Evaluation of the Utility of the 'Velocity Field Diagram' and 'Timed-Up-and-Go Test' as Fall Screening Tools Among Community-Dwelling Older Adults: An Observational Study

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Research Article

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Abstract

Background: Evidence from systematic reviews demonstrated that gait variables are the most reliable predictors of future falls, yet are rarely included in fall screening tools. It explains why most tools have higher specificity than sensitivity, hence may be misleading/detrimental to care. The diagnostic utility of a gait analytical tool-velocity field diagram (VFD), and "Timed-up-and-go test (TUG)'- commonly used in Nigeria, was therefore compared to a gold standard (known fallers) to evaluate their accuracy and utility in fall screening.

Method: This is an observational study of 500 older adults (280 fallers and 220 non-fallers), recruited by convenience sampling technique at a community health forum on fall prevention. The number of steps and time they spent to complete a-7metre distance was determined and used to calculate the stride length, stride frequency, and velocity, which regression lines were used to form the VFD. TUG test was simultaneously conducted to discriminate fallers from non-fallers. The cut-off points for falls: TUG times ≥13.5 seconds; and VFD's intersection point of the stride frequency, and velocity regression lines (E_1) ≥3.5velots. Receiver operating characteristic (ROC) area under the curves (AUC) was used to explore the ability of the E_1≥3.5velots to discriminate between fallers and non-fallers. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of the VFD and TUG were determined. Alpha was set at $p<0.05$.

Results: The sensitivity, specificity, PPV and NPV of the VFD versus TUG is 71%, 27%, 72%, and 43%, versus 39%, 59%, 40%, and 43%, respectively. The ROC's AUC were 0.74(95%CI:0.597,0.882, p=0.001) for the VFD. The optimal categorizations for discrimination between fallers/non-fallers were ≥3.78 versus ≤3.78 for VFD (fallers and non-fallers prevalence 60.71% versus 95.45%, respectively), with an accuracy of 0.76 unlike TUG with AUC=0.53 (95% CI:0.353, 0.700, p=0.762), and an accuracy of 0.68, and optimal characterization of ≥12.81s versus ≤12.81 (fallers and non-fallers prevalence = 92.86% versus 36.36%, respectively).

Conclusion: The VFD demonstrated a fair discriminatory power and greater accuracy in identifying fallers than the TUG. Therefore, the VFD could serve as a primary tool in screening those at the risk of fall than the TUG.

Introduction

Falls occur when an individual unintentionally rests in a new position on the ground, and therefore relates to the instability of the body's center of gravity in an upright stance. Most times, falls could be life-threatening, accounting for 40% of all injury deaths as well as 20-30% of mild to severe injuries (including soft tissue injuries to fractures) in the older adults [1–5]. This warrants the development of fall prevention strategies which include screening for those at the risk of falls and targeting them with appropriate fall prevention measures before a fall occurs. Some simple and practical fall screening methods [6–9], include the "Timed Up and Go" test (TUG) [9]and "velocity field diagram" (VFD) [10, 11]. Cumbersome and highly sophisticated equipment are not desirable as they are not easily deployed in various settings [12]. However, several systematic reviews found that none of 29 fall-risk assessment tools (including the TUG) were accurate enough to identify people at risk of falling in hospitals and care homes [13–15]. For instance, Gates et al [15] found that the screening tests had higher specificity than sensitivity, indicating that a higher proportion of non-fallers than fallers were correctly identified. Perhaps, this limitation relates to the non-inclusion of history of falls, gait abnormalities, and balance assessment in some screening tools. These variables have been reported as the best predictors of falls [13, 14]. Given that the VFD detects gait abnormalities, balance dysfunctions, and fallers [16–18] it may be a more reliable instrument than the commonly used TUG which shows some weakness in this area.

The VFD is a simple non-invasive method of gait analysis which analyses the linear regressions of the basal gait parameters – namely, stride length, stride frequency, and stride length – as they interact independently in response to a neural drive [10, 11]. VFD employs the entire spectrum of human walking speed - from very slow to very fast - to explain the events that occur during walking. Moreover, the parameters of the VFD form into equations very easily, which is characteristic of a neural-driven process [11]. Given that gait alterations are known to precede falls [13, 14], it is expected that the underlying biomechanical factors should likewise find expression in the equation definition method of the VFD, and justifies its application in fall screening. This explains why the VFD, which was first described by Eke-Okoro [10, 11] has useful clinical application in fall screening [19]. The strong clinical characteristics of the VFD have enabled diverse clinical studies, in both developed and developing countries involving knee osteoarthritis [17], hemiparesis [20], high-heeled walking [16], and prediction of onset of diabetic foot ulcer among others [18, 21, 22]. A previous systematic review provided evidence that the VFD have basic scientific applications that are relevant in clinical studies [23], and thus its potential as a fall screening tool [11] could be justified.

Some fall screening tools include the “Get-up and Go” test [24], the TUG test, (which was developed in 1991 as a modified form of the ‘Get up and Go test.’),[8] the Bohannon’s ordinal scale for standing balance [25], and the Berg balance tests [6], which when combined with a test of walking speed, shows a high sensitivity and specificity as a screening method [26]. The same applies to the Bartel Index for activities of daily life [27], Tinetti’s sub-scale for balance [28], the Fugl-Meyer scale for isolated movements and balance [29], the Minimal Chair Height Standing Ability Test (MCHSAT) [30] and a test of functional mobility [31]. But unlike the VFD, some of the above instruments focus on assessment of motor performances in non-ambulant activities of daily living (ADL), while others (e.g. TUG) employ gait assessment at ordinary walking speed alone, over a distance of 3 meters. This is an obvious weakness, which does not allow for a full expression of gait pattern across the entire spectrum of (slow, normal and fast) walking speeds. Therefore, such fall screening tools may not reliably account for the behaviour of the biomechanical correlates of fall at slow and fast walking speeds. A more holistic picture would have been provided by a screening tool that accounts for changes in the biomechanical correlates of falls across the entire spectrum of human walking speeds, within which ADLs are likely to be executed.

Perhaps, more worrisome is the fact that some fall screening tools are often used in settings for which they have no basis in evidence. Thus, tools validated in acute hospitals are used in mental or community care settings/nursing homes, and vice versa. Apart from the STRATIFY score [32, 33] and the Morse Falls Scale [34, 35], most fall screening tools including the VFD, are rarely validated in more than two settings or patient cohorts. So, it is not certain what value they add to the clinical decision-making process involving screening, prevention, and management of falls. In essence, despite the apparent attractiveness of an easy-to-use tool in falls prevention, its use may prove to be misleading or detrimental to care if its reliability and validity are not evaluated in care settings of intended use, where falls are likely to occur. Since the TUG and VFD are commonly used in Nigeria, we sought to explore the reliability of their measurements in falls screening among community-dwelling older adults to guide practice. Therefore, the research question for this study was: What is the validity and reliability of the 'VFD' test and TUG in fall screening compared to the gold standard (fallers), among community-dwelling older adults?

Methods

Design

This is an observational study of 500 (220 non-fallers and 280 fallers) community-dwelling older adults aged 65-85years. Data were collected between April 2017 – July 2018. Fallers and non-fallers were simultaneously tested with TUG and VFD, to evaluate the discriminatory power of the instruments to detect fallers and non-fallers, and to classify future falls risk with sensitivity, specificity, and predictive values of VFD's fall index - i.e., the value of intersection point of the stride frequency, and velocity regression lines (E_1) measured in velots described in the VFD- and TUG times (measured in seconds).

Setting

This study was held at the community health centres, in Igboeze South Local Government Area (LGA), Nsukka senatorial zone, Enugu State, Nigeria comprising 10 towns, namely: Alor-Agu, Unadu, Itchi, Nkalagu-Obukpa, Ibagwa Aka, Iheakpu -Awka, Uhunowerre, Ovoko-Ulo, Ovoko-Agu, and Iheaka. This location was selected following a rise in the number of falls involving resident older adults of the rural communities in Igboeze South LGA, who reported at the Physiotherapy unit of the University of Nigeria Teaching Hospital's rural outpost in Obukpa, Nsukka. Therefore, a rural health education outreach programme on risk factors for falls and falls prevention strategies among older adults in Igboeze South LGA was planned by the research team. The health outreach programme involved the community health committees and the traditional rulers of the communities within Igboeze South LGA. The traditional rulers, therefore, convened community health fora in their respective community health centres, and the town criers were mobilized to disseminate information to all clans and villages, for at least four market days to ensure a wide publicity. In addition, various age-grade groups were also invited by the traditional rulers, through their leaders to the health programme. Out of 2880 rural community dwellers who attended the health fora, eighty-eight (880) were community-dwelling older adults aged ≥65years and above. This group were subsequently targeted and were invited to participate in this study.

Participants

In a previous study of mobility by Sosnoff et al [36], individuals classified as fallers demonstrated diminished mobility scores for all assessments when compared to non-fallers. There was an apparent difference in walking coordination and walking speed, and the differences between fallers and non-fallers were of moderate magnitude based on effect sizes for TUG (d=−0.45) and timed walking speed (d= −0.46) over a 25-foot distance (i.e., 7.62 metres), which is similar to 7 meters used in this study. Using the Power analysis of 80% to detect a difference between means at an effect size of 0.46, with a significance level (alpha) of 0.05 (one-tailed), a sample size of 840 was mathematically determined. Considering the likelihood of attrition, 10% of the calculated sample (84) was required, however only 40 (about 5%) were available and were included in the study making a total of 880 older adults. The participants flow through the study is presented in Figure 1. Criteria for participation included only those who are: -

1. ≥65 years or older, and
2. able to walk independently and
3. those who have a Mini-Mental Score Examination (MMSE) score higher than 23 [37].
4. not blind

Based on their self-reported history of locomotive falls, participants were categorized into 2 groups, namely: i. fallers, and ii. non-fallers. The fallers were operationalized in the context of this study as individuals who satisfied the fall frequency requirement of at least two falls within 18 months. The fall frequency was provided by the participants and confirmed by participants' relatives/neighbors. Nevertheless, 120 participants who were unable to do so, were excluded from the study. Non-fallers were older adults who have not fallen during the past 12 months [19]. However, all those who had fallen once were screened for co-morbidities of fall, and educated on fall prevention strategies. They were given some exercise regimens to strengthen their muscles and placed on the watch list for follow-up visitations. All participants provided written informed consent following approval by the Institutional Human Ethics Research Board. The study process involved three stages: obtaining informed consent, anthropometric assessment, and measurement of the risk of fall using the TUG and VFD, respectively.

With the help of four trained research assistants, the 880 older adults who participated in the health forum were screened for eligibility to participate in the study. One hundred and sixty were found ineligible, while the remaining 720 were invited to participate in the study. Out of this number, 500 (280 self-reported fallers and 220 self-identified non-fallers) individuals accepted and 220 declined to participate. The 500 willing participants were requested to provide their fall history.

The instruments used in the study included the weighing (Hana Bathroom) scale, stadiometer, measuring tape and stopwatch (Hanhart, Germany). The Hanhart stopwatch is impact resistant, dustproof and water resistant, with diamond-turned metal case, 55mm diameter, built-in strap ring, time intervals 1/5 secs, display 30 mins, a resolution of 0.20 sec and has a measuring capacity 00:30:00 hr: min: sec. These instruments were used to measure the body weight, height, distance to walk/cover and walk time, respectively. To eliminate inter-observer variability, only one investigator was assigned the task of evaluating the participants for the primary outcome measures. The primary outcome measures were the TUG and the VFD.

An instrument for Determining Cognitive status:

Mini-mental state examination was used to assess global cognition level, which comprised items concerning attention, language, following commands and figure copying, orientation, registration and recall for all participants. The cutoff score was 23 [37], and none of the Participants fell below the cutoff. A score of 19–23 point suggests mild dementia, whereas scores above 23 suggest normal cognition.

Primary outcome measures

TUG test: Timed-Up-and-Go test' was done with the participants sitting correctly in the chair with an armrest, with an approximate seat height of 46 cm, and arm height 65 cm. Participants were instructed that on hearing the command "go" they were to get up and walk at a comfortable and safe pace to a line on the floor 3 meters away, turn, return to the chair and sit down again. The timing started immediately the participant got up from the chair and stopped when the participant has seated again with the back resting on the back of the chair. However, each participant was required to walk through the test once before being timed in order to become acquainted with the procedure. The participants were required to perform the test three times, and the fastest time of the three was used in this study. Participants were also allowed to wear their regular footwear and use their customary walking aids (none, cane, walker), but no physical assistance was given. A TUG time is a time in seconds that participants needed to complete the test. Longer time indicates worse balance and mobility performance. Times under 10 seconds are suggestive of completely free and independent individuals; however, times $\geq$ 13.5 seconds is the cutoff point for fallers [1].

VFD: The participants were required to walk a 7-meter distance (measured out on the ground using the measuring tape) barefoot or in their normal shoes after the purpose of the study was explained to them. They were requested to walk the distance at five self-selected speeds: ordinary, very slow, slow, fast and very fast, in that order. For each speed, the number of steps and time taken to complete the distance were obtained (using a Stop-Watch-Hanbart Germany), and used to calculate the mean values of stride length (L), stride frequency (F), and velocity (V), for each participant as indicated in equations 1-4 [10, 11]. For each participant recruited, data were collected over a 23-minute time frame.

1. Strides = $\frac{No\ \ of\ \ Steps}{2}$
2. Stride length (metres) = $\frac{Disance}{\text{No. of strides}}$
3. Stride frequency = $\frac{No\ \ of\ \ Strides}{Time}$
4. Velocity (V)= Stride Length (L) x Stride frequency (F) OR Velocity = $\frac{Disance}{Time}$

The regression lines of L, F and V are known as L-line, F-line, and V-line, respectively [10, 11]. These parameters were adapted to describe the VFD [16-19]. Ordinarily, the VFD consists of the graphical regression plots of the three basal gait parameters (stride length, frequency, and velocity) expressed in five self-selected speeds. The five self-selected speeds of walking, varying from very slow, slow, normal, fast and very fast speeds, were serially numbered, 1-5, and assigned arbitrary units - velots. The numbers were used for the X-axis, while the numerical values of velocity, stride length, and stride, were used on the Y-axis. These lines make up the primary features of the VFD [10, 11]. The point of equality for the numerical values of velocity and stride frequency (E_1) marked the upper limit of very slow speed and a speed transition to the path of minimal energy trajectory [16-19]. Similarly, the point of equality for the numerical values of velocity and stride length (E_2) marked the upper limit of normal speed and a speed transition to fast walking speed. Eke-Okoro [19] demonstrated that 3.5 velots is the value of E_1 on the VFD of fallers, which discriminated them from non-fallers(≤3.5velots) and therefore has a diagnostic utility. Consequently, he predicted that the critical point for the onset of fall is $E_1 \geq 3.5$ velots.

Covariates

Information on age and gender were obtained by self-report. Co-morbidities (defined as a history of dizziness, vestibular disease, diabetes, alcoholism, and arthritis), were ascertained by self-report questionnaires. Alcohol consumption was dichotomized, and defined as weekly alcohol consumption of ≥11 units for men and ≥8 units for women Body mass index (BMI), was determined as weight in kilograms divided by the square of height in meters, and categorized according to the National Institutes of Health obesity standards <18.5 = underweight, 18.5-24.9 = normal weight, 25.0-29.9 = overweight, and >30 = obese [38].

Data Analysis

Participants' characteristics, as well as means and SD values for continuous variables and percentages for categorical variables, were determined within both males and females. Data were principally analyzed for males and females combined, but analyses were repeated for males and females separately. Differences in gait parameters between fallers and non-fallers were determined with and without adjustment for the potential confounding effects of history of diseases of orthopedic or neurological nature; use of alcohol within 72 hours of gait recording [39-41], use of sedatives within 72 hours of gait recording [39, 41], chronic co-morbidities (history of dizziness, vestibular disease, cardiovascular risk factors, and diabetes), alcoholism, gender and the use of anti-anxiety drugs [41-45]. Normality of distribution of the basal gait parameters (stride velocity, stride frequency and stride length), was confirmed by the Kolmogorov-Smirnov test. Mean differences in VFD performance (absolute and adjusted) and physical characteristics between fallers and non-fallers were determined using independent-sample t-tests. Data collected for this study were presented in tables. Descriptive statistics and independent t-test were used to analyze the biodata, anthropometric indices, and gait variables. McNemar test was used to check for the diagnostic accuracy of the VFD relative to the TUG, while weighted Kappa was used to check for the level of agreement between the TUG and VFD in screening out fallers from non-fallers. For all kappa statistics, κ values were interpreted as follows: below 0 as less than chance, 0.01–0.20 as slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as good and above 0.80 as very good levels of agreement. Sensitivity and specificity of the VFD and TUG were also determined. The estimated population midpoints and 95% confidence intervals were calculated for: i. prevalence of the condition; ii. test sensitivity (conditional probability that the test will be positive if the condition is present); iii. test specificity (conditional probability that the test will be negative if the condition is absent); iv. predictive values of the test (probabilities for true positive, true negative, false positive, and false negative); and, v. positive and negative likelihood ratios.

After stratification on the basis of sex, weighted linear regression analysis was applied to explore the relation of E_1 and gait speed as a performance-based physical measure. The distributions of E_1 in both men and women were right-skewed. Consequently, it was considered appropriate to use natural-log-transformed values, which gave the best-fitting model for analysis in which the E_1 values were treated as continuous variables. For both males and females, standard-deviation scores of E_1 were obtained from the formula (Xi-Xm) ÷ SD, where Xi was the natural-log-transformed E_1 in the individual male/female subject, Xm is the mean natural-log-transformed E_1 in the male/female subjects, and SD the standard deviation of the natural-log-transformed E_1 in the male/female subjects. With this calculation., it was possible to determine the change in the gait speed for each increment of 1SD in the natural-log-transformed E_1. The relations of E_1 to gait speed were also estimated with a quartile-based analysis by dividing E_1 values into quartiles with subjects in the lowest quartile as the reference group. Comorbidities were assessed by referring to the self-reported physician's diagnosis and included dizziness, vestibular disease, diabetes, alcoholism, and arthritis. An extended-model approach was applied for covariates adjustments: Model 1 = Age, body mass index categories, smoking status, alcohol consumption, and use of walking devices; Model 2 = Model 1 + co-morbidities (dizziness, vestibular disease, diabetes, alcohol consumption, and arthritis); Model 3 = Model 2 + markers of cardiovascular risk (natural-log-transformed levels of the use of anti-anxiety drugs). BMI was also controlled in the association between E_1 and gait velocity (Model 4) in order to observe the possible change of association.

A 5% significance level was principally used to identify statistically significant associations, but a Bonferroni correction was also applied to enable identification of significant associations after allowance for multiple comparisons. Receiver operating characteristic (ROC) curves were calculated to analyze the diagnostic validity of the VFD. ROC computes the true positive and false positive for each test value and plots them on a curve. The area under the ROC curve (AUC) could be interpreted as a measure of classification quality of the test. The AUC values range from 0 and 1, with higher values indicating better classification accuracy. As much as its value is closer to 0.5, the poorer the accuracy of the test is because the value of 0.5 corresponds to a random classification. XLSTAT-BIOMED statistical software was used for this analysis, which computes the *p*-value with a logistic regression model. A p-value <.05 implies that the logistic regression classifies the fallers based on the empirical data better than by chance. The 95% confidence interval (CI) estimates the interval of the population parameter out of the study data. For any diagnostic or screening tool the lower bound of the 95% CI of the ROC curve, should be greater than 0.5 if not, the risk that the real population estimate is not better than a random classification is too high.

Results

Characteristics of participants

The descriptive statistics for the biodata and anthropometric indices for the community-dwelling older adult fallers (N=280; comprising 150 males and 130 females) and non-fallers (N=220; comprising 100 males and 120 females) are presented in Table 1. Relatively, the non-fallers were older, taller, and heavier than the fallers, but these differences were not significant ($p>0.05$). Sex distribution of the characteristics of the participants is presented in Table 2. The mean age among the 250 males was 69.8 years (age range of 65 to 85 years), and among the 250 females, it was 74.48 years (age range of 65 to 85 years). The males had higher fasting plasma glucose, E1 values, BMI, as well as a higher prevalence of anxiety disorders compared to females. The presence of dizziness and arthritis was more common in females than in males. The males smoked more than the females and consumed more alcohol.

Table 3 presented the basal gait parameters of the fallers and non-fallers. From the results, the mean velocity of the non-fallers was significantly higher than that of the fallers at slow walking speeds. The association between E1 and gait velocity is presented in table 4. The cut-off values for E1 quartiles among the males were: quartile 1 (<1.80), quartile 2 (1.80-2.51), quartile 3 (2.52-3.69), and quartile 4 (>3.69); while among the women they were quartile 1 (<1.48), quartile 2 (1.48-2.28), quartile 3 (2.29-3.52), and quartile 4 (>3.52). The males were similar to women in terms of age, weight, and gait velocity. E1 values were inversely associated with velocity among the men. After adjustment for age, BMI categories, alcohol consumption, and use of walking devices, each increment of 1SD in the E1 values were associated with a 0.037 m/sec decrease ($p = 0.017$) in velocity (Table 3). Additional adjustment of covariates including chronic co-morbidities and markers of cardiovascular risk (anti-anxiety drugs) did not alter the association among men (Model 2 and Model 3). In the fully-adjusted model where BMI was additionally adjusted (Model 4), the negative association between E1 and velocity among men were unchanged (β coefficient -0.049, $p = 0.011$). However, there was no association between E1 and velocity in the females, and a subsequent division of E1 into quartiles, showed that velocity among the females in the highest E1 quartile was 0.068 m/sec less than that for males in the lowest quartile after adjustment for Model 1 covariates (significant trend across E1 quartiles with $p = 0.038$). Likewise, supplementary adjustment for additional covariates (Models 2 to Model 4) did not alter the inverse association between E1 and velocity in the males, in the quartile-based analyses. Overall, no clear trend was established between E1 quartiles and velocity in the females. Stratified by gender, adjusted means of velocity based on different E1 quartiles were obtained from the full-adjusted regression models.

Diagnostic accuracy of the VFD and TUG relative to the fallers as the gold standard

VFD (figures 2-3) and TUG were separately used to predict fall among a group of known community-dwelling older adult fallers (gold standard) and non-fallers. When applied to the same population of 280 older adult fallers (figure 4a, and 4b), the TUG returned 110 (39.29%) positive test results, whereas the VFD returned 200 (71.43%) positive test results (table 5). A similar assessment among 220 non-fallers showed that the TUG returned 130 (59.09%) negative test result whereas the VFD returned 60 (27.27%) negative test results (table 5). Cohen's quadratic weighted Kappa, (K= 0.2804 SE 0.12; 95%:CI: 0.05- 0.51) suggest a minimal level of agreement between both instruments. It was shown (table 5) that the sensitivity, specificity, positive predictive value and negative predictive value of the VFD were 71%, 36%, 53%, and 56%, respectively. This compares favorably with 39%, 59%, 44%, and 45% recorded for the TUG in the same population.

McNemar test showed (table 6). a significant ($p<0.05$) concordance, (McNemar test: Pa= 20/28 = 0.7143, Pb = 11/28 = 0.3929, Pa/Pb = 0.3214, p = 0490; odds ratio larger/smaller) = 3.25; 95% CI: 0.9675 - 1.0597), and a small confidence interval when the predictive accuracy of the VFD was compared to the TUG. The sensitivity and specificity of the VFD and TUG were separately tested in the same population of fallers and non-fallers. Relative to the TUG, the VFD returned a positive test result for 70 of the 110 positive test results from TUG, so the estimated sensitivity of the VFD relative to the TUG is 70/110×100 %= 63.63%. In contrast, the VFD returned negative test results for 40 out of 170 negative test results from TUG, so the estimated specificity of VFD relative to the TUG is 40/170×100 %=23.53%.

ROC curves (Figure 5,) were used to explore the ability of the VFD and TUG to discriminate between fallers and non-fallers. The ROC area under the curve was 0.74 (95%CI 0.597, 0.882) for VFD (table 7); which was significant ($p=0.001$) and is suggestive of a fair discrimination between fallers and non-fallers. The optimal categorizations for discrimination between fallers and non-fallers using the VFD (figure 6a) were ≥3.78 versus ≤3.78 for E1 (fallers and non-fallers prevalence 60.71% versus 95.45%, respectively), with an accuracy of 0.76. For the TUG, the area under the curve was 0.53, with a 95% CI = [0.353, 0.700], which is not significant (p = 0. 0.762). The optimal categorizations for discrimination between fallers and non-fallers (figure 6b), were ≥12.81s versus ≤12.81 for TUG times (fallers and non-fallers prevalence 92.86% versus 36.36%, respectively), and with an accuracy of 0.68. For the entire sample (male and female combined), table 8 shows the sensitivity and the specificity of the TUG and the VFD for different thresholds. With regards to the desired balance between sensitivity and specificity, an appropriate cutoff point could be selected. A higher cutoff point increases the specificity, and a lower cutoff point increases the sensitivity.

Discussion

The main objective of this study was to determine and compare diagnostic utility of the VFD and TUG in discriminating fallers from non-fallers among community-dwelling older adults. The ROC curves were used to explore the reliability of the VFD and TUG in discriminating between fallers (gold standard) and non-fallers. The VFD's higher AUC of 0.74 ($p = 0001$) compared to TUG (AUC = 0.53, $p =.76$) shows a better risk discriminatory strength in older community-dwelling adults. The VFD's ROC area under the curve (0.74, 95%CI: 0.597, 0.882) showed a fair discrimination between fallers and non-fallers compared to the TUG.

An ideal diagnostic test should have high sensitivity and high specificity for discriminating fallers from non-fallers. High sensitivity means that there will be few false-negative results. High specificity means that there will be few false-positive results. Compared separately to the gold standard (i.e., fallers), it was demonstrated that the VFD has a higher sensitivity (ability to rule-out) than the TUIG. Therefore, a higher proportion of fallers than non-fallers were correctly identified using the VFD. The 95% CI: was narrower for the VFD than the TUG which shows a greater precision in the VFD's measurement compared to the TUG. In contrast, the VFD's specificity (ability to rule-in) was smaller compared to the TUG. This indicates that a higher proportion of non-fallers were correctly identified using the TUG. However, the VFD's overall positive predictive value was moderate (53%) unlike the TUG (44%). Similarly, the negative predictive values of the VFD (56%) was moderate unlike the TUG (45%). This means that nearly two out of four older adults with a history of falls will be expected to have a positive test with the VFD. In contrast, the TUG's corresponding sensitivity of 0.39 and PPV of 0.44 mean that only one person in four with a history of falls will be expected to have a positive test.

Overall, Cohen's quadratic weighted Kappa, ($K= 0.2804$ SE 0.12; 95%:CI: 0.05- 0.51) suggest that there was a minimal agreement between the VFD and TUG in fall discrimination implying that only 4–15% of the data are reliable if the TUG were to be a reference standard. Invariably, the differences in the sensitivity and specificity of the VFD and the TUG may explain the minimal agreement between them as observed in this study.

There were no significant differences between the fallers and non-fallers at all speeds of walking except at slow walking speeds. It suggests that the basal gait parameters were able to compensate for one another at other walking speeds as defined in the mathematical relationship: velocity = stride length x stride frequency. Ordinary/normal walking speed marks the path of minimal energy trajectory whereby the cyclic frequency of swing of the lower limb attains its natural pendulum rate and the path of minimum energy trajectory [17, 46]. Therefore, at any speed below normal walking, muscle contraction will be required to deliberately retard the lower limb swing below its natural pendulum rate. A locomotor system that is comprised of weakened muscles may be sufficiently challenged at slow walking speed and therefore unable to compensate for an anticipated reduction in the stride frequency by increasing the stride length. A shorter stride length implies a reduction in the pelvic rotation which is required to lower the vertical projection of the body's center and optimize stability. Therefore, the expectation is that the center of gravity of the older adult fallers should be high and likewise the increased tendency towards instability. The expected instability is likely to be aggravated by increased disequilibrium that may arise with stepping, and eventually predispose to locomotive fall. Therefore, the point of intersection of the regression lines of stride frequency and gait velocity, defined as E_1 on the VFD, would likely vary in fallers and non-fallers. This is the basis on which E_1 is considered as a fair discriminator of fallers from non-fallers. The TUG which screens for fallers on the basis of their ambulatory performance at only the normal but not slow walking speeds, would not have accurately discriminated fallers from non-fallers. Invariably, the TUG provides limited insights about the challenges of fallers throughout the entire spectrum of human walking speeds (apart from normal walking speeds), within which the activities of daily living are likely to occur, and likewise locomotive falls.

For this study, the normal walking speed of the older adult fallers (0.49m/s) and non-fallers (0.50m/s) was below 1 meter per second. Ordinarily, a safe, normal walking speed for an older adult is considered to be at least 1 m per second [47]. A gait speed of ≤0.8 m/s (taking longer than 5s to walk 4m) similar to what was observed in our study, has been shown to have a sensitivity of 0.99 for identifying frailty and implies an increased likelihood that an average participant in this study was frail [48]. In addition, Studenski et al [49] also demonstrated that every 0.1 m/s reduction in gait velocity in older adults is associated with a 12% increase in mortality.

Since the regression line of velocity defines E_1 on the VFD, it means that E_1 should relate to frailty and mortality, possibly arising from falls. Invariably, the inverse association between E_1 and gait speed among men in this study also suggests that an increase in E_1 implies an increased tendency to frailty and morbidity in this population. Therefore, as E_1 increases from zero to 3.5velots, so also the tendency to fall, frailty and mortality. The vice versa is also true.

The relationship between E_1 and gait speed was independent of age, BMI, smoking status, alcohol consumption, co-morbidities, and cardiovascular risk factor. This may explain why the likelihood ratios of the VFD (E_1) was high, and therefore likewise its reliability. Nevertheless, the observed relationship between these covariates and E_1 may arise from their impact on the neuromuscular architecture of the human motion apparatus. This may have predictable roles in the development of functional impairments that may affect walking/gait speed. The cut-off values for E_1 quartiles among the males were interpreted as follows: <1.80 signifies no falls or the region of optimum stability, 1.80-2.51 signifies pre-fall, 2.52-3.69 signifies falls, and >3.69 signifies severe falls; while among the women, the cut off values of E_1 <1.48 signifies no falls, 1.48-2.28 signifies pre-falls, 2.29-3.52 signifies falls and >3.52 severe falls. Invariably, the women are at a greater risk of falls than men and must be assessed using separate reference category than men.

Though the VFD has not been evaluated in prospective studies, the results of this study would indicate that it has a greater falls diagnostic accuracy (AUC of 0.74, 95% CI: 0.60, 0.88; 36% specificity, 71% sensitivity) than the Timed Up and Go (AUC of 0.53, 95% CI: 0.35, 0.70; 59% specificity, 39% sensitivity). Our findings with the sensitivity and specificity of the TUG was similar to the findings of a previous study by Barry et al [1]. Findings from another previous study not only support our findings that the VFD has a greater predictive accuracy than TUG (0.61, 95% CI: not given) [50], but also other fall predictive tools such as 25 one-leg stand (0.53, 95% CI: not given) [50], Tinetti balance (0.56, 95% CI: not reported) [50], functional reach (0.51, 95% CI: not reported) [50], medio-lateral sway (0.67, 95% CI: 0.57-0.77) [51], and tandem stand (0.61, 95% CI: 0.49-0.73) [51]. Apart from its specificity and sensitivity values, the overall predictive accuracy of the VFD was similar to the MCHSAT (0.72, 95% CI: 0.63-0.82) (75% specificity, 62% sensitivity) [52]. However, the higher specificity than sensitivity values of the MCHSAT [52] suggests that it can predict non-fallers than fallers. This is unlike the VFD that has a higher sensitivity than specificity values. Therefore, the VFD can discriminate fallers from non-fallers more than the MCHSAT.

The VFD's optimal categorizations for discrimination between fallers and non-fallers were ≥3.78Velots versus <3.78Velots for E_1 (fallers and non-fallers prevalence 60.71% versus 95.45%, respectively), with an accuracy of 0.76. This is better than E_1 ≥3.5Velots versus <3.50 Velots versus <3.50 Velots for E_1 (fallers and non-fallers prevalence 60.71% versus 95.45%, respectively), proposed by Eke-Okoro [19], which has a predictive accuracy of 0.56. For the TUG, the optimal categorizations for discrimination between fallers and non-fallers were ≥12.81s versus ≤12.81 for TUG times (fallers and non-fallers prevalence 92.86% versus 36.36%, respectively), with an accuracy of 0.68, which is better than ≥13.50s versus ≤13.50s, which has an accuracy of 0.44.

Given that the positive and negative predictive values, which are measures of reliability, are affected by disease prevalence [53], the likelihood ratios were therefore determined. This is reasonable because the likelihood ratio (LR) provides a statistic about test reliability that is (to some extent) independent of disease/outcome prevalence [54]. Since this study revealed that the weighted positive and negative likelihood ratios for the VFD were greater compared to the TUG, it also implies that the reliability of the VFD in screening fallers from non-fallers are to some extent more independent of disease/outcome prevalence than the TUG. This corroborates the validity of our findings that though age, body mass index, smoking status, alcohol consumption, and use of walking devices; as well as chronic co-morbidities (dizziness, vestibular disease, diabetes, alcoholism, and arthritis); markers of cardiovascular risk (natural-log-transformed levels of the use of anti-anxiety drugs) were all associated with an increased likelihood of being a faller in a population of community-dwelling older adults, but did not influence the relationship between E_1 and gait velocity.

Strength and Limitations of the study.

The strength of this study is that it determined the validity, reliability and diagnostic accuracy of the VFD in a population of community-dwelling older adults, which has not been done before. To the best of our knowledge, this is the first time that the validity and reliability of the VFD are tested relative to a gold standard (i.e. fallers). For each participant recruited, data were collected over a 23-minute time frame, which compared favorably to the 25-minute and 45-minute time frames recorded for similar practical tools like the TUG and MCHSAT [52]. Moreover, the VFD costs nothing and is maintenance free, which recommends it as a viable screening tool in resource-poor communities/developing countries. Furthermore, the population of the study was well described, and detailed measurements were conducted while controlling for threats to the internal and external validity of the study. However, the results of this study will be limited in its contextual interpretation to rural-community settings, with similar socio-cultural activities/attributes, and environmental factors. This is important because several factors are responsible for falls including those related to the environment (extrinsic), individual (intrinsic) and activity (behavioral) [55].

One limitation of this study is the relatively smaller sample size (n =500), which was below the projected size of 840 per group even though it is far greater than 9 participants recruited in a landmark study pilot study by Eke-Okoro [19], 50 participants and 62 participants recruited by Sosnoff et al [36] and Struble-Fitzsimmons [56] respectively. However, the cited studies did not report the ROC of the fall screen tool that was evaluated to see if the sample size also had comparable effects on their discriminatory capacities. Nevertheless, the parameters measured in this study were broad enough to characterize the gait process and therefore provided deeper insights on the differences in the gait of fallers compared to non-fallers that may have an influence on the fall precipitation point (E_1). The validity of the Hanhart stopwatch used to measure the time taken is not known but it has a resolution of 0.20 sec and has been widely used in different research studies across the world. Furthermore, the recruitment of participants from the health fora may constitute a selection bias since the sample may not be truly representative of all the older adult population in the community. Nonetheless, the recruitment approach used in this study have been applied in some community-based studies on falls [57–60] where it is difficult to enumerate all households with older adults considering the difficult terrains, unmotorable roads, poor communication, and transport system. In addition, the convenience sampling technique used in this study is weak in addressing selection bias. However, it is the preferred approach in selecting individuals with specific attributes in community-based studies as applicable to fallers and non-fallers than randomization. The possibility of a recall bias was satisfactorily addressed by selecting only participants whose relatives/neighbors were able to corroborate their self-reported fall history. Though the VFD has not been tested across various socio-cultural populations, it is not known that there is a population for which walking is not a common functional daily activity, unlike other activities, such as deep squatting, utilized by other practical tools such as The Minimal Chair Height Standing Ability Test (MCHSAT) [30, 52].

It must be noted that the test of a new instrument actually seems to depend on whether a new test instrument and the gold standards have correlated errors and how close the gold standard is to the truth. If errors are uncorrelated or the test is close to the truth, sensitivity and specificity are good measures of validity. If errors are correlated, sensitivity and specificity only indicate how close the test is to the imperfect reference, i.e., a measure of reliability. Thus, the use of fallers as the gold standard minimized the likelihood of such errors in this study. Just like all available fall screening tools, the weaknesses of the

TUG [1, 15] are well documented and suggests that to some extent there could be errors when screening for fallers with it. However, since it is the most commonly used method of predicting future fall among the older adults in community settings in Nigeria, it still has significant clinical relevance which was explored to determine how well the capacity of the VFD to predict falls compares or improves or complements available fall screening methods. Since the basic inputs into the VFD are the spatiotemporal gait parameters, it makes the fall estimation index relative and sensitive to biomechanical changes that may occur prior to falls.

Conclusion

This study presents the first evidence on the validity and reliability of the VFD in screening for the likelihood of falls in a community-dwelling older adult population. The key clinical implication of our findings is that the VFD has a fair discriminatory power and greater accuracy to identify fallers than the TUG. This questions the reliance on the TUG as a sole fall discriminatory tool in community-dwelling populations, as it could be misleading and detrimental to health. Overall, the VFD may be relevant as a primary measure in the determination of the risk of fall than the TUG. However, considering their strengths, a combination of both instruments may provide greater accuracy in fall screening and should be explored in future studies.

Declarations

Ethics approval and consent to participate

This University of Nigeria Health Research Ethics Committee approved this study – NHREC/05/01/2008B. The Health Department of Igboeze South LGA, Enugu State, Nigeria, and the Traditional rulers of the Ovoko community, also permitted the study. Participants' confidentiality was maintained by using code numbers instead of names and ensuring that records were destroyed at the end of the study. Participants gave their written informed consent, prior to participation and after the purpose of the study was explained to them. They were informed of their right to withdraw from the study at any time of their choice and these rights were strictly respected in accordance with the Helsinki declarations.

Consent to publish

Not applicable

Availability of data and materials

The datasets supporting the conclusions of this article are available in the institutional University of Nigeria repository and will be made easily available on request when required. Availability of data and materials. All requests for the study data should be addressed to the corresponding author via email: sam.ibeneme@unn.edu.ng.

Competing interests

The Authors declare that there is no conflict of interest

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Authors' Contributions

SCI conceived of the study, participated in the design of the study, field work, coordination, performed the statistical analysis and drafted the manuscript. JCE participated in the fieldwork, its design and coordination. GCI, and UPO participated in the field work, coordination, helped to perform the statistical analysis and helped to draft the manuscript. GF participated in the statistical analysis and helped to draft the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1. Biodata, and anthropometric indices for fallers (n=280) and non-fallers (n=220)

Variables	Participants (n=500)	Non-fallers (**n**=220)	Fallers (**n**=280)	Mean difference	p-value
Continuous variables X(SD)					
Age (years)		72.14(4.54)	70.04(3.76)	2.10	0.35
Height (cm)		164.00(6.78)	160.43(8.13)	3.57	0.10
Weight (Kg)		73.00(11.29)	70.61(17.23)	2.39	0.57
BMI (Kg/m^2)		25.86(0.23)	27.58(0.26)	1.72	0.0001**
Categorical variables N(%)					
Sex					
• Males	250 (50.0)	100 (45.45)	150 (53.57)		
• Females	250 (50.0)	120 (54.54)	130 (46.43)		
• Total	500 (100.0)	220 (100)	280 (100)		

Values were expressed as mean (X), standard deviation (SD), number (N) and percentage (%), ** indicates $p \leq 0.0001$

Table 2: Gender distribution of the risk factors for falls among the participants (n= 500)

Characteristics	Males	Females	Mean difference	P value
Continuous variables X(SD)				
Fasting blood sugar(mg/dL) • Fallers • Non-fallers	102.0 (0.5)	98.4 (0.5)	3.6	<0.001
Categorical variables, **N (weighted %)**				
Current smokers/tobacco users[a]				
• Fallers	110	30		
• Non-fallers	30	0		
Total N(/%)	140 (50.0)	30(10.71)		
Moderate or higher weekly alcohol intake[b, c]				0.0001
• Fallers	120	40		
• Non-fallers	20	10		
Total N(/%)	140 (50.0)	50 (17.86)		
Number on anti-anxiety Drugs Medication[c]				
• Fallers	90	30		
• Non-fallers	40	20		
Total N(/%)	130 (46.43)	50 (17.86)		
Diabetes[a]				
• Fallers	60	30		
• Non-fallers	30	0		
Total N(/%)	90 (32.14)	30 (10.71)		
Dizziness[a]				
• Fallers	90	70		
• Non-fallers	20	10		
Total N(/%)	110 (39.29)	80 (28.57)		

Vestibular disease[a]		
• Fallers • Non-fallers	50 0	20 0
Total N(/%)	50 (17.86)	20 (7.14)
Arthritis[a]		
• Fallers • Non-fallers	60 20	80 40
Total N(/%)	80 (28.57)	120 (42.86)
Ethnicity [a]		
Igbos	140 (50.0)	120 (42.86)
• Fallers • Non-fallers	70 60	
Total N(/%)		
Non-Igbos	10 (3.57)	10 (3.57)
• Fallers • Non-fallers	10 0	0 10
Total N(/%)		

Values were expressed as mean (SD) and number (weighted %); [a]Number and percentage; [b]Defined as weekly alcohol consumption of ≥11 units for men and ≥8 units for women; [c]Variable was positively skewed; median and inter-quartile range presented; ** indicates p≤0.001; *** indicates p≤0.0001

Table 3: Basal gait parameters and phases of stride for fallers (n=280) and non-fallers (N=220)

Variables	Velotype 1	Velotype 2	Velotype 3	Velotype 4	Velotype 5
	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD
Stride length (m)					
• Fallers	0.56 0.15	0.63 0.16	0.71 0.15	0.83 0.19	0.96 0.24
• Non-fallers	0.57 0.17	0.64 0.18	0.72 0.22	0.80 0.27	0.97 0.29
p-value	0.86	0.79	0.86	0.64	0.92
Stride frequency (strides/s)					
• Fallers	0.58 0.06	0.62 0.10	0.63 0.16	0.80 0.14	0.86 0.16
• Non-fallers	0.55 0.07	0.61 0.12	0.64 0.18	0.80 0.17	0.85 0.17
p-value	0.10	0.89	0.39	1.00	0.84
Velocity (m/s)					
• Fallers	0.31 0.07	0.38 0.06	0.49 0.08	0.66 0.09	0.88 0.34
• Non-fallers	0.31 0.09	0.44 0.14	0.50 0.12	0.65 0.10	0.88 0.39
p-value	0.92	0.05*	0.74	0.73	1.00

* indicates $p<0.05$; Velotype 1 – very slow walking speed; Velotype 2 = slow walking speed; Velotype 3 = normal walking speed; Velotype 4 = fast walking speed; Velotype 5 = very fast walking speed

Table 4: Association between E_1 and gait speed in male and female fallers

	Models with E_1 as a continuous variable							
	Men				**Women**			
		β* **(SE)**	**P value**			**β*** **(SE)**	**P value**	
Model 1		-0.038 (0.015)	0.017*			-0.019 (0.017)	0.172	
Model 2		-0.038 (0.017)	0.015*			-0.016 (0.016)	0.278	
Model 3		-0.046 (0.018)	0.013*			-0.014 (0.018)	0.372	
Model 4		-0.049 (0.017)	0.011*			-0.019 (0.014)	0.369	
	Models with E_1 by increasing quartiles							
	Men				**Women**			
	Quartile comparison	**β†** **(SE)**	**P value**	**P for trend**	**Quartile comparison**	**β†** **(SE)**	**P value**	**P for trend**
Model 1	Q2 v.s. Q1	-0.017 (0.037)	0.638	0.038*	Q2 v.s. Q1	0.049 (0.027)	0.092	0.464
	Q3 v.s. Q1	-0.064 (0.048)	0.146		Q3 v.s. Q1	-0.032 (0.031)	0.335	
	Q4 v.s. Q1	-0.078 (0.033)	0.078		Q4 v.s. Q1	-0.001 (0.035)	0.978	
Model 2	Q2 v.s. Q1	-0.011 (0.055)	0.790	0.056	Q2 v.s. Q1	0.052 (0.027)	0.075	0.531
	Q3 v.s. Q1	-0.059 (0.039)	0.197		Q3 v.s. Q1	-0.025 (0.030)	0.403	
	Q4 v.s. Q1	-0.058 (0.034)	0.078		Q4 v.s. Q1	0.006 (0.038)	0.908	
Model 3	Q2 v.s. Q1	-0.015 (0.029)	0.567	0.024*	Q2 v.s. Q1	0.058 (0.029)	0.048*	0.705
	Q3 v.s. Q1	-0.046 (0.031)	0.120		Q3 v.s. Q1	-0.022 (0.033)	0.508	
	Q4 v.s. Q1	-0.072 (0.035)	0.030*		Q4 v.s. Q1	0.016 (0.037)	0.707	
Model 4	Q2 v.s. Q1	-0.008 (0.036)	0.786	0.019*	Q2 v.s. Q1	0.052 (0.029)	0.059	0.673

Models with E_1 as a continuous variable

Men			Women		
	β* (SE)	**P value**		**β* (SE)**	**P value**
Q3 v.s. Q1	-0.048 (0.038)	0.167	Q3 v.s. Q1	-0.022 (0.031)	0.565
Q4 v.s. Q1	-0.063 (0.023)	0.024*	Q4 v.s. Q1	0.009 (0.036)	0.809

Adjusted covariates: Model 1 = body mass index categories, and alcohol consumption; Model 2 = Model 1 + co-morbidities (dizziness)

Model 3 = Model 2 + markers of cardiovascular risk (natural-log-transformed levels of the use of anti-anxiety drugs).

Model 4 = Model 3 + use of walking devices

* Parameter estimates (β) can be interpreted as differences in mean gait speed (m/sec) for each increment

of one standard deviation in the log transformed E_1 among men (or women).

† Parameter estimates (β) can be interpreted as differences in mean gait speed (m/sec) compared male (or female)

subjects in the 2nd, 3rd, and 4th quartiles of E_1 to those in the lowest quartile.

Abbreviations: E_1 – Equality point for the regression lines of velocity and stride frequency on the VFD; SE, standard error.

The cut-off values E_1 quartiles among the men were: quartile 1 (<1.80), quartile 2 (1.80-2.51), quartile 3 (2.52-3.69),

and quartile 4 (>3.69); while among the women the cut-off values were: quartile 1 (<1.48), quartile 2 (1.48-2.28),

quartile 3 (2.29-3.52), and quartile 4 (>3.52).

* Indicates $p \leq 0.05$,

Table 5: Sensitivity and specificity of the 'Velocity field diagram' and 'Timed-up-and-go-test' in fall prediction among fallers (N=280) and non-fallers (n=220)

				95%CI		
Variable	Non-Fallers N(%)	Fallers (gold standard) F(%)	Estimated values	Lower limit	Upper limit	Diff CI
No. of participants that tested positive						
• VFD	160(72.7)	200(71.4)				
• TUG	90(40.9)	110(39.3)				
No. of participants that tested negative						
• VFD	60(27.3)	80(28.6)				
• TUG	130(59.1)	170(60.7)				
Prevalence			0.56	0.41	0.70	0.29
Sensitivity						
• VFD			0.71	0.52	0.85	0.37
• TUG			0.39	0.22	0.59	0.37
Specificity						
• VFD			0.36	0.20	0.57	0.37
• TUG			0.59	0.37	0.79	0.42
PPV						
• VFD			0.53	0.56	0.83	0.26
• TUG)			0.44	0.27	0.55	0.28

NPV				
• VFD	0.56	0.19	0.71	0.52
• TUG	0.45	0.26	0.62	0.36
likelihood Ratios:				
Positive[C]				
• VFD	1.12	0.69	1.39	0.70
• TUG	0.79	0.49	1.90	1.41
Negative[C]				
• VFD	0.79	0.46	2.30	0.84
• TUG	1.21	0.72	1.47	0.75

PPV = positive predictive value; NPV = negative predictive value; [C] = conventional; 95%CI = 95% confidence interval, VFD=Velocity field diagram, TUG=Timed-up-and-go-test, Reference std = Reference standard; Cohen’s quadratic weighted Kappa, K= 0.28.04 SE 0.12; 95%:CI: 0.05- 0.51.

Table 6: Diagnostic accuracy of the velocity field diagram relative to the reference standard (TUG) tested among fallers (N=280)

TUG						
	Test condition	Positive	Negative	Total	Estimated sensitivity of VFD	estimated specificity of VFD
VFD	Positive	70	130	200	63.63%	23.53%
	negative	40	40	80		
	Total	110	170	280		

VFD = Velocity diagram; VFD correctly identified 70 of the 110 positive samples, so the estimated sensitivity of VFD is 70/110×100 %= 63.63%. Four of the 170 negative samples were correctly identified, so the estimated specificity of VFD is 40/170×100 %=23.53%.; McNemar test: Pa= 200/280 = 0.7143, Pb = 110/280 = 0.3929, Pa/Pb = 0.3214, p = 0490; odds ratio larger/smaller) = 3.25; 95% CI: 0.97 - 1.06

Table 7. Comparison of the Area Under the ROC Curve for Velocity field diagram’ and ‘Timed-up-and-go-test’

Fall screening tool	Area Under the ROC Curve.			Comparison of the AUC to 0.5			
	AUC	SE	95% CI	Difference	z (Observed value)	p	95% CI between AUC and 0.5 (Two-tailed test)
TUG	0.53	0.09	[0.35, 0.70]	0.03	0.30	0.76	[0.147, 0.20]
VFD	0.74	0.07	[0.60, 0.88]	0.24	3.30	0.001*	[0.091, 0.38]

* indicates p≤0.001; AUC= Area under the curve; SE= Standard error; 95% CI=95% confidence interval; z (Critical value) = 1.96

Table 8. Sensitivity and Specificity of the TUG and VFD for different thresholds

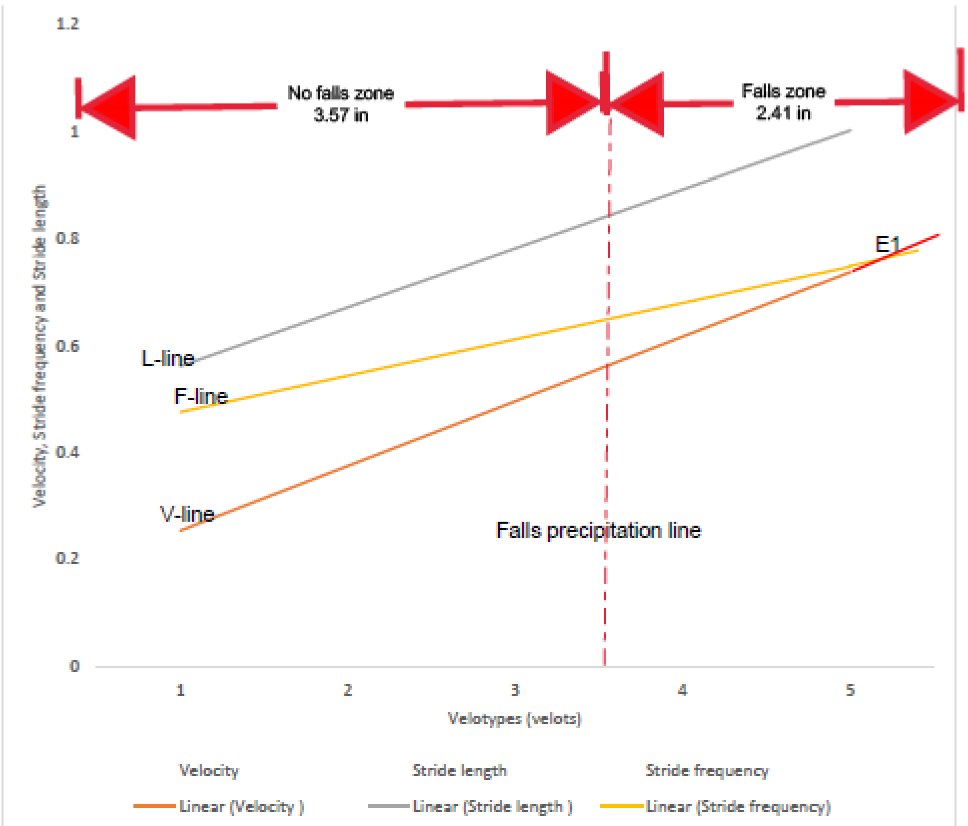
Screen tool	Sensitivity	Specificity	PPV	NPV	Accuracy
TUG **cutoff time (s)**					
≤11.77	1.00[0.83, 1.00]	0.09[0.02, 0.29]	0.52	1.00	0.60
≤12.88	**0.86[0.68, 0.95]**	**0.36[0.20, 0.57]**	**0.57**	**0.72**	**0.64**
≤13.25	0.54[0.36, 0.70]	0.36[0.20, 0.57]	0.46	0.44	0.46
≤13.72	0.36[0.21, 0.54]	0.64[0.43, 0.80]	0.50	0.50	0.48
≤13.98	0.18[0.08, 0.36]	0.82[0.61, 0.93]	0.50	0.50	0.46
VFD **cutoff values for E_1**					
≤1.80	1.00[0.88, 1.00]	0.00[0.00, 0.18]	0.50	0.00	0.56
≤2.57	0.86[9.68, 0.95]	0.23[0.01, 0.44]	0.51	0.57	0.56
≤2.93	0.75[0.56, 0.88]	0.32[0.16, 0.53]	0.52	0.56	0.56
≤3.68	**0.61[0.42, 0.76]**	**0.82[0.61, 0.93]**	**0.77**	**0.68**	**0.70**
≤4.05	0.39[0.24, 0.58]	1.00[0.82, 1.00]	1.00	0.62	0.66
≤4.29	0.18[0.08, 0.36]	1.00[0.82, 1.00]	1.00	0.55	0.54

Note. The values in brackets represent 95% confidence intervals. TUG = Timed Up and Go Test, VFD= Velocity field diagram

Figures

Figure 1

Design and flow of participants through the study



X axis:
1= Very slow walking; 2=slow walking,; 3=normal walking; 4=fast walking; 5 = very fast walking
L-Line= regression line of stride lenth; F-Line = regression line of Stride frequency;
V-Line=regression line of velocity; E1 of fallers is 3.5velots = fall precipitation line/point;

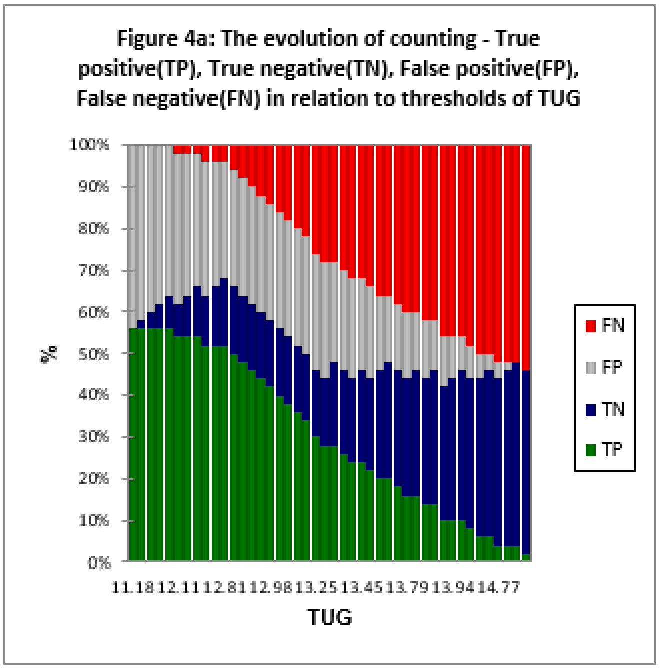
Y-axis:
Units of measurement
Velocity - metre/second, Stride frequency - Stride/second; Stride length -metre

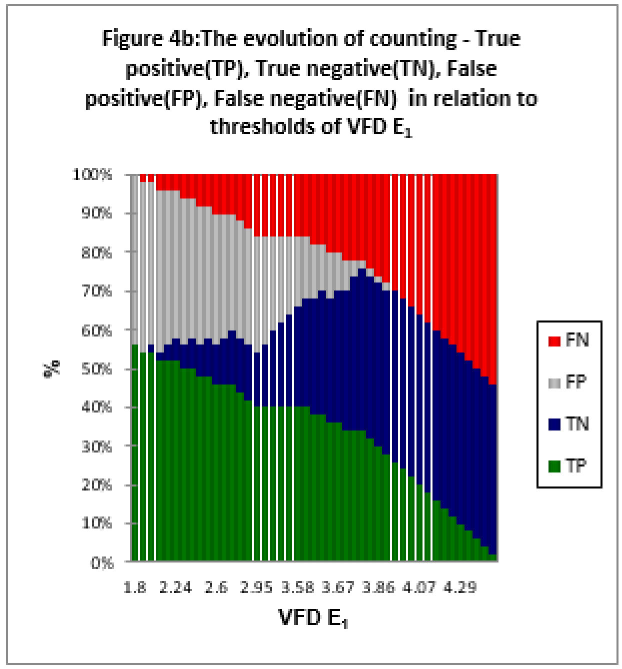
Figure 2

Velocity field diagram of a faller

Figure 3

Velocity field diagram of Non Non-fallers





TUG=Timed-up-and-go-test

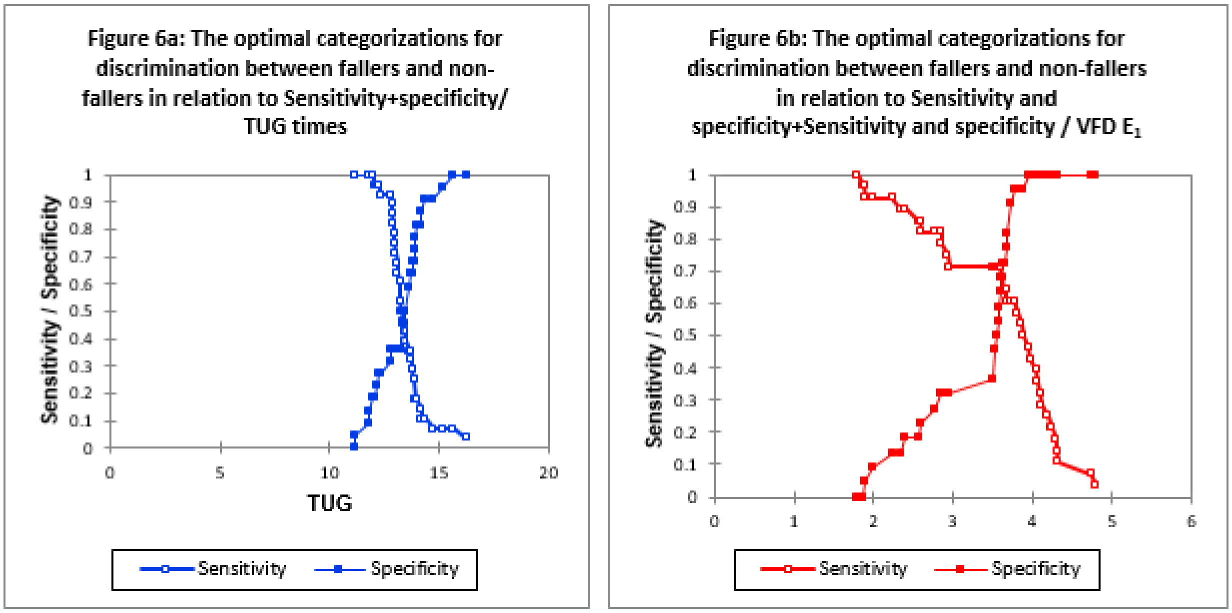
VFD=Velocity field diagram

Figure 4

a: The evolution of counting - True positive(TP), True negative(TN), False positive(FP), False negative(FN) in relation to thresholds of TUG b:The evolution of counting - True positive(TP), True negative(TN), False positive(FP), False negative(FN) in relation to thresholds of VFD E1

Figure 5

Comparison of the AUC of the ROC curves for TUG and VFD



TUG=Timed-up-and-go-test

VFD=Velocity field diagram

Figure 6

a: The optimal categorizations for discrimination between fallers and non-fallers in relation to Sensitivity+specificity/ TUG times b: The optimal categorizations for discrimination between fallers and non-fallers in relation to Sensitivity and specificity+Sensitivity and specificity / VFD E1