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An exploration of the mechanistic link between the enhanced paper grip test and the risk of falling

Mahmoud K. Mansi, Nachiappan Chockalingam, Panagiotis E. Chatzistergos *

Centre for Biomechanics and Rehabilitation Technologies, School of Health, Science and Wellbeing, Staffordshire University, Stoke-on-Trent, UK

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ABSTRACT

The enhanced paper grip test (EPGT) offers an easy-to-use measure of hallux plantar-flexion strength that does not need expensive specialised equipment. Literature suggests that it could be a useful screening tool to assess the risk of falling in older people. However, research on a specific mechanistic link to the risk of falling is lacking. It is hypothesised here that muscle weakening (assessed by the EPGT) is indicative of impaired ability to recover balance after a slip or a trip. To get an initial assessment of validity of the above hypothesis, the EPGT is compared against an established lab-based measure of lower-limb strength that is capable of assessing a person's ability to recover balance after a slip or a trip: maximum isometric leg press push-off force (leg press force). A gender-balanced sample of twenty people (median age=34 y) was recruited. Two different but equaly valid techniques of administering the EPGT were included regarding whether the participants' ankle was supported by the examiner or not. Results for the two EPGT techniques differed susbtantialy but they were both significantly associated with leg press force and therefore linked to better ability to maintain balance after a slip or a trip. The "ankle not held" EPGT technique was more strongly correlated to leg press force ($r(18) = 0.652$, $p = 0.002$) than the "ankle held" ($r(18) = 0.623$, $p = 0.003$) and appears to be the more favourable technique to administer the EPGT. These findings offer new insight on a potential mechanistic link between the EPGT and the risk of falling and support its optimal use in future research involving older people.

1. Introduction

Falls are among the most prevalent health issues that older people face. Every year, almost one-third of people over the age of 65 and approximately half of people over the age of 80 will fall[1]. It is estimated that 31% of these falls result in injuries that need medical treatment[2].

Once an individual experiences a fall, this triggers a vicious cycle of fear of falling again leading to reduced physical activity leading to increased muscle weakening which in turn increases the risk of falling again[3]. Indeed, it is estimated that half of those who fall once will fall again within the following year[1].

Multifaceted preventative programs that combine various interventions have shown notable success[4,5]. Screening within the broader older population can play a critical role in identifying individuals who can benefit the most from such intervention. Screening ensures that interventions are tailored to the specific needs of individuals and resources are allocated efficiently to those at higher risk for maximum benefit[5,6].

Existing screening tools encompass a range of assessments, including history of falling, balance assessments and functional tests[5,7]. Despite the abundance of risk assessment tools, only a limited number have been specifically developed and validated for use within the general older population[7].

Moreover, despite the importance of lower-limb muscle weakening for increased risk of falling, none of the existing assessment tools includes a direct quantitative assessment of muscle strength, which can undermine their effectiveness[7]. This limitation mainly stems from the fact that methods for the quantification of muscle strength are usually developed and used within specialised clinical or research settings and are not appropriate for testing in the community or primary care.

The enhanced paper grip test (EPGT) could fill this gap[8]. The EPGT is a simple-to-use and cost-effective test to measure hallux plantar-flexion strength[8]. This assessment involves placing a paper card under the participant's hallux and asking them to try to grip it by pushing down with their hallux as forcefully as they can. The examiner then starts pulling the card with gradually increasing force and measures the minimum force that is needed to fully pull the card from underneath

* Correspondence to: Leek Road, Stoke-on-Trent ST4 2 DF, UK.
E-mail address: Panagiotis.chatzistergos@staffs.ac.uk (P.E. Chatzistergos).

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the participant's hallux.

Literature has demonstrated that the EPGT offers an assessment of the strength of the entire foot and ankle and could potentially be used to identify people at risk of falling[8,9]. However, its outcome measure (EPGT force) has not as yet been directly linked to the risk of falling. Addressing this gap is of paramount importance before deciding whether the EPGT is a good candidate test for effective falls' screening. To this end, it is important to understand why someone with higher or lower EPGT force would have a higher/lower risk of falling.

It has been demonstrated in the literature that lower-limb muscle weakening impairs a person's ability to maintain balance after a trip or a slip, thus increasing the risk of falling[10]. Based on this, it is fair to assume that if the EPGT force is indeed a valid predictive tool for increased risk of falling, then people with higher EPGT force should be able to recover their balance more effectively after a slip or a trip compared to people with lower EPGT force. Comparing EPGT force against established biomechanical measurements linked to a person's ability to recover balance after a trip or slip can provide a first assessment of the validity of this hypothesis.

The link between muscle weakening and the capacity to recover balance after a slip or a trip was directly tested by Pijnappels et al.[11,12]. That study was conducted on healthy older adults who performed a range of muscle strength tests in a biomechanics laboratory[11]. Subsequently, the participants' capacity to regain balance after tripping or slipping was directly determined experimentally. One of their key conclusions was that whole lower-limb strength measured using a leg press offers the best assessment of a person's ability to maintain their balance and to prevent a fall after a trip or a slip[11].

In this context, the main purpose of the present study is to explore the validity of the assumed mechanistic link between the EPGT and the risk of falling, by testing its correlation to the outcome measure of the leg press testing presented by Pijnappels et al.[11,12]; namely against a biomechanical measurement that is strongly linked to a person's ability to recover balance after a slip or trip.

2. Methods

2.1. Participants

A gender-balanced sample of convenience of 20 healthy adults (10 women/10 men) was recruited for this study. All subjects were physically fit and had no orthopaedic, neuromuscular, cardiac, or visual impairment at the time of recruitment. Ethical approval was secured from Staffordshire University's ethics committee. Written informed consent was provided by each participant before data collection.

2.2. The EPGT

The EPGT has evolved from a simpler test called paper grip test. The original paper grip test was developed in the 1990 s by W.J. Theuvenet and P.W. Roche as a screening tool for muscle paralysis in the intrinsic muscles of the foot of people with leprosy [13]. This simpler test involved the examiner placing a piece of cardboard (the size of a business card) under the patient's hallux and asking them to grip it with their hallux. The examiner then pulled the card away with gradually increasing power while the participant offered resistance. This simple test is capable of detecting whether the strength of the hallux plantar flexors is above or below a certain threshold[14]. However, this threshold strongly depends on the examiner's own strength and technique. The EPGT was developed to overcome this limitation by replacing the simple pass/fail outcome of the initial paper grip test with a continuous measurement of strength[8]. This was achieved by attaching a dynamometer to the card being pulled (Fig. 1).

In the present study, the EPGT was implemented following a previously published step-by-step protocol[8]. More specifically, before conducting the EPGT the participants removed their footwear and socks

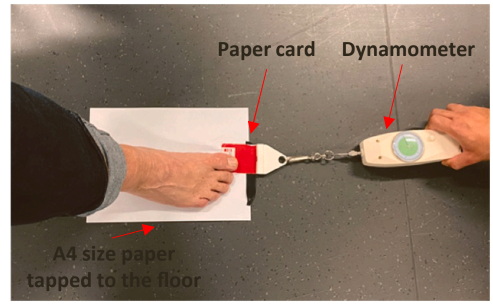

Fig. 1. Testing set-up for the EPGT.

and sat on a steardy seat without armrests. A damp cloth was used to clean the plantar area of every hallux. While waiting for the skin to dry, the test was explained following a predefined script[8]. When the skin had dried, the card was placed under the hallux. Participants were instructed to try to grip the card before the examiner started pulling the dynamometer which was set to record maximum pulling force. Throughout the assessment, subjects were also asked to prevent any lifting or sliding of the heel. The measurement ended when the card was completely withdrawn from beneath the hallux. Once the card was removed, the maximum value of the pulling force that was applied to the card during testing was recorded. After an initial familiarisation trial, the EPGT was repeated three times per foot, with at least 30 s of rest between testing on the same foot. The average of these three measurements was used as the final outcome measure of the EPGT for each foot (EPGT force)[8].

All testing was done in a gait lab fitted with a flat firm vinyl floor. To ensure consistency regarding the friction between the floor and the card, a standard A4 piece of paper was taped to the floor immediately underneath the participants' foot (Fig. 1).

In conventional applications of the paper grip test, pass/fail measurements were done while the examiner was supporting the participant's ankle with their hand to isolate the intrinsic muscles of the foot. However, in recent applications of the EPGT[8,15] no support was provided to the ankle. It was hypothesised in the literature that not supporting the ankle meant that the participants had to assume a rigid posture to successfully perform the test which required activating all muscle groups at the foot and ankle level, thus making the measurement more representative of lower-limb strength than of intrinsic foot muscle strength[8,15]. To get a first assessment of the optimal way of conducting the EPGT, both approaches were used here (i.e., ankle held, ankle not held).

2.3. Leg press testing

Following the completion of the EPGT, the participants did a 10-minute warm-up using a static bike. Maximum leg press isometric push off force for each leg was obtained for all subjects using an angled/ hack-squat leg press machine that was modified and instrumented for this purpose (Fig. 2).

More specifically to enable the measurement of isometric strength, threaded bars were added to the sides to rigidly fix the moving backrest of the leg press at different heights. The generated force on the force plate was measured using four force sensors (capacity 250 kg/ sensor, Biometrics data log FP3) which were embedded in the footplate of the leg press into a single force platform. The force sensors were connected via Bluetooth to a laptop. The readings from the four force sensors were added to produce a single continuous recording of force. The force data sampling rate was 1000 Hertz.

During testing the moving backrest was adjusted to the participant's height. A pushing position was maintained whereby the knee joint angle remained at 30° in order to avoid hyperextending the knee [11]. The participant then pushed against the platform at full force and the

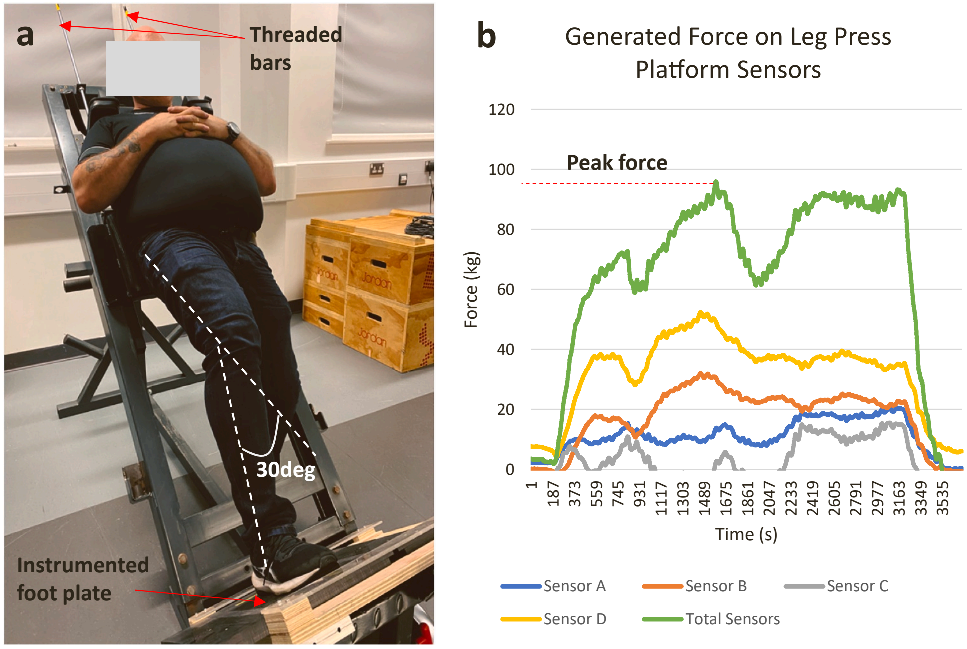

Fig. 2. (a) Testing set up for leg press testing. (b) Typical output graphs of the recorded forces over time by individual force sensors (Sensor A-D) and their sum (Total sensor). The peak recorded force in the graph that was used as the final measurement of isometric leg press puss off force is also shown.

maximum isometric push-off force was recorded. This test was repeated three times per limb [11]. For simplicity, from this point on, average maximum isometric leg press push-off force will be called “leg press force”.

2.4. Statistical analysis

The normality of recorded data was tested using the Shapiro–Wilk test. All normally distributed measurements will be represented by their average(± standard deviation), non-normally distributed data will be presented with their median(minimum value, maximum values). The significance of differences between the two testing techniques of the EPGT (ankle held/ankle not held) and between genders was tested using paired samples t-test (a=0.05). Pearson correlation analysis was used to test the association between EPGT force and leg press force. Linear regression analysis was used to assess how much of the variability in leg press force can be predicted by the EPGT force when this is measured with the ankle held or nor held. Data were screened for linearity, significant outliers, homoscedasticity, and normality of residuals to ensure that the assumptions of linear regression are met.

3. Results

Shapiro–Wilk test of normality indicated that all biomechanical measurements were normally distributed. From the demographic, anthropometric parameters that were recorded only age and body mass were not normally distributed.

The participants’ median (minimum, maximum) age was 34(22,52) years, their median body mass 70(55,109) kg, and the average (± standard deviation) height was 162.0(± 8.2) m.

The EPGT force measured for ankle held was substantially higher than what was measured when the ankle was not held (Table 1). More specifically, the average EPGT force for ankle held or not held was 65 N (± 30 N) and 32 N(± 18 N) respectively. This difference (51%) was statistically significant (paired samples t-test, two tail, $p < 0.001$). On average the participants achieved leg press force equal to 870 N (± 490 N).

Comparison between genders indicated that female participants had significantly lower leg press and EPGT forces relative to their male counterparts (Table 1). The two groups had similar median age (Mann Whitney U test, $p > 0.05$), but women had lower body mass (Mann Whitney U test, $p = 0.019$) and height (t-test, $p < 0.001$, two tail) than the recruited men (Table 1).

Table 1
Characteristics of the participants and their biomechanical measurements. All normally or non-normally distributed results are presented by their mean value (± standard deviation) or by their median (minimum value, maximum value) respectively. statistical significance of difference between genders is presented with the help of the calculated *p* value. Statistically significant differences ($p < 0.05$) are indicated by (*).

	All Subjects (n = 20)	Male (n = 10)	Female (n = 10)	*p*-value
Age (y)	35 (22,52)	32 (22,52)	34 (22,52)	1.000
Height (m)	170 (± 11)	178 (± 7)	162 (± 8)	0.001 *
Body Mass (kg)	70 (55,109)	76 (64,109)	68 (55,78)	0.019 *
Ankle held EPGT force (N)	65 (± 30)	84 (± 26)	47 (± 20)	0.003 *
Ankle not held EPGT force (N)	32 (± 19)	42 (± 19)	22 (± 13)	0.016 *
Leg press force (kg)	89 (± 50)	111 (± 57)	67 (± 32)	0.046 *

Pearson correlation analysis indicated that the EPGT force, for both ankle held, and ankle not held, was significantly correlated to leg press force (Fig. 3). Correlations were positive, moderate to strong[16] for ankle held ($r(18) = 0.623, p = 0.003$) and for ankle not held ($r(18) = 0.652, p = 0.002$).

Linear regression analysis indicated that the EPGT offers statistically significant predictions of leg press force. Based on the calculated adjusted R^2 values, EPGT forces that were measured with the ankle held accounted for 35% of the variability in leg press strength ($F(1, 18)= 11.446, p = 0.003$). EPGT forces that were measured with the ankle not held accounted for 39% of the variability in leg press strength ($F(1,18)= 13.337, p = 0.002$).

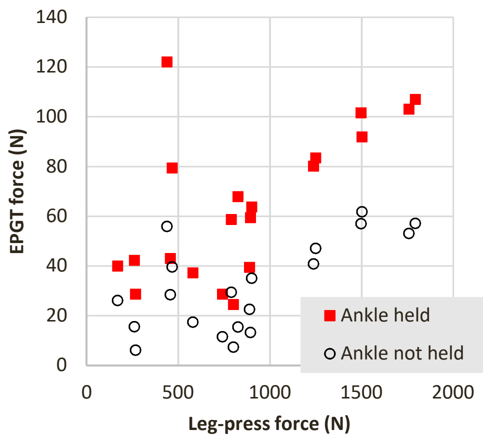

Fig. 3. Scatterplots of measured EPGT force for ankle held and ankle no held techniques over the respective measurement of leg press force for each participant.

4. Discussion

The purpose of this study was to explore the mechanistic link between the outcome of the EPGT force and the risk of falling and to provide insight on the optimum way to administer the EPGT. Considering literature on the relationship between lower-limb muscle weakening and increased risk for falling, it was hypothesised that higher values of EPGT forces would be significantly associated with higher leg press force and therefore with better ability to prevent falling. This hypothesis was based on previous research highlighting leg press force as a strong predictor for an older person's capacity to maintain balance after a slip or a trip[11,12].

The present study found statistically significant positive moderate-strong correlations between EPGT force and leg press force. This finding supports the validity of the hypothesised mechanistic link between the EPGT force and the risk of falling. At this point, it is important to point out that definitive conclusions on the capacity of the EPGT to quantify and predict the risk of falling can only be achieved through prospective studies where falling is the key outcome measure. This initial evidence supporting the existence of a mechanistic link between the value of EPGT force and the risk for falling is a key stepping stone towards realising such a prospective study.

The potential value of the EPGT for screening for the risk of falling is also supported by literature highlighting lower-limb muscle weakness and measures of hallux plantar-flexion strength as important predictors for the risk of falling[17]. Previous research in a diabetic population found that measurements of foot dorsiflexion muscle strength can be utilised to detect people at significant risk for falling[18]. In non-diabetic individuals, research indicated that the strength of the hallux plantar flexors is a significant indicator of falls[19].

The above-mentioned relationship between EPGT force and leg press force was statistically significant regardless of the specific technique that was used to do the EPGT; namely for both "ankle held" and "ankle not held" techniques. However significant differences between the two techniques were observed. More specifically, the participants achieved significantly higher EPGT force with "ankle held". This means that, as the participant does not have to exert effort to keep their heel in place, the EPGT with the ankle held is an easier task for the participants. This observation is supported by a study conducted by Soma et al.,[20] which aimed to compare toe grip strength and muscle activity during toe grip strength exertion with and without the presence of an ankle immobilisation belt and to investigate the relationship between the differences in muscle activity and toe grip strength. The researchers found that both toe grip strength and the percentage of integrated electromyography of the medial head of the gastrocnemius muscle were significantly greater when measured in the presence of ankle belt immobilisation compared to measurements taken without immobilisation.

In terms of the potential relevance of the two EPGT techniques, we found that the "ankle not held" appears to be more favourable. This is due to the higher R^2 value when compared with "ankle held" obtained from a linear regression analysis indicating that it might be a stronger predictor of average leg press force. This disparity between techniques indicates that when less support is provided, the EPGT may produce a more relevant representation of the person's lower-limb strength than when support is provided.

The results of the present study also highlight differences in EPGT force between genders, with men scoring significantly higher than women. Accounting for these gender differences could be vital when attempting to link the outcome of the EPGT to the risk of falling.

A key limitation of the present study is that the ability to recover balance after a slip or trip was not directly assessed. It was indirectly assessed with the help of an established leg press test. The significance of incorporating comprehensive leg strength measures is underscored by the multitude of strength assessment methods present in the literature [21]. With a wide array of options available, our selection of the leg press as a comparative measure was chosen to replicate the leg press used by Pijnappels et al.[11], whereby, a relationship was established between a greater leg press force and better ability to recover balance after a slip or a trip. The leg press test by Pijnappels et al.[11] stands out as a suitable comparison due to its ability to evaluate the overall strength of the lower extremities, encompassing various muscle groups that contribute to functional movements like walking, standing, and ascending stairs. This choice aligns with the aim of capturing a more comprehensive picture of lower-limb strength and its relationship with the EPGT force, thereby contributing to the robustness of our findings.

In the present study, leg press force was assessed using a standing hack squat/leg press machine whereby the participant stood with their knees bent at 30 °. However, the study conducted by Pijnappels et al. [11] had participants in a supine position. The standing approach was validated and found to be a reliable measure of lower-limb strength by Blazevich et al.[22]. This method was found to be highly reliable (ICC = 1.00), therefore, our method and relationship established remains valid regardless of the minor departure from the technique used by Pijnappels et al.[11].

Another noteworthy limitation pertains to the fact that the recruited participants were relatively younger (median age 34 y). Considering that muscle strength and function deteriorates with ageing, one would expect older cohorts (aged ≥65) to score significantly lower[23]. Even though the absolute values of the biomechanical measurements presented here are not representative of the targeted population the conclusions drawn regarding the potential link between the EPGT force and leg press force and the application of the EPGT remain valid.

5. Conclusions

The results of this study support the hypothesis that people who achieve lower EPGT forces are at higher risk of having a fall relative to people who score higher because their capacity to maintain balance after a slip or a trip is relatively reduced. This is the first ever attempt to associate the outcome of the EPGT with falling through a mechanistic link. These first encouraging results open the way for the application of the EPGT in older populations to directly assess the EPGT's capacity to enhance risk assessment for falls.

At the same time, this study also provided insight regarding the application of the EPGT which will be valuable during follow up research. This includes the effect of the specific technique used with the "ankle not held" technique appearing to be potentially more relevant.

Brief summary

- Measurements of lower-limb strength can enhance screening for the risk of falling in older people.
- Measuring lower-limb strength outside specialised clinics and research laboratories remains difficult.
- The enhanced paper grip test (EPGT) is an easy-to-use, cost-effective measure of hallux plantar flexion strength that can address this challenge.
- This study hypothesises the existence of a mechanistic link between the EPGT and the risk of falling.
- Results presented here indicate that people achieving lower EPGT forces are likely to have reduced ability to recover balance after a slip or trip.
- This study also offers a first assessment on the optimum technique to administer the EPGT.

Declaration of Competing Interest

None.

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