The Relationship between Isometric Mid-Thigh Pull Variables and Athletic Performance Measures: Empirical Study of English Professional Soccer Players and Meta-analysis of Extant Literature.

Liam Mason[1,2], Andy Kirkland[1,] James Steele [b] and James Wright[b]

Mr Liam Mason (Corresponding author)

Blackburn Rovers Football Club

Brockhall Village, Old Lango, Lancashire, BB6 8BA

E: Lmason@rovers.co.uk, T: 07913418609

Dr Andrew Kirkland

University of Stirling

Stirling, FK9 4LA

E: Andrew.Kirkland@stir.ac.uk

Dr James Steele

Solent University and ukactive

Solent University, Faculty of Sport, Health and Social Science, East Park Terrace, Hampshire, SO14 0YN

Ukactive, The Bloomsbury Building, 10 Bloomsbury Way, London, WC1A 2SL

E: james.steele@solent.ac.uk

Dr James Wright

Solent University

Faculty of Sport, Health and Social Science, East Park Terrace, Hampshire, SO14 0YN

E: james.wright@solent.ac.uk

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Abstract

BACKGROUND: There is currently limited evidence available to support the use of the isometric mid-thigh pull (IMTP) within professional soccer. The aim of this study was to analyse the association between IMTP variables, with common markers of athletic performance capability.

METHODS: Eleven professional development soccer players (age: 20 ± 2 years, stature: 1.82 ± 0.10 m, mass: 76.4 ± 12.8 kg) performed IMTP, 5 m and 10 m accelerations, maximal sprint speed (MSS), countermovement jump (CMJ), and the 505 change of direction test (COD).

RESULTS: Relative and absolute Peak force (PF) and force at 50, 100, 150 and 200 ms values were measured during the IMTP. Relative F150, F200, PF displayed large to very large correlations with MSS (r = 0.51, r = 0.66, and r = 0.76 respectively), while absolute PF also displayed a large correlation with MSS (r = 0.57). Relative and absolute PF showed large correlations with CMJ height (r = 0.54 and r = 0.55 respectively). Relative F150 and F200 highlighted large correlations with COD ability (r = -0.68 and r = -0.60 respectively). Relative F200 and PF had a large negative correlation with 10m acceleration (r = -0.55 and r = -0.53 respectively).

CONCLUSION: This study provides an important contribution to knowledge within the area of IMTP testing in professional soccer by evidencing the prominence of the isometric force generating capacity as an underpinning factor in relation to athletic capability.

Keywords: Football; Force; Strength; Training

INTRODUCTION

Strength and conditioning (S&C) coaches in soccer are tasked with improving physical performance and minimising injury risk for the players they work with. As such gym-based strength training is a staple in the programmes of professional soccer[1]. A key aim of this type of training is to improve the ability to generate force via the neuromuscular system[2], referred to as the force generating capacity (FGC). Therefore S&C coaches must be able to practically and accurately quantify the FGC of the players they work with in order to understand whether training interventions have been successful for this purpose[3]. However, measuring FGC within professional soccer is challenging because of the density of matches[4], player's physical competencies[5], and cultural resistance[1]. The isometric mid-thigh pull (IMTP) test may provide solutions to these challenges due to its validity, reliability, simplicity, and low level of inherent risk[6]. The isometric nature of the test ensures there is a limited skill requirement[18], with substantially less muscle damage exhibited post-test when compared to exercises containing an eccentric component[21]. This is practically essential within professional soccer in order to allow for increased testing opportunities during congested fixture schedules. Additionally, it can provide the S&C coach with insight into specific physical qualities of players regardless of injury history and mobility restrictions[18]. This is not possible with more commonly used methods, such as the back squat, which requires a good level of technical proficiency[22] and no contraindications. Consequently, the IMTP is more practical within an applied environment across a whole squad.

The IMTP test is an assessment of peak force (PF) production which is positively correlated with 1RM tests in dynamic exercises such as the squat ($r = 0.97$, $P < 0.05$ and $r = 0.72$, $P < 0.05$) (7,8), deadlift ($r = 0.88$, $P < 0.05$)[9], and power clean ($r = 0.57$, $P < 0.05$)[10]. IMTP PF has also displayed moderate to large correlations with both 20 m acceleration ($r = 0.69$, $P < 0.01$)[11] and jumping height ($r = 0.45$, $P < 0.05$)[12] in university athletes, highlighting possible diagnostic capabilities of the IMTP as a test for S&C coaches.

Important performance demands such as accelerating, sprinting, changing direction, and jumping occur within limited time constraints during soccer matches. Typical ground contact times (GCT) during maximum sprinting last <100 ms[13], <200 ms during the acceleration phase[14], and <500 ms during changes of direction[15]. As such, the ability to be able to exert large forces rapidly is also considered important in professional soccer players. Therefore, the ability to measure rapid force production capability in players may be important in order to provide insight as to the efficacy of training interventions for individual players. The IMTP does not solely inform on maximum FGC, as vertical ground reaction forces (vGRF) can also be calculated through the use of the force plate. Consequently, the resultant force-time curve enables the assessment of PF[16] and rapid force production[17]. The assessment of both PF and time-specific force from the IMTP, have been shown to be valid and reliable measurements of FGC[18]. This addition to the performance testing battery can highlight players who may be strong (high PF values), but 'slow' (have low rates of force development e.g. low force at 0–250 ms), or vice versa[3]. This data is important because it may help coaches provide more focussed training interventions which are designed to target a specific point on the force-time curve[19]. The force applied at these different time points of the IMTP have been shown to be associated with proxy measures of athletic performance. For example, the force attained at 100 ms (F100) has exhibited a moderate inverse relationship (r = –0.54 [95% CI = -0.73 to -0.27]) with 10 m acceleration capability in professional rugby league players[20]. Additionally, Thomas et al.[11] also reported moderate inverse correlations between F100, 5–20 m acceleration time (r = –0.51 [95% CI = -0.81 to 0.03] and –0.54 [95% CI = -0.83 to -0.01], respectively) and 505 change of direction speed (r = –0.57 [95% CI = -0.84 to -0.06]). Additionally, whether IMTP should be expressed relative, or allometrically scaled, to body mass is something which requires consideration as relationships between absolute and relative IMTP characteristics show varying relationships with proxies of sport performance[11,20, 24, 25].

Despite the quantity of literature exploring IMTP and its relationship to markers of athletic performance[6, 11,12,20, 24, 25], at present there is paucity of research within the field of professional soccer. The current paper aims to bridge this gap in the research in order to add to the cumulative data on this topic and better inform the soccer S&C coach when identifying their physical profiling options. Few studies have examined the IMTP within soccer specifically, and those that have were conducted in youth [3, 28, 29]. Brownlee et al.[3] explored differences between IMTP ability in professional academy and non-professional academy youth soccer players finding greater PF levels in the academy group when compared to the non-academy players. Morris et al.[29] empirically identified differences between IMTP ability and maturation status, confirming anecdotal evidence that the more physically mature players are, the higher PF values they can achieve. Further, in a large sample of elite youth soccer players reported relationships between PF and 10m (r = -0.61 [95% CI = -0.68 to -0.53]) and 30m (r = -0.75 [95% CI = -0.80 to -0.70]) sprint times, countermovement jump height (r = 0.62 [95% CI = 0.54 to 0.69]), and both right (r = 0.32 [95% CI = 0.21 to 0.41]) and left (r = 0.58 [95% CI = 0.50 to 0.65]) change of direction speed. However, in none of these studies examined time-specific force measures. Whilst these studies made welcome advances in IMTP research within soccer, further research is required to inform S&C coaches with evidence-based knowledge that is relevant to specific coaching contexts; in particular for elite adult soccer athletes. Examining associations between IMTP ability and athletic performance variables will inform coaches regarding the potential value of IMTP testing in soccer. Therefore, the aim of this study was to describe the relationship between PF, and force at 50 ms (F50), 100ms (F100), 150 ms (F150), and 200 ms (F200) derived from the IMTP, with common performance indicators used in professional soccer in a sample of elite soccer athletes. Further, with the exception of the large study of Morris et al., given that previous estimates of the correlations between IMTP measures and proxy measures of athletic performance have been relatively imprecise in part due to the small samples typical of working with sporting populations, we report an exploratory meta-analysis combining our results with previous findings in order to provide more general estimates of these relationships.

METHODS:

Experimental Approach

Testing occurred in the final two weeks of a 7-week pre-season mesocycle, over two testing sessions separated by 7 days. Both testing sessions were performed in the morning after a day off and before any training took place to ensure players were rested, to minimise any diurnal effect, and to ensure that testing fitted in with the regular squad training programme.

The first testing day was completed to determine PF and force at given time periods (50 ms, 100 ms, 150 ms and 200 ms) during the IMTP, and maximal sprinting speed recorded over 65 m. The second testing day included a counter movement jump (CMJ) to determine maximal jump height, an acceleration test with times recorded at 5 m and 10 m, and change of direction (COD) ability via the 505 COD test (COD505). If participants achieved their best score on their final attempt of any of the tests, they were allowed subsequent attempts until no further improvement was made.

Participants:

Eleven professional soccer players (age: 20 ± 2 years, stature: 1.82 ± 0.10 m, mass: 76.4 ± 12.8 kg) who played for an English Championship under 23's team participated in this study. This was a convenience sample and limited by the players which were available for participation. Following university ethical approval and in accordance with the university's ethical procedures for research, participants were briefed on the benefits and potential risk factors of the study and provided written informed consent. All testing was assessed by the lead researcher who is a NSCA certified strength and conditioning specialist. All players had been screened by the club's medical team and were deemed fit to participate. Each of the participants were familiar with all testing procedures having performed all procedures on two previous separate occasions as part of the club's performance testing battery. Given the primary purpose of this study was to describe the relationships between IMTP measures and proxies of sport performance, we conducted a sensitivity analysis to examine the precision of interval estimates which would be achieved at this sample size across a range of correlation coefficients (-1, 1), and for a range of compatibility (confidence) levels (50%, 80%, and 95%). The widths of these interval estimates can be seen in the figure in the accompanying supplementary materials (see https://osf.io/hzwg5/). Given the obvious lack of precision for estimates due to the sample size, as noted, we also aimed to combine the results from our sample with those of other studies[11, 12, 20, 24, 25, 29, 30, 31]. This resulted in the inclusion of data from 510 participants (including collegiate athletes across a range of sports, elite soccer youth athletes, professional rugby league players, and professional soccer players) across 9 studies (including the present one).

Isometric Mid-Thigh Pull

To contribute to testing reliability, all participants performed the same warm-up protocol as described by Guppy et al.,[6]. This consisted of bodyweight squats and lunges, low load mid-thigh pulls, moderate load mid-thigh pulls, and 3 x 3 s IMTP sub-maximal trials (50%, 75% & 90% perceived maximal effort). Force was measured using a portable force plates sampling at 1000 Hz (9286AA, Kistler, Switzerland), which were imbedded into a portable IMTP rack (Perform Better, UK).

The IMTP has been demonstrated to be a reliable measure of absolute peak force and absolute force-time generating capacity with a coefficient of variation (CV) of 3.2% (PF); 7.3% (F200); 8.6% (F150); 9.6% (F100) and 5.7% (F50)[15, 32]. The IMTP protocol in the current study followed the standardised methodological guidelines for the test set out by Guppy et al.,[6]. Prior to testing, the bar height pertaining to the correct body posture was determined (knee angle = 125–145° and hip angle = 140–150°). The participants were secured to the bar using lifting straps to ensure grip strength was not a limiting factor on their ability to perform maximally[17]. The instructions given to the participants were standardised. Participants were told to; “push your feet into the ground as fast and as hard as possible”[33]. They were then told to remove the ‘slack’ from the bar by assuming the correct start position, with a subtle amount of tension applied to the bar before standing still and ready for further instruction. The researcher viewed the force response from the plates and waited until it was stable with the pre-tension not <50 N above body mass[34]. Participants were then given an instruction of "3, 2, 1, PULL" and strong verbal encouragement was given throughout all trials. Trials lasted ~3-5 s, or until a drop off in force was displayed on the force-time graph[26]. If a countermovement occurred prior to the pull, the test was discarded[6]. A minimum of three trials were performed by all participants, with 1–2 min rest between trials. The force-time data was generated via ForceDecks software. All IMTP measures were examined both as absolute, and relative (i.e. normalised to body weight).

<u>Maximal Sprint Speed Testing</u>

All participants completed a standardised 15-min RAMP warm-up consisting of general dynamic movement patterns, lower body mobility exercises and finishing with explosive jumping and bounding exercises. This warm-up, along with the testing was completed on a grass training pitch on a dry day with the players wearing soccer boots. MSS was recorded from a 65 m sprint to replicate a typical box-to-box recovery sprint. Following the warm-up all participants completed 3 x maximal 65 m sprints with 4 min rest between each. Participants were instructed to 'keep trying to accelerate until you reach the 65 m poles' and to 'run as fast as possible', with loud encouragement given by the coaches throughout all of the trials. MSS was recorded using Catapult S5 GPS monitors (10 Hz), which were worn by the players. This device has been shown to be a valid (TEE = 1.19%) measurement of maximum velocity in field sport athletes[35]. The MSS chosen for analysis was the peak speed each player recorded during their 3 maximal sprints.

<u>Countermovement Jump Testing</u>

All participants performed the same standardised RAMP warm-up protocol as they did prior to the MSS testing. At the end of the 15-min warm-up protocol, participants completed 3 x CMJ's and 3 x squat jumps each at >80% of maximal intensity with their hands on their hips. The CMJ testing in the current study was performed using portable force plates sampling at 1000 Hz (9286AA, Kistler,). Each participant performed 3 sets of 3 CMJ's with a 1-min rest between each set. Instruction was standardised with all participants told to; 'jump as high as you possibly can' from a self-selected depth.

A valid repetition was one where there was the presence of a stable baseline for at least 1 s prior to the test. The participant's hands stayed on their hips throughout the jump, with no hip or knee flexion displayed while off the ground, and landed with their feet on the force plate in the same position as take-off. The lead researcher ensured correct technique was maintained throughout all repetitions, with incorrect technical repetitions discarded from the data collection and participants being asked to repeat the set. Jump height was estimated from flight-time via the ForceDecks software, which has displayed high reliability (CV = 3.8%) when performed without an arm-swing as in the current study[36].

Acceleration Testing

The acceleration testing was performed after the CMJ testing on an indoor 4G pitch at the clubs training ground. All participants completed a subsequent 5-min potentiation phase as part of a 're-warm up' following the jumps. Timing gates (TCi system, Brower, USA) were placed at 0 m, 5 m and 10 m. The timing gates used within this study have displayed excellent validity for acceleration testing over 10 m (CV = 1.13%)[37]. Participants started in a 2-point split stance, 30 cm behind the 0 m timing gate. Instruction was standardised for all participants with them being told to; 'Accelerate as fast as possible through the end timing gate'. All participants performed 3 sets of 1 x 10 m maximum acceleration with 2 min rest between each set. The fastest times were recorded for each subject at 5 m and 10 m.

505 Change of Direction Testing

Following the completion of the acceleration testing, the participants completed the change of direction speed test. This was assessed via a 505 modified test on the same surface as the acceleration testing and using the same timing gate system (CV = 2.4%)[38]. Participants started in the 2-point split stance, 30 cm behind the 0 m timing gate, with a timing gate set up 5 m further forward. Participants were instructed to accelerate to the 5 m line and plant their preferred foot before turning 180˚ back to the start/finish line[39]. Instructions were standardised for all participants; 'get to the 5 m line and back as fast as possible'. Each participant performed 3 trials with 2 min rest between each one. The fasted time for each participant was used in the analysis.

Statistical Analyses

Analysis of the dataset generated from our participants was performed such that inferential statistics were treated as highly unstable local descriptions of the relations between model assumption and data in order to acknowledge the inherent uncertainty in drawing generalised inferences from single and small samples[40]. To complement the local descriptive analyses of the dataset generated in the present study, we also combine our estimates with those from the wider literature in a meta-analysis. For all analyses we opted to avoid dichotomising the existence of effects and therefore did not employ traditional null hypothesis significance testing, which has been extensively critiqued[41, 42]. Instead we consider the implications of all results compatible with these data, from the lower limit to the upper limit of interval estimates, with the greatest interpretive emphasis placed on the point estimate. All analysis was conducted in R (v 4.0.2; R Core Team, https://www.r-project.org/) and all code utilised is presented in the supplementary materials (https://osf.io/zu4y9/).

Descriptive statistics were calculated for all measures. The reliability of repeated measures (i = 3) for those taken in the present study was explored using intra-class correlation coefficients (3,1) with accompanying 95% compatibility (confidence) intervals, using the 'psych' package[43]. Pearson correlation coefficients were used to analyse associations between all IMTP variables, and proxies of sport performance. Accompanying compatibility intervals were computed for a range of levels (50%, 80%, and 95%) so as to present gradation[44] and are presented on scatterplots as grey ribbons to aid in visual interpretation of uncertainty of estimates. Magnitude of correlation coefficients were qualitatively evaluated using recommendations from Hopkins[45]; small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89) nearly perfect (0.90–0.99), and perfect (1.0).

The meta-analysis was performed using the 'metafor' package[46]. Effects and variances were calculated using the raw correlation coefficients from each study and the escalc function. Because of the nested structure of the effects calculated from the studies included (i.e. multiple correlations nested within studies), multilevel mixed effects meta-analyses with study and included as a random effect in the model were performed. Cluster robust point estimates and precision of those estimates using 95% compatibility (confidence) intervals (CIs) were produced, weighted by inverse sampling variance to account for the within- and between-study variance (tau-squared). Restricted maximal likelihood estimation was used in all models. I^2 values were calculated to indicate the degree of heterogeneity in the effects: 0-40% were not important, 30-60% moderate heterogeneity, 50-90% substantial heterogeneity, and 75-100% considerable heterogeneity[47].

RESULTS

Descriptive statistics and ICCs for the IMTP, acceleration, sprint, jump and change of direction tests are presented in Table 1. All proxy measures of sport performance displayed good reliability (ICC = >0.75) though with interval estimates ranging from moderate to excellent. IMTP measures appeared to improve with reliability as they neared PF. For example table 1 shows that F50 showed very poor reliability, F100 and F150 showed better albeit still poor to moderate reliability, while both F200 and PF showed reliability interval estimates that ranged good to excellent. The results of the correlational analysis between the IMTP force variables and athletic performance can be found in Table 2.

Table 1 near here

Correlation precision sample near here

Present Study Correlations

As expected, estimated of the correlations within the present sample were imprecise. Thus, we highlight here only key outcomes and direct the reader to figure 1 and figure 2 where the scatterplots for all variables are presented. For absolute IMTP measures correlations with 5 m acceleration were trivial to small which was similarly to case for 10 m acceleration with the exception of moderate negative relationships for F200 and PF. This was also reflected in the moderate to large positive relationships between MSS and both F200 and PF. Interval estimates had less precision for CMJ and COD; though, PF had a large positive relationship with CMJ, and there were consistent negative relationships between all IMTP measures and COD ranging from small to moderate. Most of these were also reflected in the relative IMTP measures; however, for 5 m acceleration relationships appeared slightly improved and were small to moderate and negative.

Meta-analysis

The main model examining the relationship between IMTP measures and 'speed' measures included 65 correlations across 6 studies with an estimated correlation of r = -0.40 [95%CI = -0.65 to -0.15] and an I^2 of 62%. The main model examining the relationship between IMTP measures and 'jump' measures included 158 correlations across 7 studies with an estimated correlation of r = 0.33 [95%CI = 0.18 to 0.49] and an I^2 of 41%. The main model examining the relationship between IMTP measures and 'change of direction' measures included 38 correlations across 4 studies with an estimated correlation of r = -0.38 [95%CI = -0.69 to -0.07] and an I^2 of 58%.

Figures 1 & 2 near here

DISCUSSION

The primary aim of the current study was to explore the association between IMTP force variables and acceleration, MSS, CMJ and COD ability in professional Under-23 soccer players. This paper has made an important contribution to knowledge within the area of IMTP testing in professional soccer by evidencing the importance of the isometric FGC as an underpinning factor in relation to athletic capability. Furthermore, it appears the ability to express higher forces relative to soccer players body mass, may be more desirable for athletic performance than absolute FGC.

There were large negative correlations existent between both F150 (r = - 0.68) and F200 (r = - 0.60) relative to body mass and COD ability. There were also moderate negative correlations present between COD ability and all of the other relative force outputs noted at specific time points (F50: r = –0.46; F100: r = –0.47; PF: r = -0.49); however, when analysing the absolute force data within the current study only F150 (r = -0.46) and F200 (r = -0.45) were shown to display a moderate negative correlation with COD ability. While in contrast studies from Thomas et al.[11, 12] have revealed large negative correlations with absolute PF and COD time (r = 0.57 and r = 0.66). This suggests that despite the relatively longer GCT during COD activities when compared with accelerating and sprinting[13] it may still be the ability to produce force rapidly which provides an advantage during COD tasks, as opposed to the overall maximal force the player can produce. Our research is important in an applied environment because an identified COD weakness in a player may suggest an intervention is required to improve rapid force production capability. Thomas et al.,[11] supports this notion as they noted moderate negative correlations between COD505 time and force produced at 100 ms (r = –0.58) and 300 ms (r = –0.62) in university soccer and rugby league players. Research from Verheul et al.[38] helps to rationalise this further by showing the peak vGRF during deceleration tasks appear within the first 100 ms of ground contact. Therefore the ability to produce the rapid (<100ms) and high forces required during changes of direction places a large demand on the tendon qualities around ankle, knee, and hip[2]. Tendon stiffness is an important underpinning structural component within rapid force production[39,40], with increased stiffness resulting in a more effective force transmission from muscle to bone[41]. Improvements in isometric strength have been shown to display a subsequent improvement in tendon function[42]. As such it may be that the players who could produce higher isometric vGRF relative to their body weight within the current study were better equipped from a musculotendinous perspective to handle the large stresses in the deceleration phase immediately prior to the change of direction action. This may then have allowed the players to get into their acceleration pattern faster, and in a more advantageous position. Whilst it is evident the ability to change direction effectively is a critical athletic performance factor within football[1], there is still debate as to how best to efficiently improve[49] and measure it[35, 43]. A potential reason for this is due to the multi-factorial nature of the skill. The ability to change direction rapidly requires good deceleration, acceleration and kinematic skills[43], and so identifying the specific area for development within these three areas would be important for the S&C coach looking to improve COD performance. The moderate to large negative correlations between relative FGC and COD ability in the current study provides increased support for the S&C coach to seek improvements in isometric force production capacity for their athletes relative to their body weight as opposed to absolute FGC, when looking to improve change of direction capability. Further research into whether there is a cause and effect relationship between the two parameters through a training intervention study would provide further insights for the S&C coach.

CMJ height displayed a large positive correlation with both relative and absolute PF (r = 0.54 and r = 0.55 respectively). There were also some moderate positive correlations displayed between relative F50 (r = 0.30) and F200 (r = 0.30). In contrast, absolute values for F50 (r = 0.17), F100 (r = 0.10), and F200 (r = 0.20) only exhibited small positive correlations with CMJ ability. The large positive correlation between PF and CMJ height identified by our research for both relative and absolute values is consistent with research from other sports[20, 25, 44, 45, 46]. These findings can be explained by a rearrangement of Newton's second law of motion (acceleration = force/mass). The ability to exert large forces is a key factor in order to accelerate the body in a given direction and subsequently, the players who display large PF on the IMTP have an increased capacity to jump higher. However, whilst PF is an important underpinning capacity with regards to CMJ height, the ability to produce force during the IMTP does not seem to be wholly causal of CMJ performance. A possible reason for this may be the isometric nature of the test which contrasts with the triphasic action inherent within a CMJ[47]. Both absolute and relative eccentric PF have previously displayed very large and statistically significant correlations (r = 0.74, $P < 0.001$ and r = 0.79, $P < 0.001$) with CMJ height[44]. Additionally, McErlain-Naylor et al.,[48] delineated that kinematic factors (58%) explained a much higher variance of jump height than isometric ability (18%) in the CMJ, suggesting coachable technical aspects of jumping are more important determinants of CMJ than IMTP ability. Whilst this study supports the evidence base for improved PF capacity to affect CMJ height, the S&C coach may also be wise to consider eccentric PF and kinematic variable when seeking to improve a player's CMJ height.

Relative and absolute PF attained in the IMTP test and the MSS achieved by the players were shown to display very large and large positive correlations respectively (r = 0.78 and r = 0.57). This result was also supported by some large positive correlations for relative F150 (r = 0.51) and relative F200 (r = 0.68). A moderate positive correlations between MSS and absolute F200 (r = 0.45). Interestingly, these results would appear to suggest that PF attained in the IMTP may be more important to MSS ability than the force an athlete is able to produce in a shorter time period. This contrasts with the current literature relating to the kinetics of MSS, within which, it is widely accepted that the ability produce high amounts of force rapidly is a key determinant of MSS[49]. This is because GCT during maximum sprinting lasts <100 ms[13], and as such athletes have an extremely limited time frame within which to apply force into the ground. Following the current papers meta-analyses, to the best of our knowledge there are no published studies identifying a correlation between any IMTP variable and sprint speed over 20 m. This is despite several studies which highlight correlations between IMTP and 5 and 10 m acceleration time, which is subsequently discussed. Therefore, findings in the present study offer a novel and interesting outcome into the relationship between IMTP derived PF and MSS. Being able to produce a large amount of both absolute and relative isometric PF, as opposed to having the ability to produce less force in a shorter amount of time may be beneficial due to its association with increased tendon stiffness[39,40,41]. The musculotendinous unit plays a key role in maximal sprinting through the utilisation of the stretch-shortening cycle[50], with higher level sprinters displaying increased lower limb tendon stiffness[51]. This increased stiffness of the muscle-tendon unit enables increased absorption of elastic energy during the swing phase of maximal sprinting[52], subsequently equating to faster sprint speeds[51]. Interestingly, Meckel et al.[53] have also previously highlighted the importance of maximum strength with maximum running speed. Their research into female sprinters displayed a very large correlation (r = 0.89) with 1RM performance in the back squat and 100 m sprint times. This ability to exert large vGRF during strength testing may translate into larger vGRF during the first half of the stance phase in sprinting, which has been highlighted as an important capability of elite sprinters[13]. Based on the findings within this paper, we tentatively suggest that the S&C coach may wish to adopt a broad approach to improving the kinetic aspect of MSS. The current paper provides support for the rationale of the development of rapid force production (150-200ms) within soccer players who are aiming to improve MSS, whilst also adding a fresh and interesting finding to the current literature regarding the importance of isometric PF for maximal sprinting performance.

Finally, F50, F100 and F150 ms from the IMTP test displayed a trivial correlation for both relative and absolute values and 10 m acceleration performance. When participants were allowed more time to produce force however, there were large negative correlations present with 10 m acceleration ability and relative IMTP values (F200; $r = –0.55$ and PF; $r = –0.53$). This increased time available to produce force also improved the correlation between 10m acceleration and absolute figures (F200; $r = - 0.35$ and PF; $r = -0.30$). A similar trend is present when comparing relative FGC and 5 m acceleration ability, with small negative correlations appearing for F50 ($r = - 0.26$) and F100 ($r = - 0.24$), yet moderate negative correlations for relative F150 ($r = -0.36$), F200 ($r = -0.37$), and PF ($r = -0.33$). This finding suggests that the ability to produce high forces over a longer time-frame translates better to acceleration performance than the ability to produce forces rapidly. This may be explained due to the slightly longer GCT's (compared to sprinting) of <200 ms during the acceleration phase[14]. The increased available time allows for higher expressions of force to be generated during acceleration tasks[49], and so players who are able to produce large forces would seem to have an increased capacity for improved 0–10 m acceleration capability. However with the higher negative correlations appearing for relative IMTP ability when compared to absolute values for acceleration ability, the importance of the aforementioned Newton's second law of motion (acceleration = force/mass), is clearly apparent for the soccer strength and conditioning coach. PF and force at specific time bands have been previously negatively correlated with acceleration capability within research studies from other sports[11, 12, 20, 44]. The findings within the current paper and the wider IMTP literature, are in congruence within an extensive body of literature linking various strength measures and acceleration performance[49].

No research is without limitation; however, the fact that this research was conducted in a naturalistic setting adds to its credibility in 'real-world' applied settings. Notwithstanding, sample-size was constrained through the practicalities of the research being conducted in a professional team environment and caution is suggested when considering the inference-based nature of interpretation of the correlations. However, given this lack of precision for estimates due to the sample size, as noted, we also aimed to combine the results from our sample with those of other studies[11, 12, 20, 24, 25, 29, 30, 31]. This resulted in the inclusion of data from 510 participants (including collegiate athletes across a range of sports, elite soccer youth athletes, professional rugby league players, and professional soccer players) across 9 studies (including the present one). The small sample size may have also contributed to the poor reliability of F50 (ICC = 0.089) and F100 (ICC = 0.48), with large variations in these metrics being recorded in only two of the participants. This poor reliability is in contrast with previous studies showing F50 and F100 to be reliable markers (ICC = 0.76 and 0.85 respectively, CV = 12.8%)[18, 29]. This study is however in agreement with earlier research highlighting the excellent reliability of F200 and PF (ICC = 0.90 and 0.90 respectively)[18, 29]. Future research may be worthwhile measuring more longitudinally. Researchers could use repeated measures to enable the use of within participant repeated measures correlations, in order to take a closer step towards understanding whether changes in IMTP measures are 'causally' related to changes in proxies of sport performance. Importantly in this setting, implementing interventions is done on a player-by-player basis and involves complex decision-making processes concerning multiple stakeholders. We believe that this research makes an important contribution to these processes by highlighting the importance of isometric FGC within athletic performance in professional soccer players.

CONCLUSION

The current study aimed to identify relationships between IMTP and markers of athletic performance and discuss the importance of these for the S&C coach. This paper represents an important starting point for the IMTP research within professional soccer, and has already added value to the physical profiling process within the first authors applied setting. It has highlighted some interesting moderate to very large correlations between IMTP relative and absolute force parameters and 5–10m acceleration, MSS, CMJ and 505COD. Due to the associations displayed with markers of athletic performance, this study has highlighted the value of the IMTP as an assessment tool for S&C coaches working within professional soccer. The results of this test can help to direct the prioritisation of training interventions depending upon the desired athletic performance improvement. The IMTP can serve as an efficient profiling method to re-assess changes in FGC, and in doing so, the effectiveness of the programme.

DISCLOSURE STATEMENT

The authors of the current paper have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed within the current paper. There is no conflict of interest in any form.

DATA AVAILABILITY STATEMENT

The dataset generated for this study is available and can be found at the following link; https://osf.io/zu4y9/.

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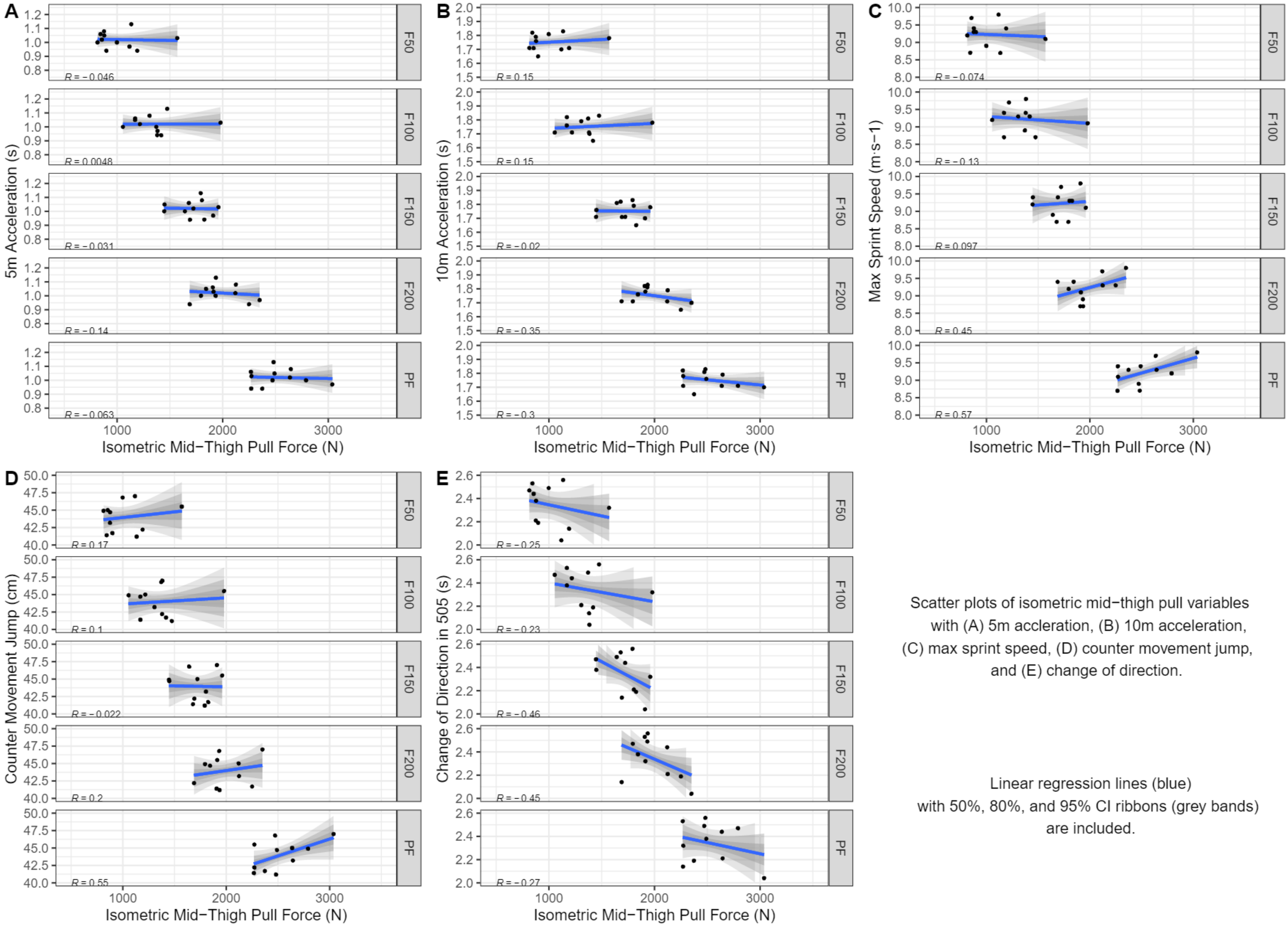
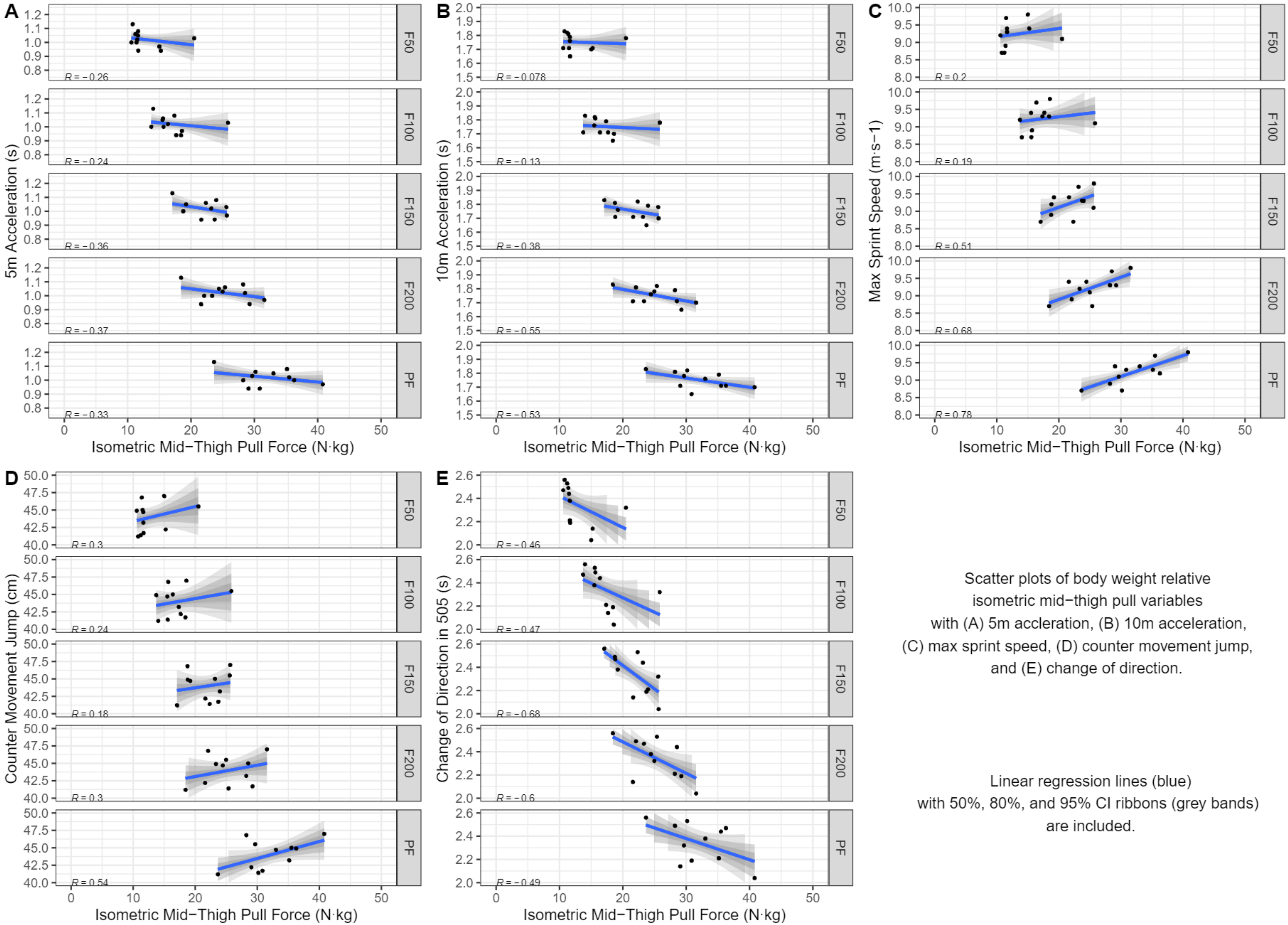
Table 1. Descriptive Statistics for IMTP variables, accelerations, maximum velocities, CMJ and COD505 ability.

	Mean ± SD	**Minimum**	**Maximum**	**CI (95%)**	**CV (%)**	**ICC(3,1) (95% CI)**
F50 (N)	886 ± 93	810	1117	831–941	10.55	0.089 (-0.18-0.46)
F100 (N)	1267 ± 199	1055	1418	1196.7–1337.3	9.42	0.51 (0.20-0.78)
F150 (N)	1705 ± 148	1446	1910	1617.6–1792.4	8.68	0.48 (0.17-0.76)
F200 (N)	1987 ± 201	1688	2350	1868.3–2105.7	10.09	0.90 (0.79-0.96)
PF (N)	2522 ± 242	2267	3038	2379–2665	9.58	0.90 (0.79-0.96)
5 m Acceleration (s)	1.02 ± 0.09	0.93	1.23	0.97–1.07	9.10	0.85 (0.72-0.94)
10 m Acceleration (s)	1.75 ± 0.06	1.65	1.83	1.71–1.79	3.58	0.85 (0.72-0.94)
MSS ($m \cdot s^{-1}$)	9.22 ± 0.38	8.60	9.80	9.00–9.44	4.08	0.76 (0.57-0.90)
CMJ (cm)	43.96 ± 2.12	41.20	47.00	42.71–45.21	4.83	0.78 (0.60–0.91)
COD505 (s)	2.34 ± 0.17	2.04	2.56	2.24–2.44	7.46	0.97 (0.94-0.99)



Scatter plots of isometric mid−thigh pull variables with (A) 5m accleration, (B) 10m acceleration, (C) max sprint speed, (D) counter movement jump, and (E) change of direction.

Linear regression lines (blue) with 50%, 80%, and 95% CI ribbons (grey bands) are included.



Scatter plots of body weight relative isometric mid−thigh pull variables with (A) 5m accleration, (B) 10m acceleration, (C) max sprint speed, (D) counter movement jump, and (E) change of direction.

Linear regression lines (blue) with 50%, 80%, and 95% CI ribbons (grey bands) are included.