The Association between Lower Extremities Muscle Strength and Hop Performance in Healthy Participants

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Abstract – The present research analyses the correlation between single horizontal (SHH) and crossover (COH) hops for distance performances, alongside measuring muscle strength. The ankle plantar flexors (APA), knee flexors (KF), extensors (KE), and hip extensors (HE) were tested isokinetically using the variances of peak torque (peak TQ) and peak torque to body weight (peak TQ to BW) as well as through isometric action. Overall, twenty recreational athletes (male, aged 32.4±4.5; height 171.1±6.0 cm; mass 78.4±16.6 kg) were analysed, who performed 3 trails of SHH and COH with their dominant leg; 3 trails of isometric testing for all muscle groups, while utilising hand-held dynamometry (HHD); and by using a Biodex system (testing speed 60°/sec) with 3 trials of isokinetic muscle tests through 5 maximal effort trials. Between the dominant and non-dominant leg during the hop performance or muscle strength tests for the first-tenth participants no differences were presented. In isometric muscle strength tests, the strongest relationships were between HE, KE and KF, with SHH ($r \geq 0.500$, $P \leq 0.029$) and between HE with COH ($r=0.597$, $P \leq 0.007$). Whilst in isokinetic tests, the strongest correlation was between peak TQ to BW of HE, KF and APF with SHH ($r \geq 0.665$, $P \leq 0.001$) and between peaks TQ of HE with COH for distance ($r \geq 0.613$, $P \leq 0.004$). Therefore, a more beneficial indicator of hop performance measurements may be demonstrated through muscle strength measurements that incorporate body weight. Furthermore, the advanced correlation between hop tests and peak force may relate to the form of muscular contraction, as a substantial correlation was shown from concentric isokinetic muscular contraction from HE, KE and KF.

Keywords: Functional Performance Tests, Isometric, Isokinetic.

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1. INTRODUCTION

Throughout both physiotherapy and sport, the outcome measurements from clinical and research practice have been detailed continuously, which assists in effectiveness comparison evaluations from various interventions in clinical trials[1], as well as through patient assessments[2,3]. The focus of various investigations has been post-operative rehabilitation for anterior cruciate ligament reconstruction (ACLR)[4], which is common in orthopedic physical therapy[5]. In fact, in the process of comparative post-operative rehabilitation strategies, outcome measures are valuable in patient assessment for those receiving physical therapy.

It is prominent for hop tests to be used as a detailed measurement of performance in order to analyse an individual's lower limb neuromuscular control, strength and confidence development[6,7]. Moreover, it has been shown that functional testing can highlight functional limitations for various populations[8-11,]. Furthermore, muscle strength and the progressive capabilities of athletes are commonly evaluated through primary assessment tools, which produce findings that correlate to a pre-injury function comparison. Thus in order to indicate this, tests have regularly incorporated an isometric Hand-held dynamometry (HHD)[12,13] or an isokinetic dynamometry (Biodex system).

In general, Isokinetic dynamometry is used to evaluate quadriceps' strength in both healthy and post-ACL athletes[14-16], although most post-ACL tests have used peak torque (peak TQ) as the outcome measurement[16]. In fact, quadriceps' peak TQ demonstrates the value where an individual is capable of producing the greatest force[17], which is during a 90-0° knee extension. However, Peak TQ sometimes only divulges restricted information in relation to muscle performance through various motions[18]. Similarly, peak TQ percentage to normalized body weight is a contrasting parameter of isokinetic muscle strength, which defines an estimated aim, and becomes more relative to active functions[10].

Several authors[18,19-21] have ascertained found invaluable correlations of a positive nature that derive from functional performance tests to isokinetic strength of knee extensors. Contrastingly, between isokinetic strength of the KE and several functional performance tests through various investigations, minimal or no correlation was observed[22,23]. Nonetheless, only one solitary research paper[24] has analysed and evaluated the function of hop performance to the isometric connection of lower extremity strength, despite the prevalence of particular investigations being restricted to the focus of knee and thigh muscles. Additionally, through distance by functional performance test measurements, that solitary study hypothesised substantial peak force relevance within the hips and thighs. However, the investigative results did not completely support the hypothesis, due to their formation of between (r= 0.10-0.29), and because it was the only study to contribute to a substantial percentage of the male variance of peak force for hip flexors (r^2 = 0.29), as signified by the SHH distance test. The majority of activities of function incorporate a combination of patterns that are either open- or closed- chain. However, due to the advanced emphasis upon exercise to be closed- chain, measurements of rehabilitation develop into a necessity through the use of exercise that is closed-chain, which is subsequently contrasted to the tests of muscle strength[25].

Overall, the present study aims to distinguish the muscle strength correlation of ankle plantar flexors, hip extensors, and knee flexors and extensors, from a single horizontal hop test that is performed both in horizontal and crossover (for distance) hops. This is measured through both isometric and isokinetic muscle actions that incorporate the peak TQ and peak TQ/BW variables.

2. METHODS

2.1 Experimental Approach to the Problem

A single group correlation design was incorporated in order to distinguish the evidential connection to the single horizontal and crossover hop distance performance from the joint muscle strength through ankle plantar flexors, knee flexors, extensors and hip extensors, which was analysed through a set group of subjects.

2.2 Subjects

Twenty recreational athletes, (male, aged 32.4±4.5; height 171.1±6.0 cm; mass 78.4±16.6 kg) were evaluated, who were deemed "healthy" by their capacity to land from jumping, whilst also being capable of independent knee, ankle and hip flexing and extension. Moreover, these athletes had to be physically active for at least 3 times per week, 1 hour at a time[26]. Likewise, subjects suffering from detrimental leg soreness were excluded, as well as those with an injury in the previous half a year. Furthermore, the University of Salford Ethics Committee provided approval, as all the participatory individuals signed a consent form prior to testing.

2.3 Procedure

All measures were collected on the dominant limb for both hop performance and muscle strength, which was determined through the stated definition by participants to their preferred foot for kicking a football[27]. Participants were also instructed to use the same footwear throughout testing in order to avoid unreliable conflicting results from additional factors. Additionally, no eating for one hour and no exercise in the 24 hours pre-testing was permitted[17].

2.4 Tests:

In total, each participant's test session lasted 45 minutes, together with a pre-test 5 minute bicycle warm-up with minimal resistance, to prevent potential injury[28], as well as a practice trial for each of the three tests was undertaken[29]. Through the incorporation of a one minute energy rejuvenation between trails, alongside a maximal 5 minute rest between the three separate tests, the entirety of the trials were randomly recorded[26].

2.4.1 Hop Tests:

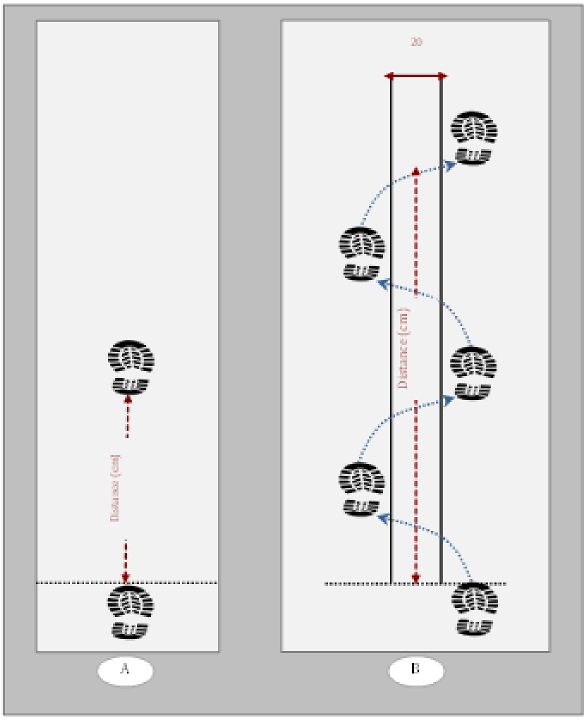
Three trials were performed for both legs that incorporated 2 hop tests, while no upper-extremity restrictions were placed. The toe of the shoe, placed at the defined line, stipulated the start measurement of the test, while the heel of the landing foot defined the landing measurement, following a two second landing hold instructed to the subject **(Figure 1)**. This was deemed "a fail" if the opposite leg or hand made contact with the ground during landing.

2.4.1.1 *Single horizontal hop for distance:*

Through a same leg landing, the participatory individual was instructed to hop forward directly to a maximal distance by the side of the measuring tape placed on the floor.

2.4.1.2 *Crossover hop for distance:*

Participants balanced on their leg to be tested at the line before alternatively hopping forward four times across a 20-cm-wide line, which assisted in measuring two equivalent landings on either side.



A. Single horizontal hop for distance

B. Crossover hop for distance

Figure 1. Hop performances:

2.4.2 Muscle strength tests:

2.4.2.1 *Isokinetic muscle strength test:*

Through the implementation of Biodex System 4, the independent muscle strength of hip extensors, knee extensors and flexors, and ankle plantar flexors were the intended measurements of this specific test (Biodex Medical Systems, Inc, Shirley, New York, USA). During the test, a random order was incorporated for the joints and muscle groups (flexors, extensors) throughout the five maximal effort trials for both legs, while the testing velocity for the muscle groups was set at a standard 60°/sec **(See Figure 2)**.

Figure 2. Isokinetic muscle test positions

Knee extensors and flexors tests: The subjects were seated at a 90° hip angle with arms positioned across the chest, and for stabilisation straps were fastened around the tested thigh and waist. Likewise, through the evaluation of knee extension and flexion, the dynamometer's rotational axis was set at the lateral femoral epicondyle, with 0°-90° (full extension) set as the average range of motion during knee testing.

Ankle plantar flexor test: Participants were seated with a hip flexion of 80°, a semi-extended knee, and arms across the chest, while for stabilisation straps were fastened around the waist. As part of the dynamometer, a guidance shoe was utilised to restrict movement, with the rotational axis set next to the fibular lateral condyle. Throughout the ankle plantar flexor test, 0° to 50°-55° was set as the approximate mean motion range.

Hip extensor test: Subjects were laid down horizontally on a reclining backrest facing upwards, and stabilised with straps around the trunk and pelvis. A pad for resistance was subsequently connected to the thigh at the distal part, while the dynamometer rotational axis was placed with the hip joint axis, while throughout the hip extensor test, 0° was set as the average maximal hip flexion. In addition, prior to the isokinetic tests, participants were informed to practice once to increase familiarisation, and then they were given 2-5 minutes rest following each section of the test.

2.4.2.2 *Isometric Muscle Strength:*

The same positions and muscles were utilised as with the isokinetic testing **(See Figure 3)**, although the subjects were required to enforce maximum effort in the restriction of the applicator in order to obtain an accurate force recording prior to the removal of the hand-held dynamometer from the tested leg. Each test comprised of 3 individual 3-seconds trails, a 5-seconds rest between each one, and a one-minute rest period for muscle changeover.

Figure 3. Isometric muscle test positions

2.5 Statistical analysis

Throughout the process of statistical analysis, in order to ascertain the results SPSS (version 22.0) was utilised, and the distance in the hop tests was measured in centimeters by a tape measure in centimeters and normalized to limb length[17]. In addition, in order to examine contrasting variables (i.e. peak TQ and peak TQ to BW) within testing for isokinetic muscle strength, Biodex software was incorporated to collect the data. Meanwhile, a hand-held dynamometer (HHD) was utilised in the measurement of peak force in Newton (N) for the testing of isometric muscle strength. Subsequently, following the full testing procedure, a spreadsheet was utilised to calculate the mean result of the three individual test sessions.

A previous reliability analysis was implemented to document the consistent reliability of between days; intra-class correlation coefficients (ICCs) model in relation to confidence intervals (CIs), and the standard error of measurement (SEM). Overall, the ICC classification (excellent = more than 0.75, between fair and good 0.4-0.75, poor = lower than 0.4) was utilised in the description of the range of values[30].

Through the use of Shapiro-Wilk testing in SPSS, the entirety of the data was analysed for normal distribution. Likewise, Pearson's product moment correlation coefficients test was calculated to ascertain the relationship between dominant and non-dominant limb performance over 10 participants, as well as to evaluate the association between the hop performance and muscle strength of the lower extremity for the dominant limb. Correlation coefficients were defined as: below 0.1 as "none", exceeding 0.1 but below 0.3 as "small", exceeding 0.3 and below 0.5 as "medium", and exceeding 0.5 as "large"[31]. Overall, in order to investigate the relationship among variables in percentages, simple linear regression analysis was utilized to determine the main predictive variables for the hop performance.

3. RESULTS

During the hop tests the ICCs values ranged between 0.926 and 0.994, the isometric testing ranged between 0.586 and 0.797, and in the isokinetic testing the range was between 0.619 and 0.958. Paired *t* tests revealed no noticeable difference to be evident between the D and ND leg during all of hop performance or muscle strength tests for the first-tenth participants, whether that be for the left or right leg **(Table 1)**. Descriptive data were recorded (means, SDs) for each variable **(Table 2)**.

Table 1. Relationship between **D** and **ND** leg performance *.

Variables		*r*	*p*	*t-test*
Hop performance				
Single horizontal hop (cm)		.855	.002	.455
Crossover hop (cm)		.965	.000	.248
Isometric muscle strength tests				
HE (N)		.890	.001	.804
KE (N)		.783	.007	.149
KF (N)		.870	.001	.878
APF (N)		.650	.042	.188
Isokinetic muscle strength tests				
HE	Peak TQ (N. M)	.819	.004	.508
	Peak TQ/BW (%)	.636	.048	.580
KE	Peak TQ (N. M)	.832	.003	.443
	Peak TQ/BW (%)	.690	.027	.343
KF	Peak TQ (N. M)	.671	.034	.121
	Peak TQ/BW (%)	.749	.013	.091
APF	Peak TQ (N. M)	.695	.026	.065
	Peak TQ/BW (%)	.888	.001	.059

* For the first-tenth participants.
D = Dominant, **ND** = Non-dominant, **HE**= Hip extensors, **KE**= Knee extensors, **KF**= Knee flexors, **APF**= Ankle plantar flexors.

Table 2. Mean ± Standard deviations values.

Variables		Dominant-leg
Hop performance		
Single horizontal hop (cm)		131.8 ± 22.1
Crossover hop (cm)		473 ± 95.7
Isometric muscle strength tests		
HE (N)		277.7 ± 43.5
KE (N)		299.1 ± 59.7
KF (N)		166.7 ± 41.0
APF (N)		232.6 ± 22.5
Isokinetic muscle strength tests		
HE	Peak TQ (N. M)	146.3 ± 26.1
	Peak TQ/BW (%)	191.7 ± 42.7
KE	Peak TQ (N. M)	198.7 ± 15.3
	Peak TQ/BW (%)	254.5 ± 48.7
KF	Peak TQ (N. M)	150.4 ± 16.1
	Peak TQ/BW (%)	191.8 ± 37.3
APF	Peak TQ (N. M)	213.1 ± 33.4
	Peak TQ/BW (%)	273.8 ± 58.4

HE= Hip extensors, **KE**= Knee extensors, **KF**= Knee flexors, **APF**= Ankle plantar flexors.

Following isometric muscle strength tests, the strongest relationships were evaluated between HE, KE and KF with a single horizontal hop ($r \geq 0.500$, $P \leq 0.029$) and between HE with crossover hops for distance (r = 0.597, P ≤ 0.007). Whilst in isokinetic muscle tests, the most prevalent relationship was between peak TQ to BW of HE, KF and APF with a single horizontal hop (r ≥ 0.665, P ≤ 0.001) and between peak TQ of HE with crossover hops for distance (r ≥ 0.613, P ≤ 0.004) **(Table 3)**.

In addition, stepwise linear regression modeling **(Figure 8)**, using isometric muscle strength of the lower extrimity to predict hop performance, demonstrated that the strongest predictor was knee extensors' strength. However, the strongest predictor of isokinetic muscle strength was peak TQ to BW of knee flexors for single horizontal hop and peak TQ of hip extensors for the crossover hop. Indeed, the isometric knee strength test predicts 45.19% of the single horizontal hop for distance **(Figure 4)**, and 35.61% of crossover hop for distance **(Figure 5)**. While the isokinetic (peak TQ to BW) knee flexors strength predicts 43.27% of a single horizontal hop for distance **(Figure 6)**. Moreover, isokinetic (peak TQ) hip extensors strength predicts 37.46% of crossover hop for distance **(Figure 7)**.

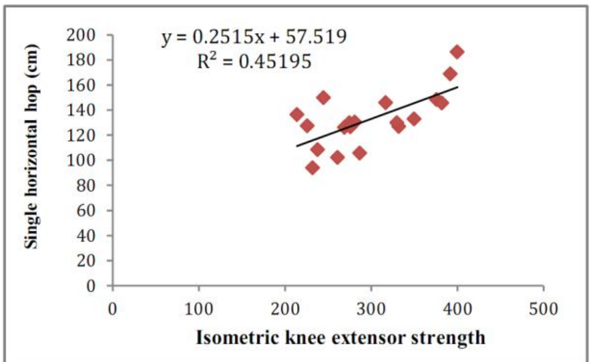


Figure 4. Isometric knee extensor strength predicting the single horizontal hops performance.

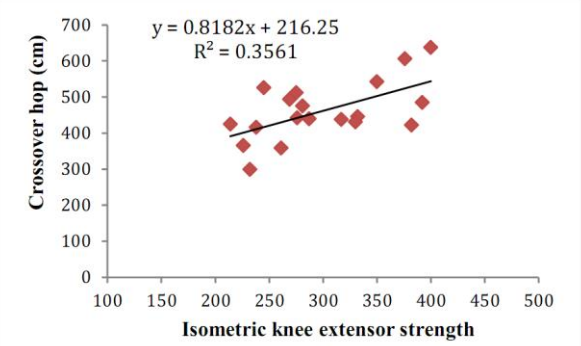


Figure 5. Isometric knee extensor strength predicting the crossover hops performance.

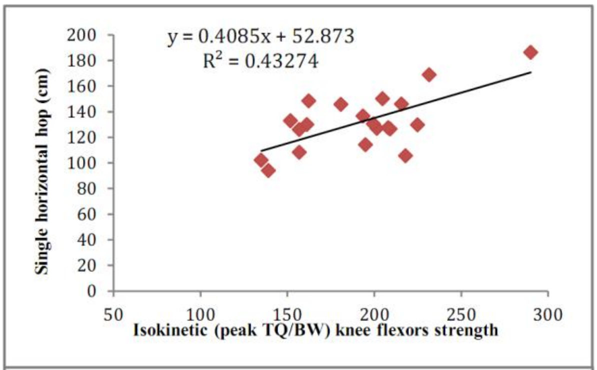


Figure 6. Isokinetic (peak TQ to BW) knee flexors strength predicting the single horizontal hops performance.

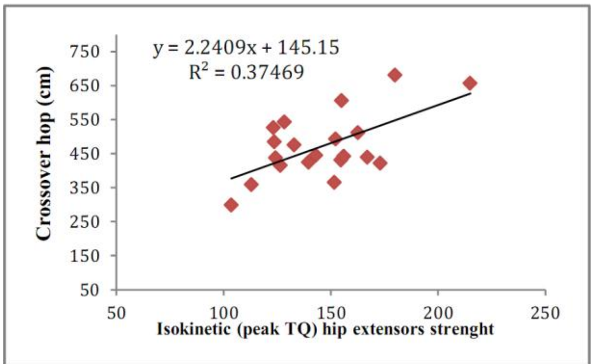
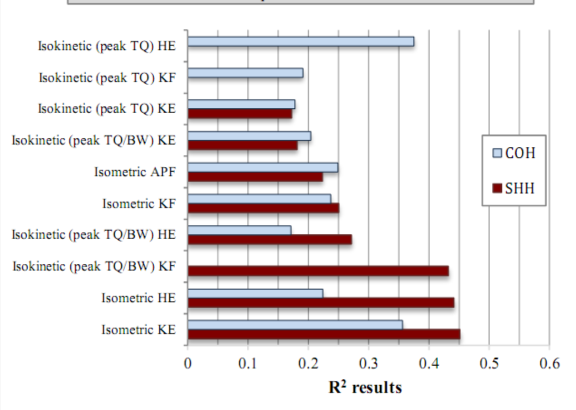


Figure 7. Isokinetic (peak TQ) hip extensors strength predicting the crossover hops performance.

Figure 8. linear regression modeling of muscle strength predicting hop performance



4. DISCUSSION

It is feasible to evaluate the capability of an athlete's return to their pre-injury level through various tests, although a functional test is perceived as the most recommendable, as these tests function with strenuous activities, such as hopping. Thus, it will become possible to develop factors, such as muscle strength[32], motion control while positioned in the preparatory squat, and the production of a substantial concentric contraction that functions against individual body weight.

Initially, the current study's results have demonstrated that no significant differences are evident between the D and ND limbs when testing muscle strength (isometric and isokinetic), as well as in the hop performance (SHH and COH), as these findings substantiate previous research[23,33,34]. In fact, only 3 individuals from the focus group of 20 were observed to have their left leg as the dominant limb.

It can be discerned that the results from the present study indicate the existence of a moderate to strong correlation (r ≥ 0.464) between isokinetic muscle strength of KE and KF and the hop performance, as these results were mostly confirmed by previous studies[23,7,18]. Similar findings (r ≥ 0.487) have been obtained when testing the relationship between isometric muscle strength and both SHH and COH for distance. However, weak to moderate correlations have been shown in a separate study[9] to be evident following the performance of a single leg hop (0.13 – 0.42) and concentric knee extensor strength at 60°/sec during the week post-arthroscopic meniscectomy. Nevertheless, those correlations results decreased to between 0.10 and 0.25 by the fifth week of the rehabilitation programme. Consequently, depending on the elapsed post-surgical duration, together with the methodology, it is possible to perceive an evident small to medium correlation between the functional hop and isokinetic measurements.

In addition, a significant correlation (r ≥ 0.463) is indicated to exist through the present study when comparing the combined isometric and isokinetic strength of HE, together with SHH and COH for distance. Indeed, one possible explanation for this can be obtained from a previous study[35], where through the increase of hip muscle activity during a vertical jump, the quadriceps' and hamstrings' ability in force resistance was shown to significantly improve during the jumping process. Likewise, as a more rapid manner has been distinguished in comparison to the contrasting movements within the joints of the lower limb joint, it has been stipulated that the mono-form of upward–forward acceleration increase from the central point of mass originates from the advancement of hip-joint movements.

The current study also ascertains a more accurate reflection of an individual's ability in a functional hop test performance by utilising the muscle synergies that are imperative in optimal performance, which is obtained through the isokinetic peak TQ/BW variable that functions through an subject's weight. Furthermore, One of the main findings from the current study is presented by no significant evidential contrasts within outcome measurements between isokinetic peak TQ/BW for HE, KE and KF, or isometric measures for the same muscles group. Hence, as no significant differences were founded between the two measurements, which means that the practitioner is required to consider the utilisation of either form, or the incorporation of a measurement type combination of for patient rehabilitation.

As a consequence of the minimal literature in this field of research, it has become increasingly challenging in the comparison between more findings to those from prior studies, although comparisons are permitted through the results found between SHH for distance and muscle strength. It has been stated by researchers that from the SHH test with isokinetic speed 60°/sec[20,34] that a possibility to predict 40% to 44% of the variance in KE peak TQ becomes feasible. The current study demonstrated that SHH for distance explained 45.1% and 44.1 of the variance in isometric KE and isometric HE peak force respectively, which was closer to an earlier report[20,34] using isokinetic instrumentation at 60°/sec for KE. Nonetheless, the correlation between hop performance and KF strength in the present research was below the values those investigators reported, who had utilised isokinetic instrumentation [1].

Through previous study[21], it has been stated that 57% of the variance of isokinetic KF peak TQ at 60°/sec could hypothesise the distance of a triple-hop, where two individual investigations[27,21] represented a unisex study group. Comparatively, one other specific unisex investigation[24] ascertained that 36% of the variance in KE peak force was the percentage from the triple hop distance, which aligns with the results of the current research that demonstrated 35.6% of the COH for distance to be predicted by the peak force of KE. Therefore, the overall results reiterate that separate data analysis for individual gender is an evidential requirement within research, as variance overestimation that is accounted for by the specific measurement of functional performance is a common result of unisex investigative groupings. Invariably, the contrasts between genders may have been presented by the connections in previous investigations[21,23,36], as men generally represented higher values than women.

As a consequence, clinicians may not be provided with the adequate information in order to discern evidence-based decisions regarding the strength of an isolated muscle group following the mere conduction of hop tests. Thus, researchers in the future need to progress the investigations to fully comprehend the correlation from hop tests to strength from other factors that are presented by characteristics of muscle fibers, the consideration of force development levels, and the muscle-tendon complex integration.

Overall, the present study has acknowledged four specific limitations within its structure and process. Firstly, the results may not be generalizable beyond the present sample, as a sample of convenience was studied and not a random sample. Secondly, only 20 participants were analysed, which may require a size increase in order to discern different variable contrasts. Thirdly, different forms and levels of athletic participation, together with years of experience, could have proven beneficial on the performance for both the muscle strength and functional performance tests performed by the recreational athletes. Fourthly, due to the fact that purely male individuals participated in the current study, it is acknowledged that the results cannot be rationalised to females.

5. PRACTICAL APPLICATION

In comparison to isometric or isokinetic instrumentation[21,37], functional performance tests as a practical form represent a more time-efficient and cost-effective method in the assessment of muscle function. Through the evaluation of muscle function, different methodological approaches, such as integration versus isolation, are represented in the process of functional performance tests, as well as this is also prevalent through single-joint isometric or isokinetic procedures of testing. Hence, the unsegregated form of an entire leg's function is duly analysed through an individual's functional performance, as varied velocities of movement are measured in neuromuscular coordination, power and strength, together with their multiple joint functional stability[21,38].

The findings from the current study indicate that in order for the provision of an improved hop performance measurement; body weight needs to be incorporated into the muscle strength measurements. Moreover, the strength of the relationship between hop tests and peak force is a function of the manner of muscular contraction, as the greater associations noted with concentric isokinetic muscular contractions are based on the isometric findings from the current research study, as well as related to previous isokinetic investigations. Nonetheless, it may be more beneficial in the determinant process into lower extremity strength deficits during pre-participation examinations, as well as sideline evaluations in the assessment of return to action, to conjoin hop tests with a separate form of performance test in order to demonstrate maximal strength[16] , even though hop tests are generally cost and time efficient.

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