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Original article

Percentile Rank Data for the Countermovement Vertical Jump Measured by a Jump-and-Reach Device in Law Enforcement Recruits

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Abstract

The countermovement vertical jump (VJ) has been used to indirectly measure the lower-body power of law enforcement recruits. Different methods can be adopted to measure the VJ; there is limited research that has published normative data for the VJ measured with a jump-and-reach device as performed by recruits. This study calculated normative percentile rank data for VJ height and peak anaerobic power measured in watts (PAPw) derived from the VJ for law enforcement recruits. Retrospective analysis on 833 recruits (683 men, 150 women) from one agency was conducted. Recruits completed the VJ as part of a battery of fitness assessments prior to their training academy. Jump height was recorded and used to derive percentile rankings for all recruits, men, and women, in the following bands: 90-100, 80-89, 70-79, etc. Jump height was also used to calculate PAPw, and percentile rankings for this variable were derived. All recruits, men, and women, had a mean VJ height of 52.63±11.59, 55.34±10.16, and 40.33±9.54 cm, respectively. For PAPw, the means for all recruits, men, and women, were 4756.07±1088.23, 5072.49±877.87, and 3315.33±732.54 watts, respectively. The data indicated the male recruits tended to perform better than female recruits; 74% of all women were in the bottom three percentile bands for VJ height, and 93% of women were in the bottom three bands for PAPw. Female recruits will likely need specific strength and power training prior to and during academy. The provision of normative VJ data provide recruit benchmarking and could inform fitness program design for staff.

Keywords: First Responder, Lower-Body Power, Normative Data, Peak Anaerobic Power, Police, Tactical

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Introduction

Law enforcement personnel have a need for lower-body power in their occupation. For practitioners who work with and train law enforcement personnel, it is important that they have a method for measuring this particular fitness domain. Lower-body power is often extrapolated from performance in different jump assessments (McGuigan, 2015). Jump assessments are easy to administer and provide a valid metric of an individual's capacity, even if they do not provide a direct measure of power (Burr et al., 2007). The absolute measure of jump height or distance is often used as the metric for lower-body power; the greater the jump height or distance, the more powerful the individual. Jump height has been critiqued as an interpretation for lower-body power (Morin et al., 2019). Although jump height may not always be the most optimal lower-body power interpretation, it still has its place in law enforcement testing. Officers may need to clear fences and obstacles in their occupation, and often will be assessed on their ability to perform these types of tasks. For example, 6-foot walls have been used in exit occupational exams for law enforcement recruits (Lockie et al., 2022a; Lockie et al., 2021; Lockie et al., 2020d). An obstacle such as a wall not change its height relative to the power produced by individual, so absolute jump performance is relevant (Lockie et al., 2022b). Nonetheless, power can be calculated from jump performance (Sayers et al., 1999).

The countermovement vertical jump (VJ) is a common assessment used to measure lower-body power in law enforcement personnel (Lockie et al., 2018b). Numerous studies have shown the value of the VJ in law enforcement testing. For example, police recruits who reported an injury or illness during their training academy had a lower VJ height compared to recruits who did not (injured/non-injured: 42.03 ± 7.35 centimeters [cm] vs. 44.00 ± 7.56 cm; illness/no illness: 41.88 ± 7.48 cm vs. 44.44 ± 7.47 cm) (Orr et al., 2016). Moreover, Orr et al. (2016) stated that recruits with the lowest VJ heights were more than three times as likely to suffer injury and/or illness when compared to those with the highest VJ heights. Other studies have demonstrated that recruits who graduate academies tend to have a better VJ performance than those who do not successfully complete academy requirements (Dawes et al., 2019b; Lockie et al., 2020a). Better VJ displacement related to a faster 5-meter (m), 10-m, and 20-m sprint in Special Weapons and Tactics officers (r = -0.572 to -0.608) (Dawes et al., 2015). Moreno et al. (2019) detailed significant correlations between VJ height (r = 0.209) and VJ peak power (r = 0.568) with a 74.84-kilogram (kg) body drag velocity over 9.75 m in law enforcement recruits. When performed by male and female civilians, Moreno et al. (2024) found a significant relationship between VJ height and 74.84-kg body drag time (r = -0.356). Peak anaerobic power measured in watts (PAPw) derived from the VJ related to 74.84-kg and 90.72-kg body drag times (r = -0.465 to -0.668). Lockie et al. (2021) found that a better VJ related to faster completion of a 99-yard obstacle course (r = -0.35), 6-foot chain link fence climb (r = -0.25), 6-foot solid wall climb (r = -0.25), and 500-yard run (r = -0.21) when performed by recruits. Thus, VJ performance can provide useful information for law enforcement personnel.

Despite the value of the VJ in law enforcement fitness assessments, there is a lack of historical or normative data, especially for law enforcement recruits. A further consideration is that different equipment can be used to measure the VJ, including force plates, jump mats, and jump-and-reach devices (Lockie et al., 2018b; McGuigan, 2015). A jump-and-reach device involves the individual reaching and displacing vanes at the height of the jump, such that the practitioner finds the difference between standing reach height and the maximal jump height to provide the VJ metric (Lockie et al., 2018b). Jumps measured by different equipment may not be directly comparable (Nuzzo et al., 2011). Dawes et al. (2017) documented percentile rank data for the VJ measured by a jump mat performed by male patrol officers. Lockie et al. (2022c) provided normative data for police officers performing the VJ while being measured by a jump-and-reach device. Notwithstanding any equipment differences, recruits tend to outperform incumbent officers in fitness testing for a number of reasons (e.g., recruits tend to be younger, their focus is on training and they have more time to train) (Dawes et al., 2023; Lockie et al., 2020d; Orr et al., 2018). Thus, normative data for incumbent personnel may not always be directly applicable to recruits. There is normative recruit data for the standing broad jump for law enforcement recruits (Štefan et al., 2022), but not for the VJ. Additionally, given that PAPw can be derived from the VJ (Sayers et al., 1999), and this variable has featured in law enforcement research (Cocke et al., 2016; Collins et al., 2022; Dawes et al., 2019a; Moreno et al., 2024; Moreno et al., 2019; Wiley et al., 2020), it would be also useful to present normative PAPw data for law enforcement recruits.

The generation of normative data for the VJ measured by a jump-and-reach device is useful for law enforcement training staff, as it will allow for benchmarking of recruits, in addition to highlighting those recruits who have above or below average power as measured by the VJ. The presence of VJ normative data could also assist staff with training program design for their recruits. Therefore, this descriptive study detailed percentile ranks of jump height and PAPw for the VJ assessment in male and female law enforcement recruits. Retrospective analysis was conducted on pre-existing de-identified data provided by one law enforcement agency. The data composed in this study could be used to drive training practices for law enforcement candidates, as well as recruits in the lead-up to and during academy.

Methods

Design

The cross-sectional, descriptive analysis conducted in this study was similar to previous research that has documented normative data for first responder personnel (Hernandez et al., 2021; Lockie & Hernandez, 2020; Lockie & Moreno, 2020; Lockie et al., 2020b; Lockie et al., 2022c). Retrospective analysis on de-identified recruit data provided by one law enforcement agency from 10 academy classes was conducted. Percentile rankings were produced for all recruits combined, men, and women for VJ height and PAPw derived from the VJ.

Participants

Retrospective analysis was conducted on de-identified data from 833 recruits (age: 27.21 ± 6.20 years; height: 1.73 ± 0.11 m; body mass: 80.21 ± 13.69 kg), including 683 men (age: 27.19 ± 6.10 years; height: 1.75 ± 0.09 m; body mass: 83.38 ± 12.56 kg) and 150 women (age: 27.25 ± 6.31 years; height: 1.62 ± 0.07 m; body mass: 65.47 ± 10.55 kg). All available data from the 10 academy classes was used for this study. Based on the use of archival data in this study, the institutional ethics committee approved the use of pre-existing data (HSR-17-18-370). The study followed the recommendations of the Declaration of Helsinki (World Medical Association, 1997).

Measurements and Procedures

The VJ was completed as part of a battery of fitness assessments which were completed by recruits prior to their training academy (Bloodgood et al., 2020; Collins et al., 2022; Lockie et al., 2019; Lockie et al., 2020a; Lockie et al., 2018a; Lockie et al., 2021). The other fitness assessment data were not considered in this study. Before testing, the recruit's age, height, and body mass were recorded. Height was measured using a portable stadiometer (Seca, Hamburg, Germany). Body mass was recorded by electronic digital scales (Omron Healthcare, Kyoto, Japan). Testing was conducted at the agency's training facility on a day scheduled by the staff and occurred between 9:00am-2:00pm for all classes. The weather conditions for testing were typical of the Southern California climate (Bloodgood et al., 2020).

A jump-and-reach device (Perform Better, Rhode Island, USA) was used to measure the VJ, and the same protocols were used for all academy classes (Bloodgood et al., 2020; Collins et al., 2022; Lockie et al., 2019; Lockie et al., 2020a; Lockie et al., 2018a; Lockie et al., 2021). The VJ protocols adopted by the agency staff have been shown to have very high test-retest reliability ($r > 0.99$) (Beck et al., 2015). The recruit initially stood side-on to the jump-and-reach device (on the recruit's dominant side), reached upward as high as possible, and fully elevated the shoulder to displace as many vanes as possible while keeping their heels on the ground (Figure 1A). The last vane moved became the zero reference. The recruit then performed a countermovement (no restrictions were placed on the range of countermovement; Figure 1B), with no preparatory step, and jumped as high as possible. Jump height was recorded from highest vane moved (Figure 1C). The height of the VJ was calculated in inches by subtracting the standing reach height from the jump height, before being converted to cm. Each recruit completed two trials, with the best trial used for analysis. Peak anaerobic power measured in watts from the VJ was calculated for the best trial by using the equation from Sayers et al. (1999): *Peak Anaerobic Power (watts) = (60.7·VJ height [cm]) + (45.3·body mass [kg]) - 2055*.

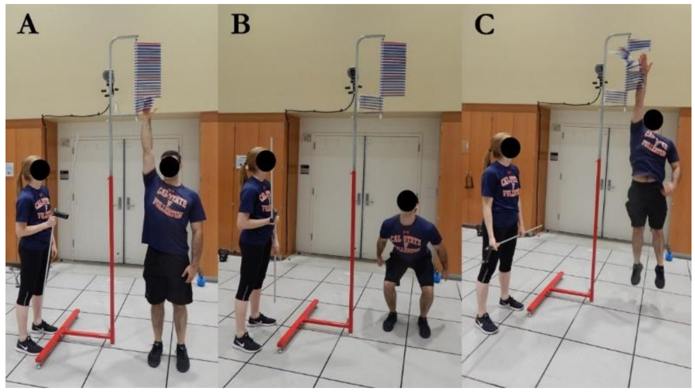

Figure 1. The countermovement vertical jump performed with a jump-and-reach device. (A) Measurement of standing reach height. (B) Preparatory countermovement. (C) Maximal jump height.

Statistical analyses
Data were collated for all recruits for the different academy classes, with the descriptive (mean ± standard deviation) data derived for VJ height and PAPw for all recruits combined, male recruits, and female recruits. Similar to previous research (Hernandez et al., 2021; Lockie & Hernandez, 2020; Lockie & Moreno, 2020; Lockie et al., 2020b; Lockie et al., 2022c), Microsoft Excel (Microsoft Corporation™, Redmond, Washington, USA) was used to calculate the percentile ranks for all, male, and female recruits. The following bands/ranks were derived for VJ height and PAPw: 90-100, 80-89, 70-79, 60-69, 50-59, 40-49, 30-39, 20-29, 10-19, and 0-9.

Results
Figures 2 and 3 displays the descriptive data for all recruits combined, men, and women for VJ height and PAPw, respectively. The percentile rank data for VJ height for all recruits, men, and women, are shown in Tables 1, 2, and 3, respectively. The number of men and women in each ranking band for all recruits is noted and number of recruits in each ranking band was documented when the sexes were analyzed separately. The PAPw percentile rank data for all recruits, men, and women, are shown in Tables 4, 5, and 6, respectively.

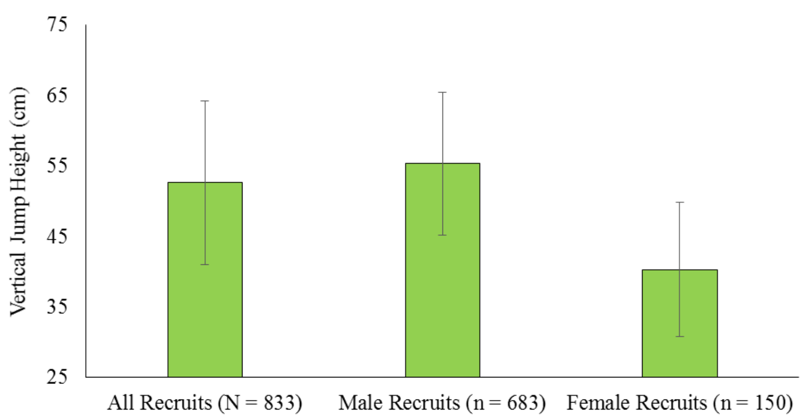

Figure 2. Descriptive (mean ± standard deviation) data for countermovement vertical jump height measured by a jump-and-reach device for all recruits, male recruits, and female recruits.

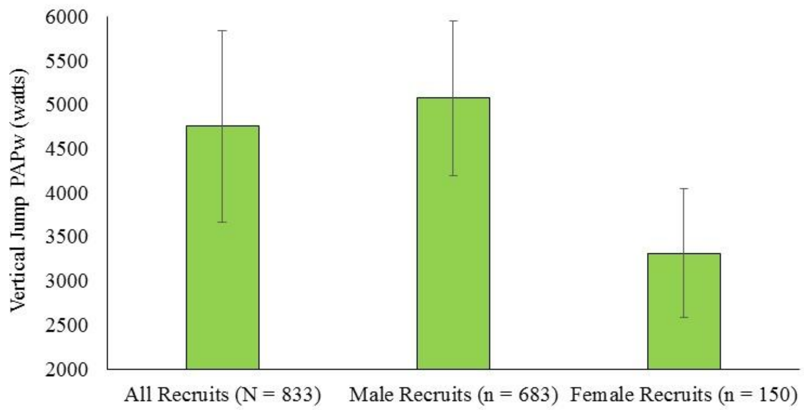

Figure 3. Descriptive (mean ± standard deviation) data for peak anaerobic power measured in watts (PAPw) derived from countermovement vertical jump height measured by a jump-and-reach device for all recruits, male recruits, and female recruits.

Table 1. Percentile rankings for countermovement vertical jump (VJ) height measured by a jump-and-reach device for male and female law enforcement recruits combined.

Percentile Rank	VJ Height (cm)	Males (n = 683)	Females (n = 150)
90-100	68.58-78.74	73	2
80-89	62.24-67.31	92	1
70-79	59.32-62.23	83	2
60-69	56.90-58.42	83	2
50-59	52.32-55.88	93	3
40-49	50.80-52.07	68	7
30-39	48.26-49.53	73	10
20-29	44.45-46.99	63	17
10-19	39.37-43.18	41	37
0-9	<38.10	30	57

Table 2. Percentile rankings for countermovement vertical jump (VJ) height measured by a jump-and-reach device for male law enforcement recruits.

Percentile Rank	VJ Height (cm)	Number
90-100	69.85-78.74	63
80-89	64.77-68.58	69
70-79	61.47-63.50	52
60-69	59.32-60.96	64
50-59	55.88-58.42	90
40-49	52.32-54.61	61
30-39	50.80-52.07	68
20-29	48.26-49.53	73
10-19	41.92-46.99	77
0-9	<41.91	66

Table 3. Percentile rankings for countermovement vertical jump (VJ) height measured by a jump-and-reach device for female law enforcement recruits.

Percentile Rank	VJ Height (cm)	Number
90-100	50.80-76.50	16
80-89	46.99-49.53	13
70-79	44.45-45.72	14
60-69	43.18	15
50-59	41.91	7
40-49	40.64	15
30-39	38.10-39.37	20
20-29	34.29-36.83	18
10-19	30.48-33.02	15
0-9	<29.21	17

Table 4. Percentile rankings for peak anaerobic power measured in watts (PAPw) derived from the countermovement vertical jump measured by a jump-and-reach device for male and female law enforcement recruits combined.

Percentile Rank	PAPw (watts)	Males (n = 683)	Females (n = 150)
90-100	6043.67-7485.23	87	1
80-89	5704.15-6043.55	83	0
70-79	5382.62-5700.49	82	1
60-69	5112.75-5381.99	79	4
50-59	4842.98-5110.25	84	0
40-49	4543.60-4839.94	83	0
30-39	4272.12-4543.52	77	5
20-29	3777.80-4271.96	68	16
10-19	3216.00-3777.19	29	54
0-9	<3211.55	11	69

Table 5. Percentile rankings for peak anaerobic power measured in watts (PAPw) derived from the countermovement vertical jump measured by a jump-and-reach device for male law enforcement recruits.

Percentile Rank	PAPw (watts)	Number
90-100	6148.41-7485.23	72
80-89	5816.81-6145.37	68
70-79	5549.66-5808.58	69
60-69	5308.61-5544.97	68
50-59	5076.75-5296.53	68
40-49	4853.77-5074.78	68
30-39	4625.22-4851.66	68
20-29	4389.66-4621.56	69
10-19	4013.99-4389.58	68
0-9	<4012.88	65

Table 6. Percentile rankings for peak anaerobic power measured in watts (PAPw) derived from the countermovement vertical jump measured by a jump-and-reach device for female law enforcement recruits.

Percentile Rank	PAPw (watts)	Number
90-100	4065.47-6145.37	16
80-89	3759.28-4058.81	15
70-79	3610.27-3754.18	15
60-69	3469.76-3605.97	15
50-59	3279.65-3456.17	15
40-49	3066.03-3261.46	15
30-39	2898.82-3052.68	15
20-29	2792.28-2894.29	14
10-19	2536.56-2766.82	15
0-9	<2526.81	15

Discussion

The VJ has featured as an entry-level fitness test for law enforcement training academies (Dawes et al., 2019b), and has been incorporated into fitness assessments of law enforcement recruits prior to academy training (Bloodgood et al., 2020; Collins et al., 2022; Lockie et al., 2019; Lockie et al., 2020a; Lockie et al., 2018a; Lockie et al., 2021). The law enforcement organization from which the current data was drawn did not use the VJ assessment as a means to remove recruits from their training academy, so there was no hard minimum cut score for the VJ that dictated employment decisions. Rather, the VJ was used as part of a testing battery to assess recruit fitness to assist with the implementation of the academy training programs. Further, the goals of this study were not to provide cut scores for VJ height and PAPw. Instead, the goals were to present normative percentile data for jump performance and PAPw in a large sample of law enforcement recruits. In addition to this, the normative data produced for VJ height and PAPw VJ can provide practical information for training staff.

It is important to present normative fitness testing data that represents all law enforcement recruits. Some law enforcement organizations will use general fitness assessments as part of a reward system during academy and may not use sex-specific standards (Lockie et al., 2020b). When considering their recruit classes, staff could use the percentile ranks produced from this research to identify where recruits currently reside with regards to their lower-body power, and how their VJ performance changes over time. Improving VJ performance is important, as absolute jump height has been related to job-specific tasks such as running and sprinting (Dawes et al., 2015; Lockie et al., 2021), body drags (Moreno et al., 2024; Moreno et al., 2019), and obstacle clearance, fence climbs, and wall climbs (Lockie et al., 2021). Percentile rank data could also be used to document improvements in recruits who may have lesser jump performance. For example, a recruit could be in the 20-29% rank after academy training, which could be considered less than ideal. However, if they started in the 0-9% rank, this would be evidence of an improved VJ that could also hopefully benefit job task performance.

To provide some context for the VJ data, when compared to 20-29 year old police officer normative data, the VJ height mean from the current study was slightly below that from Lockie et al. (2022c) (~58 cm vs. 52.63 ± 11.59 cm), who used similar methodology to measure the VJ as that from this research. The police officers from Lockie et al. (2022c) were part of a health and wellness program, so they could have been receiving exercise interventions as part of the program, or the data could have been influenced by the healthy worker effect. The healthy worker effect is where fitter officers are likely to participate in a voluntary health and wellness program (Chowdhury et al., 2017; Lockie et al., 2022c). Nonetheless, the equivalent percentile ranks in the current study were relatively similar to the two years documented by Lockie et al. (2022c). The current study also adds normative data specific to law enforcement recruits to the literature.

Although not as common in law enforcement testing, normative PAPw metric could be useful to present to recruits as it demonstrates how they generate power with regard to their body mass. Although heavier individuals will typically have a higher PAPw (Carlock et al., 2004), if a lighter recruit experiences an increase in PAPw following training, the staff could infer they have become better at moving their body mass quickly. Moreover, it may not just be more body mass that influences PAPw. Collins et al. (2022) detailed that a greater PAPw derived from the VJ significantly ($p < 0.001$) related to more lean body mass in law enforcement recruits ($r = 0.543$-0.558). Thus, training that develops lean body mass (i.e., resistance training) could also lead to improved PAPw. Greater PAPw has been correlated with a faster 74.84-kg and 90.72-kg body drag over 9.75 m when performed by civilians (Moreno et al., 2024). Notably, Moreno et al. (2024) found that civilians who could not complete a standard body drag with a 90.72-kg dummy had a PAPw of 3599.84 ± 627.86 watts. This value would fall in the 0-9% rank for men, but the 60-69% rank for women. These data highlight the importance of PAPw for executing heavier body drags (Moreno et al., 2024), which is important with the population shift towards heavier mean body mass for men and women (Fryar et al., 2018).

Previous research has shown between-sex differences in VJ performance in law enforcement recruits (Lockie et al., 2020a; Lockie et al., 2018a; Lockie et al., 2022b), which was also reflected in the normative data from this study. When all recruits were combined for VJ height, 74% of all female recruits were in the bottom three percentile bands from 0-29%. For PAPw, 93% of women were in the 0-29% bands. These results were likely influenced by body mass being included in the PAPw calculation (Sayers et al., 1999), and women on average being lighter than men (Fryar et al., 2018). Nonetheless, when the sexes were analyzed separately, men tended to have greater values for VJ height and PAPw in the equivalent bands compared to women. This is not to say that women lack the power for a successful career in law enforcement. Indeed, similar to other law enforcement normative data studies (Lockie & Hernandez, 2020; Lockie & Moreno, 2020; Lockie et al., 2020b), there were women who outperformed many men in the VJ. Nonetheless, similar to recommendations made in previous studies (Lockie et al., 2020a; Lockie et al., 2018a; Moreno et al., 2024), what these data reinforce is that women attempting a career in law enforcement should complete specific power training prior to and during academy.

A foundation of this power training should be strength development, which is supported by research noting relationships between lower-body strength and jump performance in law enforcement populations (Dawes et al., 2019a). With effective training program design incorporating strength and power exercises, both male and female recruits could improve in their jump performance after academy training. Lockie et al. (2020c) documented improvements in VJ performance following 27 weeks of academy training in male and female law enforcement recruits, which the authors linked in part to improvements in lower-body strength. Specific to male recruits, both VJ (increase of 7.37 ± 5.91 cm) and PAPw (increase of 373.97 ± 377.90 watts) significantly ($p < 0.01$) improved following a 6-month training academy, where the fitness program incorporated a mix of muscular strength, power, and endurance exercises (Cocke et al., 2016). Although not significant ($p = 0.06$), Crawley et al. (2016) found an approximate 8% increase in VJ height in male and female police cadets following a 16-week training academy. The sex-specific normative data could aid training program design, especially for women (and possibly men with lighter body mass) who may need more targeted strength and power training before they can work safely and effectively in the field.

There are limitations for this descriptive research that should be documented. De-identified data from one agency was analyzed in this study. As fitness assessment performance can vary across agencies (Myers et al., 2019), the current normative data may not be applicable to all law enforcement organizations. This research only provided a descriptive analysis of recruit VJ height and PAPw data; the effects of VJ performance on academy survivability and future job performance cannot be determined from the current data analysis. There was a large between-sex discrepancy in the study data (i.e., 683 men, 150 women), although this is typical of many law enforcement organizations. Jump height was measured by a jump-and-reach device. Other equipment (e.g., force plates) could provide more accurate VJ data, notwithstanding that other law enforcement organizations may use different equipment. If different equipment is used to measure the VJ, this could make normative data comparisons challenging (Nuzzo et al., 2011).

Conclusion

This study documented normative data for law enforcement recruits in the VJ, for both jump height and PAPw. With regards to between-sex comparisons, the data indicated the male recruits tended to perform better than female recruits; 74% of all female recruits were in the bottom three percentile bands for VJ height, and 93% of women were in the bottom three bands for PAPw. Female recruits will likely need specific strength and power training prior to and during academy. The provision of normative VJ height and PAPw data provide benchmarking of the lower-body power of recruits and could inform fitness training program design for academy staff.

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References

Beck, A.Q., Clasey, J.L., Yates, J.W., Koebke, N.C., Palmer, T.G., & Abel, M.G. (2015). Relationship of physical fitness measures vs. occupational physical ability in campus law enforcement officers. *Journal of Strength and Conditioning Research, 29*(8), 2340-2350. https://doi.org/10.1519/jsc.0000000000000863

Bloodgood, A.M., Moreno, M.R., Cesario, K.A., McGuire, M.B., & Lockie, R.G. (2020). An investigation of seasonal variations in the fitness test performance of law enforcement recruits. *Facta Universitatis - series: Physical Education and Sport, 18*(2), 271-282. https://doi.org/10.22190/FUPES200713025B

Burr, J.F., Jamnik, V.K., Dogra, S., & Gledhill, N. (2007). Evaluation of jump protocols to assess leg power and predict hockey playing potential. *Journal of Strength and Conditioning Research, 21*(4), 1139-1145. https://doi.org/10.1519/r-21496.1

Carlock, J.M., Smith, S.L., Hartman, M.J., Morris, R.T., Ciroslan, D.A., Pierce, K.C., Newton, R.U., Harman, E.A., Sands, W.A., & Stone, M.H. (2004). The relationship between vertical jump power estimates and weightlifting ability: a field-test approach. *Journal of Strength and Conditioning Research, 18*(3), 534-539. https://doi.org/10.1519/r-13213.1

Chowdhury, R., Shah, D., & Payal, A.R. (2017). Healthy worker effect phenomenon: Revisited with emphasis on statistical methods - A review. *Indian Journal of Occupational and Environmental Medicine, 21*(1), 2-8. https://doi.org/10.4103/ijoem.ijoem_53_16

Cocke, C., Dawes, J., & Orr, R.M. (2016). The use of 2 conditioning programs and the fitness characteristics of police academy cadets. *Journal of Athletic Training, 51*(11), 887-896. https://doi.org/10.4085/1062-6050-51.8.06

Collins, K.S., Christensen, B., Orr, R.M., Dulla, J.M., Dawes, J.J., & Lockie, R.G. (2022). Analysis of total and segmental body composition relative to fitness performance measures in law enforcement recruits. *International Journal of Exercise Science, 15*(4), 245-260. https://doi.org/10.70252/eder1570

Crawley, A.A., Sherman, R.A., Crawley, W.R., & Cosio-Lima, L.M. (2016). Physical fitness of police academy cadets: Baseline characteristics and changes during a 16-week academy. *Journal of Strength and Conditioning Research, 30*(5), 1416-1424. https://doi.org/10.1519/jsc.0000000000001229

Dawes, J.J., Lockie, R.G., Kornhauser, C.L., Holmes, R.J., & Orr, R.M. (2019a). Relationships between absolute and relative strength and power in male police officers of varying strength levels. *Journal of Science in Sport and Exercise, 1*, 281-288. https://doi.org/10.1007/s42978-019-00033-5

Dawes, J.J., Lockie, R.G., Orr, R.M., Kornhauser, C., & Holmes, R.J. (2019b). Initial fitness testing scores as a predictor of police academy graduation. *Journal of Australian Strength and Conditioning, 27*(4), 30-37.

Dawes, J.J., Lopes Dos Santos, M., Kornhauser, C., Holmes, R.J., Alvar, B.A., Lockie, R.G., & Orr, R.M. (2023). Longitudinal changes in health and fitness measures among state patrol officers by sex. *Journal of Strength and Conditioning Research, 37*(4), 881-886. https://doi.org/10.1519/jsc.0000000000004327

Dawes, J.J., Orr, R.M., Elder, C.L., Krall, K., Stierli, M., & Schilling, B. (2015). Relationship between selected measures of power and strength and linear running speed amongst Special Weapons and Tactics police officers. *Journal of Australian Strength and Conditioning, 23*(3), 23-28.

Dawes, J.J., Orr, R.M., Flores, R.R., Lockie, R.G., Kornhauser, C., & Holmes, R. (2017). A physical fitness profile of state highway patrol officers by gender and age. *Annals of Occupational and Environmental Medicine, 29*(16), 16. https://doi.org/10.1186/s40557-017-0173-0

Fryar, C.D., Kruszon-Moran, D., Gu, Q., & Ogden, C.L. (2018). Mean body weight, height, waist circumference, and body mass index among adults: United States, 1999-2000 through 2015-2016. *National Health Statistics* Reports (122), 1-16.

Hernandez, E., Dawes, J.J., Dulla, J., Orr, R., & Lockie, R.G. (2021). Fitness percentile rank data for percentile rank data for female percentile rank data for female law enforcement recuits in the USA. *Facta Universitatis, Series: Physical Education and Sport, 19*(1), 109-118. https://doi.org/10.22190/FUPES210609014H

Lockie, R., & Hernandez, E. (2020). The 75-yard pursuit run performed by law enforcement recruits–Percentile rankings and implications for training. *TSAC* Report (57), 16-22.

Lockie, R., & Moreno, M. (2020). The 165-lb body drag–Benchmarking and training implications for law enforcement recruits. *TSAC Report,* (58), 6-11.

Lockie, R.G., Balfany, K., Bloodgood, A.M., Moreno, M.R., Cesario, K.A., Dulla, J.M., Dawes, J.J., & Orr, R.M. (2019). The influence of physical fitness on reasons for academy separation in law enforcement recruits. *International Journal of Environmental Research and Public Health, 16*(3), 372. https://doi.org/10.3390/ijerph16030372

Lockie, R.G., Beitzel, M.M., Dulla, J.M., Dawes, J.J., Orr, R.M., & Hernandez, J.A. (2022a). Between-sex differences in the Work Sample Test Battery performed by law enforcement recruits: Implications for training and potential job performance. *Journal of Strength and Conditioning Research, 36*(5), 1310-1317. https://doi.org/10.1519/jsc.0000000000003671

Lockie, R.G., Dawes, J.J., Dulla, J.M., Orr, R.M., & Hernandez, E. (2020a). Physical fitness, sex considerations, and academy graduation for law enforcement recruits. *Journal of Strength and Conditioning Research, 34*(12), 3356-3363. https://doi.org/10.1519/jsc.0000000000003844

Lockie, R.G., Dawes, J.J., Orr, R.M., & Dulla, J.M. (2020b). Recruit fitness standards from a large law enforcement agency: Between-class comparisons, percentile rankings, and implications for physical training. *Journal of Strength and Conditioning Research, 34*(4), 934-941. https://doi.org/10.1519/jsc.0000000000003534

Lockie, R.G., Dawes, J.J., Orr, R.M., Stierli, M., Dulla, J.M., & Orjalo, A.J. (2018a). An analysis of the effects of sex and age on upper- and lower-body power for law enforcement agency recruits prior to academy training. *Journal of Strength and Conditioning Research, 32*(7), 1968-1974. https://doi.org/10.1519/jsc.0000000000002469

Lockie, R.G., MacLean, N.D., Dawes, J.J., Pope, R.P., Holmes, R.J., Kornhauser, C.L., & Orr, R.M. (2020c). The impact of formal strength and conditioning on the fitness of police recruits: A retrospective cohort study. *International Journal of Exercise Science, 13*(4), 1615-1629. https://doi.org/10.70252/mtcy9871

Lockie, R.G., Moreno, M.R., Bloodgood, A.M., & Cesario, K.A. (2018b). Practical assessments of power for law enforcement populations. *TSAC* Report (49), 6-12.

Lockie, R.G., Moreno, M.R., & Dawes, J.J. (2022b). A research note on relationships between the vertical jump and standing broad jump in law enforcement recruits: Implications for lower-body power testing. *Journal of Strength and Conditioning Research, 36*(8), 2326-2329. https://doi.org/10.1519/jsc.0000000000003821

Lockie, R.G., Moreno, M.R., Rodas, K.A., Dulla, J.M., Orr, R.M., & Dawes, J.J. (2021). With great power comes great ability: Extending research on fitness characteristics that influence Work Sample Test Battery performance in law enforcement recruits. *Work, 68*(4), 1069-1080. https://doi.org/10.3233/wor-213437

Lockie, R.G., Orr, R.M., & Dawes, J.J. (2022c). Slowing the path of time: Age-related and normative fitness testing data for police officers from a health and wellness program. *Journal of Strength and Conditioning Research, 36*(3), 747-756. https://doi.org/10.1519/jsc.0000000000004197

Lockie, R.G., Pope, R.P., Saaroni, O., Dulla, J.M., Dawes, J.J., & Orr, R.M. (2020d). Job-specific physical fitness changes measured by the Work Sample Test Battery within deputy sheriffs between training academy and their first patrol assignment. *International Journal of Exercise Science, 13*(4), 1262-1274. https://doi.org/10.70252/nchz6196

McGuigan, M.R. (2015). Principles of Test Selection and Administration. In G. G. Haff & N. T. Triplett (Eds.), *Essentials of Strength Training and Conditioning* (4th ed., pp. 249-258). Champaign, IL: Human Kinetics.

Moreno, M.R., Dawes, J.J., Orr, R.M., Dulla, J.M., & Lockie, R.G. (2024). Relationships between strength and power with the 74.84-kg (165-lb) and 90.72-kg (200-lb) body drags. *Journal of Strength and Conditioning Research, 38*(7), 1305-1313. https://doi.org/10.1519/jsc.0000000000004763

Moreno, M.R., Dulla, J.M., Dawes, J.J., Orr, R.M., Cesario, K.A., & Lockie, R.G. (2019). Lower-body power and its relationship with body drag velocity in law enforcement recruits. *International Journal of Exercise Science, 12*(4), 847-858.

Morin, J.B., Jimenez-Reyes, P., Brughelli, M., & Samozino, P. (2019). When jump height is not a good indicator of lower limb maximal power output: Theoretical demonstration, experimental evidence and practical solutions. *Sports Medicine, 49*(7), 999-1006. https://doi.org/10.1007/s40279-019-01073-1

Myers, C.J., Orr, R.M., Goad, K.S., Schram, B.L., Lockie, R., Kornhauser, C., Holmes, R., & Dawes, J.J. (2019). Comparing levels of fitness of police officers between two United States law enforcement agencies. *Work, 63*(4), 615-622. https://doi.org/10.3233/wor-192954

Nuzzo, J.L., Anning, J.H., & Scharfenberg, J.M. (2011). The reliability of three devices used for measuring vertical jump height. *Journal of Strength and Conditioning Research, 25*(9), 2580-2590. https://doi.org/10.1519/jsc.0b013e3181fee650

Orr, R., Dawes, J.J., Pope, R., & Terry, J. (2018). Assessing differences in anthropometric and fitness characteristics between police academy cadets and incumbent officers. *Journal of Strength and Conditioning Research, 32*(9), 2632-2641. https://doi.org/10.1519/jsc.0000000000002328

Orr, R., Pope, R., Peterson, S., Hinton, B., & Stierli, M. (2016). Leg power as an indicator of risk of injury or illness in police recruits. *International Journal of Environmental Research and Public Health, 13*(2), 237. https://doi.org/10.3390/ijerph13020237

Sayers, S.P., Harackiewicz, D.V., Harman, E.A., Frykman, P.N., & Rosenstein, M.T. (1999). Cross-validation of three jump power equations. *Medicine and Science in Sports and Exercise, 31*(4), 572-577. https://doi.org/10.1097/00005768-199904000-00013

Štefan, L., Kasović, M., & Culej, M. (2022). Normative values for health-related physical fitness in first-year police officers. *Journal of Strength and Conditioning Research, 36*(9), 2530-2535. https://doi.org/10.1519/jsc.0000000000003853

Wiley, A., Joseph, A., Orr, R., Schram, B., Kornhauser, C.L., Holmes, R.J., & Dawes, J.J. (2020). The impact of external loads carried by police officers on vertical jump performance. *International Journal of Exercise Science, 13*(6), 1179-1189. https://doi.org/10.70252/mtpb8978

World Medical Association. (1997). World Medical Association Declaration of Helsinki. Recommendations guiding physicians in biomedical research involving human subjects. *Journal of the American Medical Association, 277*(11), 925-926.

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Original article

20-m Multistage Fitness Test Normative Percentile Rank Data for Law Enforcement Recruits

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Abstract

The 20-m multistage fitness test (20MSFT) has been used to assess the aerobic fitness of law enforcement candidates prior to academy, and recruits during academy. There is limited research that has published normative data for the 20MSFT as performed by recruits. This study provided normative percentile rank data for 20MSFT shuttles and estimated maximal aerobic capacity ($\dot{V}O_{2max}$) for law enforcement recruits. Retrospective analysis on 1040 recruits (850 men, 190 women) from one law enforcement agency was conducted. Recruits completed the 20MSFT as part of a battery of fitness tests prior to their training academy. The number of completed shuttles was recorded and used to calculate 20MSFT percentile rankings for all recruits, men, and women, in the following bands: 90-100, 80-89, 70-79, 60-69, 50-59, 40-49, 30-39, 20-29, 10-19, and 0-9. Once the 20MSFT shuttle percentile ranks were developed, estimated $\dot{V}O_{2max}$ for these rankings was derived. All recruits combined, men, and women, had a 20MSFT mean of 52.38±18.06, 53.70±18.23, and 46.46±16.05 shuttles, respectively. The data indicated the male recruits tended to perform better than female recruits, although 36% of the women were in the top half of all recruits in completed 20MSFT shuttles. Nevertheless, female recruits will likely need specific aerobic conditioning prior to and during academy. The $\dot{V}O_{2max}$ data suggested limitations in recruit aerobic fitness when compared to population norms. Familiarity with the 20MSFT and high-intensity running exposure could have influenced the $\dot{V}O_{2max}$ results. The provision of normative 20MSFT data provide recruit benchmarking and could inform fitness program design for staff.

Keywords: Aerobic Fitness, First Responder, Maximal Aerobic Capacity, Normative Data, Police, Tactical

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Introduction

Law enforcement can incorporate physically demanding tasks that place great stress on officers. During the course of a shift, law enforcement officers may be required to drive at high speeds, push and pull heavy objects, lift, carry, and drag civilians from dangerous situations, jump obstacles, pursue and apprehend offenders, and use firearms (Decker et al., 2022; Schram et al., 2018). Numerous studies have shown that aerobic capacity underpins many law enforcement job tasks such as obstacle clearance, dragging, lifting, carrying, and running (Beck et al., 2015; Dawes et al., 2017a). In addition to job performance, superior aerobic fitness has been linked to the ability to tolerate the stress of academy training and successfully graduate to become sworn personnel (Dawes et al., 2019; Lockie et al., 2019; Lockie et al., 2022a; Lockie et al., 2020a; Shusko et al., 2017). Accordingly, aerobic fitness tests are often included in law enforcement-specific fitness testing.

For example, the 2.4-km (1.5-mile) run has been included within entry physical ability tests for law enforcement candidates (Bloodgood et al., 2021) and recruits during academy (Lockie et al., 2020b; Shusko et al., 2017). Normative data has been presented for the 2.4-km run when performed by law enforcement recruits (Lockie et al., 2020b) and first-year officers (Štefan et al., 2022). However, Lockie et al. (2021b) noted some limitations associated with the 2.4-km run as an assessment. One challenge is that the 2.4-km run is self-paced, whereby the participant needs to be motivated to maintain a faster pace. This self-pacing strategy is atypical of many law enforcement job tasks (Brewer et al., 2013). For most agencies using the 2.4-km run, they will have to perform this test outdoors, where weather conditions could impact performance. Another issue identified by Lockie et al. (2021b) that is especially notable for candidates and recruits is that because the 2.4-km run is a set distance timed run, low fitness participants will actually be required to run/walk for more time (i.e., it will take them longer to cover the 2.4-km distance). Lockie et al. (2021b) suggested that this could place low fitness participants at greater risk of cardiovascular strain.

In partial response to the issues identified by Lockie et al. (2021b), the 20-m multistage fitness test (20MSFT) has been used to assess aerobic fitness in law enforcement personnel (Dawes et al., 2019; Dawes et al., 2017b; Lockie et al., 2021a; Lockie et al., 2020c; Orr et al., 2016). Indeed, the Los Angeles County Sheriff's Depart switched from using the 2.4-km run to the 20MSFT as part of their Validated Physical Ability Testing during the hiring process for candidates (Los Angeles County Sheriff's Department, 2019). The 20MSFT is externally paced, with participants running back-and-forth over 20 m and speed increasing each minute until the participant can no longer keep pace (Léger et al., 1988). Although the 20MSFT is not without its limitations (e.g., learning effects, stress induced by the direction changes), Lockie et al. (2021b) recognized several positives relative to its use in law enforcement fitness testing. External pacing, ability to conduct the test over a smaller area, opportunities for indoor testing, low fitness participants not lasting as long in the test were all documented as positive reasons behind the use of the 20MSFT.

A lack of historical data for the 20MSFT and law enforcement personnel was also identified as a limitation (Lockie et al., 2021b). Dawes et al. (2017b) has documented percentile rank data for the number of 20MSFT shuttles completed by male and female patrol officers. However, what is lacking is normative, percentile rank data for this test when it is performed by recruits. Hernandez et al. (2021) did present normative 20MSFT shuttle data for 200 female law enforcement recruits from 14 law enforcement academy classes across three different states in the USA, but there is currently no normative data available for male recruits. The generation of normative data for the 20MSFT is important for academy training staff, as it will allow for benchmarking of recruits, in addition to highlighting those recruits who are above or below average in their aerobic capacity as assessed by the 20MSFT. The presence of normative data could also assist staff with training program design for their recruits. Additionally, given that maximal aerobic capacity ($\dot{V}O_{2max}$) can be estimated from the 20MSFT (Ramsbottom et al., 1988), it would be also useful to present normative $\dot{V}O_{2max}$ data for law enforcement recruits.

Therefore, this descriptive study detailed percentile ranks of male and female law enforcement recruits' performance in the 20MSFT by shuttles completed and estimated $\dot{V}O_{2max}$. This was done to better distinguish fitness levels for law enforcement recruits. Retrospective analysis was conducted on pre-existing de-identified data provided by one law enforcement agency. The percentile rank data composed in this research could be used to drive training practices for candidates for a law enforcement agency, recruits in the lead-up to and during academy.

Methods

Design

The cross-sectional, descriptive analysis conducted in this study was similar to previous research that has documented normative data for first responder personnel (Hernandez et al., 2021; Lockie & Hernandez, 2020; Lockie & Moreno, 2020; Lockie et al., 2020b; Lockie et al., 2022b). Retrospective analysis on de-identified recruit data provided by one law enforcement agency from 12 academy classes was conducted. Percentile rankings were produced for all recruits combined, men, and women for the number of shuttles completed. Following this, estimated $\dot{V}O_{2max}$ from these rankings was derived using the table by Ramsbottom et al. (1988). The greater focus for the percentile rankings was on the number of shuttles completed, as law enforcement agencies generally do not use $\dot{V}O_{2max}$ as part of hiring standards (Lockie et al., 2021a).

Participants

As stated, retrospective analysis was conducted on de-identified data from 1040 recruits (age: 27.20 ± 6.14 years; height: 1.72 ± 0.10 m; body mass: 80.10 ± 14.05 kg), including 850 men (age: 27.19 ± 6.10 years; height: 1.75 ± 0.09 m; body mass: 83.38 ± 12.56 kg) and 190 women (age: 27.25 ± 6.31 years; height: 1.62 ± 0.07 m; body mass: 65.47 ± 10.55 kg). Based on the use of archival data in this study, the institutional ethics committee approved the use of pre-existing data (HSR-17-18-370). The study followed the recommendations of the Declaration of Helsinki (World Medical Association, 1997).

Measurements and Procedures

The 20MSFT was completed as part of a battery of fitness tests completed by recruits (Bloodgood et al., 2020; Collins et al., 2022; Lockie et al., 2019; Lockie et al., 2022a; Lockie et al., 2020a; Lockie et al., 2018; Lockie et al., 2021c). Data from the other fitness tests were not considered within the context of the current research. Prior to all testing, each recruit's age, height, and body mass were recorded. Height was measured using a portable stadiometer (Seca, Hamburg, Germany), while body mass was recorded by electronic digital scales (Omron Healthcare, Kyoto, Japan). Testing was conducted at the law enforcement agency's training facility on a day scheduled by the agency staff. Testing occurred between 9:00am-2:00pm for all classes, depending on recruit availability. Recruits generally did not eat in the 2-3 hours before their testing session as they were required to complete paperwork for the agency, but they were allowed to consume water as needed during testing. The weather conditions for testing were typical of the Southern California climate (Bloodgood et al., 2020).

The 20MSFT was used to measure maximal aerobic capacity in the recruits and was conducted outdoors on an asphalt surface according to procedures described in a multitude of law enforcement studies (Bloodgood et al., 2020; Collins et al., 2022; Lockie et al., 2019; Lockie et al., 2022a; Lockie et al., 2020a; Lockie et al., 2018; Lockie et al., 2021c). Although outdoor testing may not be ideal for the 20MSFT, this was the only available space at the agency's training facility. The 20MSFT has high reliability (intraclass correlation coefficient = 0.96) (Aandstad et al., 2011). Recruits typically completed the 20MSFT in groups of 14-16 and were supervised by staff working on behalf of the agency. The structure of the test is shown in Figure 1. Recruits ran back and forth between two lines spaced 20 m apart, which were indicated by markers. The speed of running for this test was standardized by pre-recorded auditory cues (i.e. beeps) played from an iPad handheld device (Apple Inc., Cupertino, California) connected via Bluetooth to a portable speaker (ION Block Rocker, Cumberland, Rhode Island). The speaker was located central to the running area, and positioned so that it would not interfere with the recruits. The test was terminated when the recruit was unable to reach the lines twice in a row in accordance with the auditory cues. This test was scored according to the final level and stage the recruit was able to achieve, and the level and stage results was used to calculate the total number of shuttles completed.

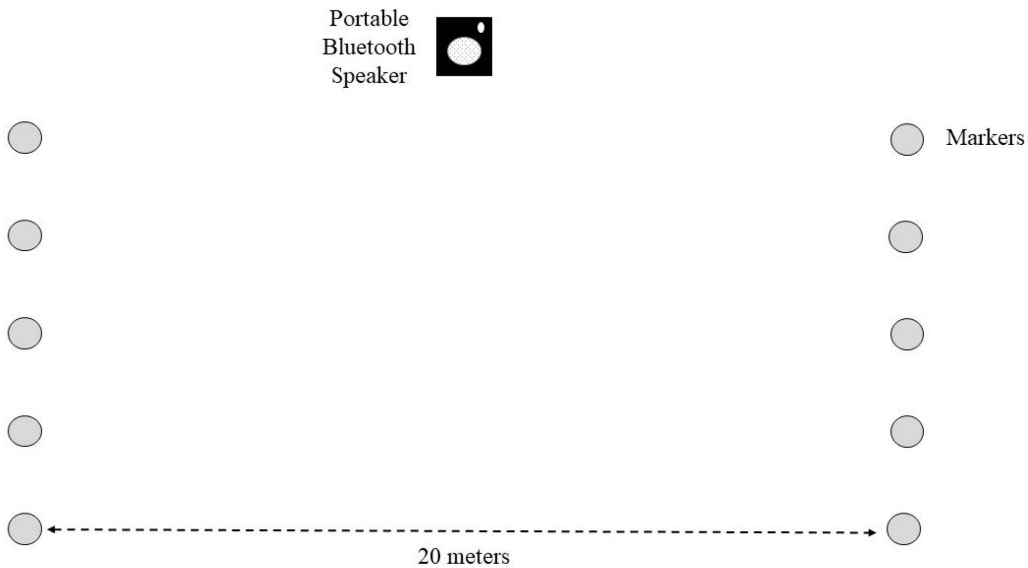

Figure 1. The 20-m multistage fitness test (20MSFT) dimensions and location of portable speaker.

Statistical analyses

Data were collated for all recruits for the different academy classes, with the descriptive (mean ± standard deviation) data derived for completed 20MSFT shuttles for all recruits combined, male recruits, and female recruits. Microsoft Excel (Microsoft Corporation™, Redmond, Washington, USA) was used to calculate the percentile ranks for all recruits combined, and male and female recruits separately (Hernandez et al., 2021; Lockie & Hernandez, 2020; Lockie & Moreno, 2020; Lockie et al., 2020b; Lockie et al., 2022b). The "Rank and Percentile" tool within the Data Analysis ToolPak was used to calculate the percentile rankings for the 20MSFT in the following bands or ranks: 90-100, 80-89, 70-79, 60-69, 50-59, 40-49, 30-39, 20-29, 10-19, and 0-9. Once the percentile ranks were developed for the 20MSFT shuttles for all recruits combined, men, and women, the estimated $\dot{V}O_{2max}$ for these rankings was derived using the table by Ramsbottom et al. (1988). The same percentile ranks/bands were used for estimated $\dot{V}O_{2max}$.

Results

Figure 2 displays the descriptive data for all recruits combined, men, and women. The percentile rank data for all recruits combined, men, and women, and shown in Tables 1, 2, and 3, respectively. The number of men and women in each band are noted for all recruits combined. When the sexes were documented separately, the number of recruits in each band was noted. The equivalent estimated $\dot{V}O_{2max}$ for the percentile rank data for all recruits combined, men, and women, are shown in Tables 4, 5, and 6, respectively. For the estimated $\dot{V}O_{2max}$ rankings, that there is overlap between the different bands. This was due to the estimations provided by Ramsbottom et al. (1988), whereby there is not a $\dot{V}O_{2max}$ score for every shuttle level.

Figure 2. Descriptive (mean ± standard deviation) data for the number of completed 20-m multistage fitness test (20MSFT) shuttles for all recruits combined, male recruits, and female recruits.

Table 1. Percentile rankings for 20-m multistage fitness test (20MSFT) shuttles for male and female law enforcement recruits combined.

Percentile Rank	20MSFT Shuttles	Males (n = 850)	Females (n = 190)
90-100	77-118	97	11
80-89	67-76	90	11
70-79	61-66	82	15
60-69	55-60	94	15
50-59	50-54	92	17
40-49	46-49	74	13
30-39	42-45	91	19
20-29	38-41	74	24
10-19	33-37	70	37
<10	8-32	86	28

Table 2. Percentile rankings for 20-m multistage fitness test (20MSFT) shuttles for male law enforcement recruits.

Percentile Rank	20MSFT Shuttles	Number
90-100	78-118	89
80-89	69-77	81
70-79	62-68	87
60-69	57-61	71
50-59	52-56	97
40-49	47-51	89
30-39	44-46	58
20-29	39-43	95
10-19	33-38	97
<10	17-32	86

Table 3. Percentile rankings for 20-m multistage fitness test (20MSFT) shuttles for female law enforcement recruits.

Percentile Rank	20MSFT Shuttles	Number
90-100	68-100	20
80-89	60-67	19
70-79	54-59	17
60-69	48-53	17
50-59	44-47	21
40-49	40-43	17
30-39	38-39	14
20-29	35-37	23
10-19	28-34	23
<10	8-27	19

Table 4. Percentile rankings for maximal aerobic capacity ($\dot{V}$O2max) estimated from the 20-m multistage fitness test for male and female law enforcement recruits combined.

Percentile Rank	$\dot{V}O_{2max}$ (ml/kg/min)	Males (n = 850)	Females (n = 190)
90-100	44.5-57.1	97	11
80-89	41.8-44.5	90	11
70-79	39.9-41.1	82	15
60-69	37.8-39.2	94	15
50-59	35.7-37.8	92	17
40-49	34.3-35.7	74	13
30-39	32.9-34.3	91	19
20-29	31.8-32.9	74	24
10-19	29.5-31.0	70	37
<10	<29.5	86	28

Table 5. Percentile rankings for maximal aerobic capacity ($\dot{V}$O2max) estimated from the 20-m multistage fitness test for male law enforcement recruits combined.

Percentile Rank	$\dot{V}O_{2max}$ (ml/kg/min)	Number
90-100	45.2-57.1	89
80-89	42.4-44.5	81
70-79	39.9-42.4	87
60-69	38.5-39.9	71
50-59	36.4-38.5	97
40-49	35.0-36.4	89
30-39	33.6-35.0	58
20-29	31.8-33.6	95
10-19	29.5-31.8	97
<10	<29.5	86

Table 6. Percentile rankings for maximal aerobic capacity ($\dot{V}O2max$) estimated from the 20-m multistage fitness test for female law enforcement recruits combined.

Percentile Rank	$\dot{V}O_{2max}$ (ml/kg/min)	Number
90-100	41.8-51.9	20
80-89	39.2-41.8	19
70-79	37.1-39.2	17
60-69	35.0-37.1	17
50-59	33.6-35.0	21
40-49	31.8-33.6	17
30-39	31.0-31.8	14
20-29	30.2-31.0	23
10-19	27.6-30.2	23
<10	<27.6	19

Discussion

The 20MSFT has featured as an entry-level fitness test for law enforcement candidates (Los Angeles County Sheriff's Department, 2019), and has incorporated into fitness testing of law enforcement recruits prior to academy training (Bloodgood et al., 2020; Collins et al., 2022; Lockie et al., 2019; Lockie et al., 2022a; Lockie et al., 2020a; Lockie et al., 2018; Lockie et al., 2021c). The law enforcement organization from which the current data was drawn do not have a hard minimum cut score for the 20MSFT that dictates recruitment decisions, but rather uses a score based upon performance in different tests (push-ups, sit-ups, 75-yard pursuit run, and 20MSFT) (Los Angeles County Sheriff's Department, 2019). The goal was to present normative percentile data for the 20MSFT in a large sample of law enforcement recruits. Additionally, normative data for estimated $\dot{V}O_{2max}$ derived from the number of completed shuttles in each percentile band was included to provide more practical information for training staff. As will be discussed, the data from the current descriptive study have useful implications for law enforcement academy training staff.

The first data presented was for all recruits combined in the 20MSFT. Some law enforcement organizations will not use sex-specific standards, so it is important to present data that represents all recruits. The recruits in the current sample were tested prior to their training academy, and it could be expected that their aerobic fitness would improve after training (Crawley et al., 2016; Lockie et al., 2020c). Nonetheless, staff could use the percentile ranks to identify where recruits currently reside, and how 20MSFT and aerobic performance changes over time. The application of percentile ranking data could be especially important for recruits with lower aerobic fitness such that specific training programs can be designed. For example, a recruit could be in the 30-40% rank after academy training, which on the surface could be considered less than ideal. However, if they started academy in the 10-19% rank, this could be evidence of an effective aerobic training program for this recruit.

To provide some context for the current data, when compared to the male 20-29 year old state patrol officer normative data, the 20MSFT mean from the current study was slightly below that from Dawes et al. (2017b) (53.70 ± 18.23 shuttles vs. 55.63 ± 20.90 shuttles). The equivalent percentile ranks in the current study tended to be a few shuttles lower than those documented by Dawes et al. (2017b). The female percentile rank data was very similar to that from Hernandez et al. (2021). Interestingly, specialist male police officers completed more than 70 shuttles in the 20MSFT (Maupin et al., 2018). Recruits from the current sample interested in pursuing specialist roles (e.g., Specialist Weapons and Tactics) would likely need to improve their aerobic fitness over the course of their careers.

Men tend to exhibit greater power and work efficiency in aerobic exercise tasks compared to women (Pate & Kriska, 1984), which can be related to differences in lean body mass which influence aerobic capacity (Janssen et al., 2000). When comparing the percentile ranks for the men versus the women, for each equivalent rank, the men tended to have a high number of completed shuttles compared to the women. Nonetheless, within the combined data, 69 female recruits (36% of the total sample of women) were in the top 50% of all recruits. This is indicative of other law enforcement normative data studies which has shown that there are women who outperform men in certain fitness tests (Lockie & Hernandez, 2020; Lockie & Moreno, 2020; Lockie et al., 2020b). Further, in an analysis of the 20MSFT in law enforcement recruits, Lockie et al. (2021a) found that although male recruits completed 15% more 20MSFT shuttles compared to female recruits, the difference only had a small effect of 0.44. Lockie et al. (2021a) suggested that the 20MSFT may have had less of a disparate impact on women and could be reflective of the preparation made by recruits prior to academy (i.e., completion of aerobic conditioning and high-intensity running prior academy by better performing recruits). These data do reinforce that women attempting a career in law enforcement likely need to target aerobic conditioning as men could have physiological advantages in aerobic activities. However, with effective training, women can develop their aerobic capacity to the extent where they are on par or better than their male colleagues.

As stated, law enforcement agencies generally do not use $\dot{V}O_{2max}$ as part of hiring standards (Lockie et al., 2021a). Although estimations will vary depending on the aerobic fitness test used to calculate $\dot{V}O_{2max}$ (e.g., 2.4-km run vs. the 20MSFT) (Lockie et al., 2021a; Lockie et al., 2021b), $\dot{V}O_{2max}$ data does provide some additional context for the recruits. When compared to general population norms (Riebe et al., 2018), the recruits from this organization exhibited relatively lesser aerobic fitness. For example, the 80-89% rank for the male recruits (42.4-44.5 ml.kg/min) would actually fall within a 'poor' classification for 20-29 year olds (Riebe et al., 2018). This was less extreme for the female recruits; those women in the 40-49% rank would be classified as poor according the 20-29 year age group standards. These results could be indicative of some of the challenges associated with law enforcement recruitment. Less people are applying to law enforcement positions (International Association of Chiefs of Police, 2019), and within the general population, there has been shifts towards greater obesity and physical inactivity (Centers for Disease Control and Prevention, 2020; Fryar et al., 2020). These actualities reinforce why it is important to produce law enforcement-specific recruit normative data, as it profiles what recruits look like at a certain point in time, and any shifts in recruit fitness can be documented. The downstream effect of this could be how fitness programs should be administered at training academies, especially if there is a greater volume of recruits reporting with lesser aerobic fitness. However, the results could have also been influenced by the learning effects associated with the 20MSFT (Aandstad et al., 2011; Lockie et al., 2021a). Recruits less familiar with the running demands of this test may not have performed as well, which led to a lower estimated $\dot{V}O_{2max}$. Nonetheless, given the external pacing of the 20MSFT (Léger et al., 1988), and typical law enforcement job tasks (Brewer et al., 2013), this test is still very applicable for law enforcement recruits.

There are study limitations that should be noted. Only data from one agency was analyzed in this study. Fitness test performance can vary across different agencies (Myers et al., 2019), so the current normative data may not be applicable to all departments. The current research only provided a descriptive analysis of recruit 20MSFT data; the effects of 20MSFT performance on academy survivability and future job performance cannot be determined. There was a large discrepancy of men and women in the sample (i.e., 850 men vs. 190 women), although this is typical of many law enforcement organizations. As stated, is plausible that learning effects influenced the 20MSFT performance in the recruits (Aandstad et al., 2011; Lockie et al., 2021a). Law enforcement training academies have historically featured high volumes of long, slow distance running (Lockie et al., 2021a; Lockie et al., 2020c). Recruits more experienced with this type of training may not have performed as well in the 20MSFT.

Conclusion

This study documented normative data for law enforcement recruits in the 20MSFT. With regards to between-sex comparisons, the data indicated the male recruits tended to perform better than female recruits, although 36% of the female recruits were in the top half of all recruits in completed 20MSFT shuttles. Nonetheless, female recruits will likely need specific aerobic conditioning prior to and during academy. The estimated $\dot{V}O_{2max}$ data suggested limitations in recruit aerobic fitness when compared to population norms. Familiarity with the 20MSFT and exposure to high-intensity running could have influenced these results. Nevertheless, the provision of normative 20MSFT data provide benchmarking of the aerobic fitness of recruits and could inform fitness training program design for academy staff.

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References

1. Aandstad, A., Holme, I., Berntsen, S., & Anderssen, S.A. (2011). Validity and reliability of the 20 meter shuttle run test in military personnel. *Military Medicine, 176*(5), 513-518. https://doi.org/10.7205/milmed-d-10-00373
2. Beck, A.Q., Clasey, J.L., Yates, J.W., Koebke, N.C., Palmer, T.G., & Abel, M.G. (2015). Relationship of physical fitness measures vs. occupational physical ability in campus law enforcement officers. *Journal of Strength and Conditioning Research, 29*(8), 2340-2350. https://doi.org/10.1519/jsc.0000000000000863
3. Bloodgood, A.M., Dawes, J.J., Orr, R.M., Stierli, M., Cesario, K.A., Moreno, M.R., Dulla, J.M., & Lockie, R.G. (2021). Effects of sex and age on physical testing performance for law enforcement agency candidates: Implications for academy training. *Journal of Strength and Conditioning Research, 35*(9), 2629–2635. https://doi.org/10.1519/jsc.0000000000003207
4. Bloodgood, A.M., Moreno, M.R., Cesario, K.A., McGuire, M.B., & Lockie, R.G. (2020). An investigation of seasonal variations in the fitness test performance of law enforcement recruits. *Facta Universitatis - series: Physical Education and Sport, 18*(2), 271-282. https://doi.org/10.22190/FUPES200713025B
5. Brewer, J., Buckle, P., & Castle, P. (2013). The use of work place physiological measurements to establish the minimum fitness standards required for entry into the United Kingdom Police Service. *Journal of Athletic Enhancement, 2*(4), doi:10.4172/2324-9080.1000121.
6. Centers for Disease Control and Prevention. (2020). Adult Physical Inactivity Prevalence Maps by Race/Ethnicity. Retrieved from https://www.cdc.gov/physicalactivity/data/inactivity-prevalence-maps/index.html
7. Collins, K.S., Christensen, B., Orr, R.M., Dulla, J.M., Dawes, J.J., & Lockie, R.G. (2022). Analysis of total and segmental body composition relative to fitness performance measures in law enforcement recruits. *International Journal of Exercise Science, 15*(4), 245-260. https://doi.org/10.70252/eder1570
8. Crawley, A.A., Sherman, R.A., Crawley, W.R., & Cosio-Lima, L.M. (2016). Physical fitness of police academy cadets: Baseline characteristics and changes during a 16-week academy. *Journal of Strength and Conditioning Research, 30*(5), 1416-1424. https://doi.org/10.1519/jsc.0000000000001229
9. Dawes, J.J., Lindsay, K., Bero, J., Elder, C., Kornhauser, C., & Holmes, R. (2017a). Physical fitness characteristics of high vs. low performers on an occupationally specific physical agility test for patrol officers. *Journal of Strength and Conditioning Research, 31*(10), 2808-2815. https://doi.org/10.1519/jsc.0000000000002082
10. Dawes, J.J., Lockie, R.G., Orr, R.M., Kornhauser, C., & Holmes, R.J. (2019). Initial fitness testing scores as a predictor of police academy graduation. *Journal of Australian Strength and Conditioning, 27*(4), 30-37.
11. Dawes, J.J., Orr, R.M., Flores, R.R., Lockie, R.G., Kornhauser, C., & Holmes, R. (2017b). A physical fitness profile of state highway patrol officers by gender and age. *Annals of Occupational and Environmental Medicine, 29*(16), 16. https://doi.org/10.1186/s40557-017-0173-0
12. Decker, A., Hilton, B., Dawes, J., Lockie, R., & Orr, R.M. (2022). Physiological demands of common occupational tasks among Australian police officers: A descriptive analysis. *Annals of Work Exposures and Health, 66*(7), 960–966. https://doi.org/10.1093/annweh/wxac012
13. Fryar, C.D., Carroll, M.D., & Afful, J. (2020). Prevalence of overweight, obesity, and severe obesity among adults aged 20 and over: United States, 1960–1962 through 2017–2018. *NCHS Health E-Stats.* Retrieved from https://www.cdc.gov/nchs/data/hestat/obesity-adult-17-18/obesity-adult.htm
14. Hernandez, E., Dawes, J.J., Dulla, J., Orr, R., & Lockie, R.G. (2021). Fitness percentile rank data for percentile rank data for female percentile rank data for female law enforcement recuits in the USA. *Facta Universitatis, Series: Physical Education and Sport, 19*(1), 109-118. https://doi.org/10.22190/FUPES210609014H
15. International Association of Chiefs of Police. (2019). The State of Recruitment: A Crisis for Law Enforcement. Retrieved from https://www.theiacp.org/sites/default/files/239416_IACP_RecruitmentBR_HR_0.pdf

16. Janssen, I., Heymsfield, S.B., Wang, Z., & Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *Journal of Applied Physiology, 89*(1), 81-88. https://doi.org/10.1152/jappl.2000.89.1.81
17. Léger, L.A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6*(2), 93-101. https://doi.org/10.1080/02640418808729800
18. Lockie, R., & Hernandez, E. (2020). The 75-yard pursuit run performed by law enforcement recruits–Percentile rankings and implications for training. *TSAC Report*, (57), 16-22.
19. Lockie, R., & Moreno, M. (2020). The 165-lb body drag–Benchmarking and training implications for law enforcement recruits. *TSAC Report,* (58), 6-11.
20. Lockie, R.G., Balfany, K., Bloodgood, A.M., Moreno, M.R., Cesario, K.A., Dulla, J.M., Dawes, J.J., & Orr, R.M. (2019). The influence of physical fitness on reasons for academy separation in law enforcement recruits. *International Journal of Environmental Research and Public Health, 16*(3), 372. https://doi.org/10.3390/ijerph16030372
21. Lockie, R.G., Dawes, J.J., Dulla, J.M., & Orr, R.M. (2022a). Extending research on law enforcement academy graduation and fitness: A research note on receiver operating characteristic curves. *Journal of Strength and Conditioning Research, 36*(7), 2018-2022. https://doi.org/10.1519/jsc.0000000000004268
22. Lockie, R.G., Dawes, J.J., Dulla, J.M., Orr, R.M., & Hernandez, E. (2020a). Physical fitness, sex considerations, and academy graduation for law enforcement recruits. *Journal of Strength and Conditioning Research, 34*(12), 3356-3363. https://doi.org/10.1519/jsc.0000000000003844
23. Lockie, R.G., Dawes, J.J., Moreno, M.R., Cesario, K.A., Balfany, K., Stierli, M., Dulla, J.M., & Orr, R.M. (2021a). Relationship between the 20-m multistage fitness test and 2.4-km run in law enforcement recruits. *Journal of Strength and Conditioning Research, 35*(10), 2756-2761. https://doi.org/10.1519/jsc.0000000000003217
24. Lockie, R.G., Dawes, J.J., Orr, R.M., & Dulla, J.M. (2020b). Recruit fitness standards from a large law enforcement agency: Between-class comparisons, percentile rankings, and implications for physical training. *Journal of Strength and Conditioning Research, 34*(4), 934-941. https://doi.org/10.1519/jsc.0000000000003534
25. Lockie, R.G., Dawes, J.J., Orr, R.M., Stierli, M., Dulla, J.M., & Orjalo, A.J. (2018). An analysis of the effects of sex and age on upper- and lower-body power for law enforcement agency recruits prior to academy training. *Journal of Strength and Conditioning Research, 32*(7), 1968-1974. https://doi.org/10.1519/jsc.0000000000002469
26. Lockie, R.G., Dulla, J.M., Orr, R.M., & Dawes, J.J. (2021b). The 20-m Multistage Fitness Test and 2.4-km Run: Applications to law enforcement fitness assessment. *Strength and Conditioning Journal, 43*(6), 68-75. https://doi.org/10.1519/SSC.0000000000000637
27. Lockie, R.G., Hernandez, J.A., Moreno, M.R., Dulla, J.M., Dawes, J.J., & Orr, R.M. (2020c). 2.4-km run and 20-m multistage fitness test relationships in law enforcement recruits after academy training. *Journal of Strength and Conditioning Research, 34*(4), 942-945. https://doi.org/10.1519/jsc.0000000000003489
28. Lockie, R.G., Moreno, M.R., Rodas, K.A., Dulla, J.M., Orr, R.M., & Dawes, J.J. (2021c). With great power comes great ability: Extending research on fitness characteristics that influence Work Sample Test Battery performance in law enforcement recruits. *Work, 68*(4), 1069-1080. https://doi.org/10.3233/wor-213437
29. Lockie, R.G., Orr, R.M., & Dawes, J.J. (2022b). Slowing the path of time: Age-related and normative fitness testing data for police officers from a health and wellness program. *Journal of Strength and Conditioning Research, 36*(3), 747-756. https://doi.org/10.1519/jsc.0000000000004197
30. Los Angeles County Sheriff's Department. (2019). Validated Physical Ability Test. Retrieved from https://lasd.org/careers/physicaltest/
31. Maupin, D., Robinson, J., Wills, T., Irving, S., Schram, B., & Orr, R. (2018). Profiling the metabolic fitness of a special operations police unit. *Journal of Occupational Health, 60*(5), 356-360. https://doi.org/10.1539/joh.2018-0029-oa
32. Myers, C.J., Orr, R.M., Goad, K.S., Schram, B.L., Lockie, R., Kornhauser, C., Holmes, R., & Dawes, J.J. (2019). Comparing levels of fitness of police officers between two United States law enforcement agencies. *Work, 63*(4), 615-622. https://doi.org/10.3233/wor-192954
33. Orr, R.M., Ford, K., & Stierli, M. (2016). Implementation of an ability-based training program in police force recruits. *Journal of Strength and Conditioning Research, 30*(10), 2781-2787. https://doi.org/10.1519/jsc.0000000000000898
34. Pate, R.R., & Kriska, A. (1984). Physiological basis of the sex difference in cardiorespiratory endurance. *Sports Medicine, 1*(2), 87-98. https://doi.org/10.2165/00007256-198401020-00001
35. Ramsbottom, R., Brewer, J., & Williams, C. (1988). A progressive shuttle run test to estimate maximal oxygen uptake. *British Journal of Sports Medicine, 22*(4), 141-144. https://doi.org/10.1136/bjsm.22.4.141
36. Riebe, D., Ehrman, J.K., Liguori, G., & Magal, M. (2018). *ACSM's Guidelines for Exercise Testing and Prescription* (D. Riebe, J. K. Ehrman, G. Liguori, & M. Magal Eds. 10th ed.). Philadelphia: Wolters Kluwer.
37. Schram, B., Hinton, B., Orr, R., Pope, R., & Norris, G. (2018). The perceived effects and comfort of various body armour systems on police officers while performing occupational tasks. *Annals of Occupational and Environmental Medicine, 30*(1), 15. https://doi.org/10.1186/s40557-018-0228-x
38. Shusko, M., Benedetti, L., Korre, M., Eshleman, E.J., Farioli, A., Christophi, C.A., & Kales, S.N. (2017). Recruit fitness as a predictor of police academy graduation. *Occupational Medicine, 67*(7), 555-561. https://doi.org/10.1093/occmed/kqx127

39. Štefan, L., Kasović, M., & Culej, M. (2022). Normative values for health-related physical fitness in first-year police officers. *Journal of Strength and Conditioning Research, 36*(9), 2530-2535. https://doi.org/10.1519/jsc.0000000000003853
40. World Medical Association. (1997). World Medical Association Declaration of Helsinki. Recommendations guiding physicians in biomedical research involving human subjects. *Journal of the American Medical Association, 277*(11), 925-926.

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Original article

Relationships between maximum Hand Grip Strength and Motor Abilities in primary School Children

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Abstract

The aim of this study was to determine the structure of qualitative relationships between a test for assessing strength status and a battery of tests for assessing motor abilities in primary school children from rural areas. The research was conducted on a sample of 141 students from primary schools, from the first to the eighth grade, in Kušiljevo and Vraćevšnica (central Serbia). The tested sample included 27 girls and 33 boys (from the first to the fourth grade) and 42 girls and 39 boys (from the fifth to the eighth grade). The following variables were used for this research: age, maximum muscle strength of the dominant (F_{max}D) and non-dominant hand grip (F_{max}N), as well as the total sum (F_{max}SUM), sit-and-reach test, standing long jump, sit-ups test, isometric chin-up, and 4x10m running test. Pearson correlation results showed that age correlates with the sit-and-reach (r=0.387, p=0.034), standing long jump (r=0.536, p=0.002), and 4×10 m running test (r=–0.561, p=0.001) in boys from the first to the fourth grade, and with the isometric chin-up test in girls (r=–0.402, p=0.042). Additionally, the absolute value of hand grip strength, regardless of whether it is the result of the dominant, non-dominant, or the sum of both hands, generally does not correlate with any test for assessing motor abilities in the tested sample, except for boys from the fifth to the eighth grade, where a statistically significant correlation was found with the standing long jump (FmaxD: r=0.479, p=0.002; FmaxN: r=0.454, p=0.004; FmaxSUM: r=0.471, p=0.002). When age was controlled through partial correlation analysis, significant relationships between hand grip strength and standing long jump remained only in boys from the fifth to the eighth grade (FmaxD: r=0.459, p=0.004; FmaxN: r=0.425, p=0.009; FmaxSUM: r=0.447, p=0.006). In addition, a significant negative correlation was found between FmaxN and sit-ups in boys from grades 1–4 (r=–0.401, p=0.031), and between FmaxD and 4×10 m running in boys from grades 5–8 (r=–0.331, p=0.046).Since the hand grip strength test is a standardized test for assessing overall body strength, it can be concluded that the standard battery of tests does not cover the entire range of physical, i.e., motor abilities. Based on the obtained results, it can be concluded that the hand grip strength test can be recommended as an addition to testing physical, i.e., motor abilities in primary schools, as a proven and simple screening test for assessing overall body strength.

Keywords: Battery of tests, physical fitness, isometric contraction

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Introduction

Generally speaking, motor tests are used to assess the motor and physical potential of subjects. In the system of primary and high-school education in the Republic of Serbia, physical and health education includes mandatory monitoring, evaluation, and recording of students' physical abilities, which should be conducted at the beginning and at the end of the school year (Radisavljević & Milanović, 2019). The Eurofit test battery for testing the motor abilities of primary school children has been used for many years to assess the level of development of basic physical abilities in school children in the Republic of Serbia (Adam et al., 1988). However, standard tests cannot always accurately assess students' potential, leading to ongoing debates about new, more appropriate tests. Given that today's school-age children increasingly fail to meet the basic need for movement, the question arises whether their motor abilities are declining and, consequently, whether this poses a health problem for them (Smajić et al., 2017). For this reason, there is a constant need to search for solutions that will yield better results.

A large number of factors can influence the manifestation of physical abilities when talking about primary school children (Suchomel et al., 2016). These include factors such as genetics, type of training, and absolute and relative muscle strength. Muscle strength is defined as the ability to generate force against an external object or resistance (Siff, 2000), and depending on the activity's requirements, muscle strength can be expressed relative to body mass (running, gymnastics), relative to an opponent's body (martial arts, sports games), or relative to an external object (weightlifting, discus throw, javelin throw, etc.).

There are various tests that assess and measure muscle strength, and one of the tests considered the gold standard is the hand grip strength test (Gallup et al., 2007; Norman et al., 2011; Dopsaj et al., 2019). The hand grip strength test can be applied in various areas of research (Kljajić et al., 2012), and there are studies that have used this test in different sports disciplines, both in recreational and elite athletes (Koley et al., 2010; Gerodimos, 2012; Iermakov et al., 2016). Additionally, this test can be used in rehabilitation to diagnose musculoskeletal injuries and monitor the effects of rehabilitation treatment (Bohannon, 2001; Beloosesky et al., 2010). There is scientific evidence that this test is very reliable in assessing physical abilities, as well as genetic, biological, and behavioral potentials of a person. There is also evidence that this test can reliably assess general strength in children, adolescents, and the elderly, relative to gender (Frederiksen et al., 2002; Wind et al., 2010; Atkinson et al., 2012; Marković et al., 2018; Dopsaj et al., 2019; Lim et al., 2020; Vaidya & Nariya, 2021). Since the hand grip strength test is used in the assessment of physical abilities, it can also show the correlation with other motor tests in the school battery (Matsudo et al., 2014).

The aim of this paper was to determine the relationships between the test for assessing overall strength and a battery of tests for assessing motor abilities in primary school children. The main hypothesis is that there will be correlations between the handgrip test and the long jump (Matsudo. 2014), but it will be interesting to see if there will be correlation with other tests.

Methods

Participants

The research was conducted on a sample of 141 primary school students from the first to the eighth grade. The sample consisted of students from rural areas of the Republic of Serbia, specifically from the "Desanka Maksimović" Primary School in Vraćevšnica, Gornji Milanovac municipality, and the "Vožd Karadjordje" Primary School in Kušiljevo, Svilajnac municipality. The tested sample included 27 girls (F_{1-4}), aged 8.76±1.06 years, weight 30.9±9.54 kg, height 135.12±10.65 cm, 33 boys (M_{1-4}), aged 8.54±1.09 years, weight 34.38±11.51 kg, height 135.15±10.14 cm (from the first to the fourth grade), and 42 girls (F_{5-8}), aged 12.33±2.08 years, weight 52.84±14.95 kg, height 158.83±9.29 cm, 39 boys (M_{5-8}), aged 12.83±1.31 years, weight 55.05±16.52 kg, height 161.51±11.47 cm (from the fifth to the eighth grade). Students were divided into groups according to educational age categories, i.e., lower and upper primary school grades (Newman et al., 1984; Haager-Ross et al., 2002; Radisavljević & Milanović, 2019). Before the start of testing, school management, as well as students and their parents, were informed about the protocol and purpose of the testing, and all gave verbal consent for its implementation.

Measurements and Procedures

Hand Grip Strength

The protocol of the isometric hand grip strength test was conducted with standardized equipment for upper grades, and adapted equipment for lower grades (Sports Medical Solutions, All4gym d.o.o., Serbia), according to standardized procedures (Trajkov et al., 2018; Zarić et al., 2018; Dopsaj et al., 2019). This test was chosen as a highly referential and simple to implement, even in young individuals, with a very high level of reliability (intraclass correlation coefficient from 0.938 to 0.977 for maximum force values (Marković et al., 2018)).

The testing protocol involved explaining the realization of the test to each child, and verbal instructions were given during the testing procedure. Each participant was familiarized with the equipment and performed a specific warm-up (2 randomized attempts at medium intensity). After familiarization and specific warm-up, participants were tested with two randomized attempts with each hand alternately, with a 2-minute break between individual attempts. Instructions for the test were: grip as hard and as fast as possible and hold for at least 2 seconds (Marković et al., 2020). If the participant did not adequately perform the test during the regular procedure according to the assessor's evaluation, the test was performed a third time. A specially designed software-hardware system for isometric measurement (Sports Medical Solutions Isometrics, ver. 3.4.0) was used for data collection. All results for the applied test were recorded in a specialized database, and the best attempts of measured maximum forces were selected for final analysis.

Motor Test Battery

The testing of motor abilities was conducted using the procedure of a standardized battery of tests used in the school system of the Republic of Serbia (Radisavljevic-Janic & Milanovic, 2019).

Variables

The basic morphological characteristics of the students were recorded, including body weight (BW) expressed in kg, body height (BH) expressed in cm, and body mass index (BMI) expressed in kg/m^2. For these purposes, a digital scale with a measurement accuracy of up to 0.1 kg was used (for measuring body weight), an anthropometer according to Martin (for measuring body height), while BMI was calculated according to the standardized procedure.

The following variables defined the space of the analyzed physical and motor abilities:

1. Age
2. Hand grip strength - maximum muscle strenght of the dominant (F_{maxD}) and non-dominant hand (F_{maxN}), as well as the total sum of both hands (F_{maxSUM}), expressed in newtons (N);
3. Sit-and-reach test (SR) - a test assessing the flexibility of the lower spine and hamstring muscles, expressed in centimeters (cm);
4. Standing long jump (SLJ) - a test assessing leg muscle strength, expressed in centimeters (cm);
5. Sit-up test (SU) - a test assessing endurance in abdominal muscle strength in 30 s;
6. Isometric chin-up test (ICU) - a test assessing endurance in arm flexor muscle strength, expressed in seconds;
7. 4 x 10 m sprint (4x10m) - a test assessing repeated sprint speed, expressed in seconds.

The research was conducted in accordance with current ethical standards and with the approval of the Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade, under the number 484–2. All measurements were carried out by master professors of physical education and sport.

Statistical analyses

Basic descriptive and statistical parameters (mean value and standard deviation) were calculated for all variables. The relationship between the criterion variable (hand grip strength) and other motor ability tests was determined using Pearson's correlation, with the significance level set at $p < 0.05$. In addition, a partial correlation analysis was performed, controlling for age, in order to examine the relationships between the variables independently of the effect of age. All analyses were performed using the IBM Statistical Package for the Social Sciences (SPSS) (version 24.0; IBM Corporation, New York, USA).

Results

Table 1 presents the basic descriptive indicators for age and morphological variables, while Table 2 shows the basic descriptive indicators for the tested variables. Tables 3 and 4 display the results of Pearson's correlation according to school age groups and gender, while tables 5 and 6 display the result of Pearson's correlation between the variables independently of the effect of age.

Table 1: Descriptive indicators of anthropometric variables for the sampled boys (M) and girls (F).

Variables	Age (years)	BW (kg)	BH (cm)	BMI (kg/m^2)
F_{1-4}	8.8 ± 1.1	30.9 ± 9.5	135.1 ± 10.6	16.6 ± 3.2
M_{1-4}	8.5 ± 1.1	34.4 ± 11.5	135.1 ± 10.1	18.4 ± 4
F_{5-8}	12.3 ± 2.1	52.8 ± 14.9	158.8 ± 9.3	20.6 ± 4.3
M_{5-8}	12.8 ± 1.3	55.1 ± 16.5	161.5 ± 11.5	20.8 ± 4.5

F_{1-4} - Female (1. to 4. Grade), M_{1-4} - Male (1. to 4. Grade), F_{5-8} - Female (5. to 8. Grade), M_{5-8} - Male (5. to 8. Grade), BW - Body weight, BH - Body height, BMI - Body mass index.

Table 2: Descriptive indicators of strength and motor variables for the sampled boys (M) and girls (F).

Variables	F_{max}D (N)	F_{max}N (N)	F_{max}SUM (N)	SR (cm)	SLJ (cm)	SU (n)	ICU (s)	4x10m (s)
F_{1-4}	107 ± 37	97 ± 32	204 ± 67	3 ± 6	110 ± 16	17 ± 4	11 ± 9	13.3 ± 0.8
M_{1-4}	133 ± 57	124 ± 51	288 ± 200	2 ± 5	116 ± 24	18 ± 4	19 ± 19.7	13 ± 1.4
F_{5-8}	212 ± 61	194 ± 55	406 ± 113	4 ± 7	136 ± 28	19 ± 4	14.8 ± 14.8	12.3 ± 1
M_{5-8}	267 ± 104	249 ± 94	516 ± 197	1 ± 6	149 ± 35	21 ± 6	23.3 ± 22.9	11.6 ± 1.1

F_{1-4} - Female (1. to 4. Grade), M_{1-4} - Male (1. to 4. Grade), F_{5-8} - Female (5. to 8. Grade), M_{5-8} - Male (5. to 8. Grade), F_{max}D - maximum muscle strenght of the dominant hand, F_{max}N - maximum muscle strenght of the non-dominant hand, F_{max}SUM - maximum muscle strength, total sum of both hands, SR - Sit-and-reach test, SLJ - Standing long jump, SU - Sit-up test, ICU - Isometric chin-up test, 4x10m - 4 x 10 m sprint.

Table 3: Correlation between hand grip strength and battery of motor ability tests for students in grades 1-4

Variables		SR (cm)		SLJ (cm)		SU (n)		ICU (s)		4x10m (s)	
		M	F	M	F	M	F	M	F	M	F
Age	*r*	**.387**	-.226	**.536**	-.036	.163	-.222	.168	**-.402**	**-.561**	-.379
	p	.034	.268	.002	.863	.390	.276	.375	.042	.001	.056
F_{max}D	*r*	.286	-.369	.266	.059	-.178	-.207	-.127	-.250	-.233	-.226
	p	.125	.063	.156	.776	.347	.310	.504	.218	.215	.266
F_{max}N	*r*	.250	-.297	.298	-.026	-.195	-.122	-.074	-.167	-.287	-.251
	p	.182	.140	.110	.899	.302	.553	.696	.414	.124	.215
F_{max}Sum	*r*	.054	-.343	.208	.020	-.194	-.171	-.114	-.216	-.070	-.243
	p	.778	.086	.269	.925	.305	.403	.548	.289	.713	.232

M - male, F - Female, F_{max}D - maximum muscle strenght of the dominant hand, F_{max}N - maximum muscle strenght of the non-dominant hand, F_{max}SUM - maximum muscle strength, total sum of both hands, SR - Sit-and-reach test, SLJ - Standing long jump, SU - Sit-up test, ICU - Isometric chin-up test, 4x10m - 4 x 10 m sprint.

Table 4: Correlation between hand grip strength and battery of motor ability tests for boys (M) and girls (F) in grades 5-8.

Variables		SR (cm)		SLJ (cm)		SU (n)		ICU (s)		4x10m (s)	
		M	F	M	F	M	F	M	F	M	F
Age	*r*	-.059	-.049	.186	.127	.138	.011	.106	-.049	-.048	-.024
	p	.721	.760	.257	.423	.401	.944	.521	.758	.521	.882
F_{max}D	*r*	.062	.121	**.479**	.180	.296	.007	.141	-.121	-.289	-.022
	p	.707	.447	.002	.253	.068	.965	.394	.445	.074	.893
F_{max}N	*r*	.088	.002	**.454**	.063	.285	-.066	.119	-.179	-.264	.000
	p	.593	.991	.004	.691	.079	.680	.470	.256	.104	.998
F_{max}Sum	*r*	.075	.066	**.471**	.128	.293	-.029	.131	-.152	-.280	-.012
	p	.649	.679	.002	.420	.070	.859	.425	.335	.085	.941

M - male, F - Female, F_{max}D - maximum muscle strenght of the dominant hand, F_{max}N - maximum muscle strenght of the non-dominant hand, F_{max}SUM - maximum muscle strength, total sum of both hands, SR - Sit-and-reach test, SLJ - Standing long jump, SU - Sit-up test, ICU - Isometric chin-up test, 4x10m - 4 x 10 m sprint.

Table 5: Correlation between hand grip strength and battery of motor ability tests for students in grades 1-4 (Age control)

Variables		SR (cm)		SLJ (cm)		SU (n)		ICU (s)		4x10m (s)	
		M	F	M	F	M	F	M	F	M	F
F_{max}D	*r*	.053	-.301	-.120	.095	**-.373**	-.103	-.310	-.037	-.200	.018
	p	.783	.144	.535	.652	.046	.625	.101	.859	.299	.933
F_{max}N	*r*	-.002	-.216	-.079	-.009	**-.401**	-.008	-.245	.049	-.124	-.070
	p	.991	.299	.685	.965	.031	.969	.200	.815	.522	.738
F_{max}Sum	*r*	-.113	-.269	.002	.047	-.282	-.060	-.197	-.004	.192	-.025
	p	.560	.194	.993	.823	.138	.776	.306	.986	.317	.907

M - male, F - Female, F_{max}D - maximum muscle strenght of the dominant hand, F_{max}N - maximum muscle strenght of the non-dominant hand, F_{max}SUM - maximum muscle strength, total sum of both hands, SR - Sit-and-reach test, SLJ - Standing long jump, SU - Sit-up test, ICU - Isometric chin-up test, 4x10m - 4 x 10 m sprint.

Table 6: Correlation between hand grip strength and battery of motor ability tests for students in grades 5-8 (Age control)

Variables		SR (cm)		SLJ (cm)		SU (n)		ICU (s)		4x10m (s)	
		M	F	M	F	M	F	M	F	M	F
F_{max}D	*r*	.107	.199	**.459**	.124	.266	.000	.108	-.113	**-.331**	-.013
	p	.527	.225	.004	.452	.111	.1	.524	.937	.046	.937
F_{max}N	*r*	.137	.038	**.425**	-.012	.252	-.101	.081	-.197	-.294	.021
	p	.420	.818	.009	.941	.132	.541	.632	.901	.078	.901
F_{max}Sum	*r*	.123	.128	**.447**	.062	.262	-.049	.096	-.158	-.316	.003
	p	.470	.436	.006	.762	.117	.767	.570	.336	.056	.987

M - male, F - Female, F_{max}D - maximum muscle strenght of the dominant hand, F_{max}N - maximum muscle strenght of the non-dominant hand, F_{max}SUM - maximum muscle strength, total sum of both hands, SR - Sit-and-reach test, SLJ - Standing long jump, SU - Sit-up test, ICU - Isometric chin-up test, 4x10m - 4 x 10 m sprint.

Discussion

The aim of this paper was to determine the relationships between the test for assessing overall strength and a battery of tests for assessing motor abilities in primary school children. Based on the results, it can be concluded that significant correlations were found between the criterion space, i.e., measured values of age the sit-and-reach (r=0.387, p=0.034), standing long jump (r=0.536, p=0.002), and 4×10 m running test (r=–0.561, p=0.001) in boys from the first to the fourth grade, and with the isometric chin-up test in girls (r=–0.402, p=0.042). Also, significant correlations were found between hand grip strength in both dominant and non-dominant hands, and long jump, only in boys from fifth to eighth grade (FmaxD: r=0.479, p=0.002; FmaxN: r=0.454, p=0.004; FmaxSUM: r=0.471, p=0.002). After controlling for the effect of age, these correlations remained statistically significant (FmaxD: r=0.459, p=0.004; FmaxN: r=0.425, p=0.009; FmaxSUM: r=0.447, p=0.006). Additionally, significant partial correlations were found in boys from first to fourth grade between non-dominant hand grip strength and sit-ups (FmaxN: r=–0.401, p=0.031), and in boys from fifth to eighth grade between dominant hand grip strength and 4×10 m running (FmaxD: r=–0.331, p=0.046). No statistically significant correlations were found among girls between the measured criterion variable, i.e., hand grip strength results and the results of motor tests, so it can be told that the main hypothesis is just partly proven.

One possible explanation why statistically significant relationships were not found between maximum hand grip strength and other tests could be due to the nature of the muscle contraction type during the execution of these tests as muscle contraction in dynamic and static conditions are two different phenomena (Masuda et al. 1999). Hand grip strength was measured under isometric conditions, while other tests (i.e., standing long jump, sit-up test, 4x10m) were conducted dynamically, using the subject's own body weight as resistance. Considering that there are essentially two different types of loads covered by these tests such as maximal power output (standing long jump, 4x10m), and local muscular endurance (sit-ups, isometric chin-up) it could be concluded that the maximum hand grip strength test does not explain the variation in school test battery. Another reason for not achieving statistically significant correlations, lie in the varying biological ages of students, as it is well known that biological age can significantly differ from chronological age (Rogol et al., 2000). As we can see from the results in partial correlation, there are signifacant results in more variables, sit – ups, and 4x10m sprint.

The results of this study show that the tested physical abilities are within the range of previous research (Momčilović et al. 2019), where authors reported that the average standing long jump distance for 10-year-old boys was 124.5 ± 22.2 cm. In this study, boys of the same age jumped on average 131 ± 17.5 cm, indicating less variability on average, suggesting a higher sample homogeneity. Regarding girls of the same age, the same authors found that they averaged 116 ± 19.6 cm, while in this study, girls averaged 110 ± 18.1 cm in standing long jump distance.

When we talk about maximum hand grip strength, older school-age boys from England have an average maximum hand grip strength of 300 ± 71 N, while boys of the same age in this study showed slightly lower results at 267 ± 105 N. Similarly, girls in this study also showed weaker results compared to their peers from England, with a maximum hand grip strength of 212 ± 61 N compared to 240 ± 50 N for English girls (Cohen et al., 2010). On the other hand, our 10-year-old children showed greater strength compared to their peers from Italy (Montalcini et al., 2016). Boys from Italy had a maximum hand grip strength of 152 ± 30 N, while boys from this study had 186 ± 61 N. For girls, these values were 138 ± 40 N for Italian girls vs. 143 ± 41 N in gilrs f this study.

Regarding the obtained correlations in this research, the same results were found by Matsudo et al. (2014). They found statistically significant correlations between maximum hand grip strength and the standing long jump for boys (p=0.004) and girls (p=0.002). They had a sample of 233 children from 10 to 17 years of age. Their boys had maximum muscle strength in total sum of both hands 452 ± 25.7 N, compared to 402 ± 58.2 N for boys in our research. The results for SLJ were similar. They jumped in average 134.6 ± 7.9 cm, compared to 132.5 ± 29.5 cm. When we talk about girls, results were the same. For HG, they measured 430.5 ± 43.6 N compared to 305 ± 40 N for girls in our research. For SLJ, hey jumped in average 122.1 ± 7.6 cm, compared to 123 ± 22 cm. The bigger values in their results in their research can be explained by older children in their sample. But considering that the same method was used when measuring HG strength, we can relate our correlations to their.

The results of this study indicate that there are no statistically significant correlations between the used criterion and motor tests among boys and girls from grades 1 to 4, nor among girls from grades 5 to 8. This can may be explained by previous studies Matsudo et al. 2014) having participants who were mostly older than 12 years old, whereas studies focusing on hand grip strength in younger school-aged children are still limited in number to draw definitive conclusions.

Limitations

Although maximum muscle strength has not been found to be a general predictor for other tests in the motor ability battery, other contractile characteristics such as rate of force development (RFD) and time to reach maximum force are not tested in this research, but may potentially be better predictors in assessing these tests. Therefore, there is significant scope for further research in this regard. Additionally, the values presented in this study are absolute, and it would be interesting to normalize them relative to the weight of the participants. Furthermore, the results presented in this study are from school-age children in rural areas, so it would be intriguing to explore the quality, relationships, and differences between measured tests among children in rural versus urban environments.

Conclusion

Based on the results obtained, we can conclude that a statistically significant correlation exists only among boys in grades 5 to 8, specifically with the standing long jump test. This indicates that the standardized battery of tests does not cover the entire spectrum of motor abilities in terms of load type. Given that grip strength testing is relatively simple and practical to conduct, there is a basis for recommending its inclusion in expanding the elementary school test battery. In the future, it will be necessary to explore other methods such as measuring other contractile characteristics (RFD) and normalizing the data, which leaves space for future research.

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Conflict of interest: All authors declare that they have no conflict of interest relevant to the content of this article.

References

Aung, N., Bovonsunthonchai, S., Hiengkaew, V., Tretriluxana, J., Rojasavastera, R., & Pheung-Phrarattanatrai, A. (2020). Concurrent validity and intratester reliability of the video-based system for measuring gait poststroke. *Physiotherapy Research Research International, 25(1), e1803. DOI: 10.1002/pri.1803*

Adam, C., Klissouras, V., Ravazzolo, M., Renson, R., Tuxworth, W., Kemper, H. C. G., van Mechelen, W., Hlobil, H., Beunen, G., Levarlet-Joye, H. (1987). EUROFIT-European test of physical fitness.

Atkinson, J., Pipitone, R. N., Sorokowska, A., Sorokowski, P., Mberira, M., Bartels, A., & Gallup Jr, G. G. (2012). Voice and handgrip strength predict reproductive success in a group of indigenous African females. *PLoS ONE*, 7, e41811. DOI: 10.1371/journal.pone.0041811

Beloosesky, Y., Weiss, A., Manasian, M., & Salai, M. (2010). Handgrip strength of the elderly after hip fracture repair correlates with functional outcome. *Disability and rehabilitation*, *32*(5), 367-373. DOI: 10.3109/09638280903168499

Bohannon, R. W. (2001). Dynamometer measurements of hand-grip strength predict multiple outcomes. *Perceptual and motor skills*, *93*(2), 323-328. DOI: 10.2466/pms.2001.93.2.323

Cohen, D. D., Voss, C., Taylor, M. J. D., Stasinopoulos, D. M., Delextrat, A., & Sandercock, G. R. H. (2010). Handgrip strength in English schoolchildren. *Acta Paediatrica*, *99*(7), 1065-1072. DOI: 10.1111/j.1651-2227.2010.01723.x

Dopsaj, M., Nenasheva, A. V., Tretiakova, T. N., Surina-Marysheva, E. F., Marković, S., & Dopsaj, V. (2019). Handgrip muscle force characteristics with general reference values at Chelyabinsk and Belgrade students. *Человек. Спорт. Медицина*, *19*(2), 27-36. DOI: 10.14529/hsm190204

Dopsaj, M., Andraos, Z., Richa, C., Mitri, A., Makdissi, E., Zoghbi, A., ... & Fayyad, F. (2022). Maximal and explosive strength normative data for handgrip test according to gender: international standardization approach. *Human Movement*, *23*(4), 77-87. DOI: 10.5114/hm.2022.108314

Frederiksen, H., Gaist, D., Christian Petersen, H., Hjelmborg, J., McGue, M., Vaupel, J. W., & Christensen, K. (2002). Hand grip strength: A phenotype suitable for identifying genetic variants affecting mid-and late-life physical functioning. *Genetic Epidemiology: The Official Publication of the International Genetic Epidemiology Society*, *23*(2), 110-122. DOI: 10.1002/gepi.1127

Gallup, A. C., White, D. D., & Gallup Jr, G. G. (2007). Handgrip strength predicts sexual behavior, body morphology, and aggression in male college students. *Evolution and human behavior*, *28*(6), 423-429. DOI: 10.1016/j.evolhumbehav.2007.07.001

Gerodimos, V. (2012). Reliability of handgrip strength test in basketball players. *Journal of human kinetics*, *31*(2012), 25-36. DOI: 10.2478/v10078-012-0003-y

Häger-Ross, C., & Rösblad, B. (2002). Norms for grip strength in children aged 4–16 years. *Acta Paediatrica*, *91*(6), 617-625. DOI: 10.1080/080352502760068990

Iermakov, S., Podrigalo, L. V., and Jagiełło, W. (2016). Hand-grip strength as an indicator for predicting the success in martial arts athletes. *Arch. Budo* 12, 179–186.

Kljajić, D., Eminović, F., Trgovčević, S., Dimitrijević, R., & Dopsaj, M. (2012). Funkcionalni odnos nedominantne i dominantne ruke pri motoričkom zadatku–izdržljivost u sili stiska šake. *Specijalna edukacija i rehabilitacija*, *11*(1), 67-85. DOI: 10.5937/specedreh1201067K

Koley, S., & Singh, A. P. (2010). Effect of hand dominance in grip strength in collegiate population of Amritsar, Punjab, India. *The Anthropologist*, *12*(1), 13-16. DOI: 10.1080/09720073.2010.11891125

Lim, J. P., Yew, S., Tay, L., Chew, J., Yeo, A., Ismail, N. H. (2020). Grip strength criterion matters: impact of average versus maximum handgrip strength on sarcopenia prevalence and predictive validity for low physical performance. *The journal of nutrition, health & aging*, *24*, 1031-1035. DOI: 10.1007/s12603-020-1461-x

Marković, M. R., Dopsaj, M., Koropanovski, N., Ćopić, N., & Stanković, M. (2018). Reliability of measuring various contractile functions of finger flexors of men of various ages. *Fizička kultura*, *72*(1), 37-48. DOI 10.5937/fizkul1801037M

Marković, S., Dopsaj, M., & Veljković, V. (2020). Reliability of Sports Medical Solutions handgrip and Jamar handgrip dynamometer. *Measurement Science Review*, *20*(2), 59-64. DOI: 10.2478/msr-2020-0008

Matsudo, V. K. R., Matsudo, S. M., Rezende, L. F. M. D., & Raso, V. (2015). Handgrip strength as a predictor of physical fitness in children and adolescents. *Revista Brasileira de Cineantropometria & Desempenho Humano*, *17*, 01-10. DOI: 10.5007/1980-0037.2015v17n1p1

Masuda, K., Masuda, T., Sadoyama, T., Inaki, M., & Katsuta, S. (1999). Changes in surface EMG parameters during static and dynamic fatiguing contractions. *Journal of electromyography and kinesiology*, *9*(1), 39-46. DOI: 10.1016/S1050-6411(98)00021-2

Montalcini, T., Ferro, Y., Salvati, M. A., Romeo, S., Miniero, R., & Pujia, A. (2016). Gender difference in handgrip strength of Italian children aged 9 to 10 years. *Italian Journal of Pediatrics*, *42*, 1-6. DOI: 10.1186/s13052-016-0226-y

Newman, D. G., Pearn, J., Barnes, A., Young, C. M., Kehoe, M., & Newman, J. (1984). Norms for hand grip strength. *Archives of disease in childhood*, *59*(5), 453-459. DOI: 10.1136/adc.59.5.453

Norman, K., Stobäus, N., Gonzalez, M. C., Schulzke, J. D., & Pirlich, M. (2011). Hand grip strength: outcome predictor and marker of nutritional status. *Clinical nutrition*, *30*(2), 135-142. DOI: 10.1016/j.clnu.2010.09.010

Orlić, D., Cvetković, M., Fratrić, F., Badža, V., & Stupar, D. (2012). RAZLIKE U MOTORIČKIM SPOSOBNOSTIMA DEČAKA I DEVOJČICA MLAĐEG ŠKOLSKOG UZRASTA. *Sport Mont*, *10*. UDK: 796.012.1:373.3-055.15-055.25

Radisavljević, J. S., & Milanović, I. (2019). Physical education in the Republic of Serbia. *Fizička kultura*, *73*(1), 61-71. DOI: 10.5937/fizkul1901061R

Rogol, A. D., Clark, P. A., & Roemmich, J. N. (2000). Growth and pubertal development in children and adolescents: effects of diet and physical activity. *The American journal of clinical nutrition*, *72*(2), 521S-528S. DOI: 10.1093/ajcn/72.2.521S

Siff, M. C. (2000). Biomechanical foundations of strength and power training. *Biomechanics in sport: performance enhancement and injury prevention*, 103-139. DOI: 10.1002/9780470693797

Smajić, M. S., Marinković, A., Đorđić, V., Čokorilo, N., Gušić, M., & Štajer, V. (2017). Razlike u morfološkim karakteristikama i motoričkim sposobnostima devojčica i dečaka mlađeg školskog uzrasta. *Glasnik Antropološkog društva Srbije*, *52*(1-2). DOI: 10.5937/gads52-14389

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports medicine*, *46*, 1419-1449. DOI: 10.1007/s40279-016-0486-0

Trajkov, M., Cuk, I., Eminovic, F., Kljajic, D., & Dopsaj, M. (2018). Relationship between hand grip strength and endurance and postural stability in active and sedentary older women. *Journal of Electromyography and Kinesiology*, *43*, 62-67. DOI: 10.1016/j.jelekin.2018.09.006

Vaidya, S., & Nariya, D. M. (2021). Handgrip Strength as a Predictor of Muscular Strength and Endurance: A Cross-sectional Study. *Journal of Clinical & Diagnostic Research*, *15*(1) pp. 1-4, 10.7860/jcdr/2021/45573.14437. DOI: 10.7860/JCDR/2021/45573.14437

Wind, A. E., Takken, T., Helders, P. J., & Engelbert, R. H. (2010). Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? *European journal of pediatrics*, *169*, 281-287. DOI: 10.1007/s00431-009-1010-4

Zarić, I., Dopsaj, M., & Marković, M. (2018). Match performance in young female basketball players: Relationship with laboratory and field tests. *International Journal of Performance Analysis in Sport*, *18*(1), 90-103. DOI: 10.1080/24748668.2018.1452109

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Original article

Lower-Extremity Biomechanical Characteristics of College American Football Starters: Examining the Squat, Lunge, and Vertical Jump

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Abstract

American football is a dynamic sport characterized by intense sporting actions such as blocking, tackling, jumping, and sprinting. Furthermore, these sporting actions often require athletes to repeatedly achieve extreme ranges of motion such as deep flexion and hyperextension. The aim of the present study was to assess select lower-extremity biomechanical characteristics and examine position-specific differences in those characteristics within a cohort of collegiate American football athletes. Sixteen NCAA Division-II American football starters volunteered to participate in this study. Biomechanical characteristics were assessed with a three-dimensional markerless motion capture system which examined each athlete's ability to perform bilateral and unilateral squats, lunges, and the countermovement vertical jump. Significant differences were observed in unilateral squat depth left (p=0.002), vertical jump height (p=0.033), net impulse (p=0.008), max ground reaction force (GRF) (p=0.034), right knee valgus at max loading (p=0.031), concentric left knee peak torque percent body weight (p=0.013), absorption right knee flexion (p=0.031), absorption left knee flexion (p=0.014), GRF absorption left (p=0.005), and GRF absorption right (p=0.015) between position groups. However, no significant differences were observed for measures of bilateral squat weight distribution, knee dynamic valgus, lunge characteristics, or peak power during jumping tasks. These findings, particularly unilateral squat and lunge characteristics, provide additional insight into the similarities and differences in foundational movement patterns across position groups within a cohort of NCAA Division-II American football starters. Sports performance professionals can utilize this information to develop and integrate resistance training programs that maintain and improve general as well as specific foundational movement patterns that may translate to athletic performance.

Keywords: flexibility, stability, movement screen, biomotor ability, athletic performance

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Introduction

American football is an extremely demanding sport involving violent collisions during plays for most positions during games and practice (Kerr et al., 2015; Rechel et al., 2008). During these collisions, an athlete's entire body can be exposed to ranges of motion that they are not typically exposed to, leading to both skeletomuscular and soft tissue injuries. Ensuring athletes can achieve and maintain optimal ranges of motion through compound, multi-joint exercises can be beneficial in aiding athletes in decreasing both contact and non-contact injuries (Clark et al., 2022; Edwards et al., 2019; Kiesel et al., 2011). In addition to performing movement and mobility routines, assessing an athlete's biomechanical characteristics (i.e., movement capacity) can be beneficial for quantifying and comparing kinetic variables throughout various planes of motion while also identifying potential areas of improvement. Collisions of great magnitude have led to high injury rates within the sport, where in college, the injury rate reached 39.9 per 1000 athletic exposure in competition (Kerr et al., 2015). These injury rates are ranked highest in all sports offered in high school and college (Kerr et al., 2015; Rechel et al., 2008). These high injury rates create challenges for teams with player availability at the high school and collegiate levels. Biomechanical analysis has become a common tool among sports performance professionals to assess athletes' mobility, flexibility, and stability, which plays a crucial role in the physical development of athletes as well as mitigating injury risk (Wiese et al., 2014). As part of a multidisciplinary team, sports performance professionals can collaborate to assess and address biomechanical characteristics in order to improve preparedness and optimize athletic performance while mitigating injury risks.

Coaches have used physical movement quality to assess athletes' technical skills, whereas, in a recent systematic review to establish optimal training session design, researchers investigated the relationship between physical movement quality and sport-specific technical skills in female athletes (Clark et al., 2022). From the articles in the systematic review, sport-specific technical skills in handball, volleyball, soccer, basketball, netball, lacrosse, and softball each showed significant correlations with several fundamental movement patterns (Farley et al., 2020). These findings further highlight the importance of biomechanical proficiency, motor control, and multi-joint coordination of the limbs as it relates to athletic performance, as well as its translatability across disciplines. The most common field-based movement capacity screening tools include the Functional Movement Screen (FMS) and the Y-Balance Test (YBT) (Cook et al., 2006a; Cook et al., 2006b). The FMS utilizes seven fundamental movement patterns to identify potential movement deficiencies and asymmetries (i.e., deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability), whereas the YBT uses three lower-body reaching tasks (e.g., anterior, posterolateral, and posteromedial) to identify possible deviations in dynamic balance (Clark et al., 2022; Wiese et al., 2014; Smith et al., 2015). Recent investigations using the FMS and YBT have reported correlations between poor movement capacity and increased risk for injury or re-injury, but it remains unknown how well these measures relate to sports performance ability (Smith et al., 2015; Chimera & Warren, 2015; Kiesel et al., 2011; Dorrel et al., 2018; Garrison et al., 2015; Kiesel et al., 2014; Lisman et al., 2018). Beyond sport, FMS can assess movement quality, particularly in tactical populations such as firefighters and law enforcement officers (Thompson et al., 2024; Farrokhi et al., 2008). As technology advances and becomes more available to sporting organizations and sport scientists, the careful integration of such can be utilized to understand the nuances of biomechanical characteristics. This detailed information can further guide athlete preparation, rehabilitation, and return-to-sport across disciplines and sport.

The use of markerless motion capture systems (MCS) in clinical settings has become commonplace, and it has been suggested that they can be utilized to assess flexibility, balance, and movement quality during dynamic motions while also assessing athletes' risk for injury or potential reinjury (Cabarkapa et al., 2022a; Hando et al., 2021). Several systems have developed valid and reliable analyzing software to perform such tasks (Martinez et al., 2018; Philipp et al., 2023; Sandau et al., 2014). Markerless MCS are becoming more popular than marker-based MCS primarily due to the task of placing markers on athletes being timeconsuming and less practical due to constant or dynamic movement. Furthermore, markerless MCS has been shown to provide reliable kinematic characteristics of foundational movement patterns such as the squat, lunge, and vertical jump, as well as abduction and adduction of the upper-extremities (Philipp et al., 2023; Cabarkapa et al., 2022b). A recent study focusing on hip movements during baseball bat swings detected the range of motion of the lower body accurately (Sonnenfeld et al., 2021). A direct comparison between markerless MCS and marker-based MCS on baseball pitching kinematics observed similar results but suggested further testing of the markerless MCS (Fleisig et al., 2022). In basketball, research has been focused on shooting analyses as well dunking kinetics characters (Cabarkapa et al., 2023; Cabarkapa et al., 2020). Markerless MCS, more specifically, has developed movement screening programs that provide functions similar to those of both the FMS and the YBT and have been validated by several recent studies (Cabarkapa et al., 2022a; Cabarkapa et al., 2022b; Mundermann et al., 2006). Researchers found the intraclass correlation coefficient (ICC) to be above 0.8 for every component of the functional screen scores which prompted the authors to suggest using markerless MCS to assess various types of biomechanical motion of the human body (Cabarkapa et al., 2022a). Another study showed that markerless MCS could potentially analyze basic human movement with excellent reliability and 92% agreement of the analyzed movements (Philipp et al., 2023). When comparing it to the FMS directly, the markerless MCS's algorithm seemed to agree with the FMS score and could determine potential injury risk (Bird et al., 2022; Daggett et al., 2022).

Sports performance professionals commonly use motion analysis measures to assess flexibility, balance, and movement quality to identify areas of improvement from a physical development standpoint and the potential for injury or reinjury. However, current literature has primarily investigated highly competitive levels of sport (i.e., Professional and NCAA Division-I), while limited research has investigated other levels of competition (i.e., NCAA Division-II, NCAA Division-III), especially with regards to movement capacity assessed via markerless MCS within American football. In addition, current literature has primarily focused on using biomechanical analysis to identify athlete injury risk. Still, few focused on flexibility, balance, and movement quality in relation to athletes' level of play for their respective team. Therefore, the primary purpose of the present study was to profile biomechanical characteristics of NCAA Division-II American football starters. The secondary purpose was to examine similarities and differences in biomechanical characteristics between position groups. Findings from this investigation may be utilized as further evidence to support the rationale for programming general and position-specific exercises that are designed to enhance flexibility and stability at or around critical joints, as well as support the transfer of resistance training qualities to sports skills.

Methods

Experimental Design

This study used a cross-sectional design to examine the biomechanical characteristics of NCAA Division-II American football starters. Prior to the beginning of the season, subjects participated in a voluntary performance testing battery to assess baseline biomechanical characteristics of the lower-extremity. The markerless MCS assessment was included based on the value it could provide for sports performance professionals responsible for better understanding, as well as enhancing the preparation and performance of the American football athlete. Specific measures of biomechanical characteristics were selected in alignment with prior reported evidence and with the recommendation of an academically trained biomechanist (Cabarkapa et al., 2022a; Hando et al., 2021; Philipp et al., 2023; Cabarkapa et al., 2022b). The successful development of the included research methods, organization and implementation of data collection, as well as data analysis, interpretation, and the writing of this manuscript are products of interdisciplinary collaboration that are critical for sport science initiatives with the purpose of supporting the health and safety of American football athletes.

Subjects

Sixteen resistance trained NCAA Division-II American football starters (age: 22.25 ± 1.1 years; height: 183.75 ± 7.8 cm; body mass: 97.22 ± 20.39 kgs) participated in the study. All subjects were free of musculoskeletal injuries, and prior to data collection, they regularly participated in resistance training sessions administered by their respective S&C coaches. Training sessions occurred three days per week and included exercises focused on developing football-specific muscular strength and power, explosiveness, sprinting speed, and agility. The athletes typically performed barbell squat, press, and deadlift variations to develop muscular strength. Meanwhile, they also performed Olympic weightlifting variations, plyometrics, and ballistic exercises to develop muscular power and explosiveness. The subjects who did not meet the criteria of being free of musculoskeletal injuries, regularly participating in training sessions, and being a starter were excluded from this study. According to McKay et al., this cohort of athletes would be classified as "Tier 3: Highly Trained/National", which only includes approximately 0.014% of the global population (McKay et al., 2022). The testing procedures performed in this study were approved by the University of Nebraska-Kearney's Institutional Review Board (#031022-1), and participants provided consent.

Procedures

This assessment was developed through collaboration between coaching, strength and conditioning, sports medicine, and academically trained sport scientists to provide a profile of lower-extremity biomechanical characteristics of offensive and defensive starters. Data were collected prior to the start of the football season and athletes were separated into offensive and defensive groups. Those within the offensive group were assessed on the first day (08:15 hr), while the defensive group was assessed on the second day (09:00 hr). The analysis procedures encompassed the data only from athletes who completed all relevant tests. Upon arrival at the athletic facility, subjects were familiarized with the testing procedures before having their body composition assessed. First, height was measured with a standard stadiometer (Cardinal; Detecto Scale Co, Webb City, MO, USA) and then body composition characteristics were measured utilizing a bioelectrical impedance analyzer (InBody 270, Cerritos, CA, USA). Lower-extremity biomechanical characteristics were assessed via a markerless three-dimensional motion capture movement screen (DARI Motion, Overland Park, KS, USA) that for the aim of this study assessed the functionality of the lower extremities during a bilateral squat, unilateral lunge, and countermovement vertical jump (18, 20-21, 23-24, 27). Movement capacity testing required approximately eight minutes per subject including a five-minute stationary cycle warm-up session.

Bilateral Squat

Subjects were instructed to stand at the center of the movement screening platform with their comfortable feet position (inside or at shoulder width with slightly externally rotated or straight foot position) to perform the squat movement, while maintaining upright trunk position and both arms and hands placed in front of the body. On the verbal command, subjects were instructed to perform the body squat as deep as they could and then return to the starting position. Subjects performed two bodyweight squat trials and the second trial was captured and analyzed. This method aligns with those previously published by Philipp et al., 2024.

Unilateral Lunge

Next, subjects were instructed to stand at the center of the movement screening platform with their feet in a comfortable position, similar to the squat exercise. On the verbal command, subjects were instructed to stride out with the right leg and to get as far and deep as possible. Then, return to the starting position in one fluid motion. Subjects were instructed to keep the arms out to the side for balance during the unilateral lunge movement. An identical movement was performed for the left foot. Subjects performed two trials and the second was captured and analyzed for the purpose of this investigation. This method aligns with those previously published by Philipp et al., 2024.

Bilateral and Unilateral Countermovement Vertical Jump

Then, subjects were instructed to stand at the center of the movement screening platform with their feet in a comfortable position, similar to the squat and unilateral lunge exercises. On the researcher's verbal command, subjects were instructed to load and jump as high as possible without stepping into the jump. Subjects were permitted to utilize an arm swing. For the unilateral CMJ, subjects were instructed to begin by standing on the right leg with the left foot off the ground behind the body and then load and jump as high as possible using an arm swing before ending the movement by landing on their right foot again. This method was repeated on the left leg. The depth of the squat, knee flexion, and amount of arm extension used during the CMJ was determined by each participant. Subjects performed two trials and the second was captured and analyzed for the purpose of this investigation. This method aligns with those previously published by Philipp et al., 2024.

Statistical Analyses

Descriptive statistics, means and standard deviations were calculated for each variable. Shapiro-Wilk's test corroborated that the assumption of normality was violated for 9/54 variables examined in the present study. Based on sample size, composition, and violation of normality, Kruskal-Wallis one-way analysis of variance by ranks test with Dunn test post-hoc adjustments were used to examine position group-specific differences in lower-extremity biomechanical measurements between Linemen (n=3), Big Skill (n=6), and Skill (n=7). Hedges g was used to calculate the measure of effect size [i.e., $g = 0.2$ is a small effect, $g = 0.5$ is a moderate effect, and $g > 0.8$ is a large effect] (Hedges, 1981). Statistical significance was set α priori to $p < 0.05$. To account for the sample size and to ensure accuracy, reported significance values were adjusted by the Bonferroni correction for multiple tests. All statistical analyses were completed with SPSS (Version 26.0; IBM Corp., Armonk, NY, USA).

Results

Descriptive statistics for each dependent variable are presented in Tables 1-2. As hypothesized, significant differences were observed between position groups for specific measures of lower-extremity biomechanical characteristics. However, unexpected similarities were observed within the bilateral squat and lunge tasks.

Table 1. Descriptive statistics, means and standard deviations ($\bar{x} \pm SD$), for specific bilateral and unilateral squat biomechanical variables available in DARI motion capture.

Variables (units)	Linemen	Big Skill	Skill	*p*	*g*
Bilateral Squat					
Weight Distribution Left (%)	51.05±1.22	50.24±1.36	49.88±1.79	0.388	0.46
Weight Distribution Right (%)	48.95±1.22	49.76±1.36	50.14±1.77	0.348	-0.47
Knee Dynamic Valgus Left (°)	-54.26±9.51	-55.12±12.67	-69.41±10.38	0.092	0.86
Knee Dynamic Valgus Right (°)	-62.78±2.74	-55.78±15.60	-63.84±20.24	0.861	-0.001
Unilateral Squat					
Squat Depth Left (cm)	32.35±4.92	42.01±2.71	54.76±7.47*⁑	0.002	-2.73
Squat Depth Right (cm)	31.64±3.48	42.10±4.09	50.37±14.97	0.078	-1.44
Dynamic Valgus of Left Hip and Knee (°)	11.58±6.53	23.29±12.40	30.05±27.35	0.363	-0.64
Dynamic Valgus of Right Hip and Knee (°)	6.85±13.64	24.71±8.14	37.45±20.93	0.079	-1.24
Lunge					
Stride Length Percentage of Lower-Body Left (%)	118.20±5.38	119.47±5.88	117.69±4.47	0.749	0.074
Stride Length Percentage of Lower-Body Right (%)	112.57±7.68	118.53±6.69	116.76±6.96	0.575	-0.35
Stride Length Max Left (cm)	123.61±6.50	118.45±4.36	112.70±5.71	0.089	1.20
Stride Length Max Right (cm)	117.77±8.45	117.56±7.07	111.83±6.73	0.416	0.51
Trail Hip Abduction Max Left (°)	48.20±3.57	54.25±8.25	59.36±5.09	0.056	-1.19
Trail Hip Abduction Max Right (°)	49.90±5.03	50.20±6.99	50.94±7.39	0.728	-0.091

Note: *significantly different when compared to the linemen position group ($p < 0.05$); ⁑significantly different when compared to the big skill position group ($p < 0.05$); and $g = 0.2$ is a small effect, $g = 0.5$ is a moderate effect, and $g > 0.8$ is a large effect.

Table 2. Descriptive statistics, means and standard deviations (x̄ ± SD), for specific CMJ performance, eccentric, concentric, and landing variables available in DARI motion capture.

Variables	Line	Big Skill	Skill	*p*	*g*
Performance					
Jump Height (cm)	58.25±2.69	71.84±6.51	74.82±7.66*	0.033	-1.57
Jump Height Percentage of Lower-Body (%)	55.70±2.07	72.27±4.29	77.96±6.60*	0.010	-2.76
Peak Power (W)	5614.47±662.39	5395.87±603.09	4844.03±741.37	0.166	0.68
Net Impulse (N.s)	385.57±35.64†	304.65±35.60	262.44±26.77	0.008	2.36
Ground Reactive Force Max (N)	3391.40±746.36†	2717.02±271.57	2334.41±373.76	0.034	1.59
Eccentric Phase					
Hip Abduction Left (°)	14.40±2.89†	13.62±4.64	9.16±2.87	0.042	0.97
Hip Abduction Right (°)	18.17±7.19	11.88±4.01	8.40±5.16	0.136	1.11
Hip Flexion Left (°)	100.03±10.76	92.67±11.29	84.94±12.93	0.333	0.76
Hip Flexion Right (°)	99.83±14.83	90.70±9.89	85.23±14.15	0.333	0.68
Knee Flexion Left (°)	94.00±5.73	105.28±6.29	107.76±19.06	0.179	-0.84
Knee Flexion Right (°)	95.07±0.81	105.33±6.47	107.24±22.25	0.190	-0.78
Knee Valgus at Max Loading Left (°)	6.23±0.98	5.72±0.45	12.36±18.99	0.333	-0.02
Knee Valgus at Max Loading Right (°)	6.63±0.23†⁑	4.93±1.53	5.21±0.66	0.031	1.17
Ankle Flexion Left (°)	28.70±2.54	34.68±3.19	36.97±9.31	0.226	-0.99
Ankle Flexion Right (°)	32.20±5.40	33.45±3.23	38.46±11.39	0.647	-0.46
Concentric Phase					
Hip Peak Torque Percent Bodyweight Left (%)	15.47±1.45	15.22±4.05	22.91±10.05	0.259	-0.54
Hip Peak Torque Percent Bodyweight Right (%)	18.43±2.84	16.60±6.69	22.39±10.00	0.542	-0.25
Knee Peak Torque Percent Bodyweight Left (%)	10.03±2.75	14.32±2.17	20.20±6.31*	0.013	-1.46
Knee Peak Torque Percent Bodyweight Right (%)	11.33±2.31	16.07±3.88	23.21±13.13	0.060	-0.93
Ankle Peak Torque Percent Bodyweight Left (%)	1.93±0.67	1.88±0.52	2.33±0.45	0.497	-0.54
Ankle Peak Torque Percent Bodyweight Right (%)	1.87±0.85	1.52±0.50	2.14±0.76	0.316	-0.24
Hip Flexion at Peak Torque Left (°)	54.73±21.46	63.13±18.72	54.34±23.83	0.909	0.003
Hip Flexion at Peak Torque Right (°)	48.23±12.76	62.20±21.30	154.03±271.64	0.653	-0.49
Knee Flexion at Peak Torque Left (°)	79.90±11.92	99.03±7.68	102.37±21.95	0.192	-1.02
Knee Flexion at Peak Torque Right (°)	82.60±11.37	96.95±8.42	109.33±18.54	0.076	-1.19
Ankle Flexion at Peak Torque Left (°)	12.90±23.81	26.12±11.52	34.23±10.30	0.190	-0.91
Ankle Flexion at Peak Torque Right (°)	13.93±32.62	19.55±19.77	23.63±20.76	0.879	-0.25
Landing Phase					
GRF Takeoff Max Left (N)	1406.60±164.12†	1190.20±105.72	1105.49±138.41	0.049	1.35
GRF Takeoff Max Right (N)	1484.93±119.96	1226.57±129.28	1189.23±315.89	0.051	0.97
Absorption Depth (cm)	26.92±6.59	37.21±9.99	40.02±7.40	0.069	-0.98
Absorption Hip Flexion Left (°)	83.03±3.18	92.77±20.83	88.24±24.62	0.466	-0.18
Absorption Hip Flexion Right (°)	80.87±7.47	90.98±22.31	81.40±22.43	0.491	-0.03
Absorption Knee Flexion Left (°)	88.93±9.74	105.2±14.48	96.21±37.07	0.142	-0.33
Absorption Knee Flexion Right (°)	87.23±8.24	105.95±14.48	113.76±11.79*	0.031	-1.34
Absorption Ankle Flexion Left (°)	28.70±2.05	35.93±4.10	39.73±4.72*	0.014	-1.64
Absorption Ankle Flexion Right (°)	27.57±2.86	37.67±5.79	41.87±10.02	0.080	-1.23
GRF Absorption Left (N)	1684.80±394.54†⁑	1375.18±123.82	1027.83±203.88	0.005	1.76
GRF Absorption Right (N)	1706.60±352.04†	1333.22±206.58	1086.74±111.74	0.015	1.83
Absorption Knee Dynamic Valgus Left (°)	5.00±4.33	7.40±8.38	6.77±9.53	0.740	-0.14
Absorption Knee Dynamic Valgus Right (°)	3.03±3.80	6.33±7.74	5.67±8.99	0.710	-0.22

Note: GRF = ground reaction force; *significantly different when compared to the linemen position group ($p < 0.05$); ⁑significantly different when compared to the big skill position group ($p < 0.05$); †significantly different when compared to the skill position group ($p < 0.05$); and g = 0.2 is a small effect, g = 0.5 is a moderate effect, and g > 0.8 is a large effect.

Discussion

The purpose of this investigation was to assess specific measures of lower-extremity biomechanical characteristics within a cohort of college football starters. The primary findings of this investigation identified significant differences between position groups for measures of unilateral squat depth, bilateral CMJ height, and unilateral CMJ landing characteristics. However, no significant differences between position groups were observed for measures of sagittal plane lunge ability. Therefore, the results of the current investigation suggest that more careful observation of joint kinetics can provide sports performance professionals with critical information to support approaches for achieving and maintaining general and specific biomotor abilities relevant to the sport of American football. Furthermore, this information can also be utilized to support return-to-play and performance approaches for athletes who may have suffered a lower-extremity injury requiring sports rehabilitation.

Previous studies across sports have explored lower-extremity biomechanical characteristics (i.e., flexibility, range of motion, etc.) as assessed by the bilateral and unilateral squat tasks (Clark et al., 2022; Kiesel et al., 2011; Wiese et al., 2014; Kiesel et al., 2014; Lisman et al., 2018; Marchetti et al., 2018). Each task requires appropriate neuromuscular coordination, agonist-antagonist coactivation, dynamic joint stability, and mobility. The findings of this study observed no significant differences in weight distribution, dynamic valgus of the left and right hip or knee during the bilateral squat task as assessed via the utilization of the DARI motion capture system. These findings further highlight the similarities and apparent attention needed to develop and maintain foundational movement abilities regardless of stature, body mass, or playing position within starters. However, significant differences in unilateral squat ability between position groups were identified. Specifically, skill position groups achieved a greater range of motion in their left leg compared to both big skill and skill. These findings are especially novel and may be the first to profile these differences to this degree. Regarding American football, these findings may be due to body mass, the requirements of the sport in general, and each position-groups unique technical and tactical requirement specifically (e.g., accelerating and decelerating, joint kinetics and kinematics when doing so, changing directions to avoid opponents, etc.). Previous studies have shown that this asymmetry may be due to the stronger limb's unique force absorption characteristics or a loss of frontal plane stability (Paterno et al., 2010). Future investigations should aim to quantify and compare these characteristics between starters and non-starters and potentially by position group to enhance the current understanding of specific biomechanical similarities and differences that may contribute to optimal athletic performance.

The ability to coordinate one's lower extremities throughout dynamic ranges of motion to produce optimal levels of muscular power has been found to be a key characteristic of American football players (Lisman et al., 2018). Currently, scientific evidence suggests that lower-extremity muscular power is positively correlated with muscular strength, linear sprinting speed, change of direction speed, and agility (Farley et al., 2020; Johnson et al., 2024). As hypothesized, significant differences in CMJ ability were observed between position groups. However, upon further inspection beyond CMJ height, significant differences were observed for measures of jump height percentage of the lower body, net impulse, and maximal GRF between linemen and skill groups. Whereas the skill group jumped higher in absolute and relative terms, the linemen group produced a higher net impulse and GRF. These findings are likely to be due in part to differences in anthropometry as well as technical sporting demands unique to each position group. Whereas big skill and skill position groups are more likely to perform tasks that rely upon the stretch shortening cycle in game or practice scenarios, it is less common within linemen position groups. Furthermore, findings from this investigation can be utilized by sports performance professionals to develop specific training protocols that adequately prepare athletes for the demands of their sport and the demands of playing a starting role on the respective team.

The lunge exercise requires dynamic mobility, stability, and strength of the lower extremities primarily at the ankle, knee, and hip joints. Farrokhi et al. reported gluteus maximus and biceps femoris electromyography, as well as hip flexion angles, hip extensor impulse, and plantar flexor impulse were significantly different when trunk position was changed (i.e., forward lunge variations) (Farrokhi et al., 2008). Furthermore, adequate activation of agonist, antagonist, and synergist muscle groups such as iliopsoas, gluteus maximus, hamstrings, quadriceps, and gastrocnemius muscles have been found to contribute to the proficient completion of lunge tasks (Marchetti et al., 2018). Muscles in the abdominal region such as the transverse abdominal and in the back region such as the erector spinae provide stabilization when the body is in a split stance during both eccentric and concentric movement phases. However, this requires further exploration especially as it relates to the American football athlete. The results of the current investigation quantified and compared measures of stride length and hip abduction between position groups during the forward lunge exercise. No significant differences were observed for any measure of the lunge movement. Although biomechanical demands may differ based on position group, the ability to efficiently activate the hip extensor muscle groups seems to be a common characteristic within starters which should be maintained throughout a season, while knee extensors and ankle plantar flexors should also receive special emphasis throughout the season (Deneweth et al., 2014). These findings highlight the importance of dynamic mobility, stability, and strength of the lower body for American football athletes which may enhance their ability to block, accelerate and decelerate, and change direction in order to meet the specific demands of the sport.

An athlete's ability to decelerate their body mass during dynamic movements has been found to be related to reduced injury risk and increased athletic performance. Within CMJ tasks, it has been reported that athletes who decelerate their body mass more effectively transfer ground reactive forces during the contraction or propulsive phase of this task (Claudino et al., 2017). In addition to force production, this ability provides insight into neuromuscular fatigue and effective utilization of the lower-extremity's agonist, antagonist, and synergistic muscle groups (Claudino et al., 2017). Furthermore, eccentric loading of the hip flexors and ankle dorsiflexors, particularly the quadriceps muscle group, are also common within sport specific tasks such as cutting and change of direction (Merrigan et al., 2022). Significant differences were observed between linemen and skill groups for measures of knee valgus max loading right and concentric knee peak torque percent bodyweight left. Based on their uniqueness, these findings may be contributable to the sample tested, common loading mechanisms, and musculature contractile characteristics specific to the sport of American football but require further inquiry. An athlete's ability to contract their lower-extremity musculature to produce maximal vertical forces respective of time during the CMJ have been well-reported in the literature (Donahue et al., 2023). However, limited information is available as it relates to the function of the kinetic chain and how it may influence these abilities within the American football population.

Prior research has suggested that the landing phase of the CMJ produces 2-5x greater reactive forces when compared to that of the braking (1-3x) and propulsive phases (1-3x) across collegiate athletics (Donahue et al., 2023). Furthermore, when common mechanisms of injury are investigated it should be noted that an athlete's ability to effectively absorb ground reactive forces through proximal and distal tissues, ligaments, tendons, muscles, and bones is a primary predictor of lower-extremity injuries (Claudino et al., 2017). Significant differences were observed between linemen and skill groups for measures of GRF takeoff max left and right, absorption ankle flexion left, absorption knee flexion right, and GRF absorption right, while GRF absorption left was significantly different between linemen and skill groups, and skill groups and big skill groups. The authors posit that these findings may be influenced by body mass, loading mechanisms, and kinematic sequencing unique to each position group. However, no significant differences were observed between position groups for measures of absorption depth, absorption knee dynamic valgus left and right, and absorption hip flexion left and right. Altogether, these findings provide insight into task-specific functionality at the ankle, knee, and hip joints during the landing or absorption phase of the CMJ within the American football population. Consideration should be given to how these variables may vary by position group and throughout a competitive season. By utilizing this perspective, enhanced insights may be utilized to provide adequate sports performance or possibly sports rehabilitation approaches that support short- and long-term athlete development and performance by focusing on landing mechanics.

This study has limitations that should be noted. Due to the relatively small sample size of participants in this study, it may be beneficial for future research to include larger sample sizes by coordinating and collaborating with other teams and universities. In addition to providing a more robust sample, this would also allow for a more heterogeneous dataset than the one utilized in the current study. A second limitation of the current study involves information regarding the sample itself. In the future, it may be beneficial to account for biological age, training age, role on team, and playing experience, and to examine their interactions and influence on measures of physical performance. Not only will this assist research groups with providing more context to support their findings, but it may also assist practitioners in the field with determining the best approaches for developing their respective teams.

Conclusion

In conclusion, the findings of this study identified significant differences in the lower-extremity biomechanical characteristics of linemen, big skill, and skill position groups during squat, lunge, and jumping tasks. Specifically, differences between position groups for measures of unilateral squat depth, bilateral CMJ height, and unilateral CMJ landing characteristics were observed. These findings highlight the similarities and differences between position groups that may be due to physical characteristics or potentially the demands of the sport itself. Furthermore, insights gained can also be utilized to support specific strength and conditioning approaches to ensure athletes are prepared for the demands of their sport, or sports rehabilitation approaches to ensure athletes are prepared to return to play and performance. In the future, researchers may find it beneficial to expand the sample size but to also consider differences in age, grade classification, training status, and role (i.e., starter vs. non-starter).

Practical Implications

American football is a dynamic sport characterized by intense sporting actions such as blocking, tackling, jumping, and sprinting. Furthermore, these sporting actions often require athletes to repeatedly achieve extreme ranges of motion such as deep flexion and hyperextension. Findings from this study suggest that more similarities than differences exist in the lower-extremity biomechanical characteristics of college football starters from a successful team. Specifically, these similarities are observed during the bodyweight bilateral and unilateral squat, lunge, and CMJ exercises. However, unique differences were observed at the hip and knee during the eccentric and concentric phases of the CMJ, and at the ankle during the landing phase of the CMJ. Altogether, foundational lower-extremity movement patterns such as squats, steps, and lunges should be regularly integrated into strength training programs for football athletes. Furthermore, special attention should be given not only to lower-extremity muscular strength and power development, but also to the kinematic sequencing and biomechanical loading patterns during the development of such physical characteristics.

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References

Armitano-Lago, C., Willoughby, D., & Kiefer, A. W. (2022). A SWOT Analysis of Portable and Low-Cost Markerless Motion Capture Systems to Assess Lower-Limb Musculoskeletal Kinematics in Sport. *Frontiers in Sports and Active Living*, *3*. https://doi.org/10.3389/fspor.2021.809898

Bird, M. B., Mi, Q., Koltun, K. J., Lovalekar, M., Martin, B. J., Fain, A., Bannister, A., Cruz, A. V., Doyle, T. L. A., & Nindl, B. C. (2022). Unsupervised Clustering Techniques Identify Movement Strategies in the Countermovement Jump Associated With Musculoskeletal Injury Risk During US Marine Corps Officer Candidates School. *Frontiers in Physiology*, *13*.https://doi.org/10.3389/fphys.2022.868002

Cabarkapa, D., Cabarkapa, D. V., Miller, J. D., Templin, T. T., Frazer, L. L., Nicolella, D. P., & Fry, A. C. (2023). Biomechanical characteristics of proficient free-throw shooters-markerless motion capture analysis. *Front Sports Act Living*, *5*, 1208915. https://doi.org/10.3389/fspor.2023.1208915

Cabarkapa, D., Cabarkapa, D. V., Philipp, N. M., Downey, G. G., & Fry, A. C. (2022a). Repeatability of Motion Health Screening Scores Acquired from a Three-Dimensional Markerless Motion Capture System. *Journal of Functional Morphology and Kinesiology*, *7*(3), 65. https://doi.org/10.3390/jfmk7030065

Cabarkapa, D., Fry, A. C., & Mosier, E. M. (2020). Validity of 3-D markerless motion capture system for assessing basketball dunk kinetics—A case study. *Sport J*.

Cabarkapa, D., Whetstone, J. M., Patterson, A. M., Mosier, E. M., Cabarkapa, D. V., & Fry, A. C. (2022b). Relationship between Health-Related Physical Fitness Parameters and Functional Movement Screening Scores Acquired from a Three-Dimensional Markerless Motion Capture System. *International Journal of Environmental Research and Public Health*, *19*(8), 4551. https://doi.org/10.3390/ijerph19084551

Chimera, N. J., & Warren, M. (2016). Use of clinical movement screening tests to predict injury in sport. *World J Orthop*, *7*(4), 202-217. https://doi.org/10.5312/wjo.v7.i4.202

Clark, S. C., Rowe, N. D., Adnan, M., Brown, S. M., & Mulcahey, M. K. (2022). Effective Interventions for Improving Functional Movement Screen Scores Among "High-Risk" Athletes: A Systematic Review. *International Journal of Sports Physical Therapy*, *17*(2), 131-138. https://doi.org/10.26603/001c.31001

Claudino, J. G., Cronin, J., Mezencio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrao, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *J Sci Med Sport*, *20*(4), 397-402. https://doi.org/10.1016/j.jsams.2016.08.011

Cook, G., Burton, L., & Hoogenboom, B. (2006a). Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. *N Am J Sports Phys Ther*, *1*(2), 62-72. https://www.ncbi.nlm.nih.gov/pubmed/21522216

Cook, G., Burton, L., & Hoogenboom, B. (2006b). Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. *N Am J Sports Phys Ther*, *1*(3), 132-139. https://www.ncbi.nlm.nih.gov/pubmed/21522225

Daggett, M. C., Witte, K. A., Cabarkapa, D., Cabarkapa, D. V., & Fry, A. C. (2022). Evidence-Based Data Models for Return-to-Play Criteria after Anterior Cruciate Ligament Reconstruction. *Healthcare*, *10*(5). https://doi.org/10.3390/healthcare10050929

Deneweth, J. M., Pomeroy, S. M., Russell, J. R., McLean, S. G., Zernicke, R. F., Bedi, A., & Goulet, G. C. (2014). Position-Specific Hip and Knee Kinematics in NCAA Football Athletes. *Orthop J Sports Med*, *2*(6), 2325967114534591. https://doi.org/10.1177/2325967114534591

Dick, R., Ferrara, M. S., Agel, J., Courson, R., Marshall, S. W., Hanley, M. J., & Reifsteck, F. (2007). Descriptive epidemiology of collegiate men's football injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train*, *42*(2), 221-233. https://www.ncbi.nlm.nih.gov/pubmed/17710170

Donahue, P. T., Peel, S. A., Rush, M., McInnis, A. K., Littlefield, T., Calci, C., & Brutofsky, T. (2023). Examining Countermovement Jump Strategies Between Women's NCAA Division I Sports. *The Journal of Strength and Conditioning Research*, *37*(10), 2052-2057. https://doi.org/10.1519/JSC.0000000000004505

Dorrel, B., Long, T., Shaffer, S., & Myer, G. D. (2018). The Functional Movement Screen as a Predictor of Injury in National Collegiate Athletic Association Division II Athletes. *J Athl Train*, *53*(1), 29-34. https://doi.org/10.4085/1062-6050-528-15

Edwards, T., Spiteri, T., Piggott, B., Haff, G. G., & Joyce, C. (2018). A Narrative Review of the Physical Demands and Injury Incidence in American Football: Application of Current Knowledge and Practices in Workload Management. *Sports Medicine*, *48*(1), 45-55. https://doi.org/10.1007/s40279-017-0783-2

Farley, J. B., Stein, J., Keogh, J. W. L., Woods, C. T., & Milne, N. (2020). The Relationship Between Physical Fitness Qualities and Sport-Specific Technical Skills in Female, Team-Based Ball Players: A Systematic Review. *Sports Med Open*, *6*(1), 18. https://doi.org/10.1186/s40798-020-00245-y

Farrokhi, S., Pollard, C. D., Souza, R. B., Chen, Y. J., Reischl, S., & Powers, C. M. (2008). Trunk position influences the kinematics, kinetics, and muscle activity of the lead lower extremity during the forward lunge exercise. *J Orthop Sports Phys Ther*, *38*(7), 403-409. https://doi.org/10.2519/jospt.2008.2634

Fleisig, G. S., Slowik, J. S., Wassom, D., Yanagita, Y., Bishop, J., & Diffendaffer, A. (2022). Comparison of marker-less and marker-based motion capture for baseball pitching kinematics. *Sports Biomechanics*, 1-10. https://doi.org/10.1080/14763141.2022.2076608

Frost, D. M., Beach, T. A. C., Callaghan, J. P., & McGill, S. M. (2012). Using the Functional Movement Screen™ to Evaluate the Effectiveness of Training. *Journal of Strength and Conditioning Research*, *26*(6), 1620-1630. https://doi.org/10.1519/JSC.0b013e318234ec59

Garrison, M., Westrick, R., Johnson, M. R., & Benenson, J. (2015). Association between the functional movement screen and injury development in college athletes. *International Journal of Sports Physical Therapy*, *10*(1), 21-28. http://www.ncbi.nlm.nih.gov/pubmed/25709859

Hando, B. R., Scott, W. C., Bryant, J. F., Tchandja, J. N., Scott, R. M., & Angadi, S. S. (2021). Association Between Markerless Motion Capture Screenings and Musculoskeletal Injury Risk for Military Trainees: A Large Cohort and Reliability Study. *Orthopaedic Journal of Sports Medicine*, *9*(10), 232596712110416. https://doi.org/10.1177/23259671211041656

Hedges, L. V. (1981). Distribution Theory for Glass's Estimator of Effect size and Related Estimators. *Journal of Educational Statistics*, *6*(2), 107-128. https://doi.org/10.3102/10769986006002107

Johnson, Q. R., Stahl, C. A., Yang, Y., Gabriel, T., Zaragoza, J. A., Leal-Alfaro, E. D., Smith, D.B., & Dawes, J. J. (2024). Relationships between Relative Strength, Power, and Speed among NCAA Division II Men's Lacrosse Athletes. SportLogia, 20(1). https://doi.org/10.7251/SGIA2420018Q

Kerr, Z. Y., Marshall, S. W., Dompier, T. P., Corlette, J., Klossner, D. A., & Gilchrist, J. (2015). College Sports-Related Injuries - United States, 2009-10 Through 2013-14 Academic Years. *MMWR Morb Mortal Wkly Rep*, *64*(48), 1330-1336. https://doi.org/10.15585/mmwr.mm6448a2

Kiesel, K., Plisky, P., & Butler, R. (2011). Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scandinavian Journal of Medicine & Science in Sports*, *21*(2), 287-292. https://doi.org/10.1111/j.1600-0838.2009.01038.x

Kiesel, K. B., Butler, R. J., & Plisky, P. J. (2014). Prediction of Injury by Limited and Asymmetrical Fundamental Movement Patterns in American Football Players. *Journal of Sport Rehabilitation*, *23*(2), 88-94. https://doi.org/10.1123/JSR.2012-0130

Lam, W. W. T., & Fong, K. N. K. (2022). The application of markerless motion capture (MMC) technology in rehabilitation programs: a systematic review and meta-analysis. *Virtual Reality*. https://doi.org/10.1007/s10055-022-00696-6

Lam, W. W. T., Tang, Y. M., & Fong, K. N. K. (2023). A systematic review of the applications of markerless motion capture (MMC) technology for clinical measurement in rehabilitation. *Journal of Neuroengineering and Rehabilitation*, *20*(1). https://doi.org/10.1186/s12984-023-01186-9

Lisman, P., Nadelen, M., Hildebrand, E., Leppert, K., & Motte, S. d. l. (2018). Functional movement screen and Y-Balance test scores across levels of American football players. *Biology of Sport*, *35*(3), 253-260. https://doi.org/10.5114/biolsport.2018.77825

Marchetti, P. H., Guiselini, M. A., da Silva, J. J., Tucker, R., Behm, D. G., & Brown, L. E. (2018). Balance and Lower Limb Muscle Activation between In-Line and Traditional Lunge Exercises. *J Hum Kinet*, *62*, 15-22. https://doi.org/10.1515/hukin-2017-0174

Martinez, H. R., Garcia-Sarreon, A., Camara-Lemarroy, C., Salazar, F., & Guerrero-Gonzalez, M. L. (2018). Accuracy of Markerless 3D Motion Capture Evaluation to Differentiate between On/Off Status in Parkinson's Disease after Deep Brain Stimulation. *Parkinsons Dis*, *2018(1)*, 5830364. https://doi.org/10.1155/2018/5830364

McKay, A. K., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2021). Defining training and performance caliber: a participant classification framework. International journal of sports physiology and performance, 17(2), 317-331. https://doi.org/10.1123/ijspp.2021-0451.

Merrigan, J. J., Rentz, L. E., Hornsby, W. G., Wagle, J. P., Stone, J. D., Smith, H. T., Galster, S. M., Joseph, M., & Hagen, J. A. (2022). Comparisons of Countermovement Jump Force-Time Characteristics Among National Collegiate Athletic Association Division I American Football Athletes: Use of Principal Component Analysis. *Journal of Strength and Conditioning Research*, *36*(2), 411-419. https://doi.org/10.1519/JSC.0000000000004173

Mündermann, L., Corazza, S., & Andriacchi, T. P. (2006). The evolution of methods for the capture of human movement leading to markerless motion capture for biomechanical applications. *Journal of Neuroengineering and Rehabilitation*, *3*. https://doi.org/10.1186/1743-0003-3-6

Paterno, M. V., Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., Huang, B., & Hewett, T. E. (2010). Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med*, *38*(10), 1968-1978. https://doi.org/10.1177/0363546510376053

Philipp, N. M., Cabarkapa, D., Cabarkapa, D. V., Eserhaut, D. A., & Fry, A. C. (2023). Inter-Device Reliability of a Three-Dimensional Markerless Motion Capture System Quantifying Elementary Movement Patterns in Humans. *Journal of Functional Morphology and Kinesiology*, *8*(2), 69. https://doi.org/10.3390/jfmk8020069

Philipp, N. M., Fry, A. C., Mosier, E. M., Cabarkapa, D., Nicoll, J. X., & Sontag, S. A. (2024). Biological reliability of a movement analysis assessment using a markerless motion capture system. Frontiers in Sports and Active Living, 6, 1417965. https://doi.org/10.3389/fspor.2024.1417965

Rechel, J. A., Yard, E. E., & Comstock, R. D. (2008). An epidemiologic comparison of high school sports injuries sustained in practice and competition. *J Athl Train*, *43*(2), 197-204. https://doi.org/10.4085/1062-6050-43.2.197

Sandau, M., Koblauch, H., Moeslund, T. B., Aanæs, H., Alkjær, T., & Simonsen, E. B. (2014). Markerless motion capture can provide reliable 3D gait kinematics in the sagittal and frontal plane. *Medical Engineering & Physics*, *36*(9), 1168-1175. https://doi.org/10.1016/j.medengphy.2014.07.007

Smith, C. A., Chimera, N. J., & Warren, M. (2015). Association of Y Balance Test Reach Asymmetry and Injury in Division I Athletes. *Medicine & Science in Sports & Exercise*, *47*(1), 136-141. https://doi.org/10.1249/MSS.0000000000000380

Sonnenfeld, J. J., Crutchfield, C. R., Swindell, H. W., Schwarz, W. J., Trofa, D. P., Ahmad, C. S., & Lynch, T. S. (2021). An Analysis of In Vivo Hip Kinematics in Elite Baseball Batters Using a Markerless Motion-Capture System. *Arthrosc Sports Med Rehabil*, *3*(3), e909-e917. https://doi.org/10.1016/j.asmr.2021.03.006

Thompson, M. B., Johnson, Q. R., Lindsay, K. G., & Dawes, J. J. (2024). Development of an Abbreviated Model for Predicting Functional Movement Screen Score Within Tactical Populations. The Journal of Strength & Conditioning Research, 38(3), 607-611. https://doi.org/10.1519/JSC.0000000000004701

Weinhandl, J. T., Armstrong, B. S. R., Kusik, T. P., Barrows, R. T., & O'Connor, K. M. (2010). Validation of a single camera three-dimensional motion tracking system. *Journal of Biomechanics*, *43*(7), 1437-1440. https://doi.org/10.1016/j.jbiomech.2009.12.025

Wiese, B. W., Boone, J. K., Mattacola, C. G., McKeon, P. O., & Uhl, T. L. (2014). Determination of the Functional Movement Screen to Predict Musculoskeletal Injury in Intercollegiate Athletics. *Athletic Training & Sports Health Care*, *6*(4), 161-169. https://doi.org/10.3928/19425864-20140717-01

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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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***Declaration of interests*:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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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.

References

Attenborough, A. S., Sinclair, P. J., Sharp, T., Greene, A., Stuelcken, M., Smith, R. M., & Hiller, C. E. (2017). The identification of risk factors for ankle sprains sustained during netball participation. *Physical Therapy in Sport*, *23*, 31–36. https://doi.org/10.1016/j.ptsp.2016.06.009

Beato, M., Bigby, A. E. J., De Keijzer, K. L., Nakamura, F. Y., Coratella, G., & McErlain-Naylor, S. A. (2019). Post-activation potentiation effect of eccentric overload and traditional weightlifting exercise on jumping and sprinting performance in male athletes. *PloS One*, *14*(9), e0222466. https://doi.org/10.1371/journal.pone.0222466

Boksem, M. A. S., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological Psychology*, *72*(2), 123–132. https://doi.org/10.1016/j.biopsycho.2005.08.007

Campa, F., & Coratella, G. (2021). Athlete or Non-athlete? This Is the Question in Body Composition. *Frontiers in Physiology*, *12*. https://doi.org/10.3389/fphys.2021.814572

Chatzistergos, P. E., Healy, A., Balasubramanian, G., Sundar, L., Ramachandran, A., & Chockalingam, N. (2020). Reliability and validity of an enhanced paper grip test; A simple clinical test for assessing lower limb strength. *Gait & Posture*, *81*, 120–125. https://doi.org/10.1016/j.gaitpost.2020.07.011

Chou, S.-W., Cheng, H.-Y. K., Chen, J.-H., Ju, Y.-Y., Lin, Y.-C., & Wong, M.-K. A. (2009). The role of the great toe in balance performance. *Journal of Orthopaedic Research: Official Publication of the Orthopaedic Research Society*, *27*(4), 549–554. https://doi.org/10.1002/jor.20661

Degens, H., Stasiulis, A., Skurvydas, A., Statkeviciene, B., & Venckunas, T. (2019). Physiological comparison between non-athletes, endurance, power and team athletes. *European Journal of Applied Physiology*, *119*(6), 1377–1386. https://doi.org/10.1007/s00421-019-04128-3

Eldridge, J. A., Palmer, T. B., Gillis, K., Lloyd, R., Squires, W. G., & Murray, T. D. (2014). Comparison of Academic and Behavioral Performance between Athletes and Non-athletes. *International Journal of Exercise Science*, *7*(1), 3–13. 10.70252/UVXP4768

Herlambang, M. B., Cnossen, F., & Taatgen, N. A. (2021). The effects of intrinsic motivation on mental fatigue. *PLOS ONE*, *16*(1), e0243754. https://doi.org/10.1371/journal.pone.0243754

Jacob, H. a. C. (2001). Forces acting in the forefoot during normal gait – an estimate. *Clinical Biomechanics*, *16*(9), 783–792. https://doi.org/10.1016/S0268-0033(01)00070-5

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Lorenz, D. (2011). Postactivation potentiation: An introduction. *International Journal of Sports Physical Therapy*, *6*(3), 234–240.

Machowska-Krupa, W., & Cych, P. (2023). Differences in Coordination Motor Abilities between Orienteers and Athletics Runners. *International Journal of Environmental Research and Public Health*, *20*(3), 2643. https://doi.org/10.3390/ijerph20032643

Mansi, M. K., Chockalingam, N., & Chatzistergos, P. E. (2023). An exploration of the mechanistic link between the enhanced paper grip test and the risk of falling. *Foot (Edinburgh, Scotland)*, *57*, 102059. https://doi.org/10.1016/j.foot.2023.102059

Mansi, M. K., Chockalingam, N., & Chatzistergos, P. E. (2024). The enhanced paper grip test can substantially improve community screening for the risk of falling. *Gait & Posture*, *108*, 157–163. https://doi.org/10.1016/j.gaitpost.2023.12.006

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*(3), 857–864. https://doi.org/10.1152/japplphysiol.91324.2008

Quinlan, S., Fong Yan, A., Sinclair, P., & Hunt, A. (2020). The evidence for improving balance by strengthening the toe flexor muscles: A systematic review. *Gait & Posture*, *81*, 56–66. https://doi.org/10.1016/j.gaitpost.2020.07.006

Robbins, D. W. (2005). Postactivation potentiation and its practical applicability. *The Journal of Strength & Conditioning Research*, *19*(2), 453. https://doi.org/10.1519/r-14653.1

Rolian, C., Lieberman, D. E., Hamill, J., Scott, J. W., & Werbel, W. (2009). Walking, running and the evolution of short toes in humans. *Journal of Experimental Biology*, *212*(5), 713–721. https://doi.org/10.1242/jeb.019885

Sale, D. G. (2002). Postactivation Potentiation: Role in Human Performance. *Exercise and Sport Sciences Reviews*, *30*(3), 138.

Skuk, N., Chatzistergos, P. E., & Kozinc, Ž. (2024). Reliability of enhanced paper grip test for testing foot strength in volleyball and soccer players. *Physical Therapy in Sport*, *67*, 155–160. https://doi.org/10.1016/j.ptsp.2024.05.004

Słomka, K. J., & Michalska, J. (2024). Relationship between the strength of the ankle and toe muscles and functional stability in young, healthy adults. *Scientific Reports*, *14*, 9125. https://doi.org/10.1038/s41598-024-59906-7

Soysa, A., Hiller, C., Refshauge, K., & Burns, J. (2012). Importance and challenges of measuring intrinsic foot muscle strength. *Journal of Foot and Ankle Research*, *5*, 29. https://doi.org/10.1186/1757-1146-5-29

Spink, M. J., Fotoohabadi, M. R., Wee, E., Hill, K. D., Lord, S. R., & Menz, H. B. (2011). Foot and Ankle Strength, Range of Motion, Posture, and Deformity Are Associated With Balance and Functional Ability in Older Adults. *Archives of Physical Medicine and Rehabilitation*, *92*(1), 68–75. https://doi.org/10.1016/j.apmr.2010.09.024

Tourillon, R., Gojanovic, B., & Fourchet, F. (2019). How to Evaluate and Improve Foot Strength in Athletes: An Update. *Frontiers in Sports and Active Living*, *1*, 46. https://doi.org/10.3389/fspor.2019.00046

Tsekoura, M., Pantou, M., Fousekis, K., Billis, E., Gliatis, J., & Tsepis, E. (2023). Reliability and clinical applicability of lower limp strength using an enhanced paper grip strength. *European Journal of Translational Myology*, *33*(4), Article 4. https://doi.org/10.4081/ejtm.2023.11841

Vanhelst, J., Béghin, L., Drumez, E., Labreuche, J., Polito, A., De Ruyter, T., Censi, L., Ferrari, M., Miguel-Berges, M. L., Michels, N., De Henauw, S., Moreno, L. A., & Gottrand, F. (2023). Changes in physical activity patterns from adolescence to young adulthood: The BELINDA study. *European Journal of Pediatrics*, *182*(6), 2891–2902. https://doi.org/10.1007/s00431-023-04948-8

Yamauchi, J., & Koyama, K. (2020). Importance of toe flexor strength in vertical jump performance. *Journal of Biomechanics*, *104*, 109719. https://doi.org/10.1016/j.jbiomech.2020.109719

Young, W. (1995). *Laboratory strength assessment of athletes*. https://www.scribd.com/document/10440793/Young-1995-Lab-Tests-for-Strength

Yuasa, Y., Kurihara, T., & Isaka, T. (2018). Relationship Between Toe Muscular Strength and the Ability to Change Direction in Athletes. *Journal of Human Kinetics*, *64*, 47. https://doi.org/10.1515/hukin-2017-0183

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Original article

The Relationship Between Motor Abilities and the Performance of the Osoto Gari in Police Students

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Abstract

The aim of the study was to determine the association between motor abilities and the performance of the Osoto Gari (OSOTOG) from the special physical education (SPE) program, as a narrower part of the Physical Education field. The sample consisted of 84 male first-year students from the Faculty of Security Sciences in Banja Luka. The variable sample consisted of sixteen tests for assessing motor skills, which served as independent variables, and the dependent variable, the Osoto Gari, represented the average grades of performing the throwing technique with a backward standing leg from the SFE program. This technique differs from the classic Osoto Gari by its training methodology and level of application in defense or attack situations. Based on the results of the regression analysis, it can be concluded that motor skills are significant for the effectiveness of the throwing technique with a backward standing leg, with 46.4% of the total variability of the dependent variable OSOTOG being determined by the independent variables assessing motor skills. The statistically significant individual contributions to explaining the criterion variable OSOTOG were made by the following variables: hand tapping, side steps, twisting, side lying, forward bend on a bench, and standing long jump, which suggests that these variables are predictive for performing the throwing technique with a backward standing leg from the SPE program. The obtained results could be used to develop certain motor skills to improve the quality of performing the throwing technique with a backward standing leg.

Keywords: Tactical athletes, Self-defense, Use of force, Throwing technique, Police

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Introduction

Within the scope of security duties, martial arts should be understood as a tool for developing specific knowledge, skills, and habits necessary for the successful execution of everyday tasks, assignments, and obligations, particularly when there is no other way to overcome resistance from individuals who pose a physical threat to the safety of authorized personnel, other people, and protected property. Due to the fact that certain programs include throwing techniques within their algorithms, the study program at the Faculty of Security Sciences in Banja Luka, through the curriculum of the Special Physical Education (SPE) course, teaches, in addition to other techniques, hand, foot, and side throwing techniques from judo, which, from the biomechanical perspective of execution, can be divided into: throwing techniques by clearing, throwing techniques by kicking, throwing techniques by grasping and lifting, and throwing techniques by blocking an extended leg. In SPE, throwing techniques represent complex movement structures primarily aimed at destabilizing and inflicting pain on the "opponent" on the path to gaining full control over them (Arlov, 2001).

Like other throwing techniques, the throwing technique by sweeping out the back supporting leg (Osoto Gari throw) is characterized by the phase of destabilizing the opponent's balance, the phase of establishing contact with the opponent, and the phase of executing the throwing technique (Ćirković, Jovanović, and Kasum, 2010; Santos et al., 2014). Each of these phases is characterized by specific movements (trajectories of individual body segments), with maximum interdependence, which is why all these phases are interconnected into one whole. The efficiency of their execution depends on the precise and rapid performance of all phases. The throw is executed from a basic stance and right guard, when the opponent steps back with the right leg, pulling the performer toward them and destabilizing their balance forward. At the moment of balance disruption, the performer, through a reflexive movement, attempts to restore and maintain stable balance by stepping forward with the left leg to the left side, about 15 to 20 cm from the opponent's right foot, thereby fully transferring their weight to the left leg and stabilizing their balanced position. Continuing the action, the performer simultaneously pulls the opponent's right arm towards the waist with the left hand and pushes the opponent's left shoulder and left side of the body to the left with the right hand, destabilizing the opponent's balance. Further, through a strong external twist of the body at a 45-degree angle (with continuous contact with the opponent), the performer brings the opponent into an unbalanced position, reducing their support surface (forcing them to stand on the outer side of the right foot). Next, through a rotation of the pelvis to the left, the performer swings the right leg forward (behind the opponent's right leg, aligning the head and the toes of the right leg), after which, with a simultaneous forward and downward bend of the body, and a strong backward swing of the same (half-bent) leg, the performer establishes contact at the opponent's right knee joint, kicking their leg backward and upward. After making the contact, the performer, with synchronized and powerful pulling of the left hand toward themselves and pushing the right hand downward, throws the opponent in front of them, directing them so that they fall onto their left side on the ground (Koshida, Ishii, Matsuda & Hashimoto, 2017).

The reason why this technique is appropriately applied in the SPE program is that the initial phase of the throw involves pushing the opponent backward. A direct and rapid entry into this throw allows the performer to transfer their body weight onto the opponent, causing them to lose balance because they lack visual contact with the direction in which they are moving. As a result, it becomes more difficult for the opponent to regain stable balance and organize their defense. In performing the technique, force from the entire body must be applied to the opponent, not just from the arms (because the body relies on the lower extremities). Therefore, the lower extremities should be used in synchronization with the upper extremities and the abdominal part of the body (Liu et al., 2021). These movements can be performed in all directions, and their execution requires quick application to prevent the opponent from returning to a balanced position. Throughout all phases of the throwing technique, motor skills such as strength, speed, coordination, flexibility, balance, and precision are involved, which significantly determine the success of the throw's execution (Nurkić, 2005; Segedi et al., 2014; Paspalj & Gužvica, 2017). Additionally, numerous previous studies have shown that the effectiveness of mastering the content of the SPE course is significantly influenced by the motor skills of the students (Milošević, 1985; Božić, Milošević & Zulić, 1990).

Considering that the processes of orientation and the effectiveness of training are closely linked to motor skills (Sertić, 1997; Sertić & Vuleta, 1997; Banović, 2001; Drid, 2006; Toskić, Lilić & Toskić, 2014; Orr et al., 2019; 2020), the subject of this research was to determine the relationship between the effectiveness of performing the Osoto Gari from the SPE program and the basic motor skills. The aim of the research was to determine the magnitude and direction of the connection between motor skills and the throwing technique with a backward standing leg from the SPE program, i.e., to identify the motor skills that are significant for executing the throwing technique with a backward standing leg, and to determine whether the success of executing this throwing technique can be predicted based on certain motor skills. The basic hypothesis was that there would be a statistically significant connection between motor skills and the efficiency of executing the throwing technique with a backward standing leg, which would make it possible to predict its training and the selection of methods to improve its execution.

Methods

Participants

The sample of participants consisted of 84 male first-year students from the Faculty of Security Sciences, University of Banja Luka, with an average age of 19 ± 0.6 years. All participants were clinically healthy. The basic anthropometric indicators of the tested sample were as follows: height (Ht) = 181.85 ± 6.13 cm, body mass (BM) = 78.43 ± 9.83 kg, and BMI = 23.71 ± 2.43 kg/m^2. Before participating in the study, the participants were familiarized with the procedures and tests used in the study. Only students who voluntarily agreed and signed an informed consent form were tested as part of this study. The study was conducted in compliance with the Declaration of Helsinki for research involving humans and animals, with approval from the ethics committee.

Measurements and Procedures

The predictor variables in the system consisted of variables used to assess the students' motor skills, while the criterion variable was the assessment of the throwing technique with a backward standing leg, which evaluates the technical execution of judo techniques from the SPE program. All tests were conducted in a single indoor session in the same order, following a standardized dynamic warm-up. Passive recovery of three minutes was given between all trials. Unless otherwise indicated, the best of three trials was retained for analysis. The predictor variables were covered by 16 tests to asses Upper and Lower Limb Movement Frequency, Mobility While on the ground and Lateral agility, Balance, Flexibility, Power and Speed, and Muscular strength (Metikoša et al., 1989).

Upper and Lower Limb Movement Frequency

Upper limb movement frequency was assessed using the Hand Tapping Test (HTT). Participants were seated at a table with a wooden board (100 × 25 × 2 cm) placed in front of them. Two circular plates (20 cm diameter) were fixed on the board, 61 cm apart. With the left palm on the board center and the right hand on the left plate, participants tapped the plates alternately with the right hand for 15 seconds, moving as fast as possible. The total number of correctly alternated taps within the 15-second period was recorded.

Lower limb movement frequency was evaluated using the Foot Tapping Test (FTT). Participants sat upright with the dominant foot placed on the left side of a 30 × 60 × 2 cm foot-tapping board featuring a 15 cm central divider. At the start signal, they moved the foot laterally over the divider and tapped both sides of the board alternately as quickly as possible for 15 seconds. The total number of valid taps was counted.

Mobility While on the Ground and Lateral Agility

Mobility While on the Ground was assessed using the Agility L Test (ALT). This test was performed on a 5 × 8 m matted area with four gym mats arranged in an L shape. From a prone start, participants rolled laterally along the long arm of the “L,” crawled backward to a judo jacket held between the knees, executed a forward roll, turned 90°, and performed a backward roll while retaining the jacket. The fastest time of four trials was recorded using a stopwatch.

The Lateral Agility Test (LAT) required participants to perform six complete side-step sequences between two lines taped 4 m apart. From a straddle stance behind the starting line, they moved laterally using a step-together technique (without crossing the legs) to the opposite line and back. Time was recorded to the nearest 0.1 s using a stopwatch, and the best of six trials was retained.

Balance
Balance was evaluated using the Single Leg Balance Test (SLB). Barefoot participants stood on one leg on a balance bench, placing the support foot across the bench’s narrow rail while the non-support foot remained above the ground. Arms were held loosely by the sides. The trial ended if balance was lost or if 180 seconds was reached. The longest duration from six trials was recorded with 0.1 s precision.

Flexibility
Three tests evaluated flexibility. In the Shoulder Flexibility Test (SFT), participants grasped a 165 cm × 2.5 cm stick with the left hand fixed on a 15 cm grip mark and the right hand sliding outward while raising the bar overhead. The minimal distance between hands (in cm) achieved over three trials was recorded.

The Side-Lying Leg Abduction Test (SLLA) assessed hip abduction range. Participants lay on their left side on a horizontal board marked from 0–90°, abducted the right leg maximally while keeping the knee extended, and the peak angle at the ankle joint was noted from three trials.

The Forward Bend on Bench Test (FBB) involved standing barefoot on a 40 cm high bench with feet together. Participants slowly bent forward from the hips and reached downward along a calibrated ruler fixed to the front edge of the bench. The furthest reach point, measured in cm beyond the toes, was taken from three attempts.

Power
Power was assessed using three field-based tests. In the Standing Long Jump Test (SLJ), participants jumped forward as far as possible from a two-footed stance on a springboard onto mats, with distance measured from the take-off line to the nearest body contact. The longest of three jumps was used.

In the Medicine Ball Throw Test (MBT), participants lay supine on a mat with arms extended overhead holding a 1 kg medicine ball. They threw the ball backward over the head using a chest pass action. Distance to the first contact point was measured in decimeters; the best of three throws was recorded.

The Handball Throw Test (HBT) required subjects to sit in a straddle position and throw a standard handball forward using an overarm technique. The furthest of three throws was noted.

Speed
Speed was evaluated using the 20 m Sprint Test (20MST). Participants sprinted maximally from a standing start on a 30 m indoor track, with photocells placed at 0 and 20 m lines to record sprint time to the nearest 0.01 s. The fastest of three trials was retained.

Muscular Strength and Endurance
Muscular endurance was assessed through three strength-endurance tests. In the Bench Press Test (BPT), participants performed as many consecutive repetitions as possible with a 30 kg barbell, maintaining proper form and full range of motion. The total number of valid repetitions was recorded.

In the Sit-Up Test (SUT), participants lay supine with knees bent and feet anchored. Holding a 20 kg barbell against the chest, they performed continuous sit-ups, bringing the trunk to an upright vertical position. The test was terminated upon voluntary exhaustion or loss of form, and the number of correctly executed repetitions was noted.

The Half Squat Test (HST) involved participants performing as many half squats as possible with a 60 kg barbell on the shoulders. Squat depth was controlled using 10 cm high wooden blocks placed on a bench. The number of complete, correctly executed repetitions was recorded.

The trunk endurance test (TEN) is used to assess static trunk strength. The test requires a Swedish box (with two frames removed), a bar, a mat, two stands, a stopwatch, a 15 kg weight, and a measuring tape. It is conducted in a 3 x 2 meter space. The participant sits on the edge of the Swedish box with legs extended while an assistant secures the feet. The participant holds the 15 kg weight with an overhand grip, placing it on the chest, then lowers backward into a fully extended, unsupported horizontal position. A bar is mounted between two stands, 50 cm away from the box, parallel to it, with the bottom edge aligned with the padded surface of the box. The participant's task is to maintain this position using trunk muscle engagement for as long as possible. The outcome is recorded in seconds from the moment the participant reaches the horizontal position with the weight on the chest until the position is no longer maintained. Two trials are performed, and the better result is used for evaluation.

Osoto Gari

The technical level of knowledge in judo among students was assessed based on the execution of the Osoto Gari from the SPE program. The overall education of the throwing technique with a backward standing leg, including learning the parts of the technique, linking them into a whole, and stabilizing the technique, lasted for three weeks and was conducted over six teaching sessions during regular classes with first-year students from the Faculty of Security Sciences, in the second semester, at the martial arts hall of the Faculty of Physical Education and Sport, University of Banja Luka. The efficiency of executing the throwing technique with a backward standing leg was assessed through the average grade on a scale from 5.00 to 10.00, given by five evaluators (experts teaching SFE). Special attention during the assessment was given to specific phases of technique execution, which include destabilizing the opponent's balance, establishing contact with the opponent, achieving the correct position for the throw, and executing the throw itself.

Statistical analyses

The basic measures of central tendency and measures of dispersion of the results were defined using: arithmetic mean (Mean) and standard deviation (Std. Deviation), the minimum achieved result (Min.) and the maximum achieved result (Max.). In order to test the correctness of the data distribution, the Kolmogorov-Smirnov test was used, while regression analysis was applied to determine the relationship between predictor variables and the criterion variable at a significance level of $p = 0.05$. The statistical data processing was carried out on a Pentium 4 PC using the SPSS Statistics 17.0 application software (Hair, J., Anderson, R., Tatham, R., & Black, W., 1998).

Results

Table 1 presents the descriptive parameters of the results for the variables used to assess motor skills and OSOTOG. According to the presented results, it was established that for most of the variables, the results are well grouped. The results of the Kolmogorov-Smirnov test indicated a deviation from normal distribution for the variables: ALT, LAT, SLB, SLLA, and SU.

Table 1. Descriptive indicators of the variables for assessing motor skills and Osoto Gari from the special physical education program.

Variable	N	Mean	Std. Deviation	Min.	Max.	KS p
HTT	84	40.49	6.35	27	59	0.05
LTT	84	32.45	3.90	26	57	0.05
ALT	84	12.87	3.70	9.19	42.25	0.00
LAT	84	9.24	1.40	7.66	17.21	0.02
SLB	84	3.71	2.96	1.09	19.48	0.00
SFT	84	75.18	19.27	30	120	0.09
SLLA	84	72.29	11.33	50	100	0.04
FBB	84	50.73	9.38	28	105	0.14
SLJ	84	248.73	15.16	213	290	0.84
20mST	84	3.31	0.14	2.90	3.75	0.72
MBT	84	130.0	18.19	9.0	18.0	0.22
HBT	84	190.0	32.71	11.5	26.5	0.67
BPR	84	34.98	11.95	16	66	0.17
SU	84	26.77	9.71	12	75	0.03
HSQ	84	23.49	9.06	10	50	0.08
TEN	84	23.46	10.86	10	68	0.06
OSOTOG	84	6.45	1.176	5.0	10.0	0.00

Note: KSp – p-value of the Kolmogorov-Smirnov test; HTT, hand tapping test; FTT, foot tapping test; ALT, Agility L test; LAT, lateral agility test; SLB, single leg balance test; SFT, shoulder flexibility test; SLLA, side-lying leg abduction test; FBB, forward bend on bench test; SLJ, standing long jump test; MBT, medicine ball throw test; HBT, handball throw test; 20mST, 20 m sprint test; BPR, bench press test; SU, sit-up test; HSQ, half squat test; TEN, trunk endurance test.; OSOTOG, Osoto Gari.

Based on the results of the regression analysis, it can be concluded that motor skills significantly ($R = 0.681$, $R^2 = 0.464$, $p < 0.001$) affect the efficiency of the OSOTOG, with 46.4% of the total variability of the dependent variable being determined by the system of independent variables for assessing motor skills. From Table 2, it could be observed that the variables: HTTP, MALT, SFT, SLLA, FBB, and SLJ, individually made a statistically significant contribution in explaining the criterion variable, as confirmed by their Beta coefficients, which indicate that these variables contribute the most to explaining the dependent variable, after accounting for the variance explained by other independent variables in the model. Table 2 provides information on the individual impact of the variables used to assess motor skills on the efficiency of performing the OSOTOG from the SPE.

Table 2. Regression coefficients of motor skills and the Osoto Gari Osoto Gari from the special physical education program.

Model	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
HTT	-0.05	0.01	-0.27	-2.74	0.00
LTT	0.05	0.03	0.16	1.63	0.10
ALT	-0.02	0.03	-0.06	-0.51	0.60
LAT	-0.21	0.10	-0.25	-2.07	0.04
SLB	-0.00	0.04	-0.00	-0.01	0.98
SFT	-0.03	0.00	-0.54	-4.80	0.00
SLLA	-0.02	0.01	-0.22	-2.00	0.04
FBB	-0.02	0.01	-0.23	-2.10	0.03
SLJ	0.01	0.00	0.21	2.04	0.04
20mST	1.13	0.78	0.13	1.45	0.14
MBT	0.09	0.06	0.15	1.44	0.15
HBT	-0.03	0.04	-0.09	-0.86	0.38
BPR	0.02	0.01	0.19	1.80	0.07
SU	0.01	0.01	0.13	1.07	0.28
HSQ	-0.00	0.01	-0.06	-0.57	0.56
TEN	0.00	0.01	0.06	0.54	0.59

Note: HTT, hand tapping test; FTT, foot tapping test; ALT, Agility L test; LAT, lateral agility test; SLB, single leg balance test; SFT, shoulder flexibility test; SLLA, side-lying leg abduction test; FBB, forward bend on bench test; SLJ, standing long jump test; MBT, medicine ball throw test; HBT, handball throw test; 20mST, 20 m sprint test; BPR, bench press test; SU, sit-up test; HSQ, half squat test; TEN, trunk endurance test.; OSOTOG, Osoto Gari

Discussion

The primary problem of this research is to analyze the structure of the importance of motor skills for performing the throwing technique with the rear foot. Based on the set problem, the goal of the research was to identify the motor skills that are significant for performing the throwing technique with the rear foot, or to determine whether the success of performing the throwing technique with the rear foot can be predicted based on certain motor skills. The results of the regression analysis showed that the applied set of predictor variables is highly correlated (0.68) with the criterion variable, with the system of predictor variables explaining a total of 46.4% of the variance in the throwing technique with the rear foot. The predictor variables with the highest partial correlations with the criterion variable are: HTT, SFT, LAT, FBB, SLLA, and SLJ. Based on the obtained information, it can be asserted that in order to efficiently perform the throwing technique with the rear foot, one needs to have a good frequency of arm movements, flexibility in the shoulder girdle, torso, and hip joint, explosive strength of the lower extremities, and agility. The throwing technique with the rear foot is performed in accordance with biomechanical principles, with maximum speed and optimal force levels, during which the relationships between the body segments change. The execution of the technique is based on the biomechanical principle involving two forces, where one vector represents the force created by the performer's arms, while the other vector represents the force created by the action of the rear foot's thrust (Sacripanti, 1989; Santos, 2001; 2014; Imamura & Johnson, 2003; Kuleš, 2008; Rexhepi & Hraski, 2011; Koshida et al., 2016; 2017). It is very difficult to isolate a single motor skill and determine its impact on the execution of the throwing technique with the rear foot, because the quality of its performance is influenced not only by one motor skill but by several of them. As is already well-known, the technique is classified as a complex movement structure, as it consists of different but fluid movements and actions combined into a whole. In the first phase of the throw, when disturbing the opponent's balance, in addition to the work of the arms, the greater contribution comes from the explosive strength of the lower extremities (especially if the opponent is standing still or not moving appropriately to suit the performer). It should be emphasized that if the movement is appropriate for the performer, the contribution of explosive strength only multiplies the positive effects of the movement. When establishing contact with the opponent in the second phase of the throw, the first part refers to the initial entry into the throw (while contact with all points of the body has not yet been made), where, during the change of direction, the impact of agility and speed is emphasized. In the second part (which refers to achieving the necessary contact of all body points with the opponent's body), speed still remains the dominant factor for the performer. The final phase of the throw must be performed with full strength in order for the opponent's body to achieve maximum speed and falling amplitude (Kuleš, 2008), with the most significant influence being explosive strength (Sertić and Segedi, 2013).

The results show that the average rating of the effectiveness of executing the throw by pushing the standing leg from behind is 6.45. This relatively low average rating is most likely influenced by certain irregularities noticed by the examiners during the execution of specific phases of the technique, such as improper positioning of the performer in relation to the opponent or incorrect movement of certain body segments during the disturbance of the opponent's balance and establishing contact with the opponent's body (as a prerequisite for the technique's execution), as well as improper movement of certain body segments during the actual execution of the technique. For example, the performer's right hand remains in a holding position without performing any action while pulling the opponent off balance; the initial grip made by the performer with the left hand is at the height of the opponent's right shoulder; there is a significant separation in the sagittal plane between the right side of the performer's chest and the right side of the opponent's chest during the throw; the performer's ankle forms a right angle with the leg during the action; the 'cutting' action is interrupted in its final phase (posterior ascending) because the hip joint does not complete extension but only forms an angle of 25% relative to the vertical; the performer's trunk bending during the leg push is insufficient as it does not exceed 45% of flexion relative to the vertical; during the final phase of the 'cutting' when lifting the leg that executes the push, flexion (bending) occurs at the knee joint. Due to the kinematics and dynamics of the technique of pushing the leg from behind, a disturbance in the body's balance occurs, especially pronounced in the second phase of execution, where rapid compensatory movements are made with the body and head moving forward. At this point, the performer's support area is reduced because they are on one leg, requiring them to shift the entire body weight to the front of the standing foot in order to fully control the opponent's fall to the ground. The role of the standing (left) leg of the performer is to maintain a stable position during the execution of the throw, while the other (right) leg quickly and with full force swings backward in a 'cutting' motion to push the opponent's standing (right) leg. Just before the moment of 'cutting,' i.e., detaching the opponent's leg from the ground, the performer's standing leg tends to extend at the knee joint, which helps raise the opponent's center of gravity, highlighting the flexibility of the trunk, the back part of the thigh muscles, and the hip joint. Since, just before executing the throw, the entire weight of the opponent is on their right (standing) leg, and considering that the final phase of the throw must be executed with full power (to achieve maximum speed and amplitude of the opponent's fall), the speed of the performer's swinging leg during the 'cutting' phase is a very important factor for applying strong force to the opponent's standing leg during the execution of the throw. This highlights the explosive strength of the lower limbs and the flexibility of the trunk and hip joint. These findings are confirmed by the research of Gleeson (1967); (1977); Geesink

(1977); Sarabia (1985); Kolichine (1989); Imamura & Johnson (2003); Suárez & Cortegaza (2003); and Suarez & Baker (2005).

The reason for this level of achievement in executing the technique can be attributed to the relatively small number of training sessions. The participants, within the limited time of three weeks, were unable to perform the optimal number of repetitions, which prevented them from effectively mastering or automating the taught elements of the technique. The available number of classes not only did not provide them with the opportunity to master the external form of the technique, but also hindered them from acquiring the internal form, which involves achieving the optimal dynamics and kinematics defined by the given execution criteria. Furthermore, considering the complexity of the observed technique, such a result is somewhat expected, as it is a complex technique that requires a high level of motor and cognitive abilities. Research results by Marchoka (1988), Bratić (1993), Sertić (1993), Rađo (2001), Nurkić (2005), Sertić, Sterkowicz, & Vuleta (2009), Segedi, Sertić & Leško (2014), Paspalj & Gužvica (2017), Popović et al. (2016; 2018), Popović & Popović (2023), examining the relationship between basic motor abilities and complex motor tasks (judo techniques), support this claim. The results of individual correlations between judo techniques and the system of motor variables showed that for the judo technique Osoto-gari, there is a statistically significant relationship with motor ability variables, most often explained by variables measuring speed, explosive strength, flexibility, coordination, speed, and balance. It has been proven that participants who had these abilities at a higher level mastered the judo technique of Osoto-gari much better and in a shorter period of time.

The study is limited in that it only investigated the impact of motor abilities on the efficiency of performing the Osoto Gari from the SPE. Based on research by Rađo, Kajmović, and Kapo (2001), it has been proven that, in addition to the motor ability of balance, cognitive processing is most strongly associated with the execution of the judo technique Osoto Gari. The fact that the execution of this technique does not solely depend on motor abilities has been demonstrated by Marchocka, Nowacka & Sikorski (1984); Marchocka (1988); Sertić (1993); Francini et al. (2001); Franchini, Takito, & Bertuzzi (2005); Krstulović Žuvela & Katić (2006); Jagiello, Kalina, & Korobrelnikow (2007); Paillard, Montoya & Dupoi (2007); Sterkowicz, Leach & Almansba (2007); and Sertić, Segedi & Žvan (2007), who found a statistically significant relationship between latent anthropometric dimensions and the execution of the judo throwing technique. Furthermore, they found that body volume and mass, as well as longitudinal and transversal body dimensions, contributed to the establishment of a connection between latent anthropometric variables and the quality rating of the execution of the Osoto-gari throwing technique.

Conclusion

The study examined the impact of motor abilities on the efficiency of performing the Osoto Gari from the SPE on a sample of 84 first-year students from the Faculty of Security Studies, University of Banja Luka. Regression analysis revealed a significant relationship between the efficiency of performing the rear leg push throwing technique from the SFE program and the selected set of predictor variables for assessing motor abilities. The variables that made a statistically significant contribution to explaining the criterion variable OSOTOG individually were: Hand Taping, designed to assess hand movement frequency speed, Lateral agility, designed to assess the ability for rapid direction change, Shoulder Mobility, designed to assess shoulder joint mobility, Side Lying Leg Abduction, designed to assess hip joint lateral flexibility, Bench Forward Bend, designed to assess body flexibility, and Standing Long Jump, designed to assess explosive strength in the lower extremities. These findings suggest that the above variables are predictive for performing the Osoto Gari from the SPE program. Based on the results of the regression analysis, it ccould be concluded that the efficient execution of the rear leg push throwing technique depends on motor regulation mechanisms responsible for structuring, controlling, and regulating movement, with the participation of flexibility in the shoulder and hip joints, as well as full-body flexibility and explosive strength of the lower extremities. This confirms the main hypothesis, allowing predictions for training the throwing technique and the selection of appropriate methods for its improvement. The obtained results are consistent with previous studies that explored the relationship between motor abilities and the efficiency of throwing techniques in judo. The significance of this research also lies in the fact that the results can be used during the selection process for admission to the Faculty of Security Studies, as well as during student orientation in choosing the appropriate technique, considering the predictive significance of manifest and latent dimensions, based on which it is possible to predict success when applying appropriate throwing techniques to solve problem situations that may arise in the performance of official duties and tasks in the field of security.

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References

Arlov, D. (2001). *Alati samoodbrane*. Novi Sad, RS: SIA

Banović, I. (2001). Possible judo performance prediction based on certain motor abilities and tehnical knowledge (skills) assessment. *Kineziologija* 33 (2), 5 – 19.

Božić, S. Milošević, M., & Zulić, M. (1990). Uticaj nekih antropoloških karakteristika radnika na strukturiranje motoričkih algoritama u Specijalnom fizičkom obrazovanju. Beograd. *13. Maj*, (2), 128 – 135.

Bratić, M. (1993). *Relacije između bazičnih motoričkih sposobnosti i nekih tehničkih elemenata judoa.* Neobjavljen magistarski rad, Novi Sad: Fakultet fizičke kulture, Univerziteta u Novom Sadu.

Ćirković, Z., Jovanović, S., Kasum, G. (2010). *Borenja,* Fakultet sporta i fizičkog vaspitanja, Beograd

Drid, P. (2006). Pouzdanost nekih testova specifičnih motoričkih sposobnosti u džudou. *Sport Mont,* (10-11), 243-247.

Franchini, E., Yuri Takito, M., Cavinato, C.C., Matheus, L., Bertuzzi, R.C.M., & Vieira, D.E.B. (2001). *Relationship Between Morphological, Physiological and Technical Variables in High Level College Judo Players*. In 2nd IJF World Judo Conference Munich, Germany.

Franchini, E., Takito, M.Y., & Bertuzzi, R.C. (2005). Morphological, physiological and technical variables in high-level college judoists. *Archives of Budo*, 1, 1-7.

Franchini, E., Sterkowicz, S., Meira, C.M., Gomes, F.R., Tani, G. (2008). Technical variation in a sample of high level judo players. *Perceptual and motor skills,* 106(3), 859-869. https://doi.org/10.2466/pms.106.3.859-869

García, J. M., Carratalá, V., Sterkowicz, S., & Escobar, R. (2009). A study of the difficulties involved in introducing young children to judo techniques: A proposed teaching programme. *Archives of Budo*, 5, 121-126.

Geesink, A. (1977). *Judo in evolution*. Utrecht: A.W. Bruna Zoon.

Glesson, G.R. (1967). *Judo for the West*. London: Kaye & Ward.

Gleeson, J. R. (1977). *Judo para occidentales*. Barcelona: Hispano Europea.

Hair, J., Anderson, R., Tatham, R., & Black, W. (1998). *Multivariate data analysis* (5th ed). New Jersey, USA: Prentice-Hall. Inc

Imamura RT, & Johnson BF (2003). A kinematic analysis of a judo leg sweep: major outer leg reap-osoto-gari. *Sports Biomechanich* 2(2), 191–201. https://doi.org/10.1080/14763140308522817

Jagiello, W., Kalina, R.M., & Korobrelnikow, G. (2007). Morphological diversification of female judo athletes. *Archives of Budo*, *3*, 27-34.

Kolychkine, A. (1989). *Judo. Nueva didáctica*. Barcelona: Paidotribo.

Koshida, S.; Ishii, T.; Matsuda, T.; & Hashimoto, T. (2016). Kinematics of judo breakfall for osoto-gari: Considerations for head injury prevention. *Journal of Sports Sciences,* 35(11), 1059–1065. https://doi.org/10.1080/02640414.2016.1210194

Koshida, S., Ishii ,T., Matsuda, T., & Hashimoto, T. (2017). Biomechanics of Judo backward breakfall for different throwing techniques in novice judokas. Eru J Sport Sci. 17(4), 417 – 424. https://doi.org/10.1080/17461391.2016.1268652

Krstulović, S., Žuvela, F., & Katić, R. (2006). Biomotor systems in elite junior judoists. *Collegium antropologicum*, 30(4), 845-851. PMID: 17243560

Kuleš, B. (2008). *Trening judaša*. Zagreb, RH: Kugler

Liu L, Deguchi T, Shiokawa M, Ishii T, Oda Y, Shinya M. (2021). A biomechanics analysis of the judo osoto-gari technique: comparasion of black belt and white belt judokas. Sports Biomech. 2021 Oct 18:1-13. https://doi.org/10.1080/14763141.2021.1990993

Marchocka M, Nowacka E, & Sikorski, W. (1984): Specific body build of judo athletes depending on the fighting technique used. *Biol Sport,* 3: 261–264

Marchocka, M. (1988). Body build and preferred techniques of judo fight. *Sport Wyczynowy*, 9, 25-31.

Metikoš, D., Hofman, E., Prot, F., Pintar, Ž., & Oreb, G. (1989). *Mjerenje bazičnih motoričkih dimenzija sportaša.* Zagreb, RH: Fakultet za fizičku kulturu.

Milošević, M., (1985). *Određivanje strukture motoričkih svojstava milicionara*, Beograd.

Nurkić, M. (2005). *Uticaj motoričkih sposobnosti na efikasnost izvođenja džudo tehnika u stojećem stavu.* I. Rađo (Ur.), Zbornik naučnih i stručnih radova (str. 298-304). Sarajevo: Nove tehnologije u sportu.

Orr, R. M., Kukić, F., Čvorović, A., Koropanovski, N., Janković, R., Dawes, J., Lockie, R. (2019). *Associations between Fitness Measures and Change of Direction Speeds with and without Occupational Loads in Female Police Officers.* Int. J. Environ. Res. Public Health, 16(11):1947. https://doi.org/10.3390/ijerph16111947

Orr, R., Kukic, F., Marins, E., Lim, C., Dawes, J., & Lockie, R. (2020). *The impact of load carriage on lower-body power in SWAT police.* In proceedings of the 10th International scientific conference "Archibald Reiss Days" (Vol. 10, No 1). Belgrade: Academy of Criminalistic and Police Studies in Belgrade, November 18-19, 2019

Paillard, T., Montoya, R., & Dupui, P. (2007). Postural adaptations specific to preferred throwing techniques practiced by competition-lekel judoists. *Journal of Electromyography and Kinesiology,* 17(2), 241-244. http://dx.doi.org/10.1016/j.jelekin.2006.01.006

Paspalj, D., & Gužvica, M. (2017). Značaj ravnoteže za izvođenje tehnike bacanja izbijanjem noge otpozadi. *Sportlogija* 13(1), 18 – 28. https://doi.org/10.5550/sgia.171301.se.PG

Popovic, D., Boli, E., Popovic, M., Savic, V., Popovic, J., & Bojovic, M. (2016) Determination of differences in motor dimensions between judo and karate athletes. *Journal of Sports Science*, 170-174.

Popovic, D., Mitic, D., Popovic, J., & Boli, E. (2018). „Factor analysis as optimal method in determining motoric abilities of perspective judokas". *Facta Universitatis, Series Physi al Education and Sport,* 16 (1).

Popović, M., & Popović, J. (2023). Degree and quality of the connection of motor skills and judo techniques. *Baština* 33(59), 385 – 393. DOI: https://doi.org/10.5937/bastina33-43439

Rađo, I., Kajmović, H., & Kapo, S., (2001), *Judo,* Fakultet sporta, Sarajevo.

Rexhepi, F., & Hraski, Ž. (2011). Osnovne biomehaničke karakteristike druge faze bacanja (tsukuri) judo nožne tehnike osoto gari. *Sport Mont Journal* 31/32/33(9), 249 – 254.

Sacripanti, A. (1989). Biomechanical Classification of judo throwing techniques. In: Biomechanics in Sports Eds: Tsarouches, V.L. Terauds, J., Gowitzke, B.A., and Holt, E.L. Proceedings of the Fifth International Symposium of Biomechanics in Sports, held in Athens, Greece*, Athens Hellenic Sports Research Institute of Olympic Sports Center Athens. 181-194.*

Santos, S. G. d. e Melo, S. I. L. (2001). Biomecânica aplicada ao judô. FRANCHINI, E. *Judô desempenho competitivo,* 1, 97-125.

Santos, L.; Fernandez-Rio, J.; Ruiz, M.L.; Del Valle, M.; Callan, M.; Challis, D.; Sterkowicz, S. (2014). Three-dimensional assessment of the judo throwing techniques frequently used in competition. *Arch. Budo* 10, 107–115.

Sarabia, F. (1985). *Cinturón negro de Judo*. Madrid: Esteban Sanz Martínez. ISBN: 8485977173

Segedi, I., Sertić, H., & Leško, L. (2014). *Construction and validation of the tests for the assessment of specific coordination in judo*. 5th European Science of Judo Symposium. Montpellier, Francuska.

Sertić, H. (1993). Utjecaj longitudinalne dimenzionalnosti tijela na uspjeh u izvođenju nekih bacanja u judu. *Hrvatski športskomedicinski vjesnik,* 1, 10-16.

Sertić, H. (1997). Povezanost kordinacije s uspjehom i efikasnošću u judo borbi jedanaesto godišnjaka. *Hrvatski športkomedicinski vjesnik*, (2-3), 70-75. 74.

Sertić, H. & Vuleta, D. (1997). Utjecaj varijable za procjenu repetitivne i eksplozivne snage sa uspjehom u judo borbi kod djece od 11 godina. *Kineziologija,* 29 (2), 54-60. URI https://hrcak.srce.hr/256449

Sertić, H., Segedi, I., & Žvan, M. (2007). Relations of certain anthropometric variables with the performance quality of throwing techniques in judo. *Kinesiologia Slovenica,* 13 (1), 48-60.

Sertić, H., Sterkowicz, S., & Vuleta, D. (2009). Influence of latent motor abilities on performance in judo. *Kinesiology,* Vol. 41 (1); 76-87.

Sertić, H., & Segedi, I. (2013). *Judo osnove*. Gopal, Zagreb.

Sterkowicz, S., Lech, G., & Almansba, R. (2007). The course of fight and the level of sports achievements in judo. *Archives of Budo*, *3*, 72-81.

Suarez, S. & Cortegaza, L. (2003). O Soto Gari: errores típicos que ocurren durante su aprendizaje. Causas. *Lecturas: Educación Física y Deportes*, Revista Digital - Buenos Aires - Año 8 - Nº 58.

Suarez, C.J., & Baker, G. (2005). *Throwing Technique Structural Analysis - The Basis of Teaching Methodology.* JudoInfo.com, USA.

Toskić, D., Lilić, Lj. & Toskić, L. (2014). The influence of a year – long judo training program on the development of the motor skills of children. *Activities in PhysicalEducation and Sport*,4(1), 55-58.