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Original article

Application of enhanced paper grip test among track and field athletes: age difference, intra-session reliability and effects of fatiguing task

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Abstract

Track and Field places significant demands on the body, especially the lower limbs, where the foot plays a critical role in performance. A potentially useful tool for assessing foot strength is the Enhanced Paper Grip Test (EPGT), which measures the grip force of the big toe. This study aimed to investigate how fatigue affects EPGT performance in track and field athletes, as well as explore any potential age-related differences and intra-session reliability. A total of 21 athletes, aged 14–32 years, were tested before and after a fatigue-inducing protocol consisting five sets of 50 ankle jumps. The results showed no significant reduction in toe grip strength post-fatigue, suggesting that fatigue did not impair performance, potentially due to post-activation potentiation. Moreover, significant differences were found between adolescents (age range = 14 – 15) and adults (age range = 22 – 32), with the latter demonstrating greater EPGT force both in absolute and body-mass-normalized values. The reliability among repetitions was good to excellent (ICC = 0.86 – 0.97). These findings highlight the robustness of EPGT performance under fatigue and its potential utility for assessing lower-limb function in athletes. Future studies should explore more specific fatigue protocols and investigate long-term adaptations across various athletic disciplines. Additionally, examining the influence of other factors such as foot morphology, training status, and sex differences may further enhance the understanding of foot strength and its role in athletic performance.

Keywords: Athletics, Fatigue, Toe Grip Strength Assessment, Lower Limb Strength

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Introduction

Track and Field, with its various range of disciplines, requires significant demands on the body, particularly on the lower limbs. The primary point of contact with the ground is the foot, which is a highly complex joint system that plays a crucial role in athletics performance (Tourillon et al., 2019). Proper function of the foot and toes is essential for efficient movements (Yuasa et al., 2018), balance (Quinlan et al., 2020), force transmission during jumping (Yamauchi & Koyama, 2020), walking, running, and sprinting (Rolian et al., 2009; Tourillon et al., 2019). This is due to the fact that the foot muscles, including those supporting the big toe, play a vital role in stabilizing the longitudinal arch, which is crucial for optimal force transfer and movement efficiency (Soysa et al., 2012; Tourillon et al., 2019). The big toe, in particular, is fundamental for stabilizing the foot against ground reaction forces and aiding forward propulsion, which is achieved through the contraction of the flexor hallucis longus and brevis (Jacob, 2001). Therefore, its function is critical for effective propulsion and stability. If the stabilizing function is impaired, it can lead to various foot-related injuries or impairments (Attenborough et al., 2017; Chou et al., 2009; Quinlan et al., 2020; Słomka & Michalska, 2024; Spink et al., 2011).

Strength assessments are essential for creating an athlete's profile, which helps coaches identify their strengths and weaknesses (Young, 1995). They also enable the monitoring of training progress to ensure that the programs are achieving their intended objectives. Hence, the assessment of foot muscle strength can be important in the context of sports performance and injury prevention. The Enhanced Paper Grip Test (EGPT) quantitatively measures lower limb strength by evaluating the grip force of the hallux, which is generated by a pulling force applied to a card placed beneath the participant's big toe (Chatzistergos et al., 2020). The EGPT results has been linked to the risk of falling, as increased asymmetries in hallux strength are associated with a higher risk of falls (Mansi et al., 2024). These imbalances can compromise stability and mobility, leading to an elevated likelihood of falling, especially in elderly (Mansi et al., 2023, 2024). However, to our knowledge, only one study (Skuk et al., 2024) applied EPGT in athletic population, demonstrating excellent test-retest reliability (ICC = 0.93 – 0.97).

The primary objective of this research was to investigate fatigue effects on EGPT among track and field athletes. Additionally, we examined potential differences between adolescent and adult age groups, and examined intra-session reliability of the test. It was hypothesized that fatigue will have an impact on test performance, leading to a decrease in the results. Additionally, we hypothesize that there will be statistically significant differences between age groups. Finally, we expected EPGT to exhibit excellent intra-session reliability.

Methods

Design

We conducted a study with a repeated measures design, as the same participants are tested pre- and post-fatigue protocol. Prior to the measurements, participants completed a questionnaire collecting demographic and training-related data, including age, body weight, height, years of training experience, and injury history. Measurements were performed in one session, with EPGT applied before and after the fatigue protocol to assess the effects of fatigue and toe grip strength. All measurements were conducted by a single examiner. All assessments were conducted on a consistent surface to minimize potential variability in friction, which could affect the test results. This standardization ensured the validity and reliability of the measurements.

Participants

A total of 21 athletes of both sexes (female n = 12, male n = 9), aged 13 to 24 years, with a mean age of 19.9 ± 5.5 years, were included in the study. The participants had an average body weight of 65.0 ± 8.2 kg and an average height of 175.6 ± 7.3 cm. On average, participants had 5.14 ± 2.06 years of training experience. Eight participants (6 women, 2 men) were adolescents (age = 14 – 15 years) and 13 were young adults (6 women, 7 men). All participants were members of the Athletics Club Sečovlje and regularly participated in organized training activities. The average number of training sessions per week was 3.14 ± 0.9, and the average number of resistance training sessions per week was 1.86 ± 0.69.

The inclusion criteria for the participants to take part in the study was that they were in good general health, free of injury, and had a minimum of two years of athletic training experience. Athletes who did not meet these inclusion criteria were excluded from the study. Prior to participation, the study protocol was thoroughly explained to all participants, who subsequently provided written informed consent. In the case of minors, parental consent was also obtained. The study protocol was approved by the Ethics Committee of the University of Primorska (approval number: 4264-19-6/23). Written informed consent was obtained from all participants. For minors, parental consent was also obtained.

Measurements and Procedures

The EPGT is a standardized test that employs a dynamometer to record the pulling force. In this study, a belt-stabilized dynamometer (EasyForce, Meloq, Sweden) was used. Using this device, Skuk et al. (2024) achieved excellent test-retest reliability of the EPGT in athletes. The device capable of recording pulling forces up to 1000 N with an accuracy of ±1 N. A combined holder with a plastic plate, designed to accommodate the necessary card, was used to position the plastic plate connected to the dynamometer beneath the toe (Skuk et al., 2024).

The procedure began with participants removing their shoes and socks to ensure they were barefoot (Figure 1). They were then seated on a chair with their hips, knees, and ankles positioned at 90° angle. To ensure proper grip and contact, the plantar surface of the big toe was cleaned with a disinfectant. For hygiene purposes, the plastic plate was wiped clean before each new participant. The plastic plate was connected to the dynamometer and positioned under the toe. Participants were instructed to keep their hands relaxed on their knees throughout the test, to prevent grasping the armchair or using their arms for support, as this could influence the measurement results. They were then asked to press their toe against the plate with maximum effort while the plate was gradually pulled away. Each participant underwent two preliminary familiarization measurements, followed by three attempts per leg, starting with the right leg and then the left leg. The mean values from the three attempts were used for analysis.

Figure 1. The positioning of participant and dynamometer before the onset of the test.

Fatiguing protocol

The fatiguing protocol consisted of 5 sets of 50 consecutive ankle jumps, with a 1-minute rest interval between sets. This exercise was performed in a designated area on track&field stadium. Participants were instructed to jump as high as possible, focusing on generating power primarily from the ankle joint. The objective of the protocol was to induce significant fatigue in the muscles of the foot and toes.

Statistical analyses

The data are presented as means ± standard deviations. The reliability across repetitions (intra-session] was evaluated with intra-class correlation coefficient (ICC; single measures, absolute agreement). We considered ICC values <0.5 to be indicative of poor reliability, values between 0.5 and 0.75 to indicate moderate reliability, values between 0.75 and 0.9 to indicate good reliability, and values greater than 0.90 to indicate excellent reliability (Koo and Li, 2016). Differences between pre- and post-fatigue testing conditions were assessed with paired-sample t-test. Differences between age groups were assessed with independent-sample t-test. This was also done separately on body-mass-normalized values. Hedges g effect size was also calculated providing an indication of the magnitude of difference between groups. Values were interpreted in line with suggestions from Hopkins et al. (2009) where: <0.2 = trivial; 0.2–0.6 = small; 0.61–1.2 = moderate; 1.21–2.0 = large and 2.01–4.0 = very large. All analyses were carried out using SPSS statistical software (version 25.0, IBM: Armonk, NY, USA).

Results

Reliability

The reliability among the repetitions was good to excellent for left side before fatigue (ICC = 0.93, 95% CI = 0.87 – 0.97), excellent for right side before fatigue (ICC = 0.95, 95%CI = 0.90 – 0.98), excellent for left side after fatigue (ICC = 0.97, 95%CI = 0.93 – 0.98) and moderate to excellent for right side after fatigue (ICC = 0.86, 95%CI = 0.72 – 0.94).

Fatigue effects

Analysis for fatigue effects is displayed in Table 1. There was no statistically significant difference when comparing pre-fatigue and post-fatigue scores (p = 0.289 – 0.427).

Table 1. Analysis of fatigue effects.

Outcome	Pre		Post		Difference with 95%CI			T-test	
	Mean	SD	Mean	SD	Mean	Lower	Upper	t-value	Sig.
Left [N]	74.2	31.5	76.5	31.4	-2.2	-8.0	3.5	-0.811	0.427
Right [N]	74.5	30.0	78.5	27.5	-4.0	-12.5	4.5	-0.983	0.337
Mean [N]	74.4	30.3	77.5	28.5	-3.1	-9.1	2.9	-1.088	0.289

SD – standard deviation; CI – confidence interval

Difference between age groups

Table 2 presents the analysis of differences between adolescents and adults across various outcomes. The results indicate significant differences in all measured parameters between the two age groups. For absolute scores, adults exhibited higher mean values compared to adolescents (p ≤ 0.001) with large effect sizes (Hedge g = 1.48 – 1.65). Similar trends were observed for body-mass-normalized values (p = 0.001 – 0.003; Hedge g = 1.23 – 1.66), indicating consistently greater EPGT force in adults.

Table 2. Analysis of differences between age groups.

Outcome	Adolescents		Adults		T-test		Effect size		
	Mean	SD	Mean	SD	T-value	Sig.	Hedge's g	95%CI	
Left [N]	48.4	14.7	90.2	28.5	-4.42	< 0.001	1.65	0.64	2.66
Right [N]	51.5	9.4	88.7	29.6	-4.20	0.001	1.48	0.49	2.46
Mean [N]	49.9	11.3	89.4	28.5	-4.45	< 0.001	1.60	0.60	2.61
Left [N/kg]	0.76	0.14	1.29	0.37	-4.59	< 0.001	1.66	0.64	2.67
Right [N/kg]	0.84	0.12	1.27	0.40	-3.48	0.003	1.23	0.27	2.19
Mean [N/kg]	0.80	0.11	1.28	0.38	-4.22	0.001	1.48	0.49	2.47

SD – standard deviation; CI – confidence interval

Discussion

This study aimed to explore the effects of a fatiguing protocol on toe grip strength, assess intra-session reliability, and examine age-related differences in performance using the EPGT among track and field athletes. Our findings revealed that the fatigue protocol, consisting of high-intensity ankle jumps, did not significantly impair EPGT performance. Additionally, significant age-related differences in strength were observed, with adults demonstrating higher EPGT force strength compared to adolescents, even after normalizing for body mass. Intra-session reliability of the EPGT was determined to be good to excellent, underscoring the robustness of the test for repeated measures within the same session. These results highlight the EPGT as as a reliable and age-sensitive tool for assessing foot strength in athletic populations, while additional research is needed to understand if EPGT may be sensitive to neuromuscular fatigue.

The absence of performance decline in the EGPT results following fatigue protocols can be attributed to several factors. Firstly, post-activation potentiation (PAP) may have played a role. As explained by Robbins (2005), PAP describes the phenomenon where a muscle force production improves after a preceding contraction, emphasizing how its contractile history can enhance the mechanical performance of subsequent movements. PAP enhances muscle contraction by increasing the efficiency of calcium dynamics use within muscle fibers, particularly through phosphorylation of myosin light chains, which makes the actin-myosin interaction more sensitive to calcium (Lorenz, 2011; Robbins, 2005). This phenomenon is most pronounced in muscles with a higher proportion of fast-twitch (Type II) fibres, which are primarily involved in explosive, high-intensity activities like sprinting and jumping (Sale, 2002). The effects of PAP are time-dependent, as fatigue from the conditioning activity can counteract its benefits. Optimal recovery intervals, ranging from a few seconds to several minutes, are essential to maximize potentiation while minimizing fatigue (Lorenz, 2011; Sale, 2002). Since PAP is most prominent in muscles with a higher proportion of fast-twitch fibres, which play a crucial role in high-intensity activities such as jumping or sprinting, these fibres could have been activated during the fatiguing protocol of repetitive ankle jumps in this study. This activation may have enabled participants to maintain or even improve their grip force despite prior fatigue. When PAP is activated, it essentially primes the muscle for enhanced performance during subsequent efforts by improving both the rate of force development and overall force output (Beato et al., 2019; Robbins, 2005). This effect can counterbalance the onset of fatigue, especially when the recovery period is sufficient to allow partial dissipation of fatigue while potentiation remains active (Sale, 2002). Moreover, PAP is time-dependent (Robbins, 2005), with appropriate recovery timing allowing fatigue to subside while maintaining the potentiation effects. In this study, controlled rest likely optimized the balance, explaining why there was no decrease in performance.

Secondly, a potential explanation for the absence of performance decline may be linked to motivational factors. Participants may have been more driven to outperform their initial results during the post-fatigue test, either due to competitive instincts or a desire to demonstrate improvement. This psychological boost could have counteracted the physical effects of fatigue, leading to stable or even enhanced performance. Similar findings were found by Boksem et al. (2006), such as increased motivation can reduce the perception of effort and enable sustained performance even under fatigue effects. Both intrinsic and extrinsic motivation can modulate the effects of fatigue (Herlambang et al., 2021). Previously mentioned authors also stated that highly motivated individuals can maintain their performance longer despite increased fatigue, as they are willing to invest more effort. Moreover, Marcora et al. (2009) provide evidence on the interaction between central fatigue and motivation, emphasizing that increased psychological drive can reduce the impact of fatigue on physical performance. This phenomenon likely contributed to participants' ability to maintain or slightly enhance their performance during the post-fatigue test. These observations underline the importance of psychological elements, such as motivation and competitive mindset in influencing the outcomes of fatigue-based performance assessments.

Our analysis also revealed that age-related differences in strength metrics are significant and meaningful, as adults consistently demonstrated higher strength values. Even when body mass was accounted for adults still outperformed adolescents. This suggest that the observed differences are not exclusively due to differences in body mass but may be linked to other factors such as muscle mass and strength, body composition, hormonal differences, physical training, motivational and psychological factors (Vanhelst et al., 2023). The effect size also indicates that the observed differences in strength are considerable and not due to random variation. The literature focusing on EPGT in athletic population is limited, apart from study conducted by Skuk et al. (2024). Their average scores (75.21 ± 21.67 N) on the EPGT are consistent with ours (74.4 ± 30.3 N). These findings suggest that the performance on the EPGT test does not vary substantially across different sports. In addition, young healthy adults achieved lower results (41.54 ± 14.52 N) on the test (Tsekoura et al., 2023), indicating that the athletic population demonstrates superior performance on the EPGT in comparison to non-athletic participants, due to several factors. Athletes, in general, often have better motor skills, coordination, proprioception, physical performance, fine motor control, and mental focus (Campa & Coratella, 2021; Degens et al., 2019; Eldridge et al., 2014), that comes with athletic training. The combination of physical training and heightened neuromuscular control gives athletes an advantage on tests that require precise motor skills and coordination (Degens et al., 2019; Machowska-Krupa & Cych, 2023).

The EPGT demonstrated good to excellent intra-session reliability in this study, consistent with the findings of Skuk et al. (2024), who reported excellent test-retest reliability (ICC = 0.93–0.97) in volleyball and soccer players. These results reinforce the robustness of the EPGT as a reliable measure for assessing foot strength across different athletic populations. The slight variations in reliability indices between this study and Skuk et al. may be attributed to differences in testing protocols, athletic disciplines, or sample characteristics. Overall, the high reliability of the EPGT supports its practical applicability for both research and clinical settings in sports science.

This study uniquely examines athletes from track and field, addressing a gap in sports science by focusing on athletic populations rather than the general population. While it provides insights into the impact of age on performance and the relationship between fatigue and athletic outcomes, several limitations should be noted. The small sample size and unequal distribution of adults and adolescents may introduce bias in age-related comparisons, limiting the generalizability of the findings. Additionally, the fatigue protocol used may have been insufficient to induce the desired level of fatigue, potentially affecting the results. Future research should prioritize larger, more balanced samples, incorporate athletes from diverse sports, and employ different fatigue protocols to better evaluate the effects of exhaustion on performance.

Conclusion

Our findings show that the Enhanced Paper Grip Test (EPGT) is a reliable tool for assessing big toe strength in athletes, even under fatigue. Because the test is easy to perform and doesn't require any invasive procedures, it's well suited for everyday use in sports settings, both in clubs and training environments. Coaches can include it as part of regular lower limb assessment, as it may help detect early signs of imbalance or weakness especially in younger athletes, where strength is still developing. The fact that test performance did not significantly change after fatigue suggests that the EPGT is stable and consistent enough to be used even after demanding training sessions. This makes it practical for tracking progress over time or evaluating the effects of specific foot-strengthening exercises. This makes it practical for tracking progress over time or evaluating the effects of specific foot-strengthening exercises. Additionally, factors such as post-activation potentiation (PAP) and athlete motivation may have contributed to the stable performance observed after fatigue, further supporting the EPGT's practical value in real sports settings where testing often occurs under non-ideal, post-exercise conditions.

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***Data availability*:** All collected data are included in the manuscript. Raw data are available upon reasonable request to the corresponding author.

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