Unsupervised Physical Function Testing Using a Wearable Sensor System – A Cross-sectional Study with Community Dwelling Older Adults

Oonagh M. Giggins(✉), Grainne Vavasour, and Julie Doyle

NetwellCASALA, Dundalk Institute of Technology, Dublin Road, Dundalk, Republic of Ireland
Oonagh.giggins@dkit.ie

Abstract. This study sought to investigate whether community dwelling older adults can independently undertake a Timed Up and Go (TUG) test and capture objective data related to frailty risk using a wearable sensor system. Participants were visited in their own homes and completed a sequence of TUG tests. These TUG tests were firstly supervised by the researcher. The TUG tests were then repeated by participants, unsupervised on the subsequent two days. The kinesis QTUG system was used to capture objective data during each TUG test. Fifty-one participants took part in this investigation, and 32 participants successfully obtained a frailty risk score using the QTUG system. Overall, the system usability score for the QTUG system ranged from 2.5 to 92.5 demonstrating a wide variation in participants' perception of its usability. Results of the Spearman's rank correlation coefficient (rs) indicate there was a very strong positive correlation between the supervised and the unsupervised QTUG tests for each of the two days (rs .942 and .874 day 1 and day 2 respectively $p < .001$). These results indicate that older adults can independently capture information relevant to their risk of frailty that does not depend on a clinician or researcher for analysis.

Keywords: Frailty · Older Adults · Physical Function · Wearable Sensors

1 Introduction

The global population is ageing at an unprecedented rate. Between 2015 and 2050 the proportion of the world's population over 60 years will nearly double from 12% to 22% [1]. Frailty is one of the greatest challenges facing an ageing population. It is a progressive age-related decline in physiological systems that results in decreased reserves of intrinsic capacity, which confers extreme vulnerability to stressors and increases the risk of a range of adverse health outcomes [2]. It is reflective of biological as opposed to chronological age and is influenced by physical, psychological, and social factors [2].

Frailty impacts 24% of community-dwelling adults over 65 years of age in Ireland, while the figure for pre-frailty, those at higher risk of progressing to frailty and its negative sequelae is 45% [3, 4]. Due to the heterogeneity of studies, global figures are difficult to establish, however, a systematic review of research in Europe, USA, UK, Ireland, and

D. Salvi et al. (Eds.): PH 2023, LNICST 572, pp. 438–448, 2024.
https://doi.org/10.1007/978-3-031-59717-6_28

Asia indicates that the prevalence of frailty and pre-frailty is as high as 27% and 50% respectively [5]. Frailty places older adults at increased risk for falls, disability, hospital admissions, institutionalization and mortality [6–10]. Exercise-based interventions have been shown to reverse frailty [11–13]. These interventions are particularly effective if delivered in a timely manner at the early stages of decline [14]. As a result, the early detection of frailty is critical in the development of preventive strategies against age-related conditions.

There are two major approaches to model frailty. Fried's Frailty Phenotype (FFP) model [7] identifies frailty by the presence of at least three of five physical characteristics; weight loss, exhaustion, low energy expenditure, slow walking speed and low handgrip strength. The Deficit Accumulation Index [9] identifies frailty based on the accumulation of a range of symptoms, sensory deficits, clinical signs, diseases, disabilities and abnormal laboratory test results. Other tools include the Frail Scale [15], the Tilburg Frailty Scale [16], and the Edmonton Frail Scale [17]. However, these assessment tools are time consuming and require clinical expertise within a geriatric department to complete.

Impaired physical function and declining physical activity are major precursors to frailty. Traditional assessments of physical function carried out in clinical settings are therefore frequently used to identify frailty. At present, it is common practice amongst healthcare professionals to use a combination of unstructured and structured methods to assess physical function and physical activity in older adults. Unstructured assessment methods include free observation of patient movement (e.g. walking into the room, sitting down, reaching out for an object) and questions to investigate perceived changes in the ability to complete activities of daily living. Structured assessment methods include questionnaires to investigate the impact of physical health on quality of life and physical activity, such as the CASP-19 [18], and tests to assess motor performance, such as the Berg Balance Scale [19], Elderly Mobility Scale [20], and the Timed Up and Go (TUG) test [21]. Although these methods may yield clinically relevant information and are generally easy to use, their sensitivity for quantifying small changes in physical function is limited, and therefore they may not be sensitive to identifying the early indicators of frailty. Additionally, the opportunities to undertake these assessments are limited to clinical visits, and there is the risk that the onset of frailty might go undetected or be identified too late.

Wearable sensors has become a pervasive means of measuring physical function and physical activity [22–24]. A recent systematic review has shown that wearable sensors can be used to collect objective, quantifiable parameters of mobility and physical activity that can be used to distinguish between levels of frailty [25]. The majority of studies examined were carried out in laboratory or under test conditions. While this type of assessment, in a controlled laboratory or clinical environment is important, the collection of data in the home setting is considered more valuable [26, 27]. As the onset of frailty can be more insidious, more regular or continuous assessments of physical function, in a person's naturalistic, home environment may be more useful in identifying frailty. Facilitating older adults to undertake these assessments and capture this objective data in their own homes may not only reduce the burden of testing (e.g. clinician time, traveling to a clinic for assessment) but also allow for the earlier detection of frailty and earlier intervention. However, it needs to be investigated whether these assessments of

physical function can be performed by older adults independently and unsupervised in their homes. The QTUG system has been shown to be reliable in the measurement of gait and mobility [28], and is accurate in predicting falls in people with Parkinson's disease [29], and community dwelling older adults [30, 31]. In this current study, the Kinesis QTUG was used to provide an objective frailty risk score during a TUG test.

This study sought to investigate whether community-dwelling older adults can independently and safely undertake a TUG test in their own home and operate the Kinesis QTUG to capture an objective frailty risk score. This study also sought to examine the usability of the Kinesis QTUG system among older adults.

2 Methodology

2.1 Study Design

A cross-sectional study was conducted to investigate the ability of older adults to independently undertake a physical function test and capture objective data using the Kinesis QTUG sensor and software system.

2.2 Participants

Participants for this study were recruited through advertisements in local golf, bridge and church community groups. Those interested were assessed for eligibility by a member of the research team over the telephone using the study eligibility criteria; 65 years of age and over, independently mobile, physically capable of performing a series of mobility tests, had no cognitive or neurological deficits and no history in the past 6 months of lower limb orthopaedic trauma or surgery that would interfere with the ability to exercise. A sample of 52 was based on power 0.8, effect size 0.8, p value 0.05 (AI-Therapy Statistics 2018). This is justified in the literature with previous studies including similar sample sizes (Apsega et al. 2020).

2.3 Ethical Considerations

The study protocol received ethical approval from the School of Health and Science Ethics Committee in Dundalk Institute of Technology, and all participants signed a written informed consent form prior to participation.

2.4 Data Collection

Participants were visited on two occasions in their homes for data collection. Each visit was scheduled 48-h apart, and took place between September 2021 and December 2021. During the first visit, a frailty assessment was conducted with each participant based on Fried's Frailty Phenotype (FFP) [7]. Participants were also requested to perform a Timed Up and Go (TUG) test [32].

The FFP consists of five phenotypes of weight loss, exhaustion, low level of activity, weakness as measured by grip strength, and gait speed. Weight loss scored one point

for unintentional weight loss >4.5 kg in the previous year or a body mass index (BMI) <18.5 kg/m^2. Exhaustion was assessed subjectively through two questions regarding perception of energy and how regularly one had rested in bed during the day over the previous four weeks – one point was scored if the answer to the first question was negative and 'every day' for the latter. Low level of activity scored one point if self-reported frequency of high *and* moderate activity was "never or hardly ever". Handgrip strength and gait speed were measured objectively and scored according to pre-determined cut-off points [7] and (www.cgakit.com 2015) respectively. One point was scored for weakness if handgrip strength was less than a pre-determined cut-off weight (in kg) for sex and BMI categories. One point was scored for slowness if time to complete the TUG test was equal to or exceeded 19 s. Individuals are considered non-frail or robust if they fulfil none of the criteria, pre-frail if they fulfil one or two and frail if they meet three or more of the five criteria.

The TUG test is a reliable and valid test of function and mobility that measures in seconds (s), the time taken by a participant to stand up from a standard chair seat height, walk a distance of 3-m (m), turn 180°, walk back to the chair and sit down [32]. Prior to performing the TUG test participants were instrumented with the Kinesis QTUG sensors. Each sensor contains a tri-axial accelerometer, tri-axial gyroscope and a magnetometer. One sensor was secured on each shin, over outer clothing using reusable straps (Fig. 1). The QTUG sensors connected via Bluetooth to the Kinesis QTUG app which uses the sensor and demographic data to produce a frailty score. Values below 50% are considered non-frail, values between 50 and 70% are considered transitionary, values above 70% are frail, while values above 90% are considered very frail.

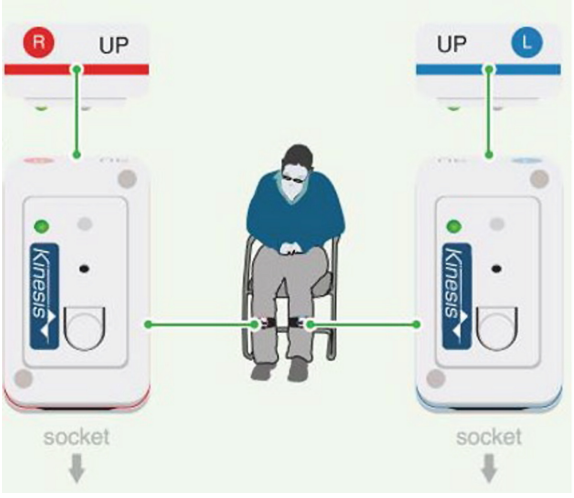

Fig. 1. Placement of the Kinesis QTUG sensors on the participant's shanks

Following the supervised TUG test, participants were requested to repeat the TUG test unsupervised, and record data using the QTUG system, once each day over the following 48-h. Participants were provided with written and verbal instructions on how to

perform the test as well as a demonstration by the researcher. Participants were instructed to perform the TUG test along the same course and using the same chair as in the supervised test. Participants were provided with an illustrated information booklet and received training in the use of the QTUG. Off-site phone support was also available where required.

Participants were visited a second time 48-h after the initial visit. During this visit, participants were asked to complete the system usability score (SUS), a validated outcome measure which measures the usability of a system [33]. It consists of a 10-item questionnaire with five response options for respondents ranging from strongly disagree to strongly agree, resulting in a score between 0 and 100. The SUS for the QTUG system was calculated using standard methodology [33].

2.5 Data Analysis

Data were collated using Microsoft Office Excel (Microsoft Corp) and analyzed using SPSS software (IBM Corp). Descriptive statistics of continuous variables are presented as mean and standard deviation (SD). The frailty risk scores from the QTUG were tested for normality using the Shapiro-Wilk test. A p value of $<.05$ was considered statistically significant. The relationships between the supervised and the unsupervised QTUG frailty risk scores were analysed using Spearman's rank correlation coefficient. Correlation coefficients were interpreted as follows; very strong (0.9–1.0), strong (0.7–0.89), moderate (0.4–0.69) or weak (0.10–0.39) [34]. Because of the relatively small sample size and the non-normally distributed data, the relationships between the supervised and the unsupervised QTUG frailty risk score were analysed using Spearman's rank correlation coefficient.

3 Results

Fifty-one participants (age 77.5 ± 8.4 years, height 163.6 ± 8.54 m, weight 72.0 ± 13.5 kg, female 76%; n = 39) took part in this investigation. Assistive walking aids were used by n = 3 participants. According to the FFP, six participants were classified as frail 31 were pre-frail, and 14 were non-frail. According to the supervised QTUG data, n = 26 participants were classified as non-frail, n = 7 were classified as transitional, n = 3 were classified as frail, while n = 15 were very frail. Sixty-three percent (n = 32) of participants successfully obtained a frailty risk score unsupervised, in their own home using the Kinesis QTUG system. A further 29% (n = 15) attempted to perform the TUG test and used the QTUG system but were unsuccessful, while 8% (n = 4) (age 82.5 ± 3.19 years) declined to take part in the training and the unsupervised test. A breakdown of the number, percentage and age of successful and unsuccessful unsupervised QTUG by frailty status is presented in Table 1.

The SUS was completed by 80% of all participants (n = 41), with missing data due to participant unavailability at the second home visit. Percentile scores of the system usability score range from 2.5 to 92.5. Mean scores are presented by frailty group in Table 2.

Table 1. Number, percentage and age of successful and unsuccessful unsupervised QTUG by frailty status

	Frailty Group	n	% of each cohort	Age mean (SD)
Unsuccessful				
	Non frail	2	14	73.5 (6.4)
	Pre-frail	14	45	82.5 (5.7)
	Frail	3	50	89.7 (2.9)
	Total	**19**	**37**	**82.7 (6.6)**
Successful				
	Non frail	12	86	71.4 (7.1)
	Pre-frail	17	55	75.2 (7.8)
	Frail	3	50	81.0 (7.9)
	Total	**32**	**63**	**74.3 (7.8)**

Includes Declined; n = 4; Pre-frail n = 1; Frail n = 3; Age 82.5 (3.19)

Table 2. SUS Percentile score by Frailty Status

Frailty Status	SUS Percentile Score	
	N	Mean (SD)
Non frail	12	65.4 (17.1)
Pre-frail	26	48.1 (30.3)
Frail	3	35.0 (26.1)
Total	41	52.2 (27.8)

Results of the Spearman's rank correlation coefficient (rs) between the QTUG frailty estimate indicate there was a very strong positive correlation between the supervised QTUG and the unsupervised QTUG tests for each of the two days (rs .942 and .874 day 1 and day 2 respectively $p < .001$). There was an equally strong positive correlation between each of the two unsupervised QTUG tests (rs .938, $p < .001$). Estimates of agreement would be more appropriate for analysing the same variables however, the data violated the assumptions of normality necessary for creating and interpreting Bland Altman plots. Neither log transformation or taking the square root of variables resulted in normal distribution.

4 Discussion

Frailty is an avoidable and reversible biopsychosocial syndrome associated with ageing, resulting in adverse outcomes that are both life-changing and life-limiting, and which ultimately impacts on scarce healthcare resources. Providing older adults with a means

that they can independently monitor for and identify the early signs of frailty could allow for earlier intervention and reduce the risk of developing frailty, thereby reducing the burden on the individual and society as a whole. The Kinesis QTUG is a wearable sensor system that provides an objective estimate of frailty in the form of a frailty risk score, which can be understood and used by the user without further analysis or interpretation required. This study examined the ability of older adults to independently perform a TUG test in their own home, and capture objective test data using the Kinesis QTUG system. Overall, this study found that the majority of participants were successful in undertaking the TUG tests and obtaining a frailty risk score independently using the Kinesis QTUG. Those who were successful in obtaining a frailty score unsupervised were younger (mean age 74.3 $\pm$ 7.8 years) than those who failed to undertake the TUG and use the QTUG successfully (mean age 82.7 $\pm$ 6.6 years). However, the percentage of those who were successful in the pre-frail and frail cohorts was comparable (45%–50% and 55%–50% for pre-frail and frail cohort for successful and unsuccessful respectively). The QTUG frailty estimates captured by participants unsupervised correlated strongly with the supervised QTUG frailty estimate performed by the researcher. This outcome is promising, suggesting that many older adults can independently capture information relevant to their risk of frailty that does not depend on a clinician or researcher for analysis.

Four participants who enrolled in this study declined to take part in the unsupervised TUG test, citing lack of interest or lack of confidence in their ability to perform the test independently. Twenty-nine percent of the participants who attempted to undertake the test and use the Kinesis QTUG independently were unsuccessful for reasons including system or battery failure, poor eyesight and self-reported lack of confidence to attempt the test without family support. The latter two reasons are related to biophysical restrictions and reduced confidence, both associated with ageing, and confirms the literature, which identifies these as limiting factors to the use of technology among older adults [35]. Lack of confidence in technology is referred to as digital anxiety and appears quite prevalent in the literature [36–38]. Self-confidence in digital skills is influenced by many factors including age, education and previous experience with technology, and in turn affects satisfaction, perceived usefulness and adoption or continued use of technology [39].

Training sessions that allow older adults to learn at an individual pace, with ongoing support and provision of educational literature have been shown to instill confidence and facilitate problem solving resulting in acceptance and adoption of technology among older adults [40]. It is recognised that older adults have the capacity and the interest to learn to use technology but again, the design of the training is important [41]. Participants were provided with one-to-one training and a reference manual prior to the unsupervised tests. The limited duration and once-off nature of the training provided in this study may have contributed to the participants not being equipped to manage system or battery failure. The training provided did not include the opportunity for participants to first engage with the technology and subsequently ask questions or experience success in tasks, both of which are understood to build confidence and facilitate successful adoption of technology [39].

Overall, the SUS score for the Kinesis QTUG ranged from 2.5 to 92.5 demonstrating a wide variation in participants' perception of its usability. The mean SUS score was

lower with each increasing level of frailty however, the lowest score was in the pre-frail group (2.5 in the pre-frail group compared with a lowest score of 5 in the frail group) indicating that some frail participants perceived the technology more usable than their pre-frail peers. The mean score of 52 falls below the score of 68 which is considered an average and acceptable score for the system usability score [42]. However, forty-four percent of those who completed the system usability score (n = 18/41) scored ≥65 demonstrating that for many participants, the technology was deemed usable. The non-frail group came closest to the average of 68 (mean 65.4, range 45–92.5). The mean system usability score reduced in accordance with frailty status and age in keeping with previous studies [43].

While the results of this study are promising, there are some limitations which must be considered. The sampling method for recruitment of participants resulted in a lack of gender balance and a lack of diversity in frailty status. The percentage of men in the overall sample was just 25%, which is in contrast with other frailty studies where the gender balance has been more reflective of the population [44, 45]. All participants in this study were recruited from community groups, and this may have influenced the imbalance in frailty status among the participants. In addition, this study took place during the COVID-19 pandemic which may have limited the recruitment of more frail older adults. However, the 73% prevalence of frailty and pre-frailty combined in the sample is comparable with other similar studies [4, 46, 47] and reflects the population prevalence [5].

The short time frame of the study which was influenced by the COVID-19 pandemic, and the once-off training session did not facilitate self-paced learning or provide the benefit of time to explore the technology with ongoing technical support. Participants may have benefitted from a follow-up training session to address questions and provide support prior to carrying out the unsupervised QTUG test, which may have influenced the results. The Kinesis QTUG platform is designed to be administered by a clinician, and to our knowledge this is the first study to evaluate its independent use by older adults. While this system is unique, the findings of this study may be useful for deploying other smartphone apps and technologies for the independent assessment of mobility and function in older adults.

5 Conclusion

Frailty is one of the greatest challenges facing our ageing population. This study has demonstrated that older adults are capable of undertaking a TUG test and of obtaining a frailty risk score unsupervised in their own home using the Kinesis QTUG system. However, the usability of the system varied, with scores ranging from 2.5 to 92.5, indicating potential challenges in the widespread adoption of this technology among older adult. Nonetheless, these findings are important as they highlight the potential for older adults to self-monitor their mobility and physical function. Providing older adults with a means to independently identify declining physical function, may allow for the earlier detection of frailty and earlier intervention, which may mitigate some of the potential adverse sequelae.

Data Availability Statement. The data that support the findings of this study are available on request from the corresponding author, OMG.

References

1. World Health Organization. Ageing and Health.
2. World Health Organization. World Report on Ageing and Health. World Health Organization (2015)
3. O'Halloran, A., O'Shea, M.: Wellbeing and Health in Ireland's Over 50s 2009–2016. Trinity College Dublin (2018). https://doi.org/10.38018/TildaRe.2018-00
4. Roe, L., Normand, C., Wren, M.-A., Browne, J., O'Halloran, A.M.: The impact of frailty on healthcare utilisation in Ireland: evidence from the Irish longitudinal study on ageing. BMC Geriatr. **17**(1), 203 (2017). https://doi.org/10.1186/s12877-017-0579-0
5. Choi, J., Ahn, A., Kim, S., Won, C.W.: Global prevalence of physical frailty by Fried's criteria in community-dwelling elderly with national population-based surveys. J. Am. Med. Dir. Assoc. **16**(7), 548–550 (2015). https://doi.org/10.1016/j.jamda.2015.02.004
6. Chang, S.-F., Lin, H.-C., Cheng, C.-L.: The relationship of frailty and hospitalization among older people: evidence from a meta-analysis. J. Nurs. Scholarsh. **50**(4), 383–391 (2018). https://doi.org/10.1111/jnu.12397
7. Fried, L.P., et al.: Frailty in older adults: evidence for a phenotype. J. Gerontol. A Biol. Sci. Med. Sci. **56**(3), M146–M157 (2001). https://doi.org/10.1093/gerona/56.3.M146
8. Liu, H.X., et al.: Association between frailty and incident risk of disability in community-dwelling elder people: evidence from a meta-analysis. Public Health **175**, 90–100 (2019). https://doi.org/10.1016/j.puhe.2019.06.010
9. Rockwood, K.: A global clinical measure of fitness and frailty in elderly people. Can. Med. Assoc. J. **173**(5), 489–495 (2005). https://doi.org/10.1503/cmaj.050051
10. Zhang, Q., Guo, H., Gu, H., Zhao, X.: Gender-associated factors for frailty and their impact on hospitalization and mortality among community-dwelling older adults: a cross-sectional population-based study. PeerJ **6**, e4326 (2018). https://doi.org/10.7717/peerj.4326
11. Woolford, S.J., Sohan, O., Dennison, E.M., Cooper, C., Patel, H.P.: Approaches to the diagnosis and prevention of frailty. Aging Clin. Exp. Res. **32**(9), 1629–1637 (2020). https://doi.org/10.1007/s40520-020-01559-3
12. Mulasso, A., Roppolo, M., Rainoldi, A., Rabaglietti, E.: Effects of a multicomponent exercise program on prevalence and severity of the frailty syndrome in a sample of Italian community-dwelling older adults. Healthcare **10**(5), 911 (2022). https://doi.org/10.3390/healthcare10050911
13. Cesari, M., et al.: A physical activity intervention to treat the frailty syndrome in older persons-results from the LIFE-P study. J. Gerontol. A Biol. Sci. Med. Sci. **70**(2), 216–222 (2015). https://doi.org/10.1093/gerona/glu099
14. Ko, F.C.-Y.: The clinical care of frail, older adults. Clin. Geriatr. Med. **27**(1), 89–100 (2011)
15. Woo, J., Leung, J., Morley, J.E.: Comparison of frailty indicators based on clinical phenotype and the multiple deficit approach in predicting mortality and physical limitation. J. Am. Geriatr. Soc. **60**(8), 1478–1486 (2012). https://doi.org/10.1111/j.1532-5415.2012.04074.x
16. Gobbens, R.J.J., Boersma, P., Uchmanowicz, I., Santiago, L.M.: The Tilburg Frailty Indicator (TFI): New Evidence for Its Validity. Clin. Interv. Aging, 265–274 (2020)
17. Rolfson, D.B., Majumdar, S.R., Tsuyuki, R.T., Tahir, A., Rockwood, K.: Validity and reliability of the Edmonton Frail scale. Age Ageing **35**(5), 526–529 (2006). https://doi.org/10.1093/ageing/afl041

18. Hyde, M., Wiggins, R.D., Higgs, P., Blane, D.B.: A measure of quality of life in early old age: the theory, development and properties of a needs satisfaction model (CASP-19). Aging Ment. Health **7**(3), 186–194 (2003). https://doi.org/10.1080/1360786031000101157
19. Berg, K.: Measuring balance in the elderly: development and validation of an instrument (1992)
20. Prosser, L., Canby, A.: Further validation of the elderly mobility scale for measurement of mobility of hospitalized elderly people. Clin. Rehabil. **11**(4), 338–343 (1997)
21. Bohannon, R.W.: Reference values for the timed up and go test: a descriptive meta-analysis. J. Geriatr. Phys. Therapy **29**(2), 64–68 (2006)
22. Bai, Y., et al.: Comparison of consumer and research monitors under semistructured settings. Med. Sci. Sports Exerc. **48**(1), 151–158 (2016)
23. Burton, E., et al.: Reliability and validity of two fitness tracker devices in the laboratory and home environment for older community-dwelling people. BMC Geriatr. **18**(1), 1–12 (2018)
24. Hsieh, K.L., Roach, K.L., Wajda, D.A., Sosnoff, J.J.: Smartphone technology can measure postural stability and discriminate fall risk in older adults. Gait Posture **67**, 160–165 (2019)
25. Vavasour, G., Giggins, O.M., Doyle, J., Kelly, D.: How wearable sensors have been utilised to evaluate frailty in older adults: a systematic review. J. Neuroeng. Rehabil. **18**(1), 112 (2021). https://doi.org/10.1186/s12984-021-00909-0
26. Brodie, M.A., et al.: New methods to monitor stair ascents using a wearable pendant device reveal how behavior, fear, and frailty influence falls in octogenarians. IEEE Trans. Biomed. Eng. **62**(11), 2595–2601 (2015)
27. Mueller, A., et al.: Continuous digital monitoring of walking speed in frail elderly patients: noninterventional validation study and longitudinal clinical trial. JMIR Mhealth Uhealth **7**(11), e15191 (2019)
28. Smith, E., Walsh, L., Doyle, J., Greene, B., Blake, C.: The reliability of the quantitative timed up and go test (QTUG) measured over five consecutive days under single and dual-task conditions in community dwelling older adults. Gait Posture **43**, 239–244 (2016)
29. Greene, B.R., et al.: Longitudinal assessment of falls in patients with Parkinson's disease using inertial sensors and the timed up and go test. J. Rehabil. Assist. Technol. Eng. **5**, 2055668317750811 (2018)
30. Greene, B.R., Redmond, S.J., Caulfield, B.: Fall risk assessment through automatic combination of clinical fall risk factors and body-worn sensor data. IEEE J. Biomed. Health Inform. **21**(3), 725–731 (2016)
31. Greene, B.R., Doheny, E.P., Walsh, C., Cunningham, C., Crosby, L., Kenny, R.A.: Evaluation of falls risk in community-dwelling older adults using body-worn sensors. Gerontology **58**(5), 472–480 (2012)
32. Podsiadlo, D., Richardson, S.: The timed 'Up & Go': a test of basic functional mobility for Frail elderly persons. J. Am. Geriatr. Soc. **39**(2), 142–148 (1991). https://doi.org/10.1111/j.1532-5415.1991.tb01616.x
33. Brooke, J.: SUS-A quick and dirty usability scale. Usab. Eval. Indust. **189**(194), 4–7 (1996)
34. Schober, P., Boer, C., Schwarte, L.A.: Correlation coefficients: appropriate use and interpretation. Anesth. Analg. **126**(5), 1763–1768 (2018). https://doi.org/10.1213/ANE.0000000000002864
35. Wang, J., Fu, Y., Lou, V., Tan, S.Y., Chui, E.: A systematic review of factors influencing attitudes towards and intention to use the long-distance caregiving technologies for older adults. Int. J. Med. Inform. **153**, 104536 (2021)
36. Yap, Y.-Y., Tan, S.-H., Choon, S.-W.: Elderly's intention to use technologies: a systematic literature review. Heliyon **8**(1), e08765 (2022)
37. Nimrod, G.: Technophobia among older Internet users. Educ. Gerontol. **44**(2–3), 148–162 (2018)

38. Di Giacomo, D., Ranieri, J., D'Amico, M., Guerra, F., Passafiume, D.: Psychological barriers to digital living in older adults: computer anxiety as predictive mechanism for technophobia. Behav. Sci. **9**(9), 96 (2019)
39. Lee, C., Coughlin, J.F.: PERSPECTIVE: older adults' adoption of technology: an integrated approach to identifying determinants and barriers. J. Prod. Innov. Manag. **32**(5), 747–759 (2015)
40. Desai, S., McGrath, C., McNeil, H., Sveistrup, H., McMurray, J., Astell, A.: Experiential value of technologies: a qualitative study with older adults. Int. J. Environ. Res. Public Health **19**(4), 2235 (2022)
41. Schlomann, A., Even, C., Hammann, T.: How older adults learn ICT—guided and self-regulated learning in individuals with and without disabilities. Front. Comput. Sci. **3**, 140 (2022)
42. Sauro, J.: Measuring Usability with the System Usability Scale (SUS) (2011). https://measuringu.com/sus/. Accessed 12 Oct 2023
43. Bangor, A., Kortum, P., Miller, J.: Determining what individual SUS scores mean: adding an adjective rating scale. J. Usability Stud. **4**(3), 114–123 (2009)
44. Xue, Q.-L.: The frailty syndrome: definition and natural history. Clin. Geriatr. Med. **27**(1), 1–15 (2011)
45. Rodríguez-Gómez, I., et al.: Relationship between physical performance and frailty syndrome in older adults: the mediating role of physical activity, sedentary time and body composition. Int. J. Environ. Res. Publ. Health **18**(1), 203 (2021)
46. O'Halloran, A.M., Hartley, P., Moloney, D., McGarrigle, C., Kenny, R.A., Romero-Ortuno, R.: Informing patterns of health and social care utilisation in Irish older people according to the Clinical Frailty Scale. HRB Open Res. **4**, 54 (2021)
47. Pradeep Kumar, D., Wendel, C., Mohler, J., Laksari, K., Toosizadeh, N.: Between-day repeatability of sensor-based in-home gait assessment among older adults: assessing the effect of frailty. Aging Clin. Exp. Res. **33**, 1529–1537 (2021)