Short Communication

Isometric mid-thigh pull force-time characteristics: A good indicator of running performance

Danny Lum, Kelvin Chua, Abdul Rashid Aziz

Objectives: The relationship between force-time characteristics obtained from isometric mid-thigh pull (IMTP) and endurance running performance has not been studied. The purpose of this study was to investigate the relationships between force-time characteristics obtained from IMTP with indicators of endurance running performance.

Design and Methods: Participants attended a familiarisation session to be familiarised with all testing protocols. Subsequently, they completed the IMTP and a 2.4-km run time trial (2.4-kmTT) on the first testing session. Post 48-72 h of the first session, they then performed a running economy (RE) test at 12 km.h^{-1} and graded exercise test on the second testing session.

Results: Significant inverse correlations between all IMTP measures and 2.4kmTT was observed (r = -0.53 to -0.78, p < 0.01). Similarly, all IMTP measures were significantly correlated to maximal aerobic speed (r = 0.38 to 0.66, p < 0.05) except Force at 150 ms. There were significant correlations between IMTP peak force, net peak force and rate of force development (0-150 ms) with lower limb stiffness (r = 0.41 to 0.49, p < 0.05). Force at 100 ms and all rate of force development measures were significantly correlated to RE (r = -0.44 to -0.68, p < 0.05).

Conclusion: Findings showed that measures obtained from IMTP are good indicators of endurance running performance and can provide insights into the force generating capability required by endurance runners. In addition, the significant correlations between strength measures and running performance suggest that muscular strength may be an important determinant of running performance.

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Key words: Muscular strength ■ Leg stiffness ■ Running economy

INTRODUCTION

The benefits of including resistance training to the endurance runners' training program are well evident within the literature.[1,2] Resistance training elicits neurological and morphological adaptations[3], resulting in changes to indicators of running performance such as enhanced running economy[4] (RE) along with maximal force and power production[1], increased velocity associated with VO_{2max}[2], and reduced rate of fatigue[5], which ultimately improves running performance. However, Ferrauti et al.[6] reported no improvement in RE after eight weeks of strength training in recreational marathon runners. Such discrepancy could be due to the difference in methods of resistance training used[7] or the volume of endurance training[2]. In view of these findings, it is important to have a better understanding of the relationship between muscular strength and indicators of running performance.

The use of the isometric mid-thigh pull (IMTP) as an assessment that can be used to measure the lower limb's maximum force generating capability (peak force), the rate at which force is developed (rate of force development) and force produced at various time point (force epoch). The IMTP was first described by Haff et al.[8] Since then, multiple studies have been conducted to investigate the relationship between isometric force-time characteristics obtained from IMTP with various sports related dynamic movements.[9] Specifically, significant inverse correlation between sprint running times for distances between 5-30 m with IMTP peak force (PF), rate of force development (RFD), and force epochs between 100-200 ms have been reported.[9,10] For example, Townsend et al.[10] reported significant correlation between IMTP PF with 5-20 m sprint time (r = -0.62 to -0.69). RFD (50-250 ms) obtained from IMTP was also significantly correlated to sprint average power (r = 0.43 to 0.59). Although multiple studies have reported significant correlation between sprint running performance with IMTP force-time characteristics, to the authors knowledge, no study has investigated the relationship between IMTP force-time characteristics and prolonged running, i.e., endurance performance. As various measures along the force-time curve can be obtained from IMTP, investigating the relationship between IMTP force-time characteristics and endurance running performance might provide further insights into the force generating capability that may contribute to improving or enhancing endurance running performance.

In view of this, the purpose of the current study was to investigate the relationships between force-time characteristics obtained from IMTP with indicators of endurance running performance. It was hypothesised that early isometric force production would be significantly correlated to indicators of endurance running performance.

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METHODS

Experimental Design

Participants attended an initial session to be familiarised with all testing protocols. Subsequently, they completed an isometric mid-thigh pull (IMTP) and a 2.4-km run time trial (2.4-kmTT) on the first testing session. Post 48-72 h of the first session, they then performed a RE and graded exercise test (GXT) on the second testing session. Gas analysis, blood lactate (Bla) concentrations and heart rate (HR) were measured during RE test and GXT. Leg and vertical stiffness and RE were measured during RE test at 12 km.h^{-1}.

Subjects

Twenty-eight endurance runners (male: *n* = 20, female: *n* = 8, age: 22 ± 4 years, stature: 1.69 ± 0.09 m, body mass: 67.6 ± 8.6 kg, VO_{2max}: 51.7 ± 6.6 ml.kg.min^{-1}) were recruited for participation in this study. Participants had a weekly running mileage of more than 30 km, had a 2.4 km running time less than 12 min and were free of any lower limb injuries, and had resistance training experience ranging from 0-5 years.

Prior to commencement of the study, all participants were briefed on the requirements and risks involved with the study and signed a written informed consent. The study commenced after obtaining ethical clearance from the institutional human research review board at the Nanyang Technological University and Singapore Sport Institute.

Procedures

All testing sessions began with 5 min moderate intensity jogging on a motorized treadmill, followed by lower limb dynamic stretches. One minute of recovery period was given prior to commencing the tests for that day.

Isometric Mid-Thigh Pull: The IMTP was performed on a dual force plates (Vald Performance, FD4000, Queensland, Australia) sampling at 1000 Hz and a customised rack. Procedures of IMTP followed the guidelines described by Comfort et al.[11] Participants were asked to adopt a posture that reflected the start of the second pull of the clean resulting in a knee flexion angle of 125º-145º and hip flexion angle of 140º-150º stance. A handheld goniometer was used to ensure that subjects adopted the required knee and hip angles. Participants were required to fully extend the elbows, hold on to the bar with hands strapped to the bar with lifting straps to prevent grip from being a limiting factor. The highest force generated during IMTP was reported as the absolute PF. In addition, force at 100, 150 and 200 ms, ($Force_{100}$, $Force_{150}$ and $Force_{200}$) and rate of force development at 0-100, 0-150 and 0-200 ms (RFD_{0-100}, RFD_{0-150} and RFD_{0-200}) from the onset of pull were determined for each trial as values correspond with ground contact time during running.[13]

2.4-km Run Time Trial: This field test was selected because it has been shown to be a valid and reliable test, with high correlation to direct VO_{2max} treadmill test.[12] Participants performed a 2.4-kmTT 10 min upon completion of IMTP. The 2.4-kmTT was conducted on an outdoor running track. The 2.4-kmTT was timed with a stopwatch (Casio, Japan). Environmental conditions of the 2.4-kmTT was 29-31ºC and 78-83% relative humidity.

Running Economy and Graded Exercise Test: The RE tests and GXT were conducted on a motorized treadmill (Venus; HP-Cosmos, Nussdoff-Traunstein, Germany). The treadmill was set to 1% grade to simulate external environmental factors.[14] During the RE tests, participants ran 4 min at 12 km.h^{-1}. Collection of finger capillary blood samples to assess Bla occurred during the 1 min period between each speed. The Bla was measured using a lactate analyser (Lactate Pro; Arkay, Kyoto, Japan). The GXT commenced after a 6-min passive recovery from the RE test. An initial speed of 8 or 9 km.h^{-1} was used. The treadmill speed increased by 1 km.h^{-1} every minute until exhaustion.[15] The speed that corresponded to VO_{2max} was taken as the individual's maximal aerobic speed (MAS).

Concentrations of O_2 and CO_2 in expired air were analysed continuously during the RE and GXT using an open circuit spirometry system (TrueOne 2400MMS; Parvomedics, East Sandy, Utah, USA) which was calibrated before each trial in accordance with the manufacturer's specifications. The sum of the two highest consecutive 30-s values during the RE run test and GXT was used as the participant's RE and VO_{2max}, respectively. Heart rate was measured using a HR monitor (RS400; Polar Electro Oy, Kempele, Finland) during the last 10-s of each stage.

Leg and Vertical Stiffness: Leg stiffness (k_{leg}) and vertical stiffness (k_{vert}) during the RE tests were determined using the sine-wave calculation method.[16] Kinematic data for calculation of the stiffness characteristics were obtained by placing an optical system consisting of 2 bars (Optogait, Microgait, Italy) beside the moving belt of the treadmill.[5]

Running Economy: The RE was calculated by combining aerobic energy metabolism, calculated from VO_2 and the respiratory exchange ratio (RER), with anaerobic energy metabolism, calculated from the change in Bla.[17]

Statistical Analysis

All tested variables are expressed by Mean (±1 SD) and 95% of confidence intervals. Normality of all data was examined using the Shapiro-Wilk test of normality and Levene's test was used to assess the heterogeneity of variance between groups. Intraclass correlation coefficient (ICC) and coefficient of variation (%CV) were used to assess the repeatability of performances between trials for IMTP. ICC values were interpreted according to the criteria of Cortina[18] where $r \geq .80$ is highly reliable.

Pearson's correlation coefficient was selected to determine the association between IMTP measures and all indicators of endurance running performance. Correlational indices were set at: (i) small effect if $0.1 \leq |r| \leq 0.29$; (ii) moderate if $0.3 < |r| \leq 0.49$; (iii) large if $0.5 \leq |r| \leq 0.69$; (iv) very large if $0.7 \leq |r| \leq 0.89$; (v) near perfect if $0.9 \leq |r| \leq 0.99$; and (vi) perfect if $|r| = 1$.[19]

RESULTS

All IMTP measures showed displayed high inter-trial reliability and acceptable variability (Table 1). Descriptive statistics for all measured variables are displayed in Table 2.

Magnitude of correlations between indicators of endurance running performance and IMTP measures are displayed in Tables 3, 4 and 5, and Figure 1. When male and female data were analysed together, all IMTP measures showed large to very large inverse correlation to 2.4-kmTT. $Force_{100}$ and all RFD measures showed moderate to large correlation with RE. Both IMTP PF and net PF were moderately correlated to k_{vert} and k_{leg}. There were moderate to large correlation between MAS and all IMTP measures except $Force_{150}$. Moderate to large correlation was also observed for PF, net PF and $RFD_{0\text{-}100}$ with VO_{2max}.

When data for male and female runners were analysed separately, significant inverse correlation was only observed between $Force_{100}$ and $RFD_{0\text{-}100}$ with 2.4-kmTT and RE for males (Table 4). While significant inverse correlation was observed between IMTP PF and net PF with 2.4-kmTT, $Force_{100}$, $Force_{200}$, $RFD_{0\text{-}100}$ and $RFD_{0\text{-}150}$ with RE, $Force_{100}$ with VO_{2max}, and significant correlation between IMTP PF and net PF with MAS.

Table 1 Reliability analysis of measures IMTP.

Variables	ICC	95%CI	%CV
IMTP PF	1.00	0.99 – 1.00	1.51
IMTP Net PF	1.00	0.99 – 1.00	2.20
$Force_{100}$	0.97	0.92 – 0.99	6.20
$Force_{150}$	0.94	0.86 – 0.97	6.47
$Force_{200}$	0.98	0.96 – 0.99	3.96
$RFD_{0\text{-}100}$	0.91	0.83 – 0.96	9.4
$RFD_{0\text{-}150}$	0.87	0.81 – 0.93	9.8
$RFD_{0\text{-}200}$	0.91	0.87 – 0.95	9.2

IMTP = isometric mid-thigh pull, PF = peak force, $Force_{100}$ = force at 100 ms, $Force_{150}$ = force at 150 ms, $Force_{200}$ = force at 200 ms, $RFD_{0\text{-}100}$ = rate of force development (0-100 ms), $RFD_{0\text{-}150}$ = rate of force development (0-150 ms), $RFD_{0\text{-}200}$ = rate of force development (0-200 ms).

DISCUSSION

The purpose of the current study was to analyse the relationship between indicators of endurance running performance and IMTP force-time characteristics. When male and female data were analysed together, IMTP measures showed large to very large inverse correlation to 2.4-kmTT, and a

Table 2 Descriptive statistics for indicator of running performance and measures obtained from CMJ and IMTP.

Variables	Mean	(SD)
2.4-kmTT (s)	586	(66)
RE ($J\cdot kg^{-1}\cdot km^{-1}$)	1.1	(0.1)
k_{vert} ($kN.m^{-1}$)	17.4	(4.9)
k_{leg} ($kN.m^{-1}$)	6.8	(2.1)
VO_{2max} ($ml.kg.min^{-1}$)	51.7	(6.6)
MAS ($km.h^{-1}$)	16.2	(1.9)
IMTP PF (N)	2028.6	(391.3)
IMTP Net PF (N)	1425.4	(351.1)
Force100 (N)	1124.0	(425.3)
Force150 (N)	1335.3	(425.3)
Force200 (N)	1536.1	(401.6)
$RFD_{0\text{-}100}$ ($N.s^{-1}$)	4363.4	(2393.1)
$RFD_{0\text{-}150}$ ($N.s^{-1}$)	4502.4	(1984.5)
$RFD_{0\text{-}200}$ ($N.s^{-1}$)	4248.2	(1710.7)

2.4-kmTT = 2.4-km run time trial, RE = running economy, k_{vert} = vertical stiffness, k_{leg} = leg stiffness, MAS = maximal aerobic speed.

Table 3 Correlation between indicators of endurance running performance and IMTP force-time characteristics.

	2.4-kmTT	RE	k_{vert}	k_{leg}	MAS	VO_{2max}
IMTP PF	-0.78**	-0.29	0.44*	0.49*	0.66**	0.53**
	$p < 0.001$	$p = 0.132$	$p = 0.018$	$p = 0.009$	$p < 0.001$	$p = 0.007$
IMTP Net PF	-0.75**	-0.21	0.41*	0.46*	0.65**	0.56**
	$p < 0.001$	$p = 0.281$	$p = 0.029$	$p = 0.015$	$p <$ d0.001	$p = 0.002$
$Force_{100}$	-0.55**	-0.44*	0.31	0.33	0.42*	0.38
	$p = 0.003$	$p = 0.019$	$p = 0.113$	$p = 0.083$	$p = 0.026$	$p = 0.059$
$Force_{150}$	-0.55**	-0.31	-0.32	0.35	0.36	0.33
	$p = 0.003$	$p = 0.106$	$p = 0.095$	$p = 0.069$	$p = 0.058$	$p = 0.110$
$Force_{200}$	-0.53**	-0.28	0.31	0.33	0.38*	0.35
	$p = 0.004$	$p = 0.151$	$p = 0.110$	$p = 0.083$	$p = 0.048$	$p = 0.086$
$RFD_{0\text{-}100}$ ($N.s^{-1}$)	-0.70**	-0.57**	0.31	0.34	0.59**	0.43*
	$p < 0.001$	$p = 0.003$	$p = 0.137$	$p = 0.092$	$p = 0.002$	$p = 0.033$
$RFD_{0\text{-}150}$ ($N.s^{-1}$)	-0.67**	-0.65**	0.36	0.40*	0.50**	0.38
	$p < 0.001$	$p < 0.001$	$p = 0.076$	$p = 0.049$	$p = 0.012$	$p = 0.061$
$RFD_{0\text{-}200}$ ($N.s^{-1}$)	-0.65**	-0.68**	0.34	0.37	0.47**	0.37
	$p < 0.001$	$p < 0.001$	$p = 0.095$	$p = 0.065$	$p = 0.017$	$p = 0.069$

*Denotes $p < 0.05$
**Denotes $p < 0.01$

Table 4 Correlation analysis for male runners.

	2.4-kmTT	RE	k_{vert}	k_{leg}	MAS	VO_{2max}
IMTP PF	-0.36	-0.046	0.34	0.34	0.15	0.26
	$p = 0.158$	$p = 0.862$	$p = 0.178$	$p = 0.178$	$p = 0.558$	$p = 0.310$
IMTP Net PF	-0.30	0.112	0.33	0.33	0.11	0.31
	$p = 240$	$p = 0.669$	$p = 0.198$	$p = 0.196$	$p = 0.675$	$p = 0.220$
$Force_{100}$	-0.50*	-0.57*	0.14	0.15	0.30	0.18
	$p = 0.041$	$p = 0.018$	$p = 0.605$	$p = 0.577$	$p = 0.235$	$p = 0.479$
$Force_{150}$	-0.33	-0.38	0.17	0.18	0.10	0.10
	$p = 0.190$	$p = 0.133$	$p = 0.507$	$p = 0.499$	$p = 0.703$	$p = 0.701$
$Force_{200}$	-0.24	-0.26	0.16	0.16	-0.007	0.04
	$p = 0.350$	$p = 0.306$	$p = 0.543$	$p = 0.553$	$p = 0.979$	$p = 0.895$
$RFD_{0\text{-}100}$ ($N.s^{-1}$)	-0.60*	-0.50*	0.21	0.22	0.42	0.34
	$p = 0.011$	$p = 0.041$	$p = 0.428$	$p = 0.405$	$p = 0.527$	$p = 0.189$
$RFD_{0\text{-}150}$ ($N.s^{-1}$)	-0.40	-0.29	0.24	0.25	0.17	0.22
	$p = 0.115$	$p = 0.\ 257$	$p = 0.347$	$p = 0.343$	$p = 0.527$	$p = 0.395$
$RFD_{0\text{-}200}$ ($N.s^{-1}$)	-0.27	-0.15	0.21	0.20	0.04	0.13
	$p = 0.300$	$p = 0.568$	$p = 0.421$	$p = 0.435$	$p = 0.893$	$p = 0.620$

*Denotes $p < 0.05$
**Denotes $p < 0.01$

Table 5 Correlation analysis for female runners.

	2.4-kmTT	RE	k_{vert}	k_{leg}	MAS	VO_{2max}
IMTP PF	-0.78*	-0.35	0.30	0.30	0.79*	0.10
	$p = 0.024$	$p = 0.396$	$p = 0.475$	$p = 0.473$	$p = 0.021$	$p = 0.823$
IMTP Net PF	-0.71*	-0.15	0.11	0.10	0.84*	0.30
	$p = 0.048$	$p = 0.717$	$p = 0.802$	$p = 0.807$	$p = 0.010$	$p = 0.507$
Force100	-0.39	-0.94**	0.36	0.40	-0.02	-0.73*
	$p = 0.346$	$p < 0.001$	$p = 0.385$	$p = 0.328$	$p = 0.960$	$p = 0.041$
Force150	-0.46	-0.62	-0.32	0.35	-0.20	-0.50
	$p = 0.255$	$p = 0.101$	$p = 0.433$	$p = 0.395$	$p = 0.631$	$p = 0.204$
Force200	-0.66	-0.81*	0.40	0.43	0.28	-0.49
	$p = 0.076$	$p = 0.016$	$p = 0.332$	$p = 0.284$	$p = 0.506$	$p = 0.216$
RFD0-100 (N.s-1)	-0.25	-0.79*	0.014	0.046	0.01	-0.68
	$p = 0.544$	$p = 0.02$	$p = 0.974$	$p = 0.914$	$p = 0.997$	$p = 0.065$
RFD0-150 (N.s-1)	-0.45	-0.78*	0.19	0.227	0.10	-0.63
	$p = 0.263$	$p = 0.024$	$p = 0.652$	$p = 0.589$	$p = 0.806$	$p = 0.094$
RFD0-200 (N.s-1)	-0.59	-0.67	0.15	0.184	0.324	-0.42
	$p = 0.127$	$p = 0.069$	$p = 0.716$	$p = 0.663$	$p = 0.434$	$p = 0.305$

*Denotes $p < 0.05$
**Denotes $p < 0.01$

moderate to large correlation between MAS, except $Force_{150}$. IMTP $Force_{100}$ and all RFD measures showed moderate to large correlation with RE, while both IMTP PF and net PF were moderately correlated to k_{vert} and k_{leg}. However, when data for male and female were separated, only $Force_{100}$ and $RFD_{0\text{-}100}$ showed significant relationship with running measures for male, while there were relationship between all IMTP measures with running measures for female. To the authors' knowledge, the current study is the first to analyse the relationship between IMTP force-time characteristics with various indicators of endurance running performance. These results suggest that lower limb strength and power are important determinants of endurance running performance and that measures obtained from IMTP are able to provide some useful insights into the force generating capability of endurance runners

In this study, all IMTP measures observed large to very large inverse relationship with 2.4-kmTT performance. Contrary to findings here, Cole et al.[20] reported no correlation between lower limb strength and indicators of endurance running performance. One reason could be due to the difference in movement & joint mechanics between the test administered and during actual running. In that study, a single joint isokinetic knee extension test was utilised.[20] While in con-

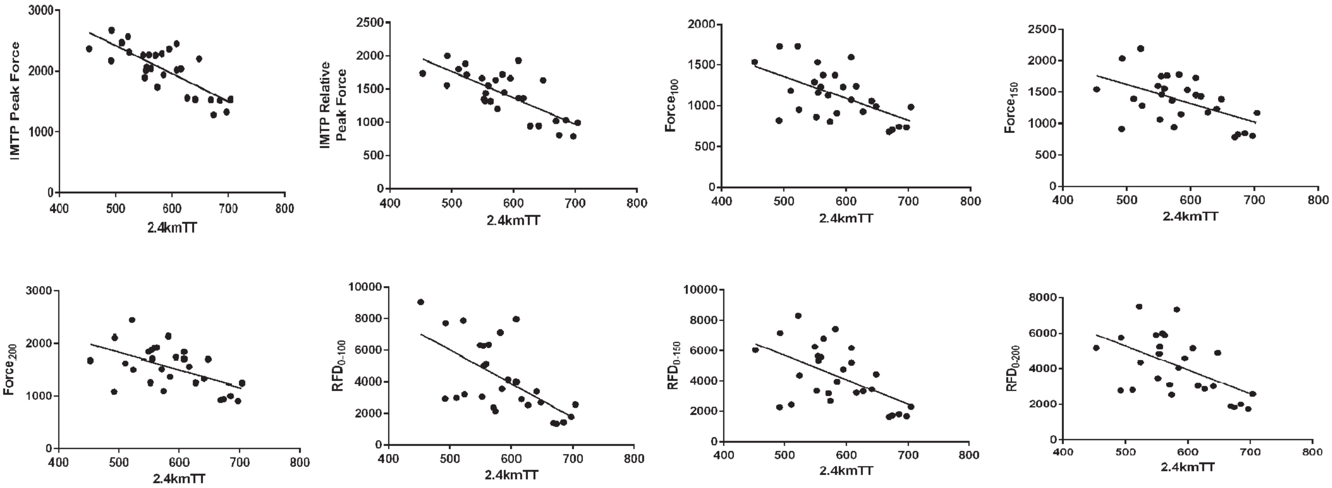

Figure 1 Correlation between 2.4-km time trial performance and IMTP measures.

2.4-kmTT = 2.4-km run time trial, RFD$_{0\text{-}100}$ = rate of force development (0-100 ms), RFD$_{0\text{-}150}$ = rate of force development (0-150 ms), RFD$_{0\text{-}200}$ = rate of force development (0-200 ms)

trast, running locomotion involves multi-joint movements, along with inter- and intra-muscular coordination.[9] The lack of specificity of using a single-joint strength assessment to relate to a multi-joint activity likely explained the lack of relationship between these variables.[20] In order to obtain a more specific strength assessment for runners, the assessed joint angles at which propulsion force is initiated must be similar to angles achieved during running.[9] The present study utilised an IMTP assessment, allowing the hip and knee joints to be relatively specific to angles obtained during running, which might explain its adjacent relationship obtained with the 2.4kmTT performance.

Most IMPT variables obtained moderate to large correlation with MAS, and IMTP Force$_{100}$ moderately correlated to RE. Based on these findings, it seems that maximum strength of the lower limb and the ability to produce high force rapidly are important factors in determining how fast an endurance runner is able to run. It can be explained that in order to increase the running speed, the lower limb is required to generate greater amount of force. Subsequently, as running speed increases, higher forces are generated, the lower limb is required to then absorb a greater amount of ground reaction forces.[21] To achieve a similar running speed, a stronger individual (i.e., greater muscular strength) is required to work at a relatively lower force ratio while producing the same amount of force as compared to a weaker individual (i.e., reduced muscular strength). For that, force absorption relative to maximum strength would be comparatively reduced for the stronger individual, thus leading to a reduction in metabolic demand.[22] In addition, possessing higher muscular strength would also mean that the rate of muscular fatigue would be lower for any given power output as the intensity of the muscle contraction to produce that power output would be relatively lower, hence allowing individuals to better sustain a given running speed which would lead to shorter time to complete the race.[5] Moreover, ground contact time decrease as running speed increase.[21] Endurance runners hence need to possess greater rate of force development in the lower limb to generate sufficient amount of force within the shorter ground contact period in order to run faster. This further explains the observed relationship between IMTP variables with MAS and RE.

Possessing greater lower limb stiffness could save energy by reducing muscle activation and enhance the transfer of energy more efficiently during running.[23] Several studies have previously reported very large correlation between k_{leg} and RE,[23] also noting that the relationship between the two variables became stronger as the running speed increases. The increase in leg stiffness as running speed increase could be a result of the decreased ground contact time.[16] The shorter contact time allows for a quicker transition from the braking to the propulsive phase, leading to reduction in speed loss during running, thereby improving RE.[24]

Findings from this study showed moderate correlation between IMTP PF and net PF with k_{vert} and k_{leg}, and large correlation with 2.4kmTT. It is evident that individuals with greater lower limb strength would exhibit increased lower limb stiffness.[23] This would then result in an increase in RE to ultimately improve running performance. However, IMTP PF and net PF showed insignificant small correlation with RE. Findings obtained are in agreement with Li et al.[23] who reported no correlation between 1RM squat and RE. This means that factors other than IMTP variables need to be considered when predicting RE.

The relationships between running performance measures and IMTP measures differ when data for male and female participants were analysed separately. For example, PF and net PF showed no relation to any running measures for the male, while for the female, PF and net PF were significantly correlated to 2.4-kmTT and MAS. However, the relationship between early force development and RFD with RE were consistent for between the three analyses. One possible reason for these findings could be because resistance training experience among the male participants varies between 0-5 years, while all female participants had no resistance training experience. The difference in resistance training experience among male participants might have resulted in varying muscular strength to aerobic fitness ratio. While for the female participants, the muscular strength they possess was a result of the running training they performed, with faster runners more likely to possess higher muscular strength due to the higher ground reaction force imposed on the lower limb when running at higher speed[21]. Nevertheless, despite the different findings on the relationships between PF and running performance measures among male and female, the ability to develop force rapidly remain significantly correlated to RE and running performance. This finding further reiterate the importance for runners to possess high RFD ability.

It is important to take note of several limitations while interpreting the current results. Firstly, the current findings might only be applicable to the sampled population of endurance runners and not for the elite level Secondly, the results might not be generalised for runners of different running distances. Therefore, future studies should attempt to recruit runners with higher training status and to use different running distances. Finally, although the results showed significant correlation between IMTP force-time characteristics and running performance indicators, there is no evidence that improving IMTP performance will directly improve running performance. An intervention or longitudinal study that includes monitoring of both IMTP measures and running performance indicators will be required.

CONCLUSION

The results of the current study showed that measures obtained from IMTP are good indicators of endurance running performance and can be used to obtain information on the force generating capability of endurance runners. Specifically, faster runners possess higher lower limb strength, and runners with more efficient RE are also able to generate force more rapidly. Therefore, practitioners can use IMTP as assessment tool to monitor the muscular fitness of endurance runners. The results also suggest that runner should focus on increasing maximum strength and RFD when performing resistance training.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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