments, while measures of the patients' ability to walk around (where, or how they walked; the use of aids or assistance, for example) were defined as 'walking activity'. Measures that included the patients' ability to move around in ways other than walking (such as wheelchair mobility, transfers, bed mobility) were defined as 'mobility activity'.

Method

The method developed for this project has been reported in detail previously in the reviews of other domains[11] and is reproduced here with the aspects that are specific to the review of measures of walking and mobility.

Identifying the articles

Electronic databases (MEDLINE, CINAHL, EMBASE, PEDro and AMED) were searched from their earliest date to October 2008 using the following keywords: 'outcome measure or measurement tool or assessment or measure or test' and 'walking or gait or ambulation or mobility' and 'stroke or cerebrovascular accident or hemiplegia or 'parkinson' or multiple sclerosis or head injury or acquired brain injury or traumatic brain injury or Guillain-Barre or motor neurone disease.

Specific searches for the following named measures and authors were also undertaken to ensure that no relevant papers had been missed: GAITrite, timed walk, six-minute walk, distance walk, multiple sclerosis functional composite, visual gait analysis, Wisconsin Gait Scale, Timed Up and Go test, Rivermead Mobility Index, Functional Ambulation Category, Walking Handicap Scale and High Level Mobility Assessment Tool. All searches were limited to English language and human adults and patients with cerebral lesions.

Two reviewers (ST and LC) independently screened the titles and abstracts of articles identified by the search and then assessed the full text against the inclusion criteria. We excluded the following measures from further analysis:

- Measures in which only one psychometric property had been assessed and so clearly had insufficient information to recommend for clinical use.
- Measures which included walking or mobility as part of a wider assessment of general motor control from which data on walking/mobility could not be extracted.
- Any instrumented measure or device which had no information about how the device could be obtained, or insufficient information about the content for operating instructions to be obtained or developed, or was clearly not commercially available. As the measure could not be implemented in clinical practice if this information was not available.

Assessment of psychometric properties and clinical utility

Data about the psychometric properties and clinical utility of the measures were then extracted from the selected articles by volunteer neurological physiotherapists from National Health Service Trusts across the north-west of England using standardized instructions and data extraction forms and with support from the authors (see previous study[11] for further details).

The data extracted from the volunteer physiotherapists were checked by ST and LC and the strength of the psychometric properties and the clinical utility of the selected measures were analysed independently. The psychometric properties assessed are detailed in shown in Table 1. A measurement tool needed to obtain 'good' scores for reliability, validity and sensitivity before it could be recommended for use in clinical practice. For ordinal scales, the scaling properties of a measure were also considered through an assessment of the hierarchy (coefficients of scalability or reproducibility) or Rasch analysis. Clinical utility was assessed against a 10-point scale developed by the authors for the purpose. It assessed the practical details of using a measurement tool in clinical practice and is detailed in Table 2. Adding the scores gave a maximum score of 10. A score of 9 or above was required before a measure could be recommended for clinical use.

Results

The searches identified 39 measures of walking or mobility. However 21 measures were subsequently rejected as only one psychometric property had been tested and/or inappropriate tests had been used. The rejected measures were:

- video-measured step length and width[12]
- inky footprints[13]
- pedometer[14]
- conducting tape to measure temporal–distance factors[15]

Table 1 The psychometric properties assessed

Psychometric property	Accepted statistical tests	Interpretation of the statistics
Inter-tester and test–retest reliability	Intraclass correlations (continuous data) κ (categorical data)	+ Weak: ICC or $\kappa = 0.4$–0.6 ++ Moderate: ICC or $\kappa = 0.6$–0.8 +++ Good: ICC or $\kappa = 0.8$ and above
Concurrent or criterion related validity	Correlation coefficients	+ Weak: $r = 0.4$–0.6 ++ Moderate: $r = 0.6$–0.8 +++ Good: $r = 0.8$ and above
Sensitivity to change	Effect sizes or measures of the MDC	+ Weak = effect size 0.2–0.5 ++ Moderate = effect size 0.5–0.8 +++ Good sensitivity = effect size > 0.8

ICC, intraclass correlation coefficient; MDC, minimum detectable change.

Table 2 The assessment of clinical utility

Question assessed	Scoring
Time taken to administer, analyse and interpret the measure	Less than 10 minutes scores 3 10–30 minutes scores 2 30–60 minutes scores 1 >1 hour scores 0
Cost	$<$£100 scores 3 £100–£500 scores 2 £500–£1,000 scores 1 $>$£1000 or unknown scores 0
Does the measure need specialist equipment and training to use?	'No' scores 2 'Yes, but only simple, easy to use equipment which does not need specialist training' scores 1 'Yes' or 'Unknown' scores 0
Is the measure portable? Can it be taken to the patient?	'Yes, easily (can go in pocket)' scores 2 'Yes, in a brief case or trolley' scores 1 'No or very difficult' scores 0

- Wisconsin Gait Scale[16]
- visual analogue scale computerized footswitches[17]
- GaitMat II[18]
- Gaitrite[19,20]
- Physilog[21]
- clinical observation of gait during push-off[22]
- mobility scale for acute stroke patients[23]
- visual gait assessment[24]
- the six-spot step test[25]
- rise to walk test[26]
- Participation Survey/Mobility PARTS/M[27]
- Tinetti Gait Assessment (with video analysis)[28]
- Walking Handicap Scale or Hoffer Ambulation Scale[29]
- ABILOCO[30]
- Rivermead Visual Gait Analysis[31]
- four-point modified Rivermead Mobility Index[32]
- Glenrose Ambulation Rating (GAR).[33]

The remaining 17 measures (4 for walking impairment, 3 for walking activity and 10 for mobility activity) were assessed for their psychometric properties and clinical utility. Each is described briefly below, including, where available, details of the scaling properties of the ordinal scales. Details of the reliability, validity, sensitivity and the groups on whom the measures have been tested are shown in Table 3 and the assessment of the clinical utility and psychometric properties are shown in Tables 4 and 5.

Measures of walking impairment

Four measures of walking impairments were identified. Two measured performance during functional tasks (timed walk tests and distance walk tests), one was an instrumented device and one was an ordinal scale.

The timed walk tests time how long it takes a patient to walk a specified distance from which the walking speed (m/s) is calculated. Different distances have been used; 5 m,[34,35] 10 m[36–38] and 30 m[39] and there is further variation in the way the test is operationalized. Some merely walk in a straight line while others include a 180 degree turn[37]; some include the use of walking aids,[35] while others do not specify whether walking aids can be used[34,40–43]; some test at a comfortable or self-selected walking pace,[44,45] while others use the patient's fastest speed[42] and some studies tell the patient to start and stop at the 'line' marking the distance tested,[41] while others use a 'rolling' start and finish in which the patient starts to walk before the 'start line' and continues until the 'finish line' is crossed.[12,34,36,38]

The distance walk tests measure the distance walked in a specified time; they are considered a measure of endurance rather than speed. Two, six, ten or twelve minutes have been tested,[46] all using the patient's self-selected, comfortable speed. However the structure of the walking task varies; some walk in a straight line with a turn (the distance walked before a turn and therefore the number of turns varies), while others walk in a circle, so there are no turns. If the patient is unable to walk for the entire testing period, the distance covered and duration they achieved is recorded, with the intention of removing any floor effect.[46]

The only instrumented measure in which more than one psychometric property had been tested appropriately used pens taped to the subjects' heels[47] to measure step length and step width. The pens leave marks on the floor as the heel makes contact at heel strike, then a tape measure is used to calculate step length and width.

The Gait and Balance Scale (GABS)[48] was the only ordinal scale to assess walking impairments. It combines self-report of ambulation level, falls and freezing with examination of 14 different gait and balance parameters (e.g. rising from chair, posture, postural stability, 5-m walk test, turning) to assess parkinsonian gait. Each item is rated on a 5-, 3- or 2-point scale assessing the severity of the impairment.

Measures of walking activity

Three measures of walking activity were identified – two ordinal scales and one instrumented device:

- *The Emory Functional Ambulation Profile* (E-FAP)[49] measures the time taken to negotiate standardized surfaces and obstacles which represent the environmental challenges commonly encountered in everyday life. They include

Table 3 The psychometric properties of the measures of walking impairment, walking activity and mobility activity

Authors and date	Psychometric property tested	Subjects	Results
5 mWT[34]	Sensitivity	61 stroke patients.	Effect size gait speed = 0.81
5 mWT[35,80]	Sensitivity, T-rT, IRR, validity wrt balance and mobility	35 first stroke patients	MDC: 5 mWT (with aid) = 4.5 s; 5 mWT (no aid) = 1.12 s T-rT ICC = 0.99, IRR ICC = 0.99 Validity wrt Berg r = 0.64; RMI r = 0.64
10 mWT; 6-minWT[12]	MDC and Tr-T	13 patients with severe TBI	T-rT ICCs: 10 mWT = 0.91–0.98; 6-minWT = 0.96. Sensitivity MCD = 0.15 m/s at usual pace; 0.25 m/s at fast pace, 45 m for 6-minWT
10 mWT[37]	T-rT	22 chronic stroke	ICC = 0.87–0.88
10 mWT[41]	T-rT	81 acute stroke patients	ICC: Comfortable walk speed = 0.98; maximum walk speed = 0.99
10 mWT[74]	T-rT, IRR, sensitivity	26 patients with Parkinson's disease, age 44–80 years	IRR ICC: 10 mWT = 0.87, step frequency=0.80 T-rT ICC: 10 mWT = 0.81, step frequency=0.88 Sensitivity MDC: 10 mWT = 0.19 m/s, step frequency = 13 steps/min
10 mWT[42]	T-rT; validity wrt ADL and EADL	40 stroke patients	Validity wrt Barthel r = –0.78; wrt IADL r = –0.76
10 mWT[81]	IRR and T-rT	60 stroke patients	IRR ICC = 0.89–0.90 T-rT = 0.99
10 mWT[82]	IRR, validity	12 mobile TBI patients.	IRR: ICC = 0.99; validity wrt infrared gating r = 1
10 mWT[83]	Sensitivity	19 hemiparetics from stroke or tumour	Effect size = 1.17
2-, 6- and 12-minWT[46]	IRR and T-rT	18 inpatient rehabilitation strokes	IRR ICC: 2-minWT = 0.85; 6-minWT = 0.78; 12-minWT = 0.68 T-rT ICC: 2-minWT = 0.85; 6-minWT = 0.74; 12-minWT = 0.71
6-minWT[84]	T-rT	23 TBI patients	ICC = 0.94
10 mWT, 6-minWT[85]	IRR, T-rT	19 mobile subjects with stable multiple sclerosis	T-rT ICC: 10 mWT = 0.91–0.95; 6-minWT = 0.96 IRR ICC: 10 mWT = 0.93–0.96; 6-minWT = 0.93
6-minWT[86]	T-rT, sensitivity, validity	37 stroke patients	T-rT ICC = 0.97. Sensitivity: MDC = 54.1 m Validity wrt gait speed r = 0.89; Walk FIM r = 0.69; motFIM r = 0.52
6-minWT, 10 mWT[45]	T-rT sensitivity	37 Parkinson's disease patients	T-rT ICC: 6-minWT = 0.96; fast speed = 0.97; comfortable speed = 0.96 Sensitivity: MDC 6-minWT = 82 m; fast speed = 0.25 m/s; comfortable speed = 0.18 m/s
Pens taped to feet[47]	IRR, validity wrt step length and width	12 mobile TBI patients	Validity wrt step length and width r > 0.93 IRR ICC = 0.94–1.0
GABS[48]	IRR, T-rT, validity wrt Balance Master	35 mobile patients with Parkinson's disease	IRR = 0.3–0.83: T-rT: κ = 0.31–0.8 Validity wrt Balance Master r = 0.46–1

(Continued)

Table 3 Continued

Authors and date	Psychometric property tested	Subjects	Results
Measures of walking activity			
E-FAP[49]	IRR, validity	28 independently mobile strokes. Mean age 56 years	IRR: total E-FAP > 0.99 Validity wrt 10mWT $r = -0.78$, wrt Berg $r = -0.59$
mEFAP[87]	IRR, T-rT validity	26 strokes for validity testing. 7 for IRR; 5 for T-rT	IRR ICC = 0.99; T-rT ICC = 0.99 Validity: wrt Berg $r = -0.52$–0.73; wrt FAM(motor) $r = -0.14$ to -0.78
mEFAP[50]	T-rT, validity	40 stroke patients	Validity: wrt 10mWT $r = 0.88$–0.93; wrt RMI; $r = -0.67$ to -0.81 T-rT: ICC = 0.97–0.99
FAC[51]	Validity	61 patients with multiple sclerosis or hemiparesis	Validity wrt velocity $r = 0.67$; wrt cadence $r = 0.62$
FAC[88]	Validity, IRR	31 stroke patients	IRR: $\kappa = 0.74$ Validity: wrt velocity $r = 0.74$–0.84; wrt no. of steps $r = 0.86$
FAC[89]	Validity	20 subacute stroke patients	Wrt gait speed $r = 0.58$; walking distance $r = 0.55$; gait energy cost $r = -0.64$ FIM $r = 0.72$
FAC[90]	Validity, IRR and T-rT	55 stroke patients	T-rT $\kappa = 0.95$; IRR $\kappa = 0.91$ Validity wrt RMI $r = 0.69$–0.89; 6-minWT 0.90–0.95; velocity $r = 0.90$–0.95; step length $r = 0.88$–0.95
SAM[91]	T-rT, validity (of mean 7-day step count)	10 patients with multiple sclerosis, Parkinson's disease or primary muscle disorder	T-rT ICC = 0.86 Validity wrt gait speed $r = 0.45$; wrt RMI $r = 0.3$
SAM[92]	Validity	19 community-dwelling stroke patients	Wrt FIM $r = 0.52$–0.62
SAM[93]	T-rT	17 chronic strokes	T-rT for total stride counts per 24 hours: ICC = 0.96
Measures of mobility activity			
Mobility Milestones[53]	IRR, T-rT	19 acute stroke patients	IRR ICC = 0.67; T-rT ICC > 0.81
TUG[94]	T-rT, validity	11 stroke patients	T-rT ICC > 0.95 Validity wrt gait parameters $r = 0.62$–0.90; ankle strength $r = -0.86$; 6-minWT $r = -0.96$
TUG[95]	T-rT, IRR	12 Parkinson's disease patients	T-rT ICC = 0.90–0.97; IRR = 0.87–0.99
TUG[74]	T-rT, IRR sensitivity	26 Parkinson's disease patients, aged 44–80 years	IRR ICC = 0.85; T-rT ICC = 0.88 MDC = 1.63 s
TUG[96]	Validity wrt UPDRS	25 Parkinson's disease patients	Wrt UPDRS $r = 0.50$
TUG[36]	T-rT	50 stroke patients	ICCs all > 0.94

HiMAT[97,98]	Validity, sensitivity, IRR and T-rT	Validity: 103 TBI in- and out-patients. Subsets for: responsiveness 14 patients; IRR 17 patients; T-rT 20 patients	Validity wrt Motor FIM $r=0.53$; wrt RMA $r=0.87$ MDC $=1.36 \rightarrow 2$ IRR ICC $=0.99$; T-rT ICC $=0.99$
Dynamic Gait Index[58]	Validity IRR and T-rT	10 multiple sclerosis patients	IRR ICC $=0.98$; T-rT: $r=0.91$–0.98 Validity wrt 6-minWT $r=0.8$
MSWS-12[59]	T-rT, validity sensitivity	766 people with multiple sclerosis	Validity wrt MSIS-29 physical scale $r>0.74$; SF-36 PF $r=-0.77$; FAM (mobility) $r=-0.7$; EDSS $r=0.65$ T-rT ICC $=0.94$–0.97; sensitivity: effect size $=0.93$
Community Balance & Mobility Scale[60]	Validity, IRR and T-rT	Phase 1: 36 adults with TBI	Validity wrt gait speed $r=0.64$
		Phase 2: 32 adults with TBI	IRR ICC $=0.977$: T-rT ICC $=0.975$
RMI[61]	Validity, sensitivity	20 neurological patients (11 multiple sclerosis, 4 stroke, 5 TBI)	Validity wrt Barthel $r=0.91$; FAC $r=0.89$; gait speed $r=0.82$; Bohannon Balance Scale $r=0.82$; 6-minWT $r=0.63$ MDC 2 points
RMI[99]	Validity, sensitivity	73 inpatient stroke patients	Validity wrt motFIM $r=0.73$–0.91; MI leg $r=0.49$–0.51; TCT $r=0.83$–0.89 Sensitivity: effect size $=0.89$
RMI[100]	Validity	38 stroke patients.	Validity wrt BI $r>0.6$; wrt Berg $r>0.8$
RMI[101]	T-rT reliability	22 chronic strokes	$\kappa=0.64$
RMI[32]	T-rT reliability	46 neuro patients	T-rT RMI ICC $=0.96$
mRMI (6-point)[64]	IRR, sensitivity	30 stroke patients	Effect size $=1.15$ (4.5 points); IRR ICC $=0.98$
PAS[65]	IRR and T-rT	29 Parkinson's disease patients	IRR $\kappa=0.86$–0.98; T-rT ICC 0.41–0.93
FMAT[67]	IRR and T-rT	12 patients with neurological deficit aged 14–81 years	IRR ICC $=0.73$–0.97; T-rT $\kappa=0.82$–0.97
AI[102]	IRR,T-rT, validity, sensitivity	64 patients with multiple sclerosis	IRR: $\kappa=0.73$; T-rT k $=0.59$ Sensitivity: effect size $=0.2$; validity wrt BI $=-0.72$;wrt SF-36 $=-0.87$

IRR, inter-tester reliability; T-rT, test–retest reliability; wrt, with respect to; TBI, traumatic brain injury; E-FAP, Emory Functional Ambulation Profile; mE-FAP, Modified Emory Functional Ambulation Profile; RMI, Rivermead Mobility Index; mRMI, Modified Rivermead Mobility Index; FIM, Functional Independence Measure; motFIM, motor section of FIM; FAM, Functional Assessment Measure; BI, Barthel Index; TUG, Timed Get Up and Go test; HiMAT, High Level Mobility Assessment Tool; WT, walk test; 6-minWT, six-minute walk test; EDSS, Expanded Disability Status Scale; AI, Ambulation Index; MSWS-12, 12-item Multiple Sclerosis Walking Scale; UPDRS, Unified Parkinson's Disease Rating Scale; SAM, Step Activity Monitor; FAC, Functional Ambulation Category; GAR, Glenrose Ambulation Rating; RMA, Rivermead Mobility Assessment; MSIS-29, Multiple Sclerosis Impact Scale; MI leg, leg section of Motricity Index; TCT, Trunk Control Test; SF-36, Short Form Health Survey; GABS, Clinical Gait and Balance Scale; FR, Functional Reach; IADL, Instrumented Activities of Daily Living.

Table 4 The clinical utility of selected measures of walking and mobility

Measurement tool	Time to complete	Cost	Portability	Specialist equipment	Total (max = 10)
5 m and 10 mWT	**3**	**3**	**2**	**2**	**10**
2-, 5- or 6-minWT	**3**	**3**	**2**	**2**	**10**
12-minWT	**2**	**3**	**2**	**2**	**9**
Pens taped to feet	**2**	**3**	**2**	**2**	**9**
GABS	3	2	1	1	7
E-FAP	2	2	0	1	5
FAC	**3**	**3**	**2**	**2**	**10**
SAM	0	0	2	0	2
Mobility milestones	**3**	**3**	**1**	**2**	**9**
TUG	**3**	**3**	**1**	**2**	**9**
HiMAT	**3**	**3**	**1**	**2**	**9**
Dynamic Gait Index	3	3	1	1	8
MSWS-12	**2**	**3**	**2**	**2**	**9**
CB&MS	1	3	1	1	6
RMI	**3**	**3**	**2**	**2**	**10**
mRMI	**3**	**3**	**2**	**2**	**10**
PAS	2	3	1	1	7
FMAT	2	3	0	0	5
AI	3	3	1	2	9

Rows in bold are measures that meet the criteria for clinical use.
E-FAP, Emory Functional Ambulation Profile; mE-FAP, Modified Emory Functional Ambulation Profile; RMI, Rivermead Mobility Index; m RMI, Modified Rivermead Mobility Index; WT, Walk test; 6-minWT, 6-minute walk test; SAM, Step Activity Monitor; FAC, Functional Ambulation Category; TUG, Timed Get Up and Go test; HiMAT, High Level Mobility Assessment Tool; MSWS-12, 12-item Multiple Sclerosis Walking Scale; CB&MS, Community Balance and Mobility Scale; PAS, Parkinson Activity Scale; FMAT, Functional Mobility Assessment Tool; AI, Ambulation Index.

walking 5 m on a floor and on a carpet, a 'get up and go' task, an obstacle course and stair climbing. It is scored by multiplying the time taken to complete each item by a factor according to the level of assistive device required. Later modifications[49,50] incorporated a weighting factor for assistance given by another person.

- *Functional Ambulation Category* (FAC)[51] is a five-point ordinal scale which assesses the level of physical support needed to walk safely and where patients can walk. It ranges from walking with support of two or more, to walking with supervision, to walking anywhere.
- *Step Activity Monitoring* (SAM)[52] is a microprocessor-based accelerometer which is attached to the patient's leg. It detects and counts the number of steps taken over a specified period. Data can be collected over several days before it needs to be downloaded.

Measures of mobility activity

Eight ordinal scales, one functional performance test and Mobility Milestones were identified that measured mobility activity. Mobility Milestones[53,54] use a novel approach to monitoring progress in rehabilitation: they measure the number of days (since stroke) taken to achieve four simple, functional, hierarchically ordered mobility 'milestones': sitting balance for 1 minute, standing balance for 10 seconds, taking 10 steps independently and walking 10 m.

- The *'Timed Up and Go' test* (TUG)[55] was originally designed as a screening test for falls risk in the frail elderly but has been used extensively in people with neurological conditions. It measures, in seconds, the time taken to stand up from a standard armchair (seat height of 46 cm, arm height 65 cm), walk 3 m, turn,

Table 5 The analysis of psychometric testing of measures of walking and mobility

	Groups tested	Validity	Test–retest reliability	Inter-tester reliability	Sensitivity
5 mWT	**Stroke**	**++ mobility, balance**	**+++**	**+++**	**+++ Effect size** **MDC with aid = 4.5 s, without aid = 1.12 s**
10 mWT	**TBI, stroke, MS, PD**	**+++ ADL/IADL**	**+++**	**+++**	**+++ Effect size** **MDC for stroke = 0.15 m/s at usual pace, 0.25 m/s at fast pace** **MDC for PD = 0.18–0.19 m/s for usual speed; 0.25 m/s for fast speed**
10 mWT with turn	Stroke	+++	+++		
25 ftWT	MS	+++			
30 mWT	MS	+++	+++		++
2-minWT	Stroke	++	+++	+++	
6-minWT	**TBI, MS, stroke**	**+++ speed** **++ mobility** **+ motor control**	**+++/++**	**+++/++**	**MDC with stroke = 45–54 m; MDC for PD 82 m**
12-minWT	Stroke	++	++	++	
Pens taped to feet	TBI	+++ gait impairment		+++	
GABS	PD	+/+++ balance	+/++/+++	+/++/+++	
E-FAP	**Stroke**	**+++ speed, ++/+++ balance** **+/+++ mobility**	**+++**	**+++**	**+++**
FAC	Stroke, MS	++/+++ mobility ++/+++speed, gait impairments	+++	+++	
Step activity monitor	MS, PD, stroke,	+speed, mobility	+++		
Mobility milestones	Stroke		++	+++	
TUG	PD, stroke	++/+++ gait +++ strength, endurance	+++	+++	
HiMAT	**TBI**	**+ motor FIM** **+++motor control, mobility**	**+++**	**+++**	**MDC 2**
DGI	MS	+++ endurance	+++	+++	
MSWS-12	MS	+++ physical ++QoL, mobility, MS severity	+++		+++ Effect size
CB&MS	TBI	++ speed	+++	+++	
RMI	**Stroke, TBI**	**+++ ADL, mobility, speed, balance, motor control, trunk control** **++ endurance** **+ strength**	**++/+++**	**+++**	**+++ Effect size** **MDC 2 points**
mRMI (6 point)	Neuro			+++	+++ Effect size
PAS	PD		+/++	+++	
FMAT	Neuro		++/+++	+++	
AI	**MS**	**+++ QoL** **++ ADL**	**++**	**+**	**+ Effect size**

Rows in bold are measures that meet the criteria for clinical use.
TBI, traumatic brain injury; E-FAP, Emory Functional Ambulation Profile; mE-FAP, Modified Emory Functional Ambulation Profile; RMI, Rivermead Mobility Index; mRMI, Modified Rivermead Mobility Index; FIM, Functional Independence Measure; motFIM, motor section of FIM; FAM, Functional Assessment Measure; BI, Barthel Index; TUG, Timed Get Up and Go test; HiMAT, High Level Mobility Assessment Tool; WT, walk test; 6-minWT, six-minute walk test; EDSS, Expanded Disability Status Scale; AI, Ambulation Index; MSWS-12, 12-item Multiple Sclerosis Walking Scale; UPDRS, Unified Parkinson's Disease Rating Scale; SAM, Step Activity Monitor; FAC, Functional Ambulation Category; GAR, Glenrose Ambulation Rating; RMA, Rivermead Mobility Assessment; MSIS-29, Multiple Sclerosis Impact Scale; GABS, Clinical Gait and Balance Scale; FR, Functional Reach; IADL, Instrumental Activities of Daily Living; MS, multiple sclerosis; PD, Parkinson's disease; QoL, quality of life; MDC, minimum detectable change.

walk back to the chair and sit down again. Patients can use walking aids although this is recorded.

- The *High Level Mobility Assessment Tool* (HiMAT)[56,57] assesses 'high-level' balance and mobility problems and was developed for people with traumatic brain injury. Items assess walking on slopes, different surfaces, long distances, changing direction, negotiating stairs and high-level balance tasks, and ability to run, skip, hop and jump. The theoretical construct and scaling has been examined; it is unidimensional, fits the Rasch model and has been tested for redundancy, with redundant items removed. It is not hierarchical, with the items on the score sheet grouped together in testing location, rather than order of difficulty.
- The *Dynamic Gait Index* (DGI)[58] scores eight items from 0 (poor) to 3 (excellent). These include walking on a level surface with horizontal head turns, vertical head turns, a pivot turn, changing speed, stepping over and around obstacles and steps.
- The *Multiple Sclerosis Walking Scale* (MSWS-12)[59] is a 12-item scale specifically designed for people with multiple sclerosis. It asks whether the patient's multiple sclerosis has affected their ability to walk, run or manage stairs over the previous two weeks on a 5-point scale from 1 (not at all) to 5 (extremely). Items are summed to generate a total score and transformed on to a 0–100 scale but the shortcomings of summing ordinal data are not acknowledged.
- The *Community Balance and Mobility Scale*[60] identifies postural instability, balance and mobility for community-dwelling adults with traumatic brain injury. It uses 6-point scales to score high-level tasks such as hopping, crouch and walk, walking and looking and running with a controlled stop.
- The *Rivermead Mobility Index* (RMI)[61] assesses the ability to perform 15 tasks ranging from turning over in bed to running which are scored on a yes/no basis. It was developed from the gross function subscale of the Rivermead Motor Assessment.[62] Rasch analysis has showed it to be unidimensional with a hierarchy of easy-to-hard items and good overall validity. Item difficulty level was stable when used with different groups of patients on different occasions.[63] Two published modifications change the scoring to a 4-point scale[32] and a 6-point scale[64] with the intention of increasing sensitivity to change, however this has not been demonstrated and these more complex versions do not appear to have any advantage over the original.
- The *Parkinson Activity Scale* (PAS)[65] assesses the movement problems experienced by people with Parkinson's disease: chair transfers, gait akinesia, bed mobility and dual tasking (testing by assessing bed mobility including manipulating a duvet cover) on a 5-point scale based on the United Parkinson's Disease Rating Scale.[66]
- The *Functional Mobility Assessment Tool*[67] measures mobility by rating eight tasks: wheelchair transfers and mobility, bed mobility, ambulation, environmental barriers, car transfers and patients' responsibility for mobility on an 8-point scale.
- The *Ambulation Index* (AI)[68] assesses mobility activity with 10 levels assessed on a yes/no basis ranging from 0 (normal status) to 9 (wheelchair-bound and unable to transfer independently).

Eleven of the measures had sufficient clinical utility to be suitable for clinical practice (bold rows in Table 3) including functional performance tests, simple instrumented measures and ordinal scales. The analysis of the psychometrics revealed that only seven measures had information on all four properties: the 5-m or 10-m timed walk tests, six-minute walk test, Emory Functional Ambulation Profile, High Level Mobility Assessment, Ambulation Index and Rivermead Mobility Index (bold rows in Table 4). However the Ambulation Index had poor reliability and sensitivity, so it was rejected. Of the remaining measures, only the timed walk tests, six-minute walk test, High Level Mobility Assessment Tool and Rivermead Mobility Index had sufficient clinical utility, as well as sufficiently robust psychometric properties to be recommended.

Discussion

The results of this study identified five psychometrically robust measures of walking and mobility

that are suitable for use in clinical practice. Three measured walking impairments (the 5-m and 10-m walk tests and the six-minute walk test) and two measured mobility activity (the High Level Mobility Assessment Tool measured high level mobility skills and the Rivermead Mobility Index measured general mobility). We were unable to recommend any of the measures of walking activity or wheelchair-based mobility. Rehabilitation of walking activity is a frequent treatment goal so there is a clear need to develop a psychometrically robust and clinically feasible measure. Two measures of walking ability – the Functional Ambulation Categories[51] and the Walking Handicap Scale[29] – are well known and feasible for use in the clinical setting but both had incomplete development of their psychometric properties, which prevented their recommendation. Further research is needed to address the missing properties.

Either the 5-m or the 10-m walk test could be used to measure walking impairment; however the 10-m walk test has been validated with a wider range of conditions and so is more generalizable. A disadvantage is that it has a higher 'floor' than the 5-m walk test as it is restricted to people who can walk 10 m, thereby excluding the most impaired patients who may only be able to walk shorter distances.

Several different testing protocols had been used for both the timed walk and the distance walk tests. Although there is little difference in the psychometrics or clinical utility, the different protocols will produce different values. It is therefore imperative that clear, standardized operating instructions are given and used consistently, or the resulting inaccurate data could lead to inappropriate clinical decisions. We recommend that patients should be tested at their self-selected, comfortable speed as this has less random measurement error (and therefore a smaller minimal detectable change) than walking at maximum speed.[69] We also recommend that they should be performed using a 'rolling start and finish' as, in our experience of using this measure, patients find it easier and more convenient than a 'standing start and finish'. Several different times for the distance walk tests have been suggested.[46] We recommend the six-minute walk test as it has been tested on the widest range of neurological conditions, has a strong relationship between clinic- and community-based measures and is the only protocol for which the minimal detectable change has been published. The disadvantage is that it would have a floor effect relative to the two-minute walk test, and may have a ceiling effect relative to the 12-minute walk test.

The least frequently assessed psychometric property was sensitivity to change yet an understanding of this property is needed to judge the clinical significance of any change of score and without it the value of any data to measure change is limited. The most clinically relevant aspect of sensitivity to change is the minimum detectable change. This is defined as the minimum change in score needed to detect a true change in performance, above and beyond the 'normal' variability in the measurement process and is simple to calculate from reliability data.[70] Future research to develop clinical measurement tools should address this important property.

The importance of assessing the minimum detectable change of a measure is gaining recognition within rehabilitation research[71–73] and an understanding is emerging that it is not a fixed number; it is specific to the context and groups in which it is tested.[36,39] For example, the minimum detectable change for the 10-m walk test for people with stroke, traumatic brain injury and Parkinson's disease is similar[12,35,45,74] but there is a 66% difference in the minimum detectable change of the six-minute walk test for people with Parkinson's disease and stroke.[45,75] Therefore further assessment of this property is needed in a range of study populations and treatment settings so that appropriate values can be established and applied in clinical practice. To date, studies of the minimum detectable difference have involved small samples and the confidence intervals are wide.[39,69,76] A more accurate and generalizable indication of the minimum detectable change could be overcome by using pooled data and meta-analysis. Until recently, the logistics of undertaking such projects has been daunting but the development of data archives, such as the recently launched Virtual International Stroke Trial Initiative (VISTA-Rehab http://www.vista.gla.ac.uk/), makes it feasible to undertake suitably powered calculations to provide generalizable values.

Instrumented devices have been suggested as an ideal method to measure mobility activity as their automation produces objective, highly accurate, sensitive data with relatively little inter-rater variability. Accelerometer-based step activity monitoring is the best developed such device to measure walking and mobility. It is a reliable and valid measure of activity in people with a normal gait pattern[77–79] but the present analysis shows that it is not valid for people with neurological conditions. It is possible that the patients' gait abnormalities are so different to normal patterns that the device is unable to recognize the patient's movement. Further technological development of specific algorithms to recognize pathological gait patterns would overcome this problem.

It is also notable that none of the recommended measures included wheelchair skills or wheelchair-based mobility. As a significant proportion of people with neurological conditions are unable to walk, whether in the short or long term, a psychometrically robust and clinical feasible measure of wheelchair-based mobility is needed. Future research to develop such measures is needed or existing measures which do include wheelchair mobility (such as the Functional Mobility Assessment Tool67 and Ambulation Index68) need further development of their psychometric properties.

To the authors' knowledge, there have been no previous systematic reviews of the clinical utility of measurement tools, other than the previous publications from this project. The system we developed to assess the utility was based on our clinical experience and the judgements of quality were arbitrary. Such judgements cannot be assumed to be appropriate for other health care systems or other areas of clinical practice. Nevertheless, they have strong face and ecological validity and were acceptable to neurological physiotherapists working across the north-west of England, so we feel they are reasonably generalizable.

Like all systematic reviews, the quality of the review is dependent on the papers identified. Although we had thorough search strategies, we only included publications in English. There may have been relevant publications in other languages that we missed. We also did not attempt to identify unpublished data or the grey literature, so there may have been a publication bias in the data identified. An unusual aspect of this project is that we involved 'volunteer' clinical physiotherapists who undertook the data extraction as part of their continued professional development. The quality of the subsequent analysis is dependent on the effectiveness with which the physiotherapists undertook this task. The steps taken to ensure the quality of data extraction have been detailed previously.[11] They include extensive training, provision of comprehensive written instructions plus one-to-one support from physiotherapists with expertise and experience in the field. Furthermore the extracted data were checked by the first two authors (ST and LC) who undertook the analysis. We are therefore as confident as we can be that the data extraction is accurate.

Clinical messages

- We recommend the 5-m and 10-m walk tests, six-minute walk test, High Level Mobility Assessment Tool and the Rivermead Mobility Index to measure walking impairments and mobility activity. They are psychometrically robust and suitable for use in clinical practice
- We were unable to recommend a measure of walking activity. The Functional Ambulation Categories and the Walking Handicap Scale measure walking activity and are well known and suitable for clinical use but their psychometric properties require further development
- There is no current psychometrically robust, clinically feasible measure of wheelchair-based mobility. As a significant proportion of people with neurological conditions are dependent on alternative (non-walking) means of mobility, a robust and feasible measure is urgently needed.

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