Relationship among Unilateral Stance Isometric Mid-thigh Pull Variables, Sprint Times, and Jump Performance in Collegiate Football Players

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This study aimed to elucidate the relationships among unilateral stance isometric mid-thigh pull (IMTP_uni) variables, sprint times, and single-leg jump performance in collegiate football players. A total of twenty male collegiate football players participated in this study. Participants were instructed to perform IMTP_uni by pulling a fixed bar on a force plate to measure the ground reaction force (GRF). Based on the GRF, two variables were calculated; force output from onset of pull (F100) and peak force (PF). Sprint performance was measured by light gates over a distance of 30 m. The height of single-leg countermovement jumps (CMJ) and the single-leg drop jump index which was the jump height divided by contact time was measured for single-leg jump performance. The legs were divided by two types of definition such as kicking/supporting legs and dominant/non-dominant leg based on PF. As the result, sprint times were significantly correlated with single-leg CMJ only in the kicking and dominant legs. On the other hand, PF of IMTP_uni was significantly correlated with sprint times in the supporting leg as well as both the dominant and non-dominant legs. However, no significant correlations were found between F100 and sprint time in both definitions. Therefore, the PF of IMTP_uni as well as CMJ can be used as an effective predictor of strength for sprint.

Keywords: IMTP, unilateral stance, sprint, strength, jump

1. Introduction

Sprint performance is of great importance for football players. According to Di Salvo et al., (2010) there are approximately 20 sprints in each football match and the number of sprints is associated with the number of goals. Cometti et al. (2010) showed that professional football players have a superior sprint performance compared to that of amateur football players. Therefore, improving sprint performance is one of the most important tasks that football players should undertake.

Several studies have suggested that lower leg strength is associated with sprint performance in various sports (Suchomel et al., 2016). A one repetition maximum (1RM) in squats and countermovement jumps (CMJ) are generally used to evaluate lower leg strength. In order to measure lower leg strength, bilateral stance isometric mid-thigh pulls (IMTP_bi) are more frequently used, as they can provide easy and accurate measurement of strength characteristics (Wang et al., 2016). Moreover, some previous studies have revealed a significant correlation between IMTP_bi variables and sprint times (Kuki et al., 2017; Wang et al., 2016; West et al., 2011).

However, there is a discrepancy in the features of force generation between IMTP_bi and sprinting. Since the body is supported by either of legs in sprinting, force is generated unilaterally. While, in IMTP_bi, force is generated bilaterally because the body is supported by both legs. Due to this discrepancy, IMTP with a unilateral stance (IMTP_uni) has been developed recently as an alternative method (Dos’ Santos et al., 2017a; Thomas et al., 2016). Although previous studies have examined strength asymmetry using IMTP_uni and described the characteristics of force generation in IMTP_uni
compared to IMTP\(_{Bi}\) (Dos' Santos et al., 2017a; Kuki et al., 2018), the relationship between IMTP\(_{Uni}\) variables and dynamic performance has not yet been well made clarify. One previous study has examined the relationship between IMTP\(_{Uni}\) variables and dynamic performance, and the authors suggested that the variables of IMTP\(_{Uni}\) could be an effective parameter for measuring strength. This is due to the significant correlation between the peak force (PF) of IMTP\(_{Uni}\) and 20-m sprint times (Thomas et al., 2016). The aforementioned study recruited junior cricket players. It seems that there are significant relationships between IMTP\(_{Uni}\) variables and sprint times in other sport events such as football and baseball so on. However, to date, it is not known whether the relationship between the IMTP\(_{Uni}\) variables and sprint times is true for the other sports. In addition, there were not enough studies to examine the relationship between IMTP\(_{Uni}\) variables and jump performances, although it could be speculated the significant relationships between them based on the studies of IMTP\(_{Bi}\) (Beattie et al., 2017; Suchomel et al., 2016). The commonly used measures of strength, including 1RM squats and IMTP\(_{Bi}\), are well established because a number of studies have been conducted to analyse the relationship between these measures of strength and dynamic performance (Suchomel et al., 2016).

On the other hand, in IMTP\(_{Uni}\), it is possible to examine how the strength of each leg could contribute separately to performances separately. For instance, Kariyama et al. (2014) has revealed that the strength of the supporting leg was mainly correlated with ball speed during instep kicking in football players. Since the discrepancy between legs might be expanded by sport specific movement especially for the football players, it is meaningful to evaluate the strength in each leg. Moreover, Newton et al. (2006) examined the asymmetry of strength between the dominant and non-dominant legs. In previous study, the capacity of force exertion in each leg was used to define the dominant and non-dominant legs. According to the authors, previous injuries would also influence into the discrepancy of force exertion between legs, so that the manner to distinguish the legs based on force generation should be useful to evaluate the current athlete's condition. Hence, the evaluation of strength in each leg with different definitions is helpful for coaches and trainers.

Therefore, the purpose of the present study was to examine the relationship among variables of IMTP\(_{Uni}\), sprint times, and single-leg jump performance in collegiate football players. We hypothesized that IMTP\(_{Uni}\) variables were significantly correlated with both sprint times and single-leg jump performance in collegiate football players.

2. Materials and methods

2.1. Participants

A total of twenty male collegiate football players (height, 1.73 ± 0.06 m; mass, 65.07 ± 6.53 kg) volunteered as participants for this study. Eighteen of them were right-foot preferred in kicking, and two of them were left-foot preferred in kicking. All participants were first year university students and were members of a university football team. They did not have any injuries that could influence the results of the tests. The participants were informed of the experimental method implemented in the present study in both, the verbal and written formats, prior to the tests. The Ethics Committee for the Institute of Health and Sport Sciences, University of **, approved all procedures.

2.2. Unilateral stance isometric mid-thigh pull (IMTP\(_{Uni}\))

In this study, the IMTP\(_{Uni}\) which stand on one leg and pull a fixed bar vertically with maximum effort was implemented to measure strength with isometric muscle contraction. It was performed by standing on force plate (Ex-Jumper, DKH, Tokyo, Japan) to measure the vertical component of the ground reaction force (GRF) using a custom designed squat rack with an adjustable-height bar. Lifting straps and athletics tape were used to eliminate the influence of grip strength on GRF. In detail, participants were introduced to fasten their hands and a bar by using lifting strap, and athletic tape was also used to wind round (Kuki et al., 2017). The method to fix the hands and bar by using both of lifting strap and athletic tape was able to minimise the influence of grip strength. All of the participants used a standard posture to perform IMTP\(_{Uni}\), with a knee angle of 120 degrees and a hip angle of 140 degrees in the supported leg, (Kuki et al., 2018). Participants were instructed to decrease the knee angle
of the unsupported leg to 90 degrees, and fix the position of the unsupported leg to avoid any swing motion. Participants were also instructed to maintain the trunk in an upright position (Beattie et al., 2017). Following a general warm up, participants performed two practice attempts using 50% and 75% of their perceived maximum effort, as a specific warm up designed to familiarize them with the technique (Kuki et al., 2017). Participants were instructed to pull the bar as fast and hard as possible for four seconds. Participants were permitted three attempts, performed in a randomized order. Three minutes of rest was provided between attempts to allow for full recovery from fatigue.

The IMTP_{Uni} assessment was performed using both a right leg stance and a left leg stance, and the vertical component of the GRF was collected at 1000 Hz (Dos’Santos et al., 2016). To generate the variables of IMTP_{Uni}, the force time curve was used to determine the force output at 100 ms after the onset of the pull and peak GRF during the IMTP_{Uni}: they were indicated as the F100 and PF (Kuki et al., 2017). The onset of the pull was defined as the point when the GRF was achieved at 110\% of a participant’s body mass (Dos’Santos et al., 2017b). The value of participant’s body mass was subtracted from the variables in order to remove the influence of body mass (West et al., 2011). In this study, the relative values of the F100 and PF (F100_{REL} and PF_{REL}) which was calculated as the force output relative to body mass were used for further analysis as well as the absolute values of the F100 and PF (F100_{ABS} and PF_{ABS}). The top two PF_{ABS} were selected from the three trials and an average was calculated. The test re-test reliability for force outputs met the standard for reliability of the IMTP_{Uni} variable, which was an intra-class correlation coefficient (ICC) >0.70 (Haff et al., 2015).

2.3. Sprint and single-leg jumps

Participants performed a 30-m sprint in order to measure 10- and 30-m sprint times. The participants were permitted a 15 minute warm up, which included dynamic stretching and two 30-m sprint attempts as practice. Light gates (TC Timing System, Brower Timing Systems, Utah, USA) were set up at 0 m (start), 10-m, and 30-m (goal). All the participants performed two trials with approximately 3 min of rest between two trials. The participants started in the three-point position maintaining a static position. In addition, the toe of a front leg was put 0.5-m behind from the first gate to prevent being triggered too early. They were instructed to run as fast as possible. The fastest 30-m sprint time achieved in the two trials was used for analysis.

As for the single-leg jump assessments, CMJ and drop jump (DJ) with unilateral stance were performed using the switch mat (Multi-Jump Tester, DKH, Tokyo, Japan). During this assessment, the participants were instructed to keep their hands on their hips, but were not provided with any specific instructions about the unsupported leg. For the single-leg CMJ, participants descended from the standing position to a self-selected depth, and jumped vertically using maximal effort. The DJ was performed from an upright standing position on a 0.3 m high box: participants stepped off the box and rebounded with the shortest possible foot contact time, jumping using maximal effort. The jump height was measured in single-leg CMJ, while the DJ-index which was the jump height divided by contact time was measured in single-leg DJ. The calculation of the jump height of CMJ and DJ was calculated by flight time and gravitational acceleration.

2.4. Definition of the legs

In this study, two definitions were used to distinguish legs: kicking/supporting and dominant/non-dominant. To distinguish the legs into the kicking and supporting legs, the participants were asked which leg was used to kick a ball preferentially, which the manner of definition was followed to a previous study by Östenberg et al., (1998). While, the dominant and non-dominant legs were determined using the PF_{ABS} of the IMTP_{Uni} to distinguish dominance, based on the ability of the leg to exert force, which the manner of definition was followed to a previous study by Kuki et al., (2019). The leg with a greater PF was defined as the dominant leg for force generation, and weaker one was defined as the non-dominant leg.

2.5. Statistics

The mean and standard deviation (SD) were presented as a descriptive analysis. Intraclass correlation coefficients (ICC) were used to assess the test re-test
reliability of the assessments. The relationship among variables of IMTP\textsubscript{Uni}, jump variables, and sprint times were analyzed using Pearson’s product-moment correlation. A paired t-test was used to determine the difference between kicking/supporting and dominant/non-dominant legs. Cohen’s d effect size was calculated using the mean and SD to show practical significance. The statistical analyses for Pearson’s correlation and paired t-test were performed using SPSS v22 software (IBM, New York, USA). The p-value threshold for statistical significance was defined as $p < 0.05$.

### 3. Results

Mean and SD of IMTP\textsubscript{Uni} variables and single-leg jump performances in kicking/supporting legs and dominant/non-dominant legs are shown in Table 1. The mean and SD of the 10 and 30 m sprint times were measured as follows; 10 m sprint time (1.77 ± 0.08 sec) and 30 m sprint time (4.33 ± 0.14 sec). In Table 1, it is also demonstrated the result of the paired t-test comparing the legs. The significant differences were found in PF\textsubscript{REL} between the kicking and supporting legs as well as in PF\textsubscript{ABS} and PF\textsubscript{REL} between the dominant and non-dominant legs.

The results of the correlation analysis between the jump performances and sprint times are shown in Table 2. The single-leg CMJ height was significantly correlated with 30-m sprint time in the kicking leg ($r = -0.499, p < 0.05$). In addition, in the dominant leg, the single-leg CMJ height was significantly correlated with 10-m ($r = -0.468, p < 0.05$) and 30-m ($r = -0.507, p < -0.507$) sprint times. While, there was no significant correlation between single-leg DJ-index and sprint times in both conditions such as dominant and non-dominant legs ($-0.202 < r < 0.509$).

The correlation coefficients for IMTP\textsubscript{Uni} variables, sprint times, and single-leg jump performances

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**Table 1** Descriptive analysis and the comparison between the kicking and supporting legs*.

| Absolute value in IMTP\textsubscript{Uni} | Kicking Leg | Supporting Leg | Paired t-test |
|------------------------------------------|------------|---------------|--------------|
|                                          | Mean ± SD  | Mean ± SD     | Significance | Effect size |
| F100\textsubscript{ABS} (N)                  | 573.46 ± 209.98 | 563.62 ± 191.47 | n.s.         | 0.05       |
| PF\textsubscript{ABS} (N)                     | 1524.99 ± 338.08 | 1417.36 ± 343.73 | n.s.         | 0.32       |
| Relative value in IMTP\textsubscript{Uni}   |            |               |              |            |
| F100\textsubscript{REL} (N/kg)              | 8.89 ± 3.07  | 8.69 ± 2.64   | n.s.         | 0.07       |
| PF\textsubscript{REL} (N/kg)                 | 23.77 ± 5.01 | 22.07 ± 4.92  | p < 0.01     | 0.34       |
| Jump Variables                              |            |               |              |            |
| CMJ (cm)                                    | 18.40 ± 3.41 | 19.46 ± 3.43  | n.s.         | 0.31       |
| DJ-index                                    | 0.64 ± 0.13  | 0.65 ± 0.14   | n.s.         | 0.07       |

| Absolute value in IMTP\textsubscript{Uni} | Dominant Leg | Non-dominant Leg | Paired t-test |
|------------------------------------------|--------------|-----------------|--------------|
|                                          | Mean ± SD    | Mean ± SD       | Significance | Effect size |
| F100 (N)                                  | 565.76 ± 223.70 | 571.32 ± 175.34 | n.s.         | 0.03       |
| PF (N)                                    | 1565.29 ± 376.98 | 1377.06 ± 278.90 | p < 0.01     | 0.57       |
| Relative value in IMTP\textsubscript{Uni} |            |                 |              |            |
| F100 (N/kg)                               | 8.76 ± 3.25  | 8.83 ± 2.42     | n.s.         | 0.02       |
| PF (N/kg)                                 | 24.35 ± 5.39 | 21.48 ± 4.18    | p < 0.01     | 0.60       |
| Jump Variables                            |            |                 |              |            |
| CMJ (cm)                                  | 18.43 ± 3.30 | 19.43 ± 3.54    | n.s.         | 0.28       |
| DJ-index                                  | 0.65 ± 0.13  | 0.64 ± 0.13     | n.s.         | 0.08       |

**Footnote:**

F100\textsubscript{ABS} = An absolute value of force output at 100 ms after onset of the pull.
PF\textsubscript{ABS} = An absolute value of peak force during IMTP\textsubscript{Uni}.
F100\textsubscript{REL} = A value of F100 relative to body weight.
PF\textsubscript{REL} = A value of PF relative to body weight.
CMJ = single-leg counter movement jump.
DJ = single-leg drop jump.
for the kicking and supporting legs are shown in Table 3. Although there was no significant correlation for the kicking leg, the PF<sub>ABS</sub> and PF<sub>REL</sub> of IMTP<sub>Uni</sub> in the supporting leg was significantly correlated with 30-m (r = −0.460, p < 0.05) and 10-m (r = −0.490, p < 0.05) sprint times respectively. While, all of the variables in IMTP<sub>Uni</sub> were not significantly correlated with any jump performances in both kicking and supporting legs.

Regarding to results of the correlation in dominant and non-dominant legs, it is shown in Table 4. The PF<sub>ABS</sub> of IMTP<sub>Uni</sub> in both dominant and non-dominant legs were significantly correlated with the 30-m sprint time (dominant leg: r = −0.456, p < 0.05 non-dominant leg; r = −0.452, p < 0.05), and the PF<sub>REL</sub> in non-dominant leg was significantly correlated with 10-m sprint time (r = −0.447, p < 0.05). While, it was found no significant correlation between all of the variables in IMTP<sub>Uni</sub> and jump performances in both dominant and non-dominant legs.

### Table 2

|                  | Sprint 10 m | Sprint 30 m |
|------------------|-------------|-------------|
| **Kicking Leg**  |             |             |
| CMJ              | −0.437      | −0.499<sup>†</sup> |
| DJ               | 0.051       | −0.083      |
| **Supporting Leg**|            |             |
| CMJ              | −0.178      | −0.276      |
| DJ               | −0.015      | −0.120      |
| **Dominant Leg** |             |             |
| CMJ              | −0.468<sup>†</sup> | −0.507<sup>†</sup> |
| DJ               | −0.091      | −0.202      |
| **Non-dominant Leg**|        |             |
| CMJ              | −0.158      | −0.276      |
| DJ               | 0.059       | −0.067      |

<sup>†</sup> = significant correlation (p < 0.05).

Footnote:
CMJ = single-leg counter movement jump.
DJ = single-leg drop jump.

### Table 3

|                  | CMJ height (Kicking) | CMJ height (Supporting) | DJ index (Kicking) | DJ index (Supporting) | Sprint 10 m | Sprint 30 m |
|------------------|----------------------|-------------------------|-------------------|------------------------|-------------|-------------|
| **Kicking Leg**  |                      |                         |                   |                        |             |             |
| F<sub>100ABS</sub> (N) | 0.365               | —                       | 0.289              | —                      | −0.113      | −0.264      |
| PF<sub>ABS</sub> (N)         | 0.037               | —                       | 0.165              | —                      | −0.291      | −0.414      |
| F<sub>100REL</sub> (N/kg)   | 0.313               | —                       | 0.259              | —                      | −0.129      | −0.229      |
| PF<sub>REL</sub> (N/kg)     | −0.046              | —                       | 0.149              | —                      | −0.331      | −0.348      |
| **Supporting Leg** |                      |                         |                   |                        |             |             |
| F<sub>100ABS</sub> (N)     | —                    | 0.376                   | —                  | 0.255                  | 0.058       | −0.213      |
| PF<sub>ABS</sub> (N)        | —                    | 0.198                   | —                  | 0.246                  | −0.439      | −0.460<sup>†</sup> |
| F<sub>100REL</sub> (N/kg)   | —                    | 0.408                   | —                  | 0.192                  | 0.044       | −0.183      |
| PF<sub>REL</sub> (N/kg)     | —                    | 0.215                   | —                  | 0.172                  | −0.490<sup>†</sup> | −0.405 |

<sup>†</sup> = significant correlation (p < 0.05).

Footnote:
F<sub>100ABS</sub> = An absolute value of force output at 100 ms after onset of the pull.
PF<sub>ABS</sub> = An absolute value of peak force during IMTP<sub>Uni</sub>.
F<sub>100REL</sub> = A value of F100 relative to body weight.
PF<sub>REL</sub> = A value of PF relative to body weight.
CMJ = single-leg counter movement jump.
DJ = single-leg drop jump.

### 4. Discussion

This study was conducted to elucidate the relationships among IMTP<sub>Uni</sub> variables, sprint times, and single-leg jump performance. Firstly, we implemented the correlation analysis between the single-leg jump performances and sprint times. As the result, the jump height of single-leg CMJ only in the kicking leg was significantly correlated with sprint time in 30-m. Also, it was found the significant relationships between the jump height of single-leg CMJ and sprint times in 10-m and 30-m only in the dominant leg. The previous study indicated that the mean force during single-leg CMJ in the dominant leg was significantly correlated with 30-m sprint time (Dobbs et al., 2015). Although...
they did not investigate the relationship between sprint times and jump height of single-leg CMJ, the result that mean force during single-leg CMJ was significantly correlated with sprint times would support the result of the present study. On the other hand, there were no significant correlations among the DJ-index and sprint times. Kariyama et al. (2016) evaluated the reactive strength by using bilateral rebound jump index and examined the relationship between reactive strength and sprint velocity in maximum velocity phase. Then, they found no significant relationship between those variables. Although sprint performance in acceleration phase was measured in this study, our results would be similar with their results.

As for the relationships between the variables of IMTP\textsubscript{Uni} and sprint times, the PF\textsubscript{ABS} and PF\textsubscript{REL} of IMTP\textsubscript{Uni} in only supporting leg was significantly correlated with sprint times, not in the kicking leg. Therefore, our hypothesis that IMTP\textsubscript{Uni} variables were significantly correlated with sprint times was partially supported. In other words, the result indicated the possibility that there were different contributions into sprint performance between the supporting and kicking legs in football players. Regarding to the ball speed during instep kick, it was revealed that the hip extensors and hip abductors in the supporting leg played meaningful role (Kariyama et al., 2014). As practical application, they also mentioned that strength training for those muscles could improve the ball speed. Although it was impossible to discuss the instep kicking and sprint equally, the previous study by Kariyama et al. (2014) would support the possibility of different contributions into sprint performance between legs in football players. Then, we also support the importance of the maximum strength particularly in the supporting leg for football players based upon the results of the correlation analysis that PF\textsubscript{ABS} and PF\textsubscript{REL} of IMTP\textsubscript{Uni} in the only supporting leg were significantly correlated with sprint times. Since a sport-specific requirement could increase the discrepancy in strength and functionality between legs (Newton et al., 2006), there was a possibility of the asymmetrical contribution of strength in lower legs into the sprint performance between legs in football players. Moreover, this study suggested that the addition of the isometric measurement like IMTP\textsubscript{Uni} into the battery of strength testing would be effective. Because it is possible to easily measure explosive and maximum strength in each leg by using IMTP\textsubscript{Uni}. While, it should be noted that those peak force variables of the supporting leg were weaker than those of the kicking leg. In the previous study of Kariyama et al. (2014), most of the peak torques which were exerted in single joint exercises such as

### Table 4 The correlations among variables in the D and ND legs*

| Dominant Leg | CMJ height (D) | CMJ height (ND) | DJ index (D) | DJ index (ND) | Sprint 10 m | Sprint 30 m |
|--------------|----------------|-----------------|--------------|--------------|-------------|-------------|
| F\textsubscript{ABS} (N) | 0.354 | — | 0.348 | — | −0.007 | −0.193 |
| PF\textsubscript{ABS} (N) | 0.054 | — | 0.251 | — | −0.256 | −0.456 |
| F\textsubscript{REL} (N/kg) | 0.295 | — | 0.290 | — | −0.022 | −0.162 |
| PF\textsubscript{REL} (N/kg) | −0.046 | — | 0.190 | — | −0.409 | −0.408 |

| Non dominant Leg | CMJ height (D) | CMJ height (ND) | DJ index (D) | DJ index (ND) | Sprint 10 m | Sprint 30 m |
|------------------|----------------|-----------------|--------------|--------------|-------------|-------------|
| F\textsubscript{ABS} (N) | — | 0.384 | — | 0.187 | −0.064 | −0.304 |
| PF\textsubscript{ABS} (N) | — | 0.251 | — | 0.111 | −0.406 | −0.452 |
| F\textsubscript{REL} (N/kg) | — | 0.427 | — | 0.142 | −0.087 | −0.272 |
| PF\textsubscript{REL} (N/kg) | — | 0.286 | — | 0.056 | −0.447 | −0.368 |

* = significant correlation (p < 0.05).

Footnotes:
D = Dominant leg.
ND = Non dominant leg.
F\textsubscript{ABS} = An absolute value of force output at 100 ms after onset of the pull.
PF\textsubscript{ABS} = An absolute value of peak force during IMTP\textsubscript{Uni}.
F\textsubscript{REL} = A value of F100 relative to body weight.
PF\textsubscript{REL} = A value of PF relative to body weight.
CMJ = single-leg counter movement jump.
DJ = single-leg drop jump.
hip extension and knee flexion etc. were significantly higher in the supporting leg than the kicking leg in football players. Although it was difficult to show the reason why the different results were obtained in the present study, the topics of the asymmetry in football players should be interesting from the perspective of risk of injury and limiting factors of performance. Thus, further studies are needed to discuss the asymmetry for football players in more detail.

On the other hand, the legs were defined as the dominant and non-dominant legs based on the PF$_{ABS}$ of IMTP$_{Uni}$. Because, a previous study has indicated that the kicking leg did not always consist with the dominant leg with force exertion (Kuki et al., 2019). As the result of this study, there was a significant correlation between PF$_{ABS}$ of IMTP$_{Uni}$ and 30-m sprint times in both of dominant and non-dominant legs. While, PF$_{REL}$ of IMTP$_{Uni}$ was also correlated with 10-m sprint time in non-dominant leg. Those results partially supported our hypothesis, and the fact that only the variables of PF were correlated with sprint times was interesting. The variables such as F100$_{ABS}$ and F100$_{REL}$ were usually used as the predictor of explosive strength. Since it is required to exert force with very limited duration in sprinting due to short contact time, those variables seemed to be in significant relationship with sprint times. In addition, some previous studies regarding to IMTP$_{Bi}$ have investigated that F100 was significantly correlated with sprint times (Kuki et al., 2017; West et al., 2011). As a possible reason why F100$_{ABS}$ and F100$_{REL}$ did not correlate with sprint time, the results in the present study might be the subject-specific results. Freshman University’s football players were recruited in the present study, so that they might not familiarise to explosive force exertion because of their insufficient experience of strength training. If our assumption is true, it would be required to perform the specific warm-up for IMTP$_{Uni}$ more carefully in order to improve the reliability of the testing, especially for the subjects with little strength training experience. In addition, the result of this study might indicate the possibility of mechanical differences in F100 between IMTP$_{Bi}$ and IMTP$_{Uni}$. As the mechanical differences in F100, it was speculated that the pre-activation before the onset of the pull might be a potential factor. Since F100 is the magnitude of force at 100 ms after the onset of the pull, there is a time constrain. Such a situation, neural drive could influence strongly into the rate of force development (Aagaard et al., 2002). Although there was no quantitative data regarding pre-activation between IMTP$_{Bi}$ and IMTP$_{Uni}$, IMTP$_{Uni}$ might be higher than IMTP$_{Bi}$ due to unilateral stance. The difference and influence in pre-activation between IMTP$_{Bi}$ and IMTP$_{Uni}$ were interesting, so that further studied would be necessary. Moreover, neither of CMJ and DJ in single-leg jump performances were correlated with all variables of IMTP$_{Uni}$. Those results did not support our hypothesis that the IMTP$_{Uni}$ variables were significantly correlated with the single-leg jump performances. Particularly, the variables such as F100$_{REL}$ and PF$_{REL}$ should be correlated with jump performances, because those jump performances were valid predictors for the lower limb strength relative to body mass. From the viewpoint of the similarity, it is required the additional examination of those relationships in future study.

In conclusion, the present study suggested that the PF$_{ABS}$ and PF$_{REL}$ of IMTP$_{Uni}$ in the supporting leg as well as both the dominant and non-dominant legs were correlated with 10-m and 30-m sprint time. However, there were no significant relationship between sprint times and the predictors of explosive strength such as F100$_{ABS}$ and F100$_{REL}$. The results supported the effectiveness of peak force variables included absolute and relative values in IMTP$_{Uni}$ for evaluating strength required in sprint performance. In addition, single-leg CMJ was also effective predictor to evaluate the strength for sprint performance because those jump height in the kicking and dominant leg was also correlated with sprint times. Moreover, this study indicated the importance of measuring maximum strength using unilateral stance exercises in addition to bilateral stance exercises.

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