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Original Article

Association between the instrumented timed up and go test and cognitive function, fear of falling and quality of life in community dwelling people with dementia

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Abstract

Objective: To explore relationships between the instrumented timed up and go test (iTUG) and the following risk factors for falls: cognitive functioning, fear of falling (FoF), and quality of life (QoL) in people with dementia. **Methods:** 83 community-dwelling older adults with dementia (mean±sd age 78.00±7.96 years; 60.2% male) completed an interview to capture global cognition (Mini-Addenbrooke's Cognitive Evaluation), FoF (Iconographical Falls Efficacy Scale) and QoL (ICEpopCAPability measure for Older people). Participants completed an iTUG whilst wearing an inertial sensor on their trunk. Linear accelerations and rotational velocities demarcated sub-phases of the iTUG. Relationships were explored through correlations and regression modelling. **Results:** Cognition was related to duration of walking sub-phases and total time to complete iTUG (r=0.25-0.28) suggesting gait speed was related to cognition. FoF was most strongly related to turning velocity (r=0.39-0.44), but also to sit-to-stand, gait sub-phases and total time to complete iTUG. Sub-phases explained 27% of the variance in FoF. There were no correlations between iTUG and QoL. **Conclusions:** Cognition and FoF were related to time to complete walking sub-phases but FoF was more closely related to turning velocity and standing acceleration. iTUG may offer unique insights into motor behaviour in people with dementia.

Keywords: Cognition, Fear of falling, Inertial Sensor, Balance, Falls

Introduction

Dementia is a highly prevalent neurodegenerative disorder characterised by changes in behaviour and cognition[1]. The prevalence and incidence of dementia has been reported at approximately 15% and 3% respectively[2] and it has been reported to affect approximately 47 million people worldwide[1]. People with dementia (PWD) show symptoms ranging from cognitive, social and motor impairment, all of which can significant affect quality of life (QoL)[3,4].

PWD have been shown to have greater falls risk compared to those either with mild cognitive impairment or intact cognition[5]. Indeed this appears to remain true for PWD within care homes[6] and for those within their own home, where the risk is double[5,7]. In addition to a greater risk of falls, the risk of hip fracture has been found to be almost 5-fold that of matched-controls[5] and PWD are 58% more likely to be admitted to hospital with a hip fracture than those without dementia, where mortality following hip fracture can be as high as 30%[8]. Therefore PWD are at great risk of injurious falling.

Dr Jonathan Williams has consulted with THETAmetrix, the company from which the sensor was purchased. Dr Samuel Nyman declares no conflicts of interest.

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Impairments to balance and gait are common in PWD and are associated with elevated falls risk[9-11]. To this end, clinical measures of balance are commonplace in the assessment of physical function in older people. Indeed, dynamic balance is highly predictive of falls rates[12,13]. One popular clinical test is the timed up and go (TUG) test[14]. This requires an individual to stand from a seated position, walk three metres, turn, walk 3 metres back, turn and sit down, with the outcome being time to completion. Originally a temporal cut off was proposed to identify fallers (≥13.5s)[15], however more recent systematic reviews have challenged this approach[16,17]. One of the inherent limitations is that the TUG test provides a single metric of overall performance despite the test calling upon different physiological constructs during different phases of the test[17]. To this end, researchers have begun to separate individual sub-phases by completing an instrumented version of the TUG, namely iTUG. Such parameterisation has been used across a wide range of disease states and commonly involves the use of an inertial sensor to provide linear accelerations and rotational velocities. Such approaches have good evidence for repeated testing reliability[18-23] and validity[19,24]. Moreover the sub-phase analysis from the iTUG has greater discriminatory ability than total time to complete TUG in those with mild cognitive impairment (in the absence of dementia)[25], frailty[26] and in individuals with Parkinson's disease[27]. This may be important for early disease detection but more so in the early rehabilitation of functional impairments, offering more timely interventions to optimise independence.

Previous research has identified links between iTUG (including time to completion) and various aspects linked to falls including cognition, fear of falling (FoF) and QoL. Correlations were observed in individuals with mild cognitive impairment and the performance of the sub-phases of the iTUG[25,28]. These studies suggested cognitive function correlated with sit-to-stand transition, and turning sub-phases along with some metrics of gait[25,28]. FoF, which has been linked to risk of falling and has been shown to correlate to sub-phases of the iTUG[29-31], however these studies have only investigated individuals with Parkinson's disease. Time to complete the TUG test has also been identified as an important correlate for FoF in older adults[32,33]. In addition, it has been shown that time to complete the TUG test was significantly correlated to QoL in the older adult, as well as in individuals with various clinical conditions[34-36]. Despite the preliminary links between the sub-phases of iTUG and total time to complete TUG with cognition, FoF and QoL, previous studies have not investigated the relationship between the sub-phases of iTUG with cognitive function, FoF and QoL in PWD.

The aims of this study were, for the first time, to:

1. Explore the relationships between the iTUG test with measures of cognitive function, FoF and QoL in PWD.
2. Determine if cognitive function, FoF and QoL can be predicted by sub-phases of the iTUG test among PWD.

Materials and methods

This study used baseline data collected as part of the TACIT trial (NCT02864056)[37]. An observational cross-section design was used with all data collected at a home visit to the address of the PWD with their informal carer present. This study was approved by the West of Scotland Research Ethics Committee 4 (reference: 16/WS/0139) and the Health Research Authority (IRAS project ID: 209193).

Participants

A total of 83 PWD and their informal carer were recruited from NHS databases, memory clinics, local charities and through self-referral from around the South of England. Inclusion criteria for PWD were aged 18 or above; living at home; have a diagnosis of a dementia (indicated on their medical record held by the NHS or general practitioner); and be able and willing to complete weekly standing Tai Chi without physical assistance. Exclusion criteria included living in a care home; in receipt of palliative care; severe dementia (defined as 9 or less on the Mini-Addenbrooke's Cognitive Evaluation [M-ACE])[38]; a Lewy body dementia or dementia with Parkinson's disease; severe sensory impairment; or lacking mental capacity to provide informed consent. Furthermore participants were excluded if they were currently completing or had completed Tai Chi (or similar) within the previous six months or were under the care of a falls clinic.

Instrumentation

The iTUG comprised a standard definition of rising from a chair, walking 3 metres to a mark on the floor, turning and walking back to the chair, finishing by sitting back down on the chair. A pragmatic approach to the particular chair was used, using those available in the individual's home. No directional information was provided for the turning phases.

Data were captured using an inertial sensor, which integrates a triaxial accelerometer and triaxial gyroscope (Balance Sensor, THETAmetrix, Portsmouth, UK) sampling at 30 Hz. The sensor was attached using an elastic belt around the middle of the lower back and data pertaining to linear accelerations and rotational velocities were exported to matlab for feature extraction. Excellent reliability of such a device has been previously reported[39].

The sub-phases of iTUG extracted were sit-to-stand, first walk period, first turn, second walk period and second turn prior to sitting again. The algorithm

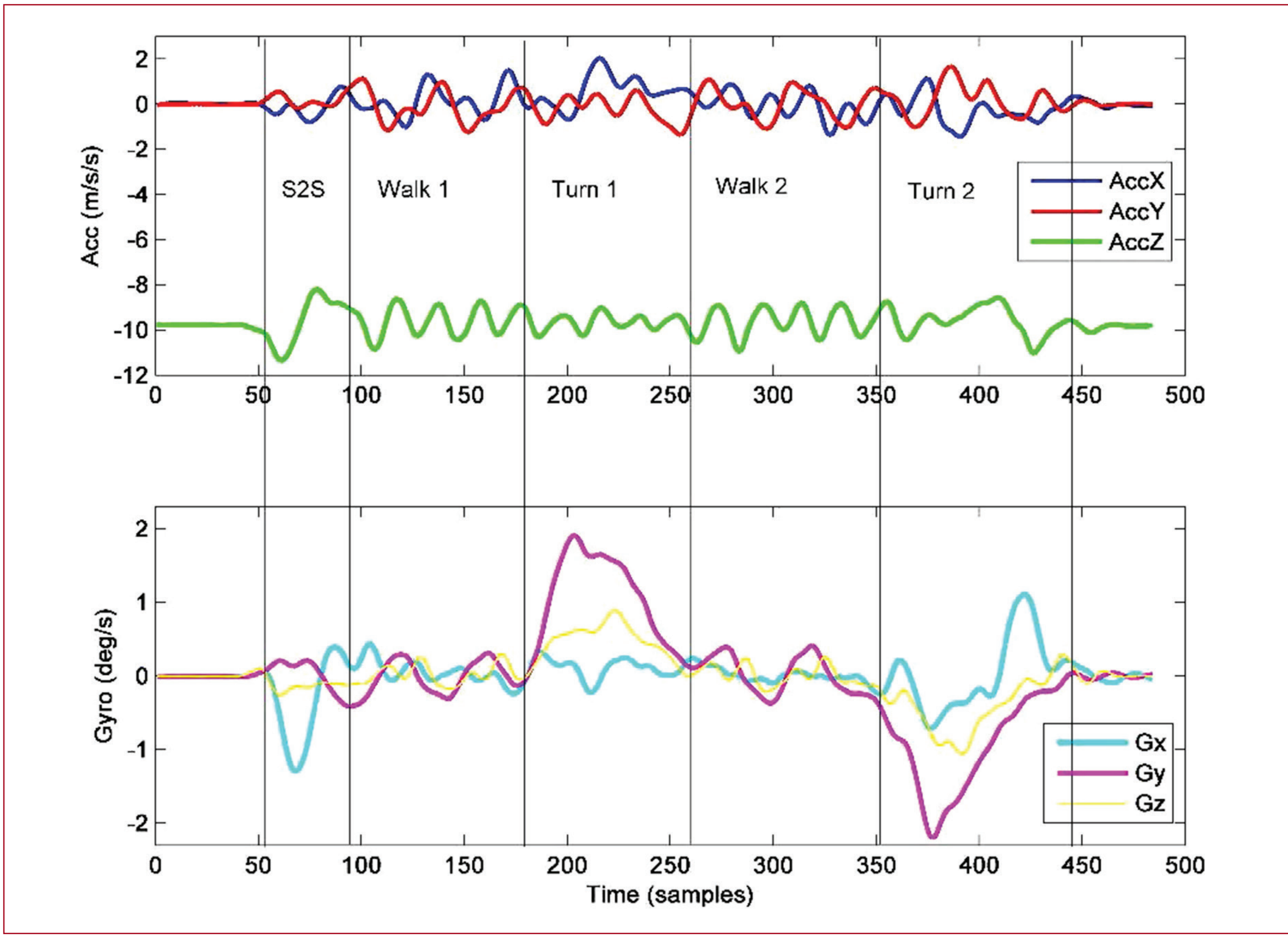

Figure 1. Example of typical iTUG output. S2S; Sit-to-stand, Acc; Acceleration, Gyro; Gyroscope.

used was based on previously published work[36]. Data were low pass filtered at 6 Hz and temporal events were determined through threshold detection or local maxima/minima detection algorithms from the appropriate sensor data. In addition some events were identified through zero crossing points in the data. Gait periods were used to compute measures of regularity and symmetry using autocorrelation methods[40,41]. Total iTUG time was recorded using a stopwatch as per standard TUG protocol.

Psychological measures

All participants completed a series of questionnaires by structured interview: the M-ACE for cognitive function, the Iconographical Falls Efficacy Scale (Icon-FES) for FoF and the ICEpopCAPability measure for Older people (ICECAP-O) for QoL. The M-ACE is a brief measure of global cognitive function and contains five items in relation to attention, memory, fluency, recall and visuospatial providing a total score out of 30 with higher scores representing higher cognitive function[38]. The Icon-FES is a 10-item scale to determine fear of falling with a maximum score of 40 and higher scores indicate greater levels of fear[42]. The ICECAP-O is a 5 item quality of life scale recorded out of 20, with higher scores indicating greater capability to have wellbeing from indicators broader than simply health, as deemed important by older people[43].

Statistical analysis

Following normality testing, pairwise correlations were used to explore relationships between iTUG variables and the scores for cognition, FoF and QoL. A multiple linear regression model was used to identify the proportion of M-ACE, FoF and QoL score that can be explained by the iTUG variables. For all analyses the significance level was set at <0.05.

	Median	IQR	Range
M-ACE	15.00	6.75	10.00 - 27.00
Icon-FES	16.01	6.75	10.00 - 32.00
ICECAP-O	9.00	4.00	5.00 - 15.00
TUG total time (s)	17.10	6.16	8.85 - 38.13
Standing Acc (ms^{-2})	-1.61	0.70	-3.39 - -0.59
S2S Duration (s)	2.06	0.82	1.21 – 11.27
Walk 1 duration (s)	4.16	2.21	1.56 – 14.25
Walk 2 duration (s)	3.75	2.33	1.24 – 11.11
Turn 1 duration (s)	2.57	0.70	1.52 – 8.22
Turn 1 Vel (°/s)	1.85	0.73	0.78 – 3.99
Turn 2 Vel (°/s)	1.96	0.88	1.01 – 3.84
AC Step walk 1	0.66	0.44	0.14 – 0.99
AC Stride walk 1	0.73	0.48	0.11 – 1.00
Step/Stride Ratio 1	1.03	0.36	0.15 – 3.86
AC Step walk 2	0.62	0.48	0.07 – 1.00
AC Stride walk 2	0.70	0.42	0.09 – 1.00
Step/Stride Ratio 2	0.98	0.42	0.19 – 3.33

M-ACE; Mini-Addenbrooke's Cognitive Examination, ICON-FES; Iconographical Falls Efficacy Scale, ICECAP-O; ICEpopCAPability measure for Older people, TUG; Timed-up-and-go, S2S; sit-to-stand, Vel; Velocity, AC; Autocorrelation.

Table 1. Central tendencies and spread of Cognitive function, Fear of Falling, Quality of life and iTUG sub-phases.

Results

Participants' mean±SD age was 78.00±7.96 years and 60.2% were male. A graphical example of the sensor output for the iTUG can be seen in Figure 1 for a typical participant. Participants' global cognitive function, FoF, QoL and iTUG data are presented in Table 1.

Cognition

Initial pairwise Spearman correlation analysis revealed total M-ACE score was significantly negatively correlated with total time for iTUG; duration of first walk period and duration of second walk period (Table 2). These negative correlations suggest that for lower M-ACE scores (indication of more severe cognitive impairment) the greater duration to complete TUG (or walking sub-phase).

A multiple regression model demonstrated that iTUG sub-phases could not predict M-ACE score, $F(11,64)=0.635$, $p=0.792$, $R^2=0.232$ with an adjusted $R^2=-0.057$.

Fear of falling

Standing acceleration was correlated to Icon-FES score as was duration of sit-to-stand; duration of first walk period; turning velocity during turn 1; duration of first turn; duration of second walk period; turning velocity during turn 2; and total iTUG duration (Table 2). Thus, those with a greater fear of falling took longer to stand, and did so with less acceleration, took longer to complete temporal sub-phases and the complete TUG test, and had lower turning velocities. A multiple regression was run to determine if Icon-FES score could be predicted from the iTUG variables. The multiple regression model statistically predicted Icon-FES score, $F(11,64)=3.522$, $p=0.001$, $R^2=0.377$ with an adjusted $R^2=0.270$.

Quality of life

There were no correlations between iTUG sub-phases and QoL and a multiple regression model demonstrated iTUG variables could not predict QoL scores $F(11,64)=1.312$, $p=0.238$, $R^2=0.184$ with an adjusted $R^2=-0.044$.

Discussion

The aim of this study was to investigate, for the first time, the relationship between iTUG sub-phases and cognitive function, FoF and QoL in PWD. The links between cognitive function and iTUG demonstrated some modest

M-ACE	Correlation Coefficient	p-value
Duration of 1st walk period	-0.267	0.020
Duration of 2nd walk period	-0.251	0.028
Total iTUG time	-0.277	0.011
Icon-FES		
Standing Acceleration	0.305	0.007
Duration of sit-to-stand	0.338	0.003
Duration of 1st walk period	0.298	0.009
Peak turning velocity for turn 1	-0.443	<0.001
Duration of 1st turn	0.231	0.045
Duration of 2nd walk period	0.282	0.014
Peak turning velocity for turn 2	-0.391	<0.001
Total iTUG duration	0.303	0.005

Table 2. Statistically significant Spearman correlation coefficients for M-ACE, Icon-FES and iTUG sub-phases (no significant relationships were evident for QoL and iTUG sub-phase).

relationships. The strongest bivariate correlations were for the total time to complete TUG and the duration of the walking periods. These gait based temporal elements are likely to consist of the same physiological construct, indeed the correlation between these two iTUG variables was 0.85 suggesting the measures were highly related. Cognition and total TUG time has been previously investigated, demonstrating that those with lower levels of cognition, perform the TUG more slowly in older people with Parkinson's disease or those with mild-moderate cognitive impairment[28,36,44,45]. The findings of the current study suggest that it is only the duration of walking phases, not turning or sit to stand, that are correlated with cognitive function. Cognitive function has been previously linked to gait speed in a number of systematic reviews[46,47], however the findings of this study extends the knowledge to include PWD. The findings are in agreement with previous studies investigating the relationship between gait speed and cognitive function in PWD[48-50]. Previous approaches to capturing gait speed have included a 3 minute walk[48], 5 metre walk[49] and 2.4 metre walk[50], therefore the findings of this previous work and the current study are in agreement that only very short distances are required to assess gait speed.

Slow walking speed and declines in walking speed have been identified as key predictors of the development of dementia[51]. Furthermore, in their large prospective longitudinal study, Hackett and colleagues[51] suggested gait slowing precedes dementia onset. This may accurately reflect the disease progression or an indication of the sensitively of clinical dementia diagnosis. This suggests that early monitoring of gait and gait changes could provide important clues regarding cognitive function and dementia risk.

The mechanistic link between gait and cognition has received less attention. One plausible mechanism to explain gait changes may be degeneration and subsequent reduced volume of both grey and white matter[51]. Degeneration, as identified through neuroimaging, has been reliably associated with poorer mobility and thus may explain this link between cognition and gait speed[52].

The current study found a correlation between a number of iTUG sub-phases and FoF as measured by the Icon-FES. To the authors knowledge this is the first study to explore this relationship in PWD. Previous research has demonstrated significant correlations between the activities-specific balance confidence scale (ABC) and peak speed of turning[12] and furthermore between Falls Efficacy Scale International and peak and mean turning velocity and sit-to-stand velocity[16]. These previous studies both investigated community dwelling older people with Parkinson's disease without cognitive impairment. Those studies investigating older adults with cognitive impairment have demonstrated through multivariate modelling that time to complete TUG was important in explaining FoF[32,33]. The results of these studies demonstrate a consistent link between both the temporal aspects and specific kinematics of the iTUG and FoF. The findings of the current study extend the understanding of individual iTUG sub-phases and their relationship with FoF in PWD.

It is evident that, when measured, turning kinematics are consistently related to FoF, a finding supported by the current study, and this may be specific to the differential kinematics of turning velocity. Turning requires a coordinated sequence of axial rotations of body parts and therefore it is possible that cognitive decline affects the sequential motor strategies required to efficiently complete such a task[53]. Additionally, turning is a task involving many interlimb coordination challenges, relatively rapid changes in orientation and significant asymmetries in kinematics and kinetics, the increased complexity could be one approached cautiously by the individual with a FoF[54]. It is possible that the increased risk is one which is identified by the PWD and a conscious slowing of the task represents an adaptive strategy to mitigate risk[55]. Moreover, high levels of anxiety have been reported in individuals with Alzheimer's disease related cognitive impairment[56]. It is possible that this anxiety affects their confidence and ultimately physical performance, however this can only be speculated as it was not measured in the current study. This is in contrast to the proposal suggesting that individuals with cognitive impairment lack appropriate attention to and perception of their function challenges, so called anosognosia[57,58]. The current study found no evidence of anosognosia therefore these differences could be explained by having only mild-moderate cognitive impairment and excluding individuals with Alzeimer's disease[52]. Therefore it seems possible that PWD in this study were cognisant of the challenges posed by for example turning and thus adopted a cautious approach to this task completion rather than lacking this insight as suggested by previous authors.

This study found that standing acceleration was related to FoF, a finding not previously reported in the literature. Sit-to-stand acceleration has been identified as a strong indicator of frailty[59] suggesting that the additional kinematic derivative (acceleration) is highly discriminatory for motor performance. A reduction in acceleration may represent an impairment of strength, power and motor strategy during sit to stand[60]. Therefore it is possible that FoF somehow results in an alteration in strength, power or motor strategy. In addition it is possible that such a ballistic motion, essentially propelling the centre of mass forwards over a new, much reduced, base of support is one which provides significant challenge and thus such a movement has a significant interaction with fear. Further investigation is required to explore the interplay of these to identify the cause.

The current study found no relationships between iTUG sub-phases and QoL, as measured by ICECAP-O. This is the first study to investigate such relationships in PWD. It has been previously documented in a study of over 7000 participants that the time to complete the TUG was significantly correlated to health-related quality of life with correlation coefficients ranging from r=0.16-0.26, depending of the dimension of interest[34]. Olivares et al.[34] did not measure cognitive function and therefore it is possible this large sample had normal cognitive function thus representing a different sample to the one currently investigated. In addition, previous authors have demonstrated a relationship between TUG (total time) and various metrics of QoL, including health related QoL and short-form health survey, for other clinical conditions such as Parkinson's disease[36], degenerative disc disease[61] and osteoporosis[35]. These findings perhaps suggest that the key determinants of quality of life in PWD are different to the constructs measured by the TUG and iTUG. TUG is reported to explore many things including strength, mobility and balance[17] and therefore would be more correlated to a health-related measure of quality of life. It is also possible that for a PWD the key determinants of QoL lie in other aspects of life. Indeed, it has been identified that delusions and apathy are the key determinants for quality of life in PWD and may explain the lack of correlation seen in our study[62].

The findings of this study seems to suggest a closer relationship is evident between FoF and sub-phases of the iTUG than cognition or QoL. Regression modelling suggests that 27% of the variance of FoF was explained by the iTUG variables. It is commonly accepted that FoF is multifactorial[63-65] and seems to be linked to impaired functional capacity[66,67]. The concept of fear affecting movement is not new and has been suggested in many conditions where fear is a dominant feature of the disorder[66]. However this is the first time such a finding has been applied to the iTUG. It is not clear whether FoF is a consequence of a previous fall, or exists prior to a first fall[55,68]. FoF may result in activity avoidance which leads to deconditioning and subsequent decline in physical function[69-71]. Such activity avoidance ultimately leads to a decline in physical function, including strength and power loss, potentially further accentuating balance impairments, fear and ultimately falls risk in a vicious cycle. The results of this study suggest fear affects the willingness to challenge the body through movements requiring greater velocity and acceleration, so called differential kinematics. Therefore, sub-phases of iTUG could be used to identify these subtle impairments.

Limitations

There were several limitations to the current study. The cross-section design does not allow for exploration of causation. The iTUG was performed in the individual's home therefore the chair and walking surfaces were not standardised. Tape placed on the floor was used to demarcate 3 m rather than a bollard or other physical structure, resulting in choice regarding turning style, i.e. pivot or step turns which may have affected temporal turning outcomes. As testing was completed in the home a standard 3 m walk was used. This may affect the ability to detect some gait parameters and is in conflict with previous studies opting for an extended walk period. However, 7 m was not feasible in a home environment. Nonetheless it is felt that these results are more relevant to current practice because of this. The use of a QoL metric which is not health-related captures novel insights but it is possible it fails to detect the same constructs of QoL as previous health-related QoL scales.

Conclusion

This study adds to the literature in demonstrating the utility of the iTUG in more accurately identifying motor behaviour impairments and perhaps early changes in gait parameters that might help in the understanding of disease progression in PWD. Our study suggests that cognition and FoF were related to time to complete walking sub-phases but FoF was more closely related to turning velocity and standing acceleration.

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