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The enhanced paper grip test can substantially improve community screening for the risk of falling

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ABSTRACT

Background: Lower-limb strength measures can enhance falls risk assessment but due to the lack of clinically applicable methods, such measures are not included in current screening. The enhanced paper grip test (EPGT) is a simple-to-use and cost-effective test that could fill this gap. However, its outcome measure (EPGT force) has not yet been directly linked to the risk of falling.

Research question: Is the EPGT a good candidate for falls risk screening in older people in the community?

Methods: Seventy-one older people living independently in the community were recruited for this prospective observational study (median age 69 y, range 65y-79y). Lower-limb and whole-body strength were assessed at baseline using the EPGT and a standardised hand-grip method respectively. Incident falls were recorded monthly for a year through follow-up telephone conversations. The capacity of individual strength measures to predict falls and to enhance an established falls risk assessment tool (FRAT) commonly used by UK's national health service (NHS) was assessed using binomial logistic regression. The analysis was repeated for the subset of participants without history of falling at baseline (prediction of first-ever falls).

Results: Increased EPGT force and increased symmetry in strength between limbs were significantly associated with reduced risk of falling. Compared to the NHS-FRAT, the EPGT correctly classified more people (73% vs 69%), it achieved higher sensitivity (56% vs 26%) and higher negative predictive value (76% vs 68%). Complementing the NHS-FRAT with the EPGT produced a more comprehensive model that correctly classified 91% of participants and achieved 98% specificity, 81% sensitivity, 89% negative and 96% positive predictive value. Replacing the EPGT with hand-grip strength consistently undermined prediction accuracy. The EPGT remained highly accurate when focused on the prediction of first-ever falls.

Significance: The EPGT can substantially enhance falls screening in the community. These results can also inform effective personalised strength exercise interventions.

1. Introduction

Screening within the broader older population can play a critical role in identifying individuals who can benefit from preventative interventions for falling [1,2]. Effective screening ensures that interventions are allocated and tailored efficiently to those at higher risk, maximising the societal impact of finite resources [2].

Existing screening tools include a range of assessments, such as history of falling, balance assessments and functional tests [3]. Despite the abundance of falls risk assessment tools (FRATs), only a limited number have been specifically developed and validated for older people living independently in the community [3].

Moreover, it has been demonstrated in the literature that muscle weakening can impair a person's ability to maintain balance after a trip or a slip significantly increasing the risk of falling [4]. Despite the importance of lower-limb muscle weakening for increased risk of falling [5–8], direct quantitative assessments of lower-limb muscle strength are still not fully integrated into daily clinical practice for falls risk assessment [3]. This limitation can undermine the effectiveness of screening [6,7,9] and mainly stems from the lack of relevant clinically applicable methods. Indeed the vast majority of methods for the direct quantification of muscle strength are developed and used within specialised clinical or research settings and are not appropriate or practical for testing in large cohorts in the community or primary care.

The enhanced paper grip test (EPGT) could fill this gap [10]. This test evolved from a simpler pass/fail paper grip test [11–14] to provide a

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quantitative assessment of hallux plantar flexion that is representative of lower-limb strength [10,15]. Literature has demonstrated that the EPGT offers an assessment of strength that could potentially be used to identify people at risk of falling [10,14–16]. However, its outcome measure (EPGT force) has not, as yet, been directly linked to the risk of falling.

The EPGT is safe, simple to use, and does not need any expensive specialised equipment or specialised training, which makes it a good candidate for large scale testing in the broader older population [10,15,16]. However, its potential value for community testing remains to be assessed. In this context, the primary objective of this study was to assess the ability of the EPGT to be a screening tool for falls in older people living independently in the community. The secondary objective was to validate its applicability outside laboratory or clinical settings and to identify the optimum method for its use. This included identifying the optimum technique for administering the test and the most relevant outcome measures to be recorded.

2. Methods

2.1. Participants

A cohort of 71 older people participated in this prospective observational study (Table 1). The specific inclusion criteria were: age≥ 65 y, living independently in the community, ability to provide informed consent (as assessed by the recruiting researcher) and ability to walk household distances unaided (>10 m)[17]. People with a history of structural surgery in the foot or a musculoskeletal or neurological condition that would make them unable to plantarflex their hallux were excluded.

Recruitment and testing took place during local community gatherings in Manchester, UK. Ethical approval was secured from Staffordshire University's ethics committee. Written informed consent was provided by each participant before data collection.

2.2. Baseline measurements

Muscle strength (EPGT force and hand-grip strength), key anthropometric (body mass, height) and demographic (sex, age) parameters were recorded at baseline. The risk of falling according to an established FRAT was also assessed [18].

The EPGT [10] was done for all participants at baseline. This test involves placing a small paper card (the size of a standard business card) under the participant's hallux and asking them to try to grip it by pushing downwards with their hallux (Fig. 1). In contrast to older paper grip methods [11–14], in the EPGT the card is linked to a dynamometer which is set to record the maximum pulling force that is needed to fully remove the card from underneath the participant's hallux [10]. This measurement is repeated three times per foot and their average is used as the EPGT force of each foot. For a detailed description of the EPGT please see Chatzistergos et al.(2020) [10] or Supplementary document A.

In the literature paper grip tests are done using two different techniques: ankle held [12,13] or ankle not held [10,11,14]. When the participant's ankle is held then enough support is applied by the examiner to ensure that the heel remains planted to the ground. When no support is provided, the participants must ensure that there is no movement at the heel. In this case, if movement is detected by the examiner, then the test is repeated. Considering that results are likely to differ significantly between techniques, both were included here and tested in a random order between participants.

In all previous applications of the EPGT, a person's EPGT force was calculated after averaging between feet. Averaging between feet is

Table 1
Characteristics of the participants at baseline. Normally distributed data are presented by their mean(± standard deviation). Non-normally distributed data are presented by their median(minimum, maximum value). The respective p values for differences between sexes or between people with history of falling and people without history of falling at baseline are also presented. Statistically significant differences are indicated with (*).

		All subjects	Male	Female	*p-value (male vs female)*	History of falling	No history of falling	*p-value (history vs no history of falls)*
Number of people		71	36	35	-	45	26	-
Age (y)*		69 (65,79)	67 (65,79)	70 (65,78)	*0.003**	69 (65,78)	68 (65,79)	*0.009**
Height (m)*		169.9 (12.4)	180.0 (± 7.3)	159.7 (± 6.9)	*< 0.001**	167 (± 12)	17 (± 12)	*0.012**
Body mass (kg)*		83.2 (18.9)	91.1 (± 19.3)	75.1 (± 14.6)	*< 0.001**	79 (± 17)	91 (± 20)	*0.006**
NHS-FRAT score		2.4 (± 1.1)	2.4 (± 1.1)	2.4 (± 1.1)	*0.556*	2.5 (± 1.0)	2.1 (± 1.1)	*0.115*
Hand-grip force (kg)		27.6 (± 3.2)	29.1 (± 3.1)	26.0 (± 2.5)	*< 0.001**	26.5 (16.3, 34.8)	28 (23.7, 35.0)	*0.016**
MinEPGT (N)	**Ankle held**	9.9 (± 2.8)	9.7 (± 2.8)	9.7 (± 2.8)	*0.001**	9.0 (± 2.7)	11.3 (± 2.4)	*< 0.001**
	NOT held	6.0 (± 2.8)	4.5 (± 1.8)	4.5 (± 1.8)	*0.006**	4.8 (± 2.3)	6.1 (± 2.5)	*0.024**
MaxEPGT (N)	**Ankle held**	14.0 (± 3.0)	13.7 (± 3.1)	13.7 (± 3.1)	*0.005**	13.2 (± 3.0)	15.0 (± 2.9)	*0.019**
	NOT held	13.8 (± 3.5)	12.3 (± 1.8)	12.3 (± 1.8)	*0.006**	12.4 (± 3.3)	14.1 (± 3.2)	*0.037**
AvgEPGT (N)	**Ankle held**	11.8 (± 2.7)	12.7 (± 2.9)	10.9 (± 2.2)	*0.004**	11.1 (± 2.6)	13.2 (± 2.4)	*0.002**
	NOT held	9.0 (± 2.6)	9.8 (± 2.8)	8.1 (± 2.0)	*0.003**	8.2 (± 2.3)	10.3 (± 2.5)	*0.001**
DiffEPGT (N)	**Ankle held**	0.30 (0.00, 0.90)	0.40 (± 0.22)	0.40 (± 0.22)	*0.653*	0.4 (± 0.2)	0.28 (± 0.1)	*0.02**
	NOT held	0.90 (0.20, 1.90)	0.80 (± 0.30)	1.00 (± 0.30)	*0.004**	0.98 (± 0.32)	0.8 (± 0.3)	*0.039**

NHS-FRAT: National Health Service – Falls Risk Assessment Tool; EPGT: Enhanced Paper Grip Test; MinEPGT: weakest limb EPGT force; MaxEPGT: strongest limb EPGT force; AvgEPGT: average between limbs EPGT force; DiffEPGT: normalised difference in strength between limbs.

Fig. 1. A demonstration of the EPGT (https://www.youtube.com/watch?v=hsNVGVDftyY&t=265s).

perfectly valid for biomechanical studies [19], but within the context of screening it also implies that average strength is most critical for the risk of falling. This assumption is not necessarily supported by literature [20]. For example, one could also argue that the strength of the weakest limb or the asymmetry in strength between limbs are also important [20]. To provide insight on the optimal outcome measure to be used in future screening applications, in addition to average EPGT force (AvgEPGT), the value of the EPGT force of the weakest limb (MinEPGT), of the strongest limb (MaxEPGT) and their normalised difference (DiffEPGT) were also calculated. Normalised difference between limbs was calculated as follows:

$$DiffEPGT=((MaxEPGT)-(MinEPGT))/AvgEPGT \quad (1)$$

Hand-grip strength was also measured according to literature to offer a comparison against an established easy-to-use measurement of whole-body strength [21]. In this case, the measurements were averaged between left and right to provide a single value of hand-grip strength per participant [21].

The risk of falling was assessed using a FRAT commonly used by the UK's National Health Service (NHS) [18,22]. More specifically the NHS-FRAT assessment comprised of 5 yes/no questions [18]:

a) Have you had a fall in the previous year?
b) Do you take four or more medications per day?
c) Have you had a stroke, or have you been diagnosed with Parkinson's disease?
d) Do you have any problems with your balance?
e) Are you unable to stand up from a chair of knee height without using your arms?

For each positive answer, a score of 1 is given. A score of 3–5 indicates a high risk of falls [18].

2.3. Follow-up

Incident falls were recorded for 12 months after baseline. These falls were documented monthly [23] through telephone conversations. Falls caused by major intrinsic events or an overwhelming extrinsic hazard were omitted from further analysis [24]. More specifically, participants were asked "in the past month, have you had any fall including a slip or trip in which you lost your balance and landed on the floor or ground or lower level?'' [23]. Participants who experience a fall remained in the study to record potential recurrent falls.

2.4. Statistical analysis

The normality of recorded data was tested using the Shapiro–Wilk test. Normally distributed data are presented by their average ($\pm$ standard deviation), non-normally distributed data by their median (min. value, max. value). Independent-samples t-test (equal variances assumed) or Mann-Whitney U test (non-normally distributed data) was used to assess the significance of differences: a) between sexes, b) between people with a history of falling and those without history of falling at baseline.

Logistic regression analysis was used to directly assess the capacity of muscle strength measures to predict the risk of falling in the following year. To this end, individual EPGT outcome measures and hand-grip force were used as the sole predictors in separate regression analyses. The ability of the NHS-FRAT score to predict the risk of falling was also assessed separately to set a benchmark for improvement.

A follow-up series of regression analyses was done to see whether strength measures can complement existing approaches for falls risk assessment. To this end, individual EPGT and hand-grip measures were combined with the questions of the NHS-FRAT. In the case of EPGT force, the analysis focused only on the specific outcome measure and technique that achieved the best predicting ability during the first round of regression analyses.

The predicting capacity of individual models was assessed based on the area under the receiver operating characteristics curve (ROC), the percentage of cases correctly classified, the achieved specificity, sensitivity, negative and positive predictive value (Supplementary document B).

The aforementioned regression analyses were conducted first for the entire recruited population and then for a subset of the same population that included only people without a history of falls at baseline. This repeat analysis aimed to test whether the prediction of first-ever falls is feasible.

Sample size was decided to enable assessing whether individual strength measures are significant predictors for the risk of falling in the general population and in the subset of participants without history of falling. Based on the rule of ten [25], we aimed to have at least ten people experiencing their first-ever fall during the follow-up period of this study. Preliminary sample-size calculations indicated that ≥ 71 people would be needed to this end (30% of people assumed to have history of falling at baseline [26], 20% assumed annual prevalence of first-ever falls [27]).

All statistical analyses were conducted using GraphPad Prism version 10.0 (GraphPad Software Inc, La Jolla) and SPSS v28(IBM, Chicago, IL, USA).

3. Results

3.1. Baseline

Out of the total of 71 participants, 45 people (63%) reported having a history of falling at baseline. Out of these, 24 people (53%) were women. The average age of people with or without a history of falling was 70.1 y ($\pm$ 3.6 y) and 68.0 y($\pm$ 3.2 y) respectively; a statistically significant difference (t-test, two tail, $p = 0.014$). When comparing strength measurements, participants with a history of falls appeared to have significantly lower hand-grip strength and lower EPGT force, regardless of the EPGT technique (ankle held or not held) or the outcome measure used (MinEPGT, MaxEPGT or AvgEPGT force) (Table 1). People with a history of falling also had a statistically significant higher asymmetry in EPGT force between limbs (DiffEPGT) (Table 1).

Male participants scored higher than their female counterparts in all strength measures (Table 1). Female participants were also relatively older, which could account for some of the difference between sexes. Higher asymmetry between limbs was also observed in females (ankle not held DiffEPGT).

MinEPGT, MaxEPGT and AvgEPGT were consistently higher for ankle held than for ankle not held. On the contrary, DiffEPGT was lower when the ankle was supported (Table 1). All differences between the two techniques were statistically significant.

3.2. Follow-up

All participants completed the study with 27 people (38%) reporting a fall within the 12-month follow-up period. For eleven of these 27 people, this was their first-ever fall. No one fell more than once during follow-up. Results are presented below separately for the general recruited population and for people without a history of falling at baseline.

3.2.1. General recruited population

Out of the 27 fallers, 14 were female (52%). People who fell during follow-up were older than those who did not fall (5% difference between median, Mann-Whittney U test, two-sided, $p < 0.001$).

The NHS-FRAT achieved a statistically significant prediction that correctly classified 69% of participants and achieved 95% specificity and 26% sensitivity (Table 2). Using strength measures as the only predictor of the risk of falling in the general population resulted in statistically significant regression models regardless of the outcome measure or the technique that was used (Table 2). The only exception was DiffEPGT for ankle held which was not a significant predictor of falling. Among the individual predictors considered, ankle not held AvgEPGT and DiffEPGT achieved the highest number of cases correctly classified (73%). With a specificity of 84% and sensitivity of 56% ankle not held AvgEPGT appears to offer a better compromise between specificity/sensitivity (Table 2).

There was a consistent trend of increased EPGT force being associated with decreased risk of falling regardless of the technique or outcome measure of the EPGT force (Table 2). Indicatively, one Newton increase in ankle not held AvgEPGT decreased risk by a factor of 0.70. Moreover, increased asymmetry in EPGT force between limbs was significantly associated with increased risk of falling. In this case, a modest increase of 10% in ankle not held DiffEPGT increased risk by a factor of 1.64 (Table 2).

Combining ankle not held AvgEPGT with the five questions of the NHS-FRAT substantially improved the prediction of the risk of falling. This more comprehensive model was able to correctly classify 91% of participants and achieve 98% specificity, 81% sensitivity, 89% negative and 96% positive predictive value. Following the same procedure for hand-grip force also improved prediction, but the predicting ability remained weaker compared to AvgEPGT (Table 3).

3.2.2. People with no history of falling at baseline

When regression analyses were repeated for the subset of the participants without a history of falling at baseline, the NHS-FRAT was able to correctly classify 62% of participants achieving 73% specificity and 45% sensitivity (Table 4).

Regression analyses where individual strength measures were used as the only predictors for the risk of a first-ever fall yielded statistically significant predictions for all outcome measures except ankle held DiffEPGT and ankle not held MaxEPGT (Table 4). Among the individual predictors considered, ankle not held MinEPGT offered the strongest prediction by correctly classifying 89% of participants and achieving a 93% specificity and 82% sensitivity (Table 4).

Same as before, increased muscle strength (EPGT or hand-grip)

Table 3
The strength of prediction for the risk of falling when ankle not held AvgEPGT force or hand-grip force are complemented by the five NHS-FRAT questions (Fall in previous year; four or more medication; stroke or Parkinson's disease; any problems with balance; unable to stand from a chair without using arms).

	Predictors	
	NHS-FRAT questions (5 parameters) +	
	Ankle not held AvgEPGT	Hand-grip force
Correctly classified (%)	91	87
Specificity (%)	98	95
Sensitivity (%)	81	74
Negative predictive value (%)	89	85
Positive predictive value (%)	96	92

NHS-FRAT: National Health Service – Falls Risk Assessment Tool; EPGT: Enhanced Paper Grip Test; AvgEPGT: average between limbs EPGT force.

Table 2
The predicting ability of individual EPGT outcome measures and of hand-grip force for the risk of falling. A regression analysis with NHS-FRAT score as the sole predictor is also included as a benchmark for improvement. The significance of each regression model is presented based on its p-value. The effect of individual predictors on the risk of falling is recorded by the respective odds ratios.

Predictors		Model *p*-value	ROC area	Correctly classified (%)	Specificity/ sensitivity (%)	Negative/ positive predictive power (%)	Odds ratio (95%CI)
NHS-FRAT		0.028	0.64	69	95/26	68/78	1.74 (1.03–2.89)
Hand-grip force (N)		0.009	0.68	66	86/33	68/60	0.80 (0.66–0.96)
MinEPGT (N)	**Ankle held**	0.005	0.68	72	84/52	74/67	0.77 (0.64–0.94)
	NOT held	< 0.001	0.76	66	82/41	69/58	0.67 (0.51–0.86)
MaxEPGT (N)	**Ankle held**	< 0.001	0.72	66	77/48	71/57	0.73 (0.59–0.89)
	NOT held	0.034	0.65	69	91/33	69/69	0.85 (0.72–0.99)
AvgEPGT (N)	**Ankle held**	< 0.001	0.73	72	82/56	75/65	0.71 (0.57–0.88)
	NOT held	< 0.001	0.73	73	84/56	76/68	0.70 (0.56–0.88)
DiffEPGT (N)	**Ankle held**	0.674	-	-	-	-	-
	NOT held	0.001	0.71	73	86/52	75/70	16.37 (2.54–105.30)

ROC: receiver operating characteristic cure; CI: confidence intervals; NHS-FRAT: National Health Service – Falls Risk Assessment Tool; EPGT: Enhanced Paper Grip Test; MinEPGT: weakest limb EPGT force; MaxEPGT: strongest limb EPGT force; AvgEPGT: average between limbs EPGT force; DiffEPGT: normalised difference in strength between limbs.

Table 4
The predicting ability of individual EPGT outcome measures and of hand-grip force for the risk of having a first-ever fall. A regression analysis with NHS-FRAT score as the sole predictor is also included as a benchmark for improvement. The significance of each regression model is presented based on its p-value. The effect of individual predictors on the risk of falling is recorded by the respective odds ratios.

Predictors		Model *p*-value	ROC area	Correctly classified (%)	Specificity/ sensitivity (%)	Negative/ positive predictive power (%)	Odds ratio (95%CI)
NHS-FRAT		0.012	0.75	62	73/45	65/56	3.16 (1.09–9.19)
Hand-grip force (N)		0.044	0.75	73	80/64	75/70	0.73 (0.52–1.03)
MinEPGT (N)	**Ankle held**	0.029	0.76	77	87/64	77/78	0.65 (0.41–1.02)
	NOT held	> 0.001	0.88	89	93/82	88/90	0.44 (0.22–0.87)
MaxEPGT (N)	**Ankle held**	0.008	0.75	77	80/73	80/73	0.63 (0.42–0.95)
	NOT held	0.096	-	-	-	-	-
AvgEPGT (N)	**Ankle held**	0.009	0.76	73	80/64	75/70	0.59 (0.36–0.95)
	NOT held	0.002	0.81	73	80/64	75/70	0.50 (0.29–0.88)
DiffEPGT (N)	**Ankle held**	0.883	-	-	-	-	-
	NOT held	0.002	0.82	77	93/55	74/86	183 (3–11760)

ROC: receiver operating characteristic cure; CI: confidence intervals; NHS-FRAT: National Health Service – Falls Risk Assessment Tool; EPGT: Enhanced Paper Grip Test; MinEPGT: weakest limb EPGT force; MaxEPGT: strongest limb EPGT force; AvgEPGT: average between limbs EPGT force; DiffEPGT: normalised difference in strength between limbs.

signifcantly decreased risk for a first-ever fall while increased difference in EPGT force between limbs significantly increased the risk for a first-ever fall. In this case one Newton increase in ankle not held MinEPGT force decreased the risk of having a first-ever fall by a factor of 0.44. A 10% increase in ankle not held DiffEPGT increased risk by a factor of 18.3 (Table 4).

Combining ankle not held MinEPGT with the remaining four questions of the NHS-FRAT reduced the predicting capacity of the model (Table 5). Complimenting hand-grip force with the NHS-FRAT questions improved prediction, but not by enough to make it better than the EPGT (Table 5). Using ankle not held MinEPGT as the sole predictor remained the most accurate model for the prediction of first-ever falls in this cohort (Table 4).

Table 5
The strength of prediction for the risk of a first-ever fall when ankle not held MinEPGT force or hand-grip force are complemented by four NHS-FRAT questions (four or more medication; stroke or Parkinson's disease; any problems with balance; unable to stand from a chair without using arms).

	Predictors	
	NHS-FRAT questions (4 parameters) +	
	Ankle not held MinEPGT	Hand-grip force
Correctly classified (%)	81	81
Specificity (%)	87	87
Sensitivity (%)	73	73
Negative predictive value (%)	81	81
Positive predictive value (%)	80	80

NHS-FRAT: National Health Service – Falls Risk Assessment Tool; EPGT: Enhanced Paper Grip Test; AvgEPGT: average between limbs EPGT force.

4. Discussion

This study demonstrates for the first time a significant association between increased EPGT force and reduced risk of falling (Tables 2,4). EPGT outcome measures remained significant independent predictors for the risk of falling even when the confounding effect of other known risk factors such as having a history of falls was considered. This finding aligns with literature highlighting the importance of lower-limb strength [6–9] and of hallux plantar flexion strength [12,28–30] for falls risk assessment.

Besides EPGT force, the asymmetry in strength between limbs was also a significant predictor for the risk of falling with greater asymmetry leading to a significantly higher risk of falling (Table 2). This finding aligns with literature emphasising the importance of asymmetry in strength between limbs to identify individuals prone to falling [20].

Seen within the context of prevention, these findings highlight the potential value of exercise programs to strengthen the extrinsic and intrinsic muscles of the foot [28–30]. They also indicate that emphasis should not be given only to increasing the average strength between limbs, but also to promoting strength symmetry between limbs.

In the recruited population, the EPGT outcome measures that were used as sole predictors were able to provide statistically significant predictions of the risk of falling in the year following the measurement. Compared against the most commonly used FRAT in the UK, the optimum EPGT outcome measure (ankle not held AvgEPGT) correctly classified more people (73% vs 69%), it achieved higher sensitivity (56% vs 26%) and higher negative predictive value (76% vs 68%). However, AvgEPGT was less specific (84% vs 95%) and had lower positive predictive value (68% vs 78%) than NHS-FRAT. Considering that sensitivity and negative predictive value are more important than specificity and positive predictive value in screening tools, it can be concluded that the EPGT offers an improvement to NHS-FRAT [31,32].

The potential of EPGT for improved falls risk assessment was made even more pronounced when it was complemented by the five questions of the NHS-FRAT to achieve 98% specificity, 81% sensitivity, 89% negative and 96% positive predictive value. 91% of participants were correctly classified by this six-predictor model (Table 3). Replacing the EPGT with hand-grip was not able to achieve the same level of prediction accuracy (Tables 2,3). This finding validates previous observations that measurements of lower-limb strength are more relevant than upper-/whole-body strength measures for assessing the risk of falling [6,7,33] and points to the EPGT as a stronger candidate for falls screening than hand-grip strength.

The potential value of the EPGT as a screening tool for falls was further tested within a subset of the recruited population without a history of falling to assess the risk of a first-ever fall. Repeating the same regression analyses in the subset of the recruited population that did not have a history of falls at baseline revealed that the EPGT remains a strong candidate for screening in this population. Further studies in larger cohorts of people without a history of falling are needed to verify this unique capability. To this end, the results presented here can play a key role for informing the design of said research.

Falling for the first time initiates a downward cycle of increased fear of falling, reduced physical activity and loss of strength leading to increased risk for further falls [27,34,35]. Because of that, preventing the first fall from happening is crucial and could significantly enhance the effectiveness/cost-effectiveness of prevention.

At this point, it is important to point out that, even though the EPGT is a relatively simple and low-cost test of strength, the 5-question NHS-FRAT remains significantly simpler and cheaper. Further research is needed to assess whether the improved screening accuracy of the EPGT also leads to effective and cost-effective falls prevention.

In support of the needed follow-up research, the present study also provides sufficient information to conclude the optimal use of the EPGT. The results indicate that conducting the EPGT without providing any support to the participant's ankle provides measures of lower limb strength that are better linked to the risk of falling [15]. Moreover, the specific outcome measures that appear to be the most useful and should be considered in future research is the between-limbs average EPGT force (AvgEPGT) as well as the EPGT force of the weakest limb (MinEPGT) and the normalised difference between limbs (DiffEPGT) (Eq.1).

A notable limitation of this study is its relatively small sample size. Expanding this research to include larger cohorts is needed to establish thresholds of EPGT force directly linked to different levels of falls risk.

5. Conclusions

The results of this study indicate that the EPGT can complement and substantially enhance existing tools for community screening for the risk of falling. They also suggest that it can support the personalisation/optimization of preventative exercise programs and open the way for unique research aiming to predict and prevent first-ever falls.

CRediT authorship contribution statement

Mahmoud K. Mansi: Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Chockalingam Nachiappan:** Conceptualization, Methodology, Resources, Writing – review & editing. **Chatzistergos Panagiotis:** Conceptualization, Data curation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2023.12.006.

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