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Reliability, measurement error and minimum detectable change in mobility measures among community-dwelling adults aged 50 years and over

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Abstract

Objective: To examine the effects of repeat assessments, rater and time of day on reliability of mobility measures using a population-based sample of Irish adults aged ≥50 years.

Design: Test-retest reliability study.

Setting: Academic health assessment centre of The Irish Longitudinal Study on Ageing (TILDA).

Participants: 128 community-dwelling adults from the Survey for Health, Ageing and Retirement in Europe (SHARE) Ireland study who agreed to take part in the SHARE-Ireland / TILDA collaboration.

Interventions: Not applicable.

Outcome Measures: Participants performed Timed Up-and-Go (TUG), repeated chair stands (RCS) and walking speed tests administered by one of two raters. Repeat assessments were conducted 1-4 months later. Participants were randomised with respect to a change in time (morning, afternoon) and whether or not the rater was changed between assessments. Within- and between-participant variance for each measure was estimated using mixed effects models. Intra-class correlation (ICC), standard error of measurement (SEM) and minimum detectable change (MDC) were reported.

Results: Average performance did not vary between baseline and repeat assessments in any test, except RCS. There were inter-rater effects for most tests (P<.001) but limited time of day effects. Reliability varied from ICC=0.66 (RCS) to ICC=0.88 (usual gait speed). MDC was 2.08 s for TUG, 4.52 s for RCS and ranged from 19.49-34.73 cm/s for walking speed tests.

Conclusions: Reliability varied for each test when measurements are obtained over 1-4 months with most variation due to rater effects. Usual and motor dual task gait speed demonstrated highest reliability. MDC estimates provide guidance on whether longitudinal change in a similar group represents a genuine change in performance.

Key words: repeatability, physical performance tests, longitudinal change, epidemiology

Article summary

Strengths and limitations of this study

- This study provides information on the effects of repeat assessments, rater and time of day on reliability of mobility measures obtained over 1-4 months using a population-based sample of relatively healthy middle-aged and older aged ≥50 years in Ireland.
- The use of common tests such as Timed Up-and-Go, repeated chair stands and GAITRite assessments makes this analysis relevant for other studies looking at change in mobility.
- Mixed effects models were used to estimate within- and between-participant variance for each measure allowing intra-class correlation (ICC), standard error of measurement (SEM) and minimum detectable change (MDC) to be presented.
- For some measures, MDC was presented on the multiplicative (logarithmic) scale and the additive scale to account for skewness and to ensure that findings are applicable across all levels of performance. .

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Competing interests: None declared

Data sharing statement: The anonymised SHARE-TILDA dataset is available through the on-site "hot desk" facility at TILDA, Trinity College Dublin. Researchers should contact tilda@tcd.ie for more information.

Introduction

Performance based measures such as Timed Up-and-Go (TUG), repeated chair stands (RCS) and walking speed tests are commonly used to assess mobility and lower limb function of older adults in clinical and research settings [1]. These measures are good predictors of falls, disability, cognitive decline and mortality [2-4]. To be useful, they also need to be reliable (consistent when measured on several occasions and when there is no change in a subject's underlying performance) and responsive (able to detect a change when there is one) [5]. Good reliability allows changes in measurements to be tracked over time [6].

However, all tests are subject to measurement error due to within-subject, inter-trial, inter-rater and day-to-day variation, and other external factors. This has several implications. Clinically, if an individual improves or declines between two testing sessions, it is important to know how likely it is that the observed change is a genuine change in performance and not due to measurement error. In research settings, unreliable measures can lead to regression dilution bias or false positive associations when testing predictors of longitudinal change [7]. To account for this, several measures of relative reliability i.e. intra-class correlation (ICC), and absolute reliability i.e. standard error of measurement (SEM) and minimum detectable change (MDC), are often reported [8].

SEM is the standard deviation of the measurement error of a measure within an individual, for a given 'true' value of the underlying construct. The SEM determines the MDC, which is the smallest difference between two single observations that can be confidently attributed to a genuine difference and not measurement error. ICC is a measure of the proportion of variance within a population that is attributable to variance across individuals as opposed to measurement error within individuals. As opposed to SEM and MDC, ICC depends on both the SEM and the variation

between members of a sample, and so is not usually comparable or applicable across samples with different levels of heterogeneity.

The within-session and one week test-retest reliability of TUG in community-dwelling, older adults is well known, and is known to be high (ICC≥0.96) [9-11] in various populations as is the inter-rater [12] [13] and intra-rater reliability [12]. MDC at the 95% confidence level (MDC_{95}) has been reported to vary between 3.33-6.87 s in healthy and cognitively impaired older adults [14-16] and up to 11 sec in Parkinson's disease patients [17]. The within-session test-retest reliability of RCS is also very high (ICC=0.93-0.95) [9] [18], however SEM and MDC for community-dwelling adults are not known.

Walking speed can be measured using stopwatches, timing gates or sensored mats. The test-retest reliability of usual gait speed (UGS) measured using a GAITRite® walkway has been reported to be between ICC=0.84 and 0.97 for assessments given up to two weeks apart [19-25]. Similar values have been reported for one hour test-retest reliability of dual task gait speed (ICC=0.85-0.93) [19] [20]. Fewer studies have reported SEM or MDC in healthy populations with MDC values of 12.4-13.6 cm/s reported for UGS [20] [22] and 15.5 cm/s for dual task gait speed [20]. However, reliability of dual task gait speed may also be dependent on the actual dual task and therefore is not comparable across studies unless the same test has been used.

Here we report the test-retest reliability measured by ICC, SEM and MDC in a pragmatic epidemiologic setting. We explore how reliability changes when lag between assessments varies between 1 month and 4 months, when rater changes or is held constant, and whether or not time of assessment varies, in a large sample of healthy adults aged 50 and older recruited at random

from the population. This data will inform both clinical interpretation and design and analysis of research studies using these tests.

Methods

Participants

Participants were a subsample from the Survey of Health, Ageing and Retirement in Europe (SHARE), a longitudinal, cross-national study on health, socio-economic status and social and family networks of more than 80,000 individuals aged 50 years and over across Europe [26]. The SHARE-Ireland sample (n=1,119) was recruited in Ireland between 2006 and 2007 with a response rate of 55% [27]. A collaboration between SHARE-Ireland and The Irish Longitudinal Study on Ageing (TILDA) was established to understand the measurement properties of a comprehensive health assessment among a representative sample of the European population. Reliability of cognitive measures and blood pressure dynamics based on this sample have been published previously [28 29].

The extant SHARE-Ireland cohort at 2010 (n=827) was contacted and invited to take part in a health assessment delivered within the TILDA health assessment centre based at Trinity College Dublin. Initial contact was made by post and followed up by telephone between September 2011 and March 2012, with 377 participants consenting to receive further information about the study. Of these, 253 agreed to an initial health assessment (see Figure 1). Ethical approval for this sub-study was obtained from the Faculty of Health Sciences Research Ethics Committee at Trinity College Dublin. All participants provided informed consent.

Health assessments and interview

The full health assessment included a 3 hour battery of tests assessing cognitive function, gait and mobility, cardiovascular function and vision [30]. Health assessments were conducted by two highly trained research nurses with approximately 3 years' experience delivering these specific tests in the current setting. They used detailed and standardised health assessment protocols which included clear explanations and demonstrations to ensure consistent instructions were provided to all participants.

A short interview was administered by the nurses before the health assessment to capture information on health, chronic disease, disability, employment, social and financial circumstances. Co-morbidity was assessed by asking participants if a doctor had ever told them that they had any of the following conditions: heart attack, high blood pressure, high cholesterol, stroke, diabetes, chronic lung disease, asthma, arthritis, osteoporosis, cancer, ulcer, Parkinson's disease, cataracts, age related macular degeneration, Alzheimer's disease and atrial fibrillation. The number of conditions was summed and categorised according to 0, 1, 2 or ≥3 conditions. Participants self-rated their health as excellent, very good, good, fair or poor.

On completing the health assessment, 180 participants were invited to take part in an identical repeat assessment, scheduled after 1-4 months. In total, 128 participants (58 men) agreed to the repeat assessment giving a response rate of 71% (25 refused and 27 were unavailable to attend the repeat assessment within the required timeframe).

Repeat assessments were arranged to distinguish within-person variation from variation caused by changing rater or time of day. The same research nurse conducted the baseline and repeat assessments for half of the participants while another nurse conducted the repeat assessment for

the other half of the participants. Time of day when the assessment took place (morning or afternoon) was also changed for half of the participants. Change of rater, change of time of day and delay between assessments (dichotomised at the median) were randomised using a minimisation routine designed to achieve balance across these covariates, as well as the age group and sex of participants. Other factors that could influence performance e.g. health assessment protocols, assessment location, equipment, etc. were held constant across both assessments.

Physical performance tests

Participants completed several mobility tests - TUG, RCS and gait assessments in single and dual task conditions. TUG, which is a common functional mobility test [12] was completed once using walking aids if required. The time taken to rise from the chair (seat height 46 cm), walk 3 m at normal pace, turn around, walk back to the chair and sit down again was recorded using a stopwatch. RCS is an indicator of mobility and lower limb muscular endurance [31]. Participants began in a seated position and the time taken to stand up five times was recorded. Participants were asked to keep their arms folded across their chest throughout the test.

Gait assessment took place using a 4.88 m computerised walkway with embedded pressure sensors (GAITRite®, CIR Systems Inc, New York, USA). Participants performed two walks at their normal pace followed by two walks under cognitive dual task conditions and manual dual task conditions. The cognitive task was to recite alternate letters of the alphabet (A-C-E, etc). The manual task was to carry a glass of water filled to 7 mm from the top. Participants started and finished 2.5 m before and after the walkway to allow for acceleration and deceleration. The two walks in each condition were combined to give mean UGS, mean cognitive dual task gait speed (CGS) and mean manual dual task gait speed (MGS).

Statistical analysis

This analysis includes participants who completed and had valid scores for baseline and repeat assessments for each of the mobility tests (Figure 1). TUG and RCS are not normally distributed and the variance is strongly related to average scores, therefore analyses were conducted and findings are presented on the natural scale for ease of interpretation and as log transformed values to allow normally distributed stable variances across groups.

To look for practice effects, rater effects and time of day effects, mean mobility performance scores were compared (i) between baseline and repeat assessments, (ii) between raters, and (iii) at different times of day using paired t-tests.

To estimate reliability, mixed effects regression models were then used to find the variation between and within participants. Baseline/repeat assessment, rater and time of day were included as fixed effects. The standard deviations of the within-person and between-person variance components arising from these models were used to estimate the residual ICC for all measures within this population. The ICC is the proportion of total variance not accounted for by within person variation, that is, $ICC = \frac{{SD_{Between}}^2}{{SD_{Between}}^2 + {SD_{Within}}^2}$. SEM is equivalent to SD_{Within}, the standard deviation of the variance of the test within individuals, assuming no genuine change in function, and so is an absolute measure of test reliability. MDC is the magnitude of observable change required to exceed the anticipated measurement error and within-subject variability. It is calculated by $\sqrt{2} \times Z \times SD_{Within}$, where Z=1.96 for the 95% limit (that is, 95% of observed differences between pairs of observations will be within this limit given there is no true difference) and Z=1.65 for the 90% limit.

Findings from previous studies suggest that the variability of TUG is related to its magnitude; that is an individual with a TUG time of 4 s is likely to have a lower absolute variation than someone with a TUG time of 12 s. For this reason, we estimate the reliability of TUG on a log-scale, as errors are more likely to be multiplicative than additive, and TUG is often analysed on a logarithmic scale in epidemiological settings.

Participant and public involvement

This research was done without participant involvement. Participants were not invited to comment on the study design and were not consulted to develop participant relevant outcomes or interpret the results. Participants were not invited to contribute to the writing or editing of this document for readability or accuracy.

Results

The median age of the sample was 66 years (range 51-89 years, IQR 61-71 years) and 55.5% were female. The majority of the sample (n=103, 81.8%) rated their own health as excellent, very good or good, 57.8% reported having no history of cardiovascular or chronic conditions while 16.0% had 3 or more conditions. Median delay between assessments was 88 days (range 28-141 days, IQR 70-104 days). Fifty-one participants had a different nurse at the repeat assessment while 60 participants had their assessment at a different time of day.

Table 1 shows the mobility performance scores at baseline and repeat assessments, with different raters and at different times of day, while Table 2 shows the variance and reliability estimates for all mobility measures.

Timed Up-and-go

TUG did not vary between baseline and repeat assessments or by time of day, however there was a significant rater effect with a difference of 1.22 s (*P*<.001) between the two nurses. The between-person SD was 1.31 s. The SEM was 0.75 s, leading to good reliability (ICC=0.75) and MDC estimates of 1.75 s at the 90% level and 2.08 s at the 95% level. This means that a difference of 1.75-2.08 s between two assessments in the same individual can be expected by chance depending on the confidence interval used and when controlling for all other factors (rater, time between assessments and time of day). Analysis of TUG on a logarithmic scale suggests similar reliability (ICC=0.71), and a SEM of 0.09. The MDC_{95} of 0.24 for log(TUG) suggests that change in TUG of up to 27% might be expected by chance in 95% of paired samples. This finding is applicable across the spectrum of baseline TUG scores.

Repeated chair stands

RCS was completed slightly more quickly at the repeat measurement (difference=0.47 s, *P*=.04) and when the assessment was carried out by Nurse 1 (difference=1.09 s, *P*<.001) but did not vary with time of day. The ICC was 0.66 and SEM was 1.63 s while MDC was estimated to be 3.80 s at the 90% level and 4.52 s at the 95% level. Time to complete RCS was also analysed on the log scale, where reliability was similar (ICC=0.68), SEM was 0.13 and MDC was 0.35 at the 95% confidence level.

Usual gait speed

UGS did not vary between baseline and repeat assessment or by time of day, however there was a significant rater effect with a difference of 7.36 cm/s (*P*<.001). Reliability was excellent (ICC=0.88)

as the between-person SD (18.65 cm/s) was much higher than the SEM (7.03 cm/s), resulting in a MDC_{90} of 16.40 cm/s and MDC_{95} of 19.49 cm/s.

Manual dual task gait speed

Gait speed became less reliable as the complexity of the dual task conditions increased. MGS was consistent across repeat assessments but varied by rater (difference=4.88 cm/s, *P*=.02) and time of day (difference=3.62 s, *P*=0.03). ICC was lower than was observed for UGS (ICC=0.83), SEM was higher (8.97 cm/s) and consequently so was MDC_{90} (20.93 cm/s) and MDC_{95} (24.87 cm/s).

Cognitive dual task gait speed

CGS did not vary by repeat assessment, rater or time of day, however reliability estimates were poorest out of all gait speed measures (ICC=0.77; SEM=12.53 cm/s; MDC_{95}=34.73 cm/s).

For all observed rater effects, including those where performance was automatically measured (i.e. with GAITRite), participants completed the mobility tasks more quickly when assessed by Nurse 1.

Discussion

We report test-retest reliability, SEM and MDC of commonly used mobility tests in a sample of relatively healthy, community-dwelling Irish adults aged 50 years and older. We found excellent test-retest reliability for walking speed and motor dual task walking speed and good reliability for TUG and cognitive dual task walking speed however, the lowest ICC was observed for RCS. These findings contrast to previous studies which reported moderate to excellent reliability for all of these measures [9-11 18 19 21-25 32]. As ICC depends on the distribution of scores within the sample it is

estimated in and reflects relative reliability, it is specific to that particular setting and population [8]. Lower reliability here is likely to reflect more homogeneous population representative samples (hence lower between-person standard deviations) compared to clinical samples with varying degrees of impairment.

SEM and MDC provide an indication of absolute reliability. MDC allows the assessor to interpret if an observed change score is above that expected due to measurement error and therefore if it represents a genuine change in performance. In this study, MDC for TUG (2.08 s at the 95% level) is lower than that presented in previous studies of healthy (MDC_{95}=4.71 s) [16] and cognitively impaired (MDC_{95}=5.88-6.87 s) older adults [14 15] and Parkinson's disease patients (MDC_{95}=11 s) [17]. However, reporting variability in TUG as a percentage change in performance rather than in absolute terms may be more appropriate. In contrast, MDC_{95} for UGS, MGS and CGS (MDC_{95}=19.49-34.76 cm/s) are generally higher than the values estimated in community-dwelling healthy adults (MDC_{95}=13.6 cm/s) [22], community-dwelling and hospitalised fallers (MDC_{95}=12.4-15.5 cm/s) [32] and in those post-stroke (MDC_{95}=20 cm/s) [33]. These differences may be due to the position on the performance scale as participants in these studies demonstrated poorer mobility than participants in the SHARE-TILDA study [22 32 33].

Many longitudinal or intervention based studies vary widely in sample characteristics, co-morbidity and time intervals between assessments. This makes cross-study comparisons difficult and therefore reliability measures are best estimated for each sample and for groups with specific diagnoses. This study provides guidance on MDC across the range of function in a generally healthy, population-based sample, when measurements are compared weeks or months apart. These estimates should be used when assessing individual changes in mobility performance over

this time-scale, when calculating required sample sizes for studies using these outcomes or applying methods to adjust for measurement error in epidemiological studies. Participants in this study were relatively healthy and so are unlikely to demonstrate a genuine change in performance in the time period examined.

These results show the significant effect of inter-rater variation even with two highly trained and experienced research nurses. This suggests that changing rater introduces additional variance in the measures beyond within-participant variation. The effect was observed in the GAITRite® assessment as well as stopwatch based tests suggesting that rater differences in reaction time do not explain this. Both nurses were highly experienced and followed standardised protocols, however one explanation could be that they have different styles of interaction with respondents, which may have impacted on the respondent's understanding of the task, or their motivation and subsequent desire to perform well. This emphasises the importance of providing appropriate training for all raters to ensure that measurements are as accurate and consistent as possible. Where possible, analyses should be adjusted to account for differences between the raters conducting the assessments.

Study Strengths and Limitations

A strength of this study is the population-based sample of relatively healthy middle-aged and older adults used in the analysis. In addition, our estimates of reliability remove time of day and rater effects. For measures that are skewed, a different MDC may be required depending on whether performance is at the higher or lower ends of the spectrum. To account for this, we represent relevant findings on the multiplicative (logarithmic) scale and the additive scale. Although a stopwatch is the easiest and most cost effective way to measure gait speed, the GAITRite® mat is

frequently used in research. Therefore, this analysis provides useful guidance on data obtained using simple and more complex instruments.

Conclusion

Gait speed obtained during normal walking conditions and when completing a manual dual task are repeatable when performed at time intervals of several weeks to months, with lower reliability observed for the cognitive dual walk, TUG and RCS. There is also a potentially large effect of rater, even for measures that are automatically measured. The estimates of MDC are presented for a population based sample of relatively healthy middle-aged and older Irish adults and can be used to assess changes in performance in individuals drawn from comparable populations. Similar robust reliability studies are recommended to inform the use and interpretation of repeated assessments in other populations such as those with specific co-morbidities. Additional analysis using anchor-based approaches could be used to examine if these changes are of clinical importance.

Author contributions:

Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work – OD, GS, AB-S, RAK; Drafting the work or revising it critically for important intellectual content – OD, GS, AB-S, RAK; Final approval of the version to be published – OD, GS, AB-S, RAK; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved – OD, GS, AB-S, RAK.

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Table 1. Mobility performance scores obtained at baseline and repeat assessments, with different raters and at different times of day.

	Assessment		Rater[a]		Time of day[b]	
	Baseline	**Repeat**	**Nurse 1**	**Nurse 2**	**Test AM**	**Test PM**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
TUG (s)	8.88 (1.39)	8.87 (1.54)	8.13 (1.20)	9.35 (1.51)***	8.83 (1.49)	8.69 (1.25)
log(TUG)	2.17 (0.02)	2.17 (0.01)	2.08 (0.02)	2.22 (0.02)***	2.16 (0.02)	2.15 (0.02)
RCS (s)	12.49 (2.87)	12.02 (2.48)*	11.80 (2.27)	12.89 (2.88)***	12.17 (2.99)	12.00 (2.46)
logRCS	2.50 (0.22)	2.46 (0.21)*	2.45 (0.20)	2.53 (0.24)**	2.47 (0.24)	2.46 (0.22)
UGS (cm/s)	137.95 (20.21)	138.20 (19.32)	145.82 (18.94)	138.46 (17.85)***	137.62 (17.68)	137.74 (17.38)
MGS (cm/s)	116.76 (21.84)	118.71 (19.93)	123.07 (18.95)	118.07 (20.45)**	117.86 (19.85)	122.19 (17.21)*
CGS (cm/s)	115.23 (24.08)	115.15 (25.21)	118.29 (25.24)	117.40 (20.99)	117.45 (24.01)	118.84 (20.18)

Notes: TUG, Timed Up-and-Go; RCS, repeated chair stands; UGS, usual gait speed; MGS, manual dual task gait speed; CGS, cognitive dual task gait speed

[a] Rater scores are calculated only among participants who changed rater at the repeat assessment

[b] Time of day scores are calculated only among participants who changed time of day at the repeat assessment.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 2. Variance and reliability estimates for all mobility tests.

	$SD_{between}$ (95% CI)	SEM (95% CI)	ICC (95% CI)	MDC_{90}	MDC_{95}
TUG (s)	1.31 (1.12-1.52)	0.75 (0.66-0.85)	0.75 (0.66-0.82)	1.75	2.08
logTUG	0.13 (0.11-0.15)	0.09 (0.08-0.10)	0.71 (0.61-0.79)	0.2	0.24
RCS (s)	2.29 (1.93-2.70)	1.63 (1.43-1.86)	0.66 (0.55-0.76)	3.8	4.52
logRCS	0.18 (0.16-0.22)	0.13 (0.11-0.14)	0.68 (0.57-0.77)	0.29	0.35
UGS (cm/s)	18.65 (16.34-21.29)	7.03 (6.20-7.98)	0.88 (0.83-0.91)	16.4	19.49
MGS (cm/s)	19.57 (17.04-22.46)	8.97 (7.90-10.19)	0.83 (0.76-0.88)	20.93	24.87
CGS (cm/s)	22.73 (19.62-26.34)	12.53 (10.99-14.28)	0.77 (0.68-0.83)	29.24	34.73

Notes: SEM, standard error of the measurement; TUG, Timed Up-and-Go; RCS, repeated chair stands; UGS, usual gait speed; MGS, manual dual task gait speed; CGS, cognitive dual task gait speed; ICC, intra-class correlation; MDC, minimum detectable change

Figure 1: Flow chart of participation in the study

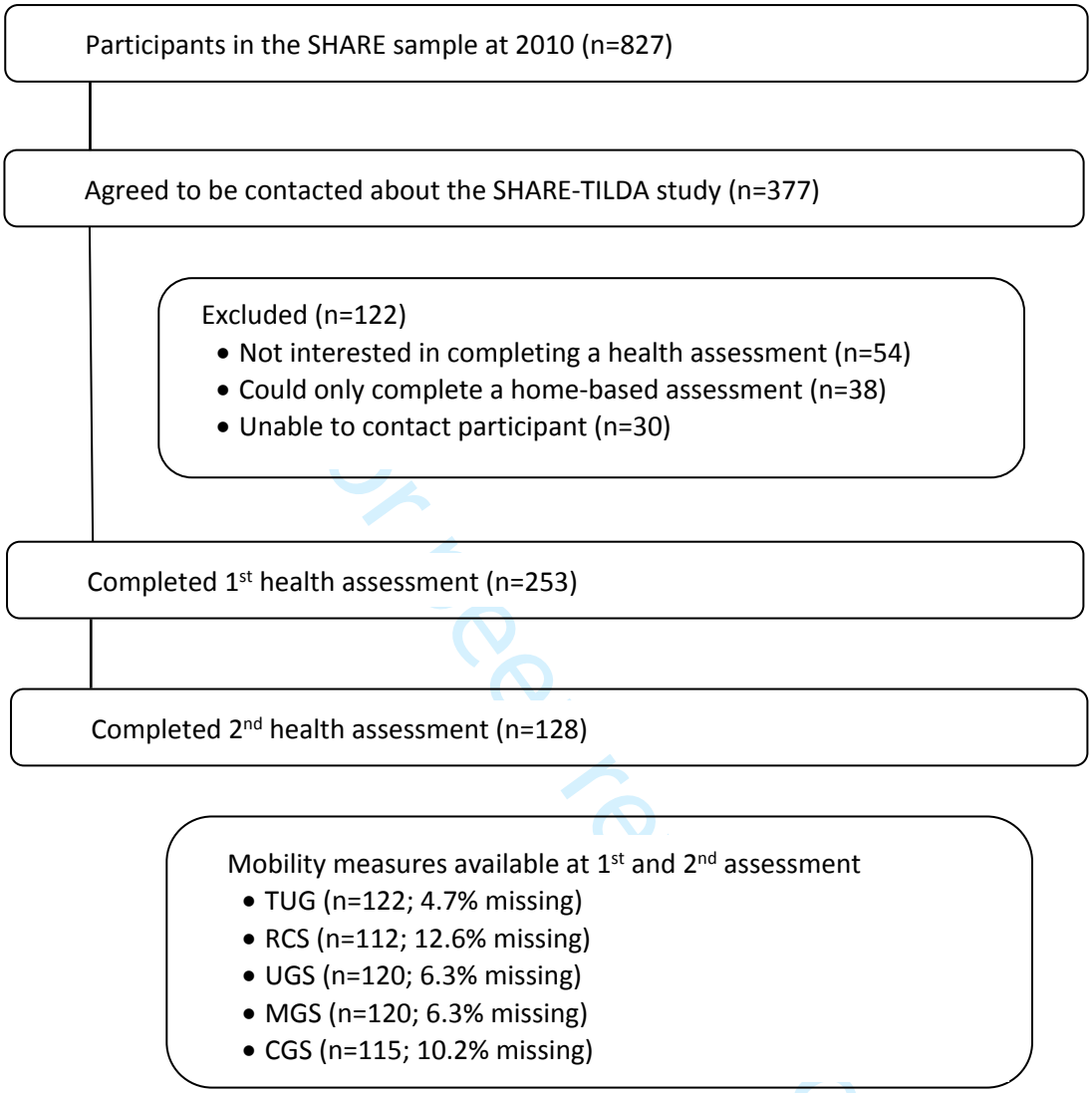
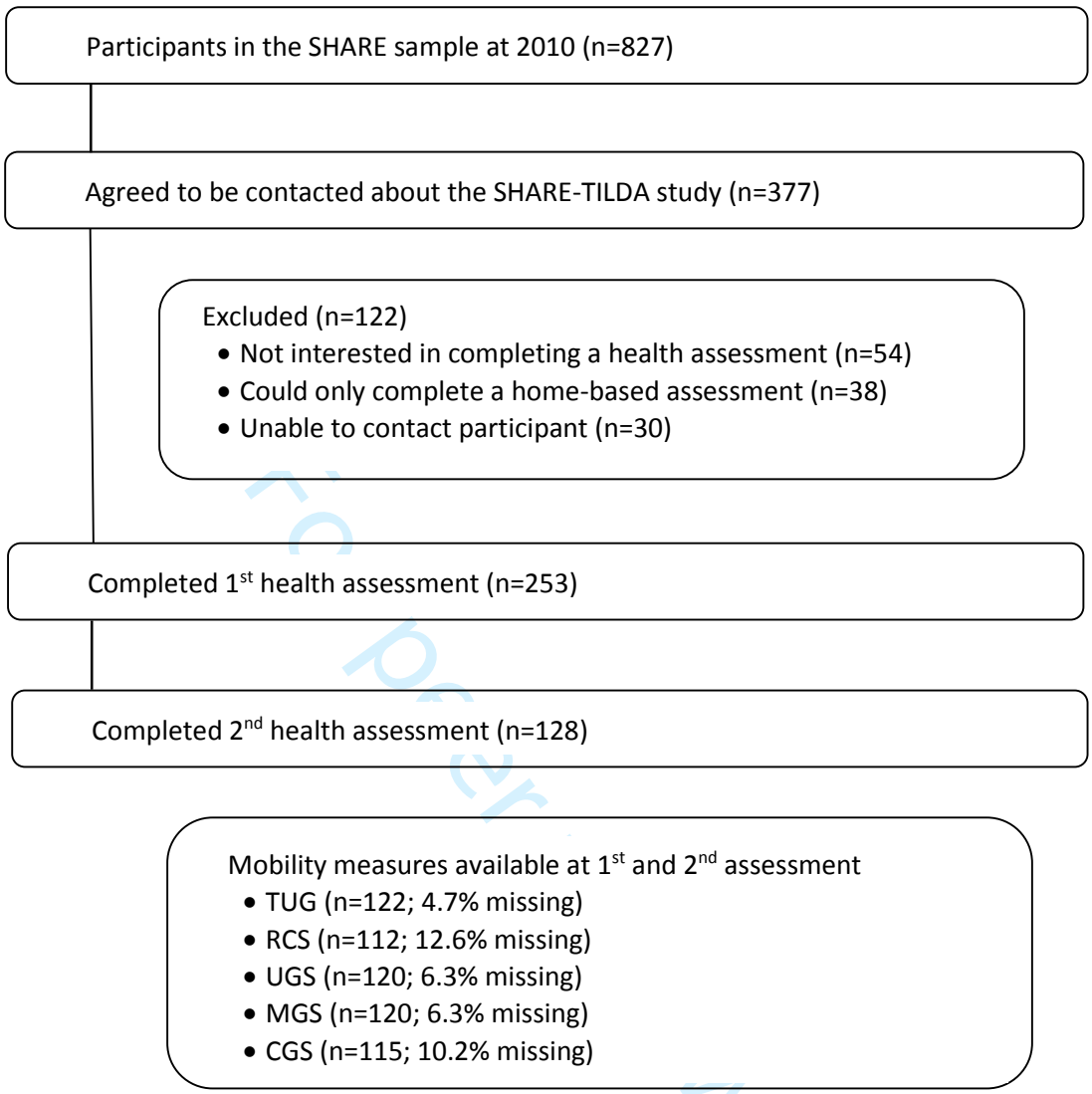


Figure 1: Exclusion criteria used to establish eligible participants for this analysis.

Note: CGS, cognitive dual task gait speed; MGS, manual dual task gait speed; RCS, repeated chair stands; SHARE, Survey for Health Ageing and Retirement in Europe; TILDA, The Irish Longitudinal Study on Ageing; TUG, Timed Up-and-Go; UGS, usual gait speed.



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Reliability, measurement error and minimum detectable change in mobility measures: a cohort study of community-dwelling adults aged 50 years and over in Ireland

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Reliability, measurement error and minimum detectable change in mobility measures: a cohort study of community-dwelling adults aged 50 years and over in Ireland

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Abstract

Objective: To examine the effects of repeat assessments, rater and time of day on reliability of mobility measures using a population-based sample of Irish adults aged ≥50 years.

Design: Test-retest cohort reliability study.

Setting: Academic health assessment centre of The Irish Longitudinal Study on Ageing (TILDA).

Participants: 128 community-dwelling adults from the Survey for Health, Ageing and Retirement in Europe (SHARE) Ireland study who agreed to take part in the SHARE-Ireland / TILDA collaboration.

Interventions: Not applicable.

Outcome Measures: Participants performed Timed Up-and-Go (TUG), repeated chair stands (RCS) and walking speed tests administered by one of two raters. Repeat assessments were conducted 1-4 months later. Participants were randomised with respect to a change in time (morning, afternoon) and whether or not the rater was changed between assessments. Within- and between-participant variance for each measure was estimated using mixed effects models. Intra-class correlation (ICC), standard error of measurement (SEM) and minimum detectable change (MDC) were reported.

Results: Average performance did not vary between baseline and repeat assessments in any test, except RCS. There were inter-rater effects for most tests (P<.001) but limited time of day effects. Reliability varied from ICC=0.66 (RCS) to ICC=0.88 (usual gait speed). MDC was 2.08 s for TUG, 4.52 s for RCS and ranged from 19.49-34.73 cm/s for walking speed tests.

Conclusions: Reliability varied for each test when measurements are obtained over 1-4 months with most variation due to rater effects. Usual and motor dual task gait speed demonstrated highest reliability. MDC estimates provide guidance on whether longitudinal change in a similar group represents a genuine change in performance.

Key words: repeatability, physical performance tests, longitudinal change, epidemiology

Article summary

Strengths and limitations of this study

- This study provides information on the effects of repeat assessments, rater and time of day on test-retest reliability of mobility measures obtained over 1-4 months using a population-based sample of relatively healthy middle-aged and older aged ≥50 years in Ireland.
- The use of common tests such as Timed Up-and-Go, repeated chair stands and GAITRite assessments makes this analysis relevant for other studies looking at change in mobility.
- Mixed effects models were used to estimate within- and between-participant variance for each measure allowing intra-class correlation (ICC), standard error of measurement (SEM) and minimum detectable change (MDC) to be presented.
- For some measures, MDC was presented on the multiplicative (logarithmic) scale and the additive scale to account for skewness and to ensure that findings are applicable across all levels of performance.
- Changes in exercise levels, activities, medications and current injury status could contribute to measurement variation.

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Competing interests: None declared

Data sharing statement: The anonymised SHARE-TILDA dataset is available through the on-site "hot desk" facility at TILDA, Trinity College Dublin. Researchers should contact tilda@tcd.ie for more information.

Introduction

Performance based measures such as Timed Up-and-Go (TUG), repeated chair stands (RCS) and walking speed tests are commonly used to assess mobility and lower limb function of older adults in clinical and research settings [1]. These measures are good predictors of falls, disability, cognitive decline and mortality [2-4]. To be useful, they also need to be reliable (consistent when measured on several occasions and when there is no change in a subject's underlying performance) and responsive (able to detect a change when there is one) [5]. Good reliability allows changes in measurements to be tracked over time [6].

However, all tests are subject to measurement error due to within-subject, inter-trial, inter-rater and day-to-day variation, and other external factors. This has several implications. Clinically, if an individual improves or declines between two testing sessions, it is important to know how likely it is that the observed change is a genuine change in performance and not due to measurement error. In research settings, unreliable measures can lead to regression dilution bias or false positive associations when testing predictors of longitudinal change [7]. To account for this, several measures of relative reliability i.e. intra-class correlation (ICC), and absolute reliability i.e. standard error of measurement (SEM) and minimum detectable change (MDC), are often reported [8].

SEM is the standard deviation of the measurement error of a measure within an individual, for a given 'true' value of the underlying construct. The SEM determines the MDC, which is the smallest difference between two single observations that can be confidently attributed to a genuine difference and not measurement error. ICC is a measure of the proportion of variance within a population that is attributable to variance across individuals as opposed to measurement error within individuals. As opposed to SEM and MDC, ICC depends on both the SEM and the variation

between members of a sample, and so is not usually comparable or applicable across samples with different levels of heterogeneity.

The within-session and one week test-retest reliability of TUG in community-dwelling, older adults is well known, and is known to be high (ICC≥0.96) [9-11] in various populations as is the inter-rater [12] [13] and intra-rater reliability [12]. MDC at the 95% confidence level (MDC_{95}) has been reported to vary between 3.33-6.87 s in healthy and cognitively impaired older adults [14-16] and up to 11 sec in Parkinson's disease patients [17]. The within-session test-retest reliability of RCS is also very high (ICC=0.93-0.95) [9] [18], however SEM and MDC for community-dwelling adults are not known.

Walking speed can be measured using stopwatches, timing gates or sensored mats. The test-retest reliability of usual gait speed (UGS) measured using a GAITRite® walkway has been reported to be between ICC=0.84 and 0.97 for assessments given up to two weeks apart [19-25]. Similar values have been reported for one hour test-retest reliability of dual task gait speed (ICC=0.85-0.93) [19] [20]. Fewer studies have reported SEM or MDC in healthy populations with MDC values of 12.4-13.6 cm/s reported for UGS [20] [22] and 15.5 cm/s for dual task gait speed [20]. However, reliability of dual task gait speed may also be dependent on the actual dual task and therefore is not comparable across studies unless the same test has been used.

Here we report the test-retest reliability measured by ICC, SEM and MDC in a pragmatic epidemiologic setting. We explore how reliability changes when lag between assessments varies between 1 month and 4 months, when rater changes or is held constant, and whether or not time of assessment varies, in a large sample of healthy adults aged 50 and older recruited at random from the population.

In epidemiologic settings, the measures we have tested are commonly used as proxies for the underlying general cognitive and physical health status of participants around the time of the assessment. Short-term fluctuations in these measures, for example due to acute illness or day-to-day variation, add error to these outcomes along with measurement error associated with the instruments themselves. Hence when comparing measures over longer time periods, that is, years or decades typical of epidemiologic research, it is important to know how well single measures of physical and cognitive function reflect the underlying health status of the participant, net of any factors that might cause a short-term fluctuation. Therefore, we tested the concordance between pairs of measures between one and four months apart, to estimate the error association with both measurement and short-term variation in each measure. Understanding natural variation in outcomes over one to four months is also essential when planning clinical trials with follow-up time in this range.

Methods

Participants

Participants were a subsample from the Survey of Health, Ageing and Retirement in Europe (SHARE), a longitudinal, cross-national study on health, socio-economic status and social and family networks of more than 80,000 individuals aged 50 years and over across Europe [26]. The SHARE-Ireland sample (n=1,119) was recruited in Ireland between 2006 and 2007 with a response rate of 55% [27]. A collaboration between SHARE-Ireland and The Irish Longitudinal Study on Ageing (TILDA) was established to understand the measurement properties of a comprehensive health assessment among a representative sample of the European population. Reliability of cognitive measures and blood pressure dynamics based on this sample have been published previously [28 29].

The extant SHARE-Ireland cohort at 2010 (n=827) was contacted and invited to take part in a health assessment that included the same tests and followed the same protocols as those used by TILDA. The health assessment was delivered to the SHARE-Ireland participants by TILDA research nurses within the TILDA health assessment centre based at Trinity College Dublin. Initial contact was made by post and followed up by telephone between September 2011 and March 2012, with 377 participants consenting to receive further information about the study. Of these, 253 agreed to an initial health assessment (see Figure 1). Ethical approval for this sub-study was obtained from the Faculty of Health Sciences Research Ethics Committee at Trinity College Dublin. All participants provided informed consent.

Health assessments and interview

The full health assessment included a 3 hour battery of tests assessing cognitive function, gait and mobility, cardiovascular function and vision [30]. Health assessments were conducted by two highly trained research nurses with approximately 3 years' experience delivering these specific tests in the current setting. Training took approximately one month and nurses used detailed and standardised health assessment protocols which included clear explanations and demonstrations to ensure consistent instructions were provided to all participants. Nurses also underwent periodic quality control procedures to ensure adherence to the protocols.

A short interview was administered by the nurses before the health assessment to capture information on health, chronic disease, disability, employment, social and financial circumstances. Co-morbidity was assessed by asking participants if a doctor had ever told them that they had any of the following conditions: heart attack, high blood pressure, high cholesterol, stroke, diabetes, chronic lung disease, asthma, arthritis, osteoporosis, cancer, ulcer, Parkinson's disease, cataracts,

age related macular degeneration, Alzheimer's disease and atrial fibrillation. The number of conditions was summed and categorised according to 0, 1, 2 or ≥3 conditions. Participants self-rated their health as excellent, very good, good, fair or poor.

On completing the health assessment, 180 participants were invited to take part in an identical repeat assessment, scheduled after 1-4 months. In total, 128 participants (58 men) agreed to the repeat assessment giving a response rate of 71% (25 refused and 27 were unavailable to attend the repeat assessment within the required timeframe).

Repeat assessments were arranged to distinguish within-person variation from variation caused by changing rater or time of day. The same research nurse conducted the baseline and repeat assessments for half of the participants while another nurse conducted the repeat assessment for the other half of the participants. Time of day when the assessment took place (morning or afternoon) was also changed for half of the participants. Change of rater, change of time of day and delay between assessments (dichotomised at the median) were randomised using a minimisation routine designed to achieve balance across these covariates, as well as the age group and sex of participants. Other factors that could influence performance e.g. health assessment protocols, assessment location, equipment, etc. were held constant across both assessments.

Physical performance tests

Participants completed several mobility tests - TUG, RCS and gait assessments in single and dual task conditions. TUG, which is a common functional mobility test [12] was completed once using walking aids if required. The time taken to rise from the chair (seat height 46 cm), walk 3 m at normal pace, turn around, walk back to the chair and sit down again was recorded using a

stopwatch. RCS is an indicator of mobility and lower limb muscular endurance [31]. Participants began in a seated position and the time taken to stand up five times was recorded. Participants were asked to keep their arms folded across their chest throughout the test.

Gait assessment took place using a 4.88 m computerised walkway with embedded pressure sensors (GAITRite®, CIR Systems Inc, New York, USA). Participants performed two walks at their normal pace followed by two walks under cognitive dual task conditions and manual dual task conditions. The cognitive task was to recite alternate letters of the alphabet (A-C-E, etc). The manual task was to carry a glass of water filled to 7 mm from the top. Participants started and finished 2.5 m before and after the walkway to allow for acceleration and deceleration. The two walks in each condition were combined to give mean UGS, mean cognitive dual task gait speed (CGS) and mean manual dual task gait speed (MGS).

Statistical analysis

This analysis includes participants who completed and had valid scores for baseline and repeat assessments for each of the mobility tests (Figure 1). Missing data was not imputed. TUG and RCS are not normally distributed and the variance is strongly related to average scores, therefore analyses were conducted and findings are presented on the natural scale for ease of interpretation and as log transformed values to allow normally distributed stable variances across groups.

To look for practice effects, rater effects and time of day effects, mean mobility performance scores were compared (i) between baseline and repeat assessments, (ii) between raters, and (iii) at different times of day using paired t-tests.

To estimate reliability, mixed effects regression models were then used to find the variation between and within participants. Baseline/repeat assessment, rater and time of day were included as fixed effects. The standard deviations of the within-person and between-person variance components arising from these models were used to estimate the residual ICC for all measures within this population. The ICC is the proportion of total variance not accounted for by within person variation, that is, $ICC = \frac{{SD_{Between}}^2}{{SD_{Between}}^2 + {SD_{Within}}^2}$. Koo & Li [32] recommend that the 95% confidence interval of the ICC estimate is used to evaluate reliability and suggest the following guidelines: <0.5 indicates poor reliability, 0.5-0.75 indicates moderate reliability, 0.75-0.90 indicates good reliability, >0.90 indicates excellent reliability.

SEM is equivalent to SD_{Within}, the standard deviation of the variance of the test within individuals, assuming no genuine change in function, and so is an absolute measure of test reliability. MDC is the magnitude of observable change required to exceed the anticipated measurement error and within-subject variability. It is calculated by $\sqrt{2} \times Z \times SD_{Within}$, where Z=1.96 for the 95% limit (that is, 95% of observed differences between pairs of observations will be within this limit given there is no true difference) and Z=1.65 for the 90% limit.

Findings from previous studies suggest that the variability of TUG is related to its magnitude; that is an individual with a TUG time of 4 s is likely to have a lower absolute variation than someone with a TUG time of 12 s. For this reason, we estimate the reliability of TUG on a log-scale, as errors are more likely to be multiplicative than additive, and TUG is often analysed on a logarithmic scale in epidemiological settings.

Participant and public involvement

This research was done without participant involvement. Participants were not invited to comment on the study design and were not consulted to develop participant relevant outcomes or interpret the results. Participants were not invited to contribute to the writing or editing of this document for readability or accuracy.

Results

The median age of the sample was 66 years (range 51-89 years, IQR 61-71 years) and 55.5% were female. The majority of the sample (n=103, 81.8%) rated their own health as excellent, very good or good, 57.8% reported having no history of cardiovascular or chronic conditions while 16.0% had 3 or more conditions. Median delay between assessments was 88 days (range 28-141 days, IQR 70-104 days). Fifty-one participants had a different nurse at the repeat assessment while 60 participants had their assessment at a different time of day.

Table 1 shows the mobility performance scores at baseline and repeat assessments, with different raters and at different times of day, while Table 2 shows the variance and reliability estimates for all mobility measures. In general, this sample was relatively robust with good levels of mobility as evidenced when comparing mean TUG and gait speed performance to normative data for community-dwelling adults in Ireland [1]. Norms for RCS are not available for the Irish population, but average performance was slightly slower than age-matched norms presented in the literature [33] although wide variation in testing protocols has been recognised [34].

Timed Up-and-go

TUG did not vary between baseline and repeat assessments or by time of day, however there was a significant rater effect with a difference of 1.22 s (P<.001) between the two nurses. The

between-person SD was 1.31 s. The SEM was 0.75 s, leading to moderate-good reliability (ICC=0.75) and MDC estimates of 1.75 s at the 90% level and 2.08 s at the 95% level. This means that a difference of 1.75-2.08 s between two assessments in the same individual can be expected by chance depending on the confidence interval used and when controlling for all other factors (rater, time between assessments and time of day). Analysis of TUG on a logarithmic scale suggests similar reliability (ICC=0.71), and a SEM of 0.09. The MDC_{95} of 0.24 for log(TUG) suggests that a relative change in TUG of up to 27% (the inverse logarithm of 0.24 is 1.27) might be expected by chance in 95% of paired samples. This finding is applicable across the spectrum of baseline TUG scores.

Repeated chair stands

RCS was completed slightly more quickly at the repeat measurement (difference=0.47 s, *P*=.04) and when the assessment was carried out by Nurse 1 (difference=1.09 s, *P*<.001) but did not vary with time of day. The ICC was 0.66 and SEM was 1.63 s while MDC was estimated to be 3.80 s at the 90% level and 4.52 s at the 95% level. Time to complete RCS was also analysed on the log scale, where reliability was similar (ICC=0.68), SEM was 0.13 and MDC was 0.35 at the 95% confidence level.

Usual gait speed

UGS did not vary between baseline and repeat assessment or by time of day, however there was a significant rater effect with a difference of 7.36 cm/s (*P*<.001). Reliability was good (ICC=0.88) as the between-person SD (18.65 cm/s) was much higher than the SEM (7.03 cm/s), resulting in a MDC_{90} of 16.40 cm/s and MDC_{95} of 19.49 cm/s.

Manual dual task gait speed

Gait speed became less reliable as the complexity of the dual task conditions increased. MGS was consistent across repeat assessments but varied by rater (difference=4.88 cm/s, *P*=.02) and time of day (difference=3.62 s, *P*=0.03). ICC was lower than was observed for UGS (ICC=0.83), SEM was higher (8.97 cm/s) and consequently so was MDC_{90} (20.93 cm/s) and MDC_{95} (24.87 cm/s).

Cognitive dual task gait speed

CGS did not vary by repeat assessment, rater or time of day, however reliability estimates were poorest out of all gait speed measures (ICC=0.77; SEM=12.53 cm/s; MDC_{95}=34.73 cm/s).

For all observed rater effects, including those where performance was automatically measured (i.e. with GAITRite), participants completed the mobility tasks more quickly when assessed by Nurse 1.

Discussion

We report test-retest reliability, SEM and MDC of commonly used mobility tests in a sample of relatively healthy, community-dwelling Irish adults aged 50 years and older. We found good test-retest reliability for walking speed and motor dual task walking speed and moderate-good reliability for TUG and cognitive dual task walking speed however, the lowest ICC was observed for RCS. These findings contrast to previous studies which reported moderate to excellent reliability for all of these measures [9-11 18 19 21-25 35]. As ICC depends on the distribution of scores within the sample it is estimated in and reflects relative reliability, it is specific to that particular setting and population [8]. Lower reliability here is likely to reflect more homogeneous population

representative samples (hence lower between-person standard deviations) compared to clinical samples with varying degrees of impairment.

SEM and MDC provide an indication of absolute reliability. MDC allows the assessor to interpret if an observed change score is above that expected due to measurement error and therefore if it represents a genuine change in performance. In this study, MDC for TUG (2.08 s at the 95% level) is lower than that presented in previous studies of healthy (MDC_{95}=4.71 s) [16] and cognitively impaired (MDC_{95}=5.88-6.87 s) older adults [14 15] and Parkinson's disease patients (MDC_{95}=11 s) [17]. However, reporting variability in TUG as a percentage change in performance rather than in absolute terms may be more appropriate. In contrast, MDC_{95} for UGS, MGS and CGS (MDC_{95}=19.49-34.76 cm/s) are generally higher than the values estimated in community-dwelling healthy adults (MDC_{95}=13.6 cm/s) [22], community-dwelling and hospitalised fallers (MDC_{95}=12.4-15.5 cm/s) [35] and in those post-stroke (MDC_{95}=20 cm/s) [36]. These differences may be due to the position on the performance scale as participants in these studies demonstrated poorer mobility than participants in the SHARE-TILDA study [22 35 36].

Many longitudinal or intervention based studies vary widely in sample characteristics, co-morbidity and time intervals between assessments. This makes cross-study comparisons difficult and therefore reliability measures are best estimated for each sample and for groups with specific diagnoses. This study provides guidance on MDC across the range of function in a generally healthy, population-based sample, when measurements are compared weeks or months apart. These estimates should be used when assessing individual changes in mobility performance over this time-scale e.g. when examining the effects of an intervention or patient progression, when calculating required sample sizes for studies using these outcomes or when applying methods to

adjust for measurement error in epidemiological studies. Participants in this study were relatively healthy and while acute changes in health and performance can occur even with shorter follow-up, they are unlikely to demonstrate a consistent, genuine change in performance in the time period examined. While using a shorter time period and/or same-day repeated measurements would likely provide higher estimates of reliability, this approach was taken to reflect the variation that is likely to be observed in real-world clinical and research settings over a longer time period.

These results show the significant effect of inter-rater variation even with two highly trained and experienced research nurses. This suggests that changing rater introduces additional variance in the measures beyond within-participant variation. The effect was observed in the GAITRite® assessment as well as stopwatch based tests suggesting that rater differences in reaction time do not explain this. Both nurses were highly experienced and followed standardised protocols, however one explanation could be that they have different styles of interaction with respondents, which may have impacted on the respondent's understanding of the task, or their motivation and subsequent desire to perform well. This emphasises the importance of providing appropriate training for all raters to ensure that measurements are as accurate and consistent as possible. In an effort to detect and address these differences, studies could examine within-day rater differences on a small number of participants although only a limited number of tests would be feasible to avoid fatigue effects. Where possible, analyses should also be adjusted to account for differences between the raters conducting the assessments.

Study Strengths and Limitations

A strength of this study is the population-based sample of relatively healthy middle-aged and older adults used in the analysis. In addition, our estimates of reliability remove time of day and rater

effects. For measures that are skewed, a different MDC may be required depending on whether performance is at the higher or lower ends of the spectrum. To account for this, we represent relevant findings on the multiplicative (logarithmic) scale and the additive scale. Although a stopwatch is the easiest and most cost effective way to measure gait speed, the GAITRite® mat is frequently used in research. Therefore, this analysis provides useful guidance on data obtained using simple and more complex instruments. However, there are also a number of limitations in this study. Participants were not asked to restrict their exercise levels, activities or medications before the assessments, all of which could contribute to measurement variation. While the participants did not report any injuries that prevented them from doing the tests, it is also possible that they may have had a low level injury or have been recovering from an injury at either assessment which may account for some of the within-subject variation observed.

Conclusion

Gait speed obtained during normal walking conditions and when completing a manual dual task are repeatable when performed at time intervals of several weeks to months, with lower reliability observed for the cognitive dual walk, TUG and RCS. There is also a potentially large effect of rater, even for measures that are automatically measured. The estimates of MDC are presented for a population based sample of relatively healthy middle-aged and older Irish adults and can be used to assess changes in performance in individuals drawn from comparable populations. Similar robust reliability studies are recommended to inform the use and interpretation of repeated assessments in other populations such as those with specific co-morbidities. Additional analysis using anchor-based approaches could be used to examine if these changes are of clinical importance.

Author contributions:

Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work – OD, GS, AB-S, RAK; Drafting the work or revising it critically for important intellectual content – OD, GS, AB-S, RAK; Final approval of the version to be published – OD, GS, AB-S, RAK; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved – OD, GS, AB-S, RAK.

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Table 1. Mobility performance scores obtained at baseline and repeat assessments, with different raters and at different times of day.

	Assessment		Rater[a]		Time of day[b]	
	Baseline	Repeat	Nurse 1	Nurse 2	Test AM	Test PM
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
TUG (s)	8.88 (1.39)	8.87 (1.54)	8.13 (1.20)	9.35 (1.51)***	8.83 (1.49)	8.69 (1.25)
log(TUG)	2.17 (0.02)	2.17 (0.01)	2.08 (0.02)	2.22 (0.02)***	2.16 (0.02)	2.15 (0.02)
RCS (s)	12.49 (2.87)	12.02 (2.48)*	11.80 (2.27)	12.89 (2.88)***	12.17 (2.99)	12.00 (2.46)
logRCS	2.50 (0.22)	2.46 (0.21)*	2.45 (0.20)	2.53 (0.24)**	2.47 (0.24)	2.46 (0.22)
UGS (cm/s)	137.95 (20.21)	138.20 (19.32)	145.82 (18.94)	138.46 (17.85)***	137.62 (17.68)	137.74 (17.38)
MGS (cm/s)	116.76 (21.84)	118.71 (19.93)	123.07 (18.95)	118.07 (20.45)**	117.86 (19.85)	122.19 (17.21)*
CGS (cm/s)	115.23 (24.08)	115.15 (25.21)	118.29 (25.24)	117.40 (20.99)	117.45 (24.01)	118.84 (20.18)

Notes: TUG, Timed Up-and-Go; RCS, repeated chair stands; UGS, usual gait speed; MGS, manual dual task gait speed; CGS, cognitive dual task gait speed

[a] Rater scores are calculated only among participants who changed rater at the repeat assessment

[b] Time of day scores are calculated only among participants who changed time of day at the repeat assessment.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$

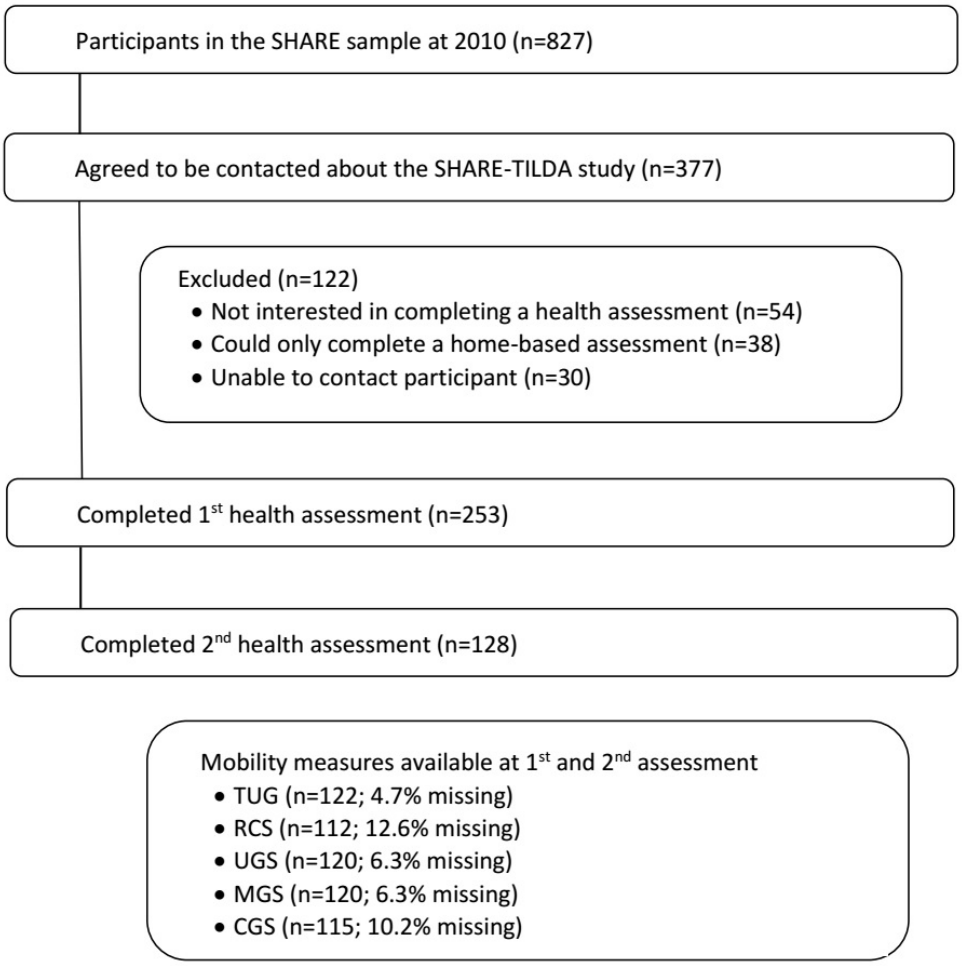
Table 2. Variance and reliability estimates for all mobility tests.

	$SD_{between}$ (95% CI)	SEM (95% CI)	ICC (95% CI)	MDC_{90}	MDC_{95}
TUG (s)	1.31 (1.12-1.52)	0.75 (0.66-0.85)	0.75 (0.66-0.82)	1.75	2.08
logTUG	0.13 (0.11-0.15)	0.09 (0.08-0.10)	0.71 (0.61-0.79)	0.2	0.24
RCS (s)	2.29 (1.93-2.70)	1.63 (1.43-1.86)	0.66 (0.55-0.76)	3.8	4.52
logRCS	0.18 (0.16-0.22)	0.13 (0.11-0.14)	0.68 (0.57-0.77)	0.29	0.35
UGS (cm/s)	18.65 (16.34-21.29)	7.03 (6.20-7.98)	0.88 (0.83-0.91)	16.4	19.49
MGS (cm/s)	19.57 (17.04-22.46)	8.97 (7.90-10.19)	0.83 (0.76-0.88)	20.93	24.87
CGS (cm/s)	22.73 (19.62-26.34)	12.53 (10.99-14.28)	0.77 (0.68-0.83)	29.24	34.73

Notes: SEM, standard error of the measurement; TUG, Timed Up-and-Go; RCS, repeated chair stands; UGS, usual gait speed; MGS, manual dual task gait speed; CGS, cognitive dual task gait speed; ICC, intra-class correlation; MDC, minimum detectable change

Figure 1: Exclusion criteria used to establish eligible participants for this analysis.

Note: CGS, cognitive dual task gait speed; MGS, manual dual task gait speed; RCS, repeated chair stands; SHARE, Survey for Health Ageing and Retirement in Europe; TILDA, The Irish Longitudinal Study on Ageing; TUG, Timed Up-and-Go; UGS, usual gait speed.



Exclusion criteria used to establish eligible participants for this analysis.

245x247mm (96 x 96 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Location
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	P1, P2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	P2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	P5-7
Objectives	3	State specific objectives, including any prespecified hypotheses	P6
Methods			
Study design	4	Present key elements of study design early in the paper	P7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	P7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	P7-8
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	P8-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	P8-10
Bias	9	Describe any efforts to address potential sources of bias	P10
Study size	10	Explain how the study size was arrived at	P7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	P10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	P10-11
		(*b*) Describe any methods used to examine subgroups and interactions	P10-11
		(*c*) Explain how missing data were addressed	P10
		(*d*) If applicable, explain how loss to follow-up was addressed	-
		(*e*) Describe any sensitivity analyses	-
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	P8, 12, Fig 1
		(b) Give reasons for non-participation at each stage	P8
		(c) Consider use of a flow diagram	Fig 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	P12
		(b) Indicate number of participants with missing data for each variable of interest	Fig 1
		(c) Summarise follow-up time (eg, average and total amount)	P12
Outcome data	15*	Report numbers of outcome events or summary measures over time	P23
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear	P12, 14, 24

		which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	-
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
Discussion			
Key results	18	Summarise key results with reference to study objectives	P12-14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	P17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	P14-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	P15-17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	P4

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Reliability, measurement error and minimum detectable change in mobility measures: a cohort study of community-dwelling adults aged 50 years and over in Ireland

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Reliability, measurement error and minimum detectable change in mobility measures: a cohort study of community-dwelling adults aged 50 years and over in Ireland

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Word count: 3161

Abstract

Objective: To estimate the effects of repeat assessments, rater and time of day on mobility measures and to estimate their variation between- and within- participants in a population-based sample of Irish adults aged ≥50 years.

Design: Test-retest study in a population representative sample.

Setting: Academic health assessment centre of The Irish Longitudinal Study on Ageing (TILDA).

Participants: 128 community-dwelling adults from the Survey for Health, Ageing and Retirement in Europe (SHARE) Ireland study who agreed to take part in the SHARE-Ireland / TILDA collaboration.

Interventions: Not applicable.

Outcome Measures: Participants performed Timed Up-and-Go (TUG), repeated chair stands (RCS) and walking speed tests administered by one of two raters. Repeat assessments were conducted 1-4 months later. Participants were randomised with respect to a change in time (morning, afternoon) and whether the rater was changed between assessments. Within- and between-participant variance for each measure was estimated using mixed effects models. Intra-class correlation (ICC), standard error of measurement (SEM) and minimum detectable change (MDC) were reported.

Results: Average performance did not vary between baseline and repeat assessments in any test, except RCS. The rater significantly affected performance on all tests except one, but time of day did not. Reliability varied from ICC=0.66 (RCS) to ICC=0.88 (usual gait speed). MDC was 2.08 s for TUG, 4.52 s for RCS and ranged from 19.49-34.73 cm/s for walking speed tests. There was no evidence for lower reliability of gait parameters with increasing time between assessments.

Conclusions: Reliability varied for each test when measurements are obtained over 1-4 months with most variation due to rater effects. Usual and motor dual task gait speed demonstrated highest reliability.

1 **Key words:** repeatability, physical performance tests, longitudinal change, epidemiology

2

Article summary

Strengths and limitations of this study

- This study provides information on the effects of repeat assessments, rater and time of day on test-retest reliability of mobility measures obtained over 1-4 months using a population-based sample of relatively healthy middle-aged and older adults aged ≥50 years in Ireland.
- The use of common tests such as Timed Up-and-Go, repeated chair stands and GAITRite assessments makes this analysis relevant for other studies looking at change in mobility.
- Mixed effects models were used to estimate within- and between-participant variance for each measure allowing intra-class correlation (ICC) and standard error of measurement (SEM) and minimum detectable change (MDC) to be presented, net of fixed effects.
- For some measures, MDC was presented on the multiplicative (logarithmic) scale as well as the natural additive scale to account for skewness and to ensure that findings are applicable across all levels of performance.
- Changes in exercise levels, activities, medications and current injury status could have contributed to measurement variation but these were not measured. However the fact that the measures did not become less reliable with increasing time since assessments suggests that this does not substantially affect the findings.

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Competing interests: None declared

Data sharing statement: The anonymised SHARE-TILDA dataset is available through the on-site "hot desk" facility at TILDA, Trinity College Dublin. Researchers should contact tilda@tcd.ie for more information.

Introduction

Performance based measures such as Timed Up-and-Go (TUG), repeated chair stands (RCS) and walking speed tests are commonly used to assess mobility and lower limb function of older adults in clinical and research settings [1]. These measures are good predictors of falls, disability, cognitive decline and mortality [2-4]. To be useful, they also need to be reliable (consistent when measured on several occasions and when there is no change in a subject's underlying performance) and responsive (able to detect a change when there is one) [5]. Good reliability allows changes in measurements to be tracked over time [6].

However, all tests are subject to measurement error due to within-subject, inter-trial, inter-rater effects. They are also liable to day-to-day variation due to patient level factors that do not reflect the underlying risk status that they are attempting to measure. This has several implications. Clinically, if an individual improves or declines between two testing sessions, it is important to know how likely it is that the observed change is a genuine change in status and is not due to measurement error or a transient effect. In research settings, unreliable measures can lead to regression dilution bias or false positive associations when testing predictors of longitudinal change [7]. To account for this, several measures of relative reliability i.e. intra-class correlation (ICC), and absolute reliability i.e. standard error of measurement (SEM) and minimum detectable change (MDC), are often reported [8].

SEM is the standard deviation of the measurement error of a measure within an individual, for a given 'true' value of the underlying construct. The SEM determines the MDC, which is the smallest difference between two single observations that can be confidently attributed to a genuine difference and not to measurement error. ICC is a measure of the proportion of variance within a

population that is attributable to variance across individuals as opposed to measurement error within individuals. As opposed to SEM and MDC, ICC depends on both the SEM and the variation between members of a sample, and so is not usually comparable or applicable across samples with different levels of heterogeneity.

The within-session and one week test-retest reliability of TUG in community-dwelling, older adults is well known, and is known to be high (ICC≥0.96) [9-11] in various populations as is the inter-rater [12] [13] and intra-rater reliability [12]. MDC at the 95% confidence level (MDC_{95}) has been reported to vary between 3.33-6.87 s in healthy and cognitively impaired older adults [14-16] and up to 11 sec in Parkinson's disease patients [17]. The within-session test-retest reliability of RCS is also very high (ICC=0.93-0.95) [9] [18], however SEM and MDC for community-dwelling adults are not known.

Walking speed can be measured using stopwatches, timing gates or sensored mats. The test-retest reliability of usual gait speed (UGS) measured using a GAITRite® walkway has been reported to be between ICC=0.84 and 0.97 for assessments given up to two weeks apart [19-25]. Similar values have been reported for one hour test-retest reliability of dual task gait speed (ICC=0.85-0.93) [19] [20]. Fewer studies have reported SEM or MDC in healthy populations with MDC values of 12.4-13.6 cm/s reported for UGS [20] [22] and 15.5 cm/s for dual task gait speed [20]. However, reliability of dual task gait speed may also be dependent on the actual dual task and therefore is not comparable across studies unless the same test has been used.

Here we report the test-retest reliability measured by ICC, SEM and MDC in a pragmatic epidemiologic setting. We explore how reliability changes when lag between assessments varies between 1 month and 4 months, when rater changes or is held constant, and whether or not time

of assessment varies, in a large sample of healthy adults aged 50 and older recruited at random from the population.

In epidemiologic settings, these measures are commonly used as proxies for the underlying general cognitive and physical health status of participants around the time of the assessment. Short-term fluctuations in these measures, for example due to acute illness or day-to-day variation, add error to these outcomes along with measurement error associated with the instruments themselves. Hence when comparing measures over longer time periods, that is, years or decades typical of epidemiologic research, it is important to know how well single measures of physical and cognitive function reflect the underlying health status of the participant, net of any factors that might cause a short-term fluctuation. Therefore, we tested the concordance between pairs of measures between one and four months apart, to estimate the error association with both measurement and day-to-day fluctuation in each measure. Understanding natural variation in outcomes over one to four months is also essential when planning clinical trials with follow-up time in this range, since this is the natural variation against which any treatment effect would be compared.

Methods

Participants

Participants were a subsample from the Survey of Health, Ageing and Retirement in Europe (SHARE), a longitudinal, cross-national study on health, socio-economic status and social and family networks of more than 80,000 individuals aged 50 years and over across Europe [26]. The SHARE-Ireland sample (n=1,119) was recruited in Ireland between 2006 and 2007 with a response rate of 55% [27]. A collaboration between SHARE-Ireland and The Irish Longitudinal Study on Ageing

(TILDA) was established to understand the measurement properties of a comprehensive health assessment among a representative sample of the European population. Reliability of cognitive measures and blood pressure dynamics based on this sample have been published previously [28 29].

The extant SHARE-Ireland cohort at 2010 (n=827) was contacted and invited to take part in a health assessment that included the same tests and followed the same protocols as those used by TILDA. The health assessment was delivered to the SHARE-Ireland participants by TILDA research nurses within the TILDA health assessment centre based at Trinity College Dublin. Initial contact was made by post and followed up by telephone between September 2011 and March 2012, with 377 participants consenting to receive further information about the study. Of these, 253 agreed to an initial health assessment (see Figure 1). Ethical approval for this sub-study was obtained from the Faculty of Health Sciences Research Ethics Committee at Trinity College Dublin. All participants provided informed consent.

Health assessments and interview

The full health assessment included a 3 hour battery of tests assessing cognitive function, gait and mobility, cardiovascular function and vision [30]. Health assessments were conducted by two highly trained research nurses with approximately 3 years' experience delivering these specific tests in the current setting. Training took approximately one month and nurses used detailed and standardised health assessment protocols which included clear explanations and demonstrations to ensure consistent instructions were provided to all participants. Nurses also underwent periodic quality control procedures to ensure adherence to the protocols.

A short interview was administered by the nurses before the health assessment to capture information on health, chronic disease, disability, employment, social and financial circumstances. Co-morbidity was assessed by asking participants if a doctor had ever told them that they had any of the following conditions: heart attack, high blood pressure, high cholesterol, stroke, diabetes, chronic lung disease, asthma, arthritis, osteoporosis, cancer, ulcer, Parkinson's disease, cataracts, age related macular degeneration, Alzheimer's disease and atrial fibrillation. The number of conditions was summed and categorised according to 0, 1, 2 or ≥3 conditions. Participants self-rated their health as excellent, very good, good, fair or poor.

On completing the health assessment, 180 participants were invited to take part in an identical repeat assessment, scheduled after 1-4 months. In total, 128 participants (58 men) agreed to the repeat assessment giving a response rate of 71% (25 refused and 27 were unavailable to attend the repeat assessment within the required timeframe).

Repeat assessments were arranged to distinguish within-person variation from variation caused by changing rater or time of day. The same research nurse conducted the baseline and repeat assessments for half of the participants while another nurse conducted the repeat assessment for the other half of the participants. Time of day when the assessment took place (morning or afternoon) was also changed for half of the participants. Change of rater, change of time of day and delay between assessments (dichotomised at the median) were randomised using a minimisation routine designed to achieve balance across these covariates, as well as the age group and sex of participants. Other factors that could influence performance e.g. health assessment protocols, assessment location, equipment, etc. were held constant across both assessments.

Physical performance tests

Participants completed several mobility tests - TUG, RCS and gait assessments in single and dual task conditions. TUG, which is a common functional mobility test [12] was completed once using walking aids if required. The time taken to rise from the chair (seat height 46 cm), walk 3 m at normal pace, turn around, walk back to the chair and sit down again was recorded using a stopwatch. RCS is an indicator of mobility and lower limb muscular endurance [31]. Participants began in a seated position and the time taken to stand up five times was recorded. Participants were asked to keep their arms folded across their chest throughout the test.

Gait assessment took place using a 4.88 m computerised walkway with embedded pressure sensors (GAITRite®, CIR Systems Inc, New York, USA). Participants performed two walks at their normal pace followed by two walks under cognitive dual task conditions and manual dual task conditions. The cognitive task was to recite alternate letters of the alphabet (A-C-E, etc). The manual task was to carry a glass of water filled to 7 mm from the top. Participants started and finished 2.5 m before and after the walkway to allow for acceleration and deceleration. The two walks in each condition were combined to give mean UGS, mean cognitive dual task gait speed (CGS) and mean manual dual task gait speed (MGS).

Statistical analysis

This analysis includes participants who completed and had valid scores for baseline and repeat assessments for each of the mobility tests (Figure 1). Missing data was not imputed. To look for practice effects, rater effects and time of day effects, mean mobility performance scores were compared (i) between baseline and repeat assessments, (ii) between raters, and (iii) at different times of day using paired t-tests.

To estimate reliability, mixed effects regression models were then used to find the variation between and within participants. Baseline/repeat assessment, rater and time of day were included as fixed effects. The standard deviations of the within-person and between-person variance components arising from these models were used to estimate the residual ICC for all measures within this population. The ICC used here is the proportion of total variance not accounted for by within person variation, that is, $CC = \frac{{SD_{Between}}^2}{{SD_{Between}}^2 + {SD_{Within}}^2}$. Koo & Li [32] recommend that the 95% confidence interval of the ICC estimate is used to evaluate reliability and also suggest the following guidelines: <0.5 indicates poor reliability, 0.5-0.75 indicates moderate reliability, 0.75-0.90 indicates good reliability, >0.90 indicates excellent reliability.

SEM is equivalent to SD_{Within}, the standard deviation of the variance of the test within individuals, assuming no genuine change in function, and so is an absolute measure of test reliability. MDC is the magnitude of observable change required to exceed the anticipated measurement error and within-subject variability. It is calculated by $\sqrt{2} \times Z \times SD_{Within}$, where Z=1.96 for the 95% limit (that is, 95% of observed differences between pairs of observations will be within this limit given there is no true difference) and Z=1.65 for the 90% limit.

The variability of TUG time and RCS time are related to their magnitude; that is, an individual with a TUG time of 4 s is likely to have a lower absolute variation than someone with a TUG time of 12 s. For this reason, we estimate the reliability of TUG and RCS on a log-scale, as errors are more likely to be multiplicative than additive, and TUG is often analysed on a logarithmic scale in epidemiological settings.

Finally, to test whether our estimate of variation is affected by the length of time between assessments we plotted the absolute difference between baseline and repeat measures against the time between assessments, along with a linear model estimated for this relationship.

Participant and public involvement

This research was done without participant involvement. Participants were not invited to comment on the study design and were not consulted to develop participant relevant outcomes or interpret the results. Participants were not invited to contribute to the writing or editing of this document for readability or accuracy.

Results

The median age of the sample was 66 years (range 51-89 years, IQR 61-71 years) and 55.5% were female. The majority of the sample (n=103, 81.8%) rated their own health as excellent, very good or good, 57.8% reported having no history of cardiovascular or chronic conditions while 16.0% had 3 or more conditions. Median delay between assessments was 88 days (range 28-141 days, IQR 70-104 days). Sixty-one participants had a different nurse at the repeat assessment while 60 participants had their assessment at a different time of day.

Table 1 shows the mobility performance scores at baseline and repeat assessments, with different raters and at different times of day, while Table 2 shows the variance components and reliability estimates. In general, this sample was relatively robust with good levels of mobility as evidenced when comparing mean TUG and gait speed performance to normative data for community-dwelling adults in Ireland [1]. Norms for RCS are not available for the Irish population, but average performance was slightly slower than age-matched norms presented elsewhere in the literature [33]

although wide variation in testing protocols has been recognised [34]. Figure 2 shows the baseline versus repeat scores for each measure, while Figure 3 shows the relationship between the absolute differences between scores and the number of days between assessments. In general, there is little evidence that lag between assessments affects the differences, although for TUG, the difference appears slightly lower with increasing time while for RCS the difference appears slightly greater.

Timed Up-and-go

TUG did not vary between baseline and repeat assessments or by time of day, however there was a significant rater effect with a difference of 1.22 s (P<.001) between the two nurses. The between-person SD was 1.31 s. The SEM was 0.75 s, leading to moderate-good reliability in this population (ICC=0.75) and MDC estimates of 1.75 s at the 90% level and 2.08 s at the 95% level. This means that a difference of 1.75-2.08 s between two assessments in the same individual can be expected by chance depending on the confidence interval used and when controlling for all other factors (rater, time between assessments and time of day). Analysis of TUG on a logarithmic scale suggests similar reliability (ICC=0.71), and a SEM of 0.09. The MDC_{95} of 0.24 for log(TUG) suggests that a relative change in TUG of up to 27% (the inverse logarithm of 0.24 is 1.27) might be expected by chance in 95% of paired samples. This finding is applicable across the spectrum of baseline TUG scores.

Repeated chair stands

RCS was completed slightly more quickly at the repeat measurement (difference=0.47 s, P=.04) and when the assessment was carried out by Nurse 1 (difference=1.09 s, P<.001) but did not vary with time of day. The ICC was 0.66 and SEM was 1.63 s while MDC was estimated to be 3.80 s at

the 90% level and 4.52 s at the 95% level. Time to complete RCS was also analysed on the log scale, where reliability was similar (ICC=0.68), SEM was 0.13 and MDC was 0.35 at the 95% confidence level (see Table 2).

Usual gait speed

UGS did not vary between baseline and repeat assessment or by time of day, however there was a significant rater effect with a difference of 7.36 cm/s (*P*<.001). Reliability was good (ICC=0.88) as the between-person SD (18.65 cm/s) was much higher than the SEM (7.03 cm/s), resulting in a MDC_{90} of 16.40 cm/s and MDC_{95} of 19.49 cm/s (see Table 2 and Figure 2).

Manual dual task gait speed

Gait speed became less reliable as the complexity of the dual task conditions increased. MGS was consistent across repeat assessments but varied by rater (difference=4.88 cm/s, *P*=.02) and time of day (difference=3.62 s, *P*=0.03). ICC was lower than was observed for UGS (ICC=0.83), SEM was higher (8.97 cm/s) and consequently so was MDC_{90} (20.93 cm/s) and MDC_{95} (24.87 cm/s) (see Table 2).

Cognitive dual task gait speed

CGS did not vary by repeat assessment, rater or time of day, however reliability estimates were poorest out of all gait speed measures (ICC=0.77; SEM=12.53 cm/s; MDC_{95}=34.73 cm/s) (see Table 2).

For all observed rater effects, including those where performance was automatically measured (i.e. with GAITRite), participants completed the mobility tasks more quickly when assessed by Nurse 1.

Discussion

We report test-retest reliability, SEM and MDC of commonly used mobility tests in a sample of relatively healthy, community-dwelling Irish adults aged 50 years and older. We found good test-retest reliability for walking speed and motor dual task walking speed and moderate-good reliability for TUG and cognitive dual task walking speed however, the lowest ICC was observed for RCS. These findings contrast to previous studies which reported moderate to excellent reliability for all of these measures [9-11 18 19 21-25 35]. As ICC depends on the distribution of scores within the sample it is estimated in and reflects relative reliability, it is specific to that particular setting and population [8]. Lower reliability here is likely to reflect more homogeneous population representative samples (hence lower between-person standard deviations) compared to clinical samples with varying degrees of impairment.

SEM and MDC provide an indication of absolute reliability. MDC allows the assessor to interpret if an observed change score is above that expected due to measurement error and therefore if it represents a genuine change in performance. In this study, MDC for TUG (2.08 s at the 95% level) is lower than that presented in previous studies of healthy (MDC_{95}=4.71 s) [16] and cognitively impaired (MDC_{95}=5.88-6.87 s) older adults [14 15] and Parkinson's disease patients (MDC_{95}=11 s) [17]. However, reporting variability in TUG as a percentage change in performance rather than in absolute terms may be more appropriate. In contrast, MDC_{95} for UGS, MGS and CGS (MDC_{95}=19.49-34.76 cm/s) are generally higher than the values estimated in community-dwelling

healthy adults (MDC_{95}=13.6 cm/s) [22], community-dwelling and hospitalised fallers (MDC_{95}=12.4-15.5 cm/s) [35] and in those post-stroke (MDC_{95}=20 cm/s) [36]. These differences may be due to the position on the performance scale as participants in these studies demonstrated poorer mobility than participants in the SHARE-TILDA study [22 35 36].

Many longitudinal or intervention based studies vary widely in sample characteristics, co-morbidity and time intervals between assessments. This makes cross-study comparisons difficult and therefore reliability measures are best estimated for each sample and for groups with specific diagnoses. This study provides guidance on MDC across the range of function in a generally healthy, population-based sample, when measurements are compared weeks or months apart. These estimates should be used when assessing individual changes in mobility performance over this time-scale e.g. when examining the effects of an intervention or patient progression, when calculating required sample sizes for studies using these outcomes or when applying methods to adjust for measurement error in epidemiological studies. Participants in this study were relatively healthy and while acute changes in health and performance can occur even with shorter follow-up, they are unlikely to demonstrate a consistent, genuine change in performance in the time period examined. While using a shorter time period and/or same-day repeated measurements would likely provide higher estimates of reliability, this approach was taken to reflect the variation that is likely to be observed in real-world clinical and research settings over a longer time period.

These results show the significant effect of inter-rater variation even with two highly trained and experienced research nurses. This suggests that changing rater introduces additional variance in the measures beyond within-participant variation. The effect was observed in the GAITRite® assessment as well as stopwatch based tests suggesting that rater differences in reaction time do

not explain this. Both nurses were highly experienced and followed standardised protocols, however one explanation could be that they have different styles of interaction with respondents, which may have impacted on the respondent's understanding of the task, or their motivation and subsequent desire to perform well. This emphasises the importance of providing appropriate training for all raters to ensure that measurements are as accurate and consistent as possible. In an effort to detect and address these differences, studies could examine within-day rater differences on a small number of participants although only a limited number of tests would be feasible to avoid fatigue effects. Where possible, analyses should also be adjusted to account for differences between the raters conducting the assessments.

Study Strengths and Limitations

A strength of this study is the population-based sample of relatively healthy middle-aged and older adults used in the analysis. In addition, our estimates of reliability remove time of day and rater effects. For measures that are skewed, a different MDC may be required depending on whether performance is at the higher or lower ends of the spectrum. To account for this, we represent relevant findings on the multiplicative (logarithmic) scale and the additive scale. Although a stopwatch is the easiest and most cost effective way to measure gait speed, the GAITRite® mat is frequently used in research. Therefore, this analysis provides useful guidance on data obtained using simple and more complex instruments. However, there are also a number of limitations in this study. Participants were not asked to restrict their exercise levels, activities or medications before the assessments, all of which could contribute to measurement variation. While the participants did not report any injuries that prevented them from doing the tests, it is also possible that they may have had a low level injury or have been recovering from an injury at either assessment which may account for some of the within-subject variation observed. It is possible

that underlying mobility among our participants genuinely varied between assessments rather than observed differences representing measurement error or transient factors. However, if this was the case for a significant number of participants, then we would expect to see the differences increase with increasing number of days between assessments. In fact, there was little evidence that the time between assessments contributed to the differences observed.

Conclusion

Gait speed obtained during normal walking conditions and when completing a manual dual task are repeatable when performed at time intervals of several weeks to months, with lower reliability observed for the cognitive dual walk, TUG and RCS. There is also a potentially large effect of rater, even for measures that are automatically measured. The estimates of MDC are presented for a population based sample of relatively healthy middle-aged and older Irish adults and can be used to assess changes in performance in individuals drawn from comparable populations. Similar robust reliability studies are recommended to inform the use and interpretation of repeated assessments in other populations such as those with specific co-morbidities. Additional analysis using anchor-based approaches could be used to examine if these changes are of clinical importance.

Author contributions:

Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work – OD, GS, AB-S, RAK; Drafting the work or revising it critically for important intellectual content – OD, GS, AB-S, RAK; Final approval of the version to be published – OD, GS, AB-S, RAK; Agreement to be accountable for all aspects of the work in

ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved – OD, GS, AB-S, RAK.

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Table 1. Mobility performance scores obtained at baseline and repeat assessments, with different raters and at different times of day.

	Assessment		Rater[a]		Time of day[b]	
	Baseline	Repeat	Nurse 1	Nurse 2	Test AM	Test PM
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
TUG (s)	8.88 (1.39)	8.87 (1.54)	8.13 (1.20)	9.35 (1.51)***	8.83 (1.49)	8.69 (1.25)
log(TUG)	2.17 (0.02)	2.17 (0.01)	2.08 (0.02)	2.22 (0.02)***	2.16 (0.02)	2.15 (0.02)
RCS (s)	12.49 (2.87)	12.02 (2.48)*	11.80 (2.27)	12.89 (2.88)***	12.17 (2.99)	12.00 (2.46)
logRCS	2.50 (0.22)	2.46 (0.21)*	2.45 (0.20)	2.53 (0.24)**	2.47 (0.24)	2.46 (0.22)
UGS (cm/s)	137.95 (20.21)	138.20 (19.32)	145.82 (18.94)	138.46 (17.85)***	137.62 (17.68)	137.74 (17.38)
MGS (cm/s)	116.76 (21.84)	118.71 (19.93)	123.07 (18.95)	118.07 (20.45)**	117.86 (19.85)	122.19 (17.21)*
CGS (cm/s)	115.23 (24.08)	115.15 (25.21)	118.29 (25.24)	117.40 (20.99)	117.45 (24.01)	118.84 (20.18)

Notes: TUG, Timed Up-and-Go; RCS, repeated chair stands; UGS, usual gait speed; MGS, manual dual task gait speed; CGS, cognitive dual task gait speed

[a] Rater scores are calculated only among participants who changed rater at the repeat assessment

[b] Time of day scores are calculated only among participants who changed time of day at the repeat assessment.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 2. Variance and reliability estimates for all mobility tests.

	$SD_{between}$ (95% CI)	SEM (95% CI)	ICC (95% CI)	MDC_{90}	MDC_{95}
TUG (s)	1.31 (1.12-1.52)	0.75 (0.66-0.85)	0.75 (0.66-0.82)	1.75	2.08
logTUG	0.13 (0.11-0.15)	0.09 (0.08-0.10)	0.71 (0.61-0.79)	0.2	0.24
RCS (s)	2.29 (1.93-2.70)	1.63 (1.43-1.86)	0.66 (0.55-0.76)	3.8	4.52
logRCS	0.18 (0.16-0.22)	0.13 (0.11-0.14)	0.68 (0.57-0.77)	0.29	0.35
UGS (cm/s)	18.65 (16.34-21.29)	7.03 (6.20-7.98)	0.88 (0.83-0.91)	16.4	19.49
MGS (cm/s)	19.57 (17.04-22.46)	8.97 (7.90-10.19)	0.83 (0.76-0.88)	20.93	24.87
CGS (cm/s)	22.73 (19.62-26.34)	12.53 (10.99-14.28)	0.77 (0.68-0.83)	29.24	34.73

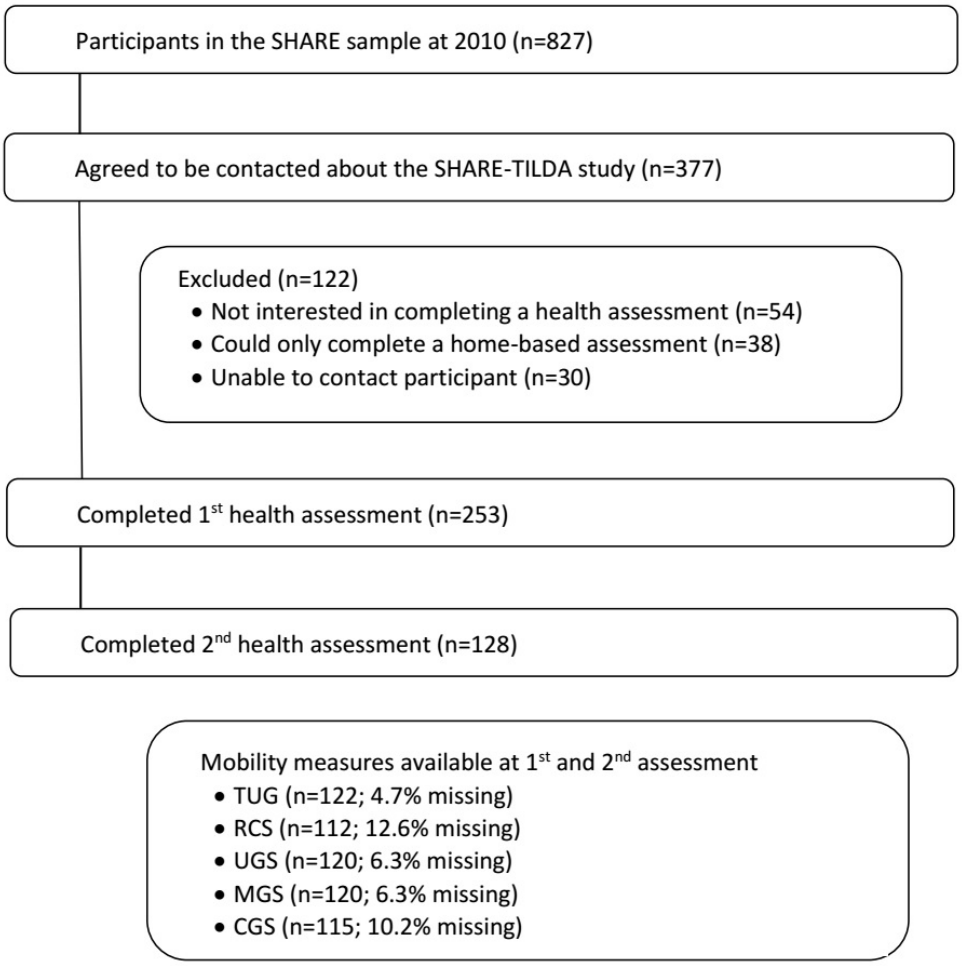
Notes: SEM, standard error of the measurement; TUG, Timed Up-and-Go; RCS, repeated chair stands; UGS, usual gait speed; MGS, manual dual task gait speed; CGS, cognitive dual task gait speed; ICC, intra-class correlation; MDC, minimum detectable change

Figure 1: Exclusion criteria used to establish eligible participants for this analysis.

Note: CGS, cognitive dual task gait speed; MGS, manual dual task gait speed; RCS, repeated chair stands; SHARE, Survey for Health Ageing and Retirement in Europe; TILDA, The Irish Longitudinal Study on Ageing; TUG, Timed Up-and-Go; UGS, usual gait speed.

Figure 2. Scatter plots showing the relationship between baseline (measure 1) and repeat (measure 2) scores for repeated chair stands (RCS), Timed Up-and-Go (TUG), and gait speed under normal conditions, with a cognitive dual task and a manual dual task. Solid line represents equality between the two measures.

Figure 3. The absolute difference between the initial and repeat score for each measure (vertical axis) plotted against the days between assessments. Lines represent linear regression models with 95% confidence bands.



Exclusion criteria used to establish eligible participants for this analysis.

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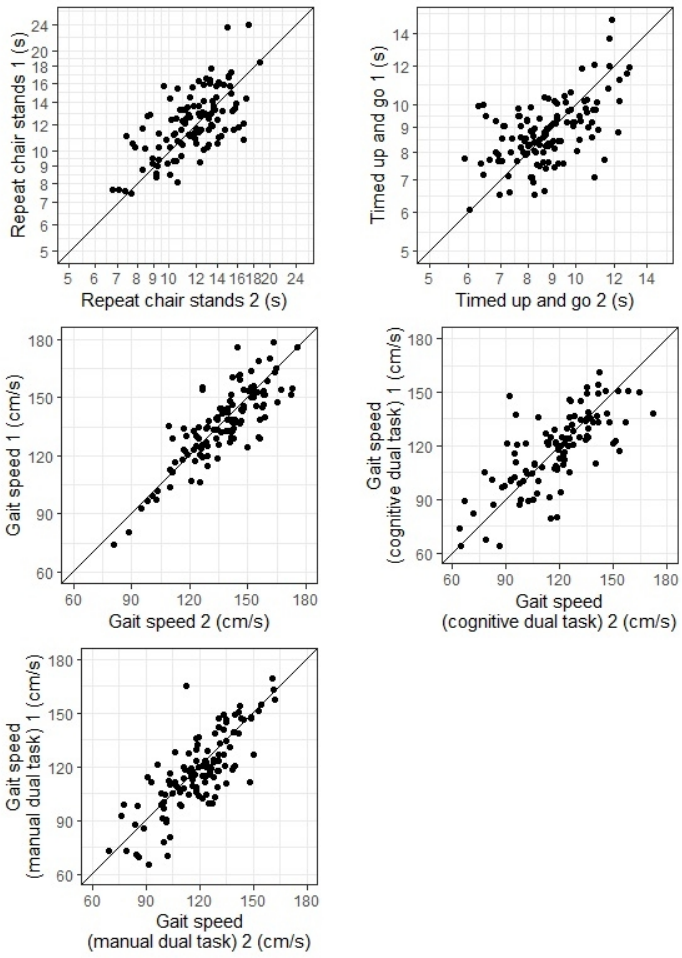

Figure 2

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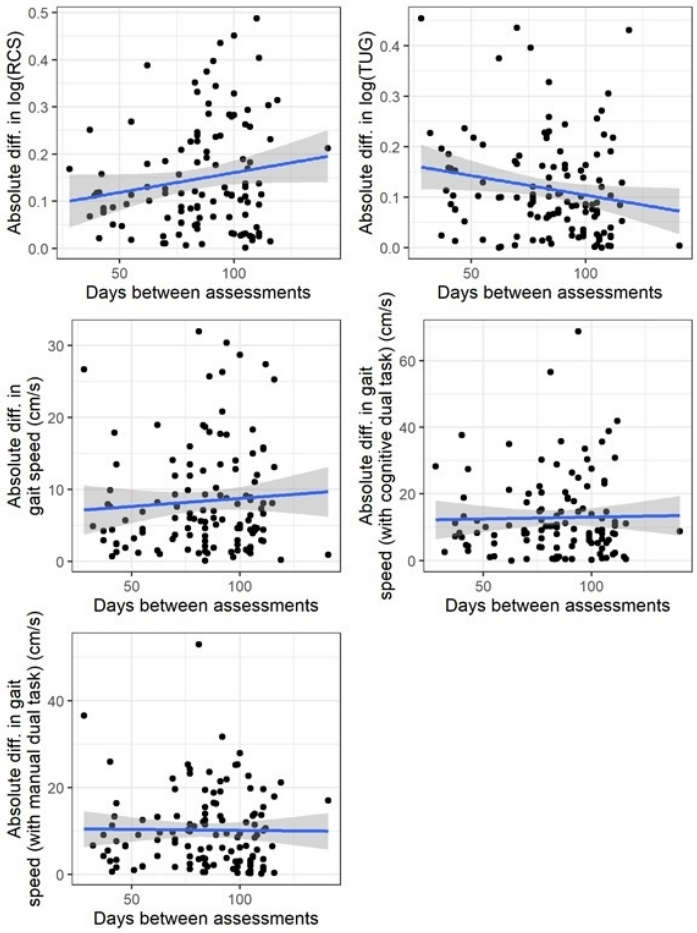

Figure 3

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Location
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	P1, P2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	P2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	P5-7
Objectives	3	State specific objectives, including any prespecified hypotheses	P6
Methods			
Study design	4	Present key elements of study design early in the paper	P7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	P7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	P7-8
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	P8-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	P8-10
Bias	9	Describe any efforts to address potential sources of bias	P10
Study size	10	Explain how the study size was arrived at	P7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	P10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	P10-11
		(*b*) Describe any methods used to examine subgroups and interactions	P10-11
		(*c*) Explain how missing data were addressed	P10
		(*d*) If applicable, explain how loss to follow-up was addressed	-
		(*e*) Describe any sensitivity analyses	-
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	P8, 12, Fig 1
		(b) Give reasons for non-participation at each stage	P8
		(c) Consider use of a flow diagram	Fig 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	P12
		(b) Indicate number of participants with missing data for each variable of interest	Fig 1
		(c) Summarise follow-up time (eg, average and total amount)	P12
Outcome data	15*	Report numbers of outcome events or summary measures over time	P23
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear	P12, 14, 24

		which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	-
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
Discussion			
Key results	18	Summarise key results with reference to study objectives	P12-14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	P17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	P14-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	P15-17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	P4

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.