RELATIONSHIPS AMONG JUMPING PERFORMANCES AND SPRINT PARAMETERS DURING MAXIMUM SPEED PHASE IN SPRINTERS

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ABSTRACT

Kale, M, Aşçı, A, Bayrak, C, and Açıkgöz, C. Relationships among jumping performances and sprint parameters during maximum speed phase in sprinters. J Strength Cond Res 23(8): 2272–2279, 2009—The purpose of this study was to investigate the relationships among jumping performances and speed parameters during maximum speed phase in sprinters. Twenty-one men sprinters volunteered to participate at the beginning of the preparation training phase. All tests—including 100-m sprint running, squat jump (SJ), countermovement jump (CMJ), drop jump (DJ), 60-second repetitive jump (RJ), standing long jump (SLJ), standing triple jump (STJ), standing quintuple jump (SQJ), and standing 10-stride jump (STJ)—were done on switching mats. Flight (FT) and contact times (CT) during the vertical jump tests and 10-m split times during 100-m sprint running were measured by a 2-channel precision timing system (PTS) connected to the mats. The trace marking method was used for measuring the stride length (SL) through 60 m in 100-m sprint running. Stride frequency (SF), maximum velocity (Vmax), jump height for all vertical jumps, and lower-body power in DJ and RJ were calculated. Statistical analysis showed that the highest significant correlation was found between Vmax and DJ height ($r = 0.69; p < 0.05$). However, the lowest significant correlation coefficient was found between SL at maximum velocity phase of sprint running and SJ ($r = 0.39; p < 0.05$). In conclusion, DJ height is demonstrated to be a more effective way to reflect Vmax during sprint running than the other vertical and horizontal jump tests at the beginning of the preparation training phase.

KEY WORDS maximum velocity, contact time, flight time, stride length, stride frequency

Successful sprint running performance requires good starting ability, highest maximum running velocity, and endurance of that velocity capacity. Maximum running velocity in elite sprinters is achieved by optimal stride length (SL) and stride frequency (SF) in the distance between 30 m and 60 m (19,24,29). Generally, shorter contact time (CT) results in greater performances in sprinting; therefore, faster sprinters have shorter contact time than slower sprinters in each stride (14). Both short coupling time and isometric transition time from eccentric to concentric phases prevent detachment of the cross bridges and then allow better utilization of their stored potential energy during the subsequent shortening phase (9). In addition, a shorter foot contact time with the ground executes more effective elastic energy (23). Higher performance is presented as a result of the recoil of elastic energy stored in the series elastic component of muscles during the eccentric phase of foot contact. This amount of stored elastic energy takes place in a higher efficiency in the following concentric phase. In the foot contact of sprint strides, muscle force continuously changes as a result of elastic energy utilization during concentric contraction (6).

Maximum muscle contraction force is necessary to achieve mechanical power in the starting speed and short sprint performance (19). More powerful sprinters have shorter foot contact time with the ground, longer stride length and flight time (FT) (18), and more stride frequency (17), which are all related to muscular power. Therefore, it is thought that greater muscle power is necessary for maximum jump and sprint running (27). Morin and Belli (32) stated that jump power is the best indicator of sprint ability. Jump tests provide evaluations for lower-limb power capability and give valid assessments of muscular power (11,27). Contracting at a high velocity and rapid stretching of the lower-limb musculature suggest that relative explosive ability of hip and knee extensors is critical to sprint performance (32). Leg stiffness was calculated in vertical jump, which is correlated with the muscular power, restituted during the eccentric–concentric phase of the leg force and contact time (reactive power). This reactive power is involved in each stride to maintain the high running velocity (13).
Maximum muscular power of athletes was found to be significantly correlated with mean 20-, 40-, and 60-m velocities and with the time to reach maximum velocity (Vmax) (32).

Sprinters produce a high lower-limb power rapidly before reaching their Vmax and maintain this power in Vmax phase. In this phase of sprint running, each sprint stride including foot contact time with the ground and flight time represents higher stride length and frequency as a result of decreasing contact time and increasing flight time (17). During each takeoff, this power increases vertical velocity that results in an increased flight time and distance covered (38). Previous studies demonstrated the relationships between sprint parameters, such as velocity at the start, average and Vmax during sprint running, and both vertical and horizontal jumps (11,20, 35). Osinski (35) stated that Vmax in 100-m sprint running was correlated with standing long jump (SLJ) and standing triple jump (STJ), which are the types of horizontal jumps. Furthermore, Bağışan (2) reported that Vmax in 100-m sprint running had relationships with both standing quintuple step jumps, 10 step jumps, and standing long and triple jumps. However, some studies showed the relationships between horizontal jump performance and 30-m to 100-m sprint running times (2,19). The relationship between Vmax during short distance sprint running and the vertical jumps have also been studied. Katja and Coh (25) stated that the Vmax measured in any distance during 60-m sprint running and the velocities at 0 to 10-, 10 to 20-, and 20 to 30-m intervals were related with squat jump (SJ) height. Furthermore, Vmax in 20-m sprint running was correlated with drop jump (DJ) performance (25). In addition, 30-m and 100-m times, and the starting velocity and the Vmax during sprint running, were also correlated with the countermovement jump (CMJ), which is 1 of other types of vertical jump tests (4,11,40). Miguel and Reis (31) have demonstrated that Vmax and sprint time were correlated with 30-second rebound jump performance that includes lactic anaerobic characteristics compared with squat, countermovement, and drop jumps.

The relationships among Vmax, sprint running times, and muscular power in horizontal and vertical jump performances were frequently studied in the literature. However, there are few attempts to examine the relationship between the horizontal jump performance or vertical jump power and sprint parameters such as Vmax, contact time, flight time, stride frequency, stride length, and running time at the start, maximum speed or speed endurance parts of sprint running. Thus, the purpose of this study was to investigate the relationship between the sprint parameters (contact time, flight time, stride frequency, stride length) occurring at the distance reaching Vmax phase in sprint running and both vertical and horizontal jump performances.

METHODS

Experimental Approach to the Problem
Vertical and horizontal jump tests, which are widely accepted as tests to evaluate lower-limb power capability and give valid assessments of muscular power, are important for sprint running. Vertical jumps, horizontal jumps, and sprint parameters were assessed to examine relationships between jumping performances and sprint parameters during the distance reaching Vmax phase in sprint running. CT, FT, SF, and SL were evaluated as sprint parameters occurring at a distance reaching Vmax in 100-m sprint running. Vertical jump heights were monitored by means of SJ, CMJ, DJ, and rebound jump (RJ). Horizontal jump lengths included SLJ, STJ, standing quintuple jump (SQJ), and standing 10-step jump (STENJ). Pearson correlation design, including voluntary sprinters to account for the relationships between sprint parameters and each jump performance assay, was used.

Subjects
Twenty-one men sprinters, who are the best of 100-m sprint performances in Turkish Track and Field Cup 1 and 2 (between 10.80 and 11.39 seconds), volunteered to participate in the study. Sprinters were trained with fitness exercises including 25 to 30 minutes of running with extensive tempo 6 times a week and 8 to 10 calisthenics exercises 3 times a week in the first week of the preparation phase following 2 to 3 weeks of a transition phase in the summer. Tests were executed in the second week of the preparation phase. Sprinters were instructed not to exercise for 24 hours preceding all testing sessions. The procedures and risks of the experiment were explained to the sprinters before they signed an institutionally approved informed consent document. No sprinters were younger than age 18 years. Furthermore, this study was approved by Hacettepe University, Institute of Health Sciences. The mean and standard deviation (M ± SD) of age, height, body weight, 100-m sprint performance, and somatotype were described by Carter and Heath (12), and the sum of 7-site skinfold measurements (Σ7-SS) described by Norton et al. (34) are shown in Table 1.

Testing Procedures
The subjects performed jump tests (horizontal and vertical) and 100-m sprint running test during a 2-day period. SJ, CMJ, SLJ, STJ, SQJ, and STENJ were performed twice at maximal efforts, and the best performance for each jump test was evaluated for statistical analysis. DJ and RJ, including many maximal efforts, were tested only once. Each period had 2 test sessions with a 4-hour rest. In the first session, subjects participated in SJ, CMJ, and DJ as the vertical jump tests. In the second session, horizontal jumps including SLJ, STJ, SQJ, and STENJ were performed following the rest period. Sixty seconds rebound jump (RJ) and 100-m sprint run were performed in the third and fourth sessions, respectively. Subjects were well acquainted, familiarized with testing procedures, and verbally encouraged prior to each performance test. Sprinters performed the tests in tight-fitting clothing and spiked track shoes.

Equipment
The time data needed to calculate the Vmax in the 100-m sprint, vertical jump height, and power in vertical jump tests
were measured by customized Precision Timing System (PTS). PTS included 2 channels of data acquisition, electronic receiver, 11 infrared photocells (Tümer Electronic, Turkey), and 60-m switching mat (4 × 15 m) (Tapeswitch, U.S.A.) (Figure 1a and 1b). ESC 2XXX Series Data Acquisition Software (Tümer Electronic, Turkey) was used to record the time data sampled at 1,000 Hz and sent to a portable computer via serial slot (RS232) during the tests. It was CT when the timer of PTS was triggered by the feet of the subject at the moment of touch down the switching mat and then stopped at the moment of release from the mat. The timer of PTS was triggered by the feet of the subject at the moment of release from the mat and then stopped at the moment of touch down (FT).

100-m Sprint Test
Sprinters with spiked shoes performed two 100-m sprints on 60-m switching mats lying on the synthetic track from standing position with full recovery following warm-up including self-paced running, calisthenics, and flexibility exercises. To preserve the mats from spike shoes, a roll rubber (0.05-m thickness, 0.60-m width, and 60-m length) was placed on the switching mat. To mark all sprint strides from the beginning to the end of 0 to 60 m in the 1000m sprint, a strip of roll paper (0.75-m width and 60-m length) was fixed to the roll rubber above the switching mat as described by Bosco and Vittori (8). Interval times of 10 m were measured with a PTS consisting of 11 infrared photocells in 100-m sprinting. The height of the photocells was adjusted to trochanter height of the subject to standardize a cutting point of infrared light on the subject’s body. CT and FT of each sprint stride through 60 m were measured with the switching mat in 100-m sprinting.

Velocity for each 10m ($V_s$) was calculated for all 10-m intervals in the better of 100-m sprints. Then CT, FT, and SF were calculated and SL was measured in the Vmax part of 100-m sprinting. $V_s$ was calculated by formula 1, and then the highest $V_s$ in m.s$^{-1}$ occurred at any 10 m during 100-m sprint termed as Vmax, where $d_s$ is the constant 10-m interval distance and $t$ is the 10 m interval time in seconds.

$$V_s = d_s \cdot t^{-1} \tag{1}$$

SL, the distance from 2 consecutive toe placements on the strip of roll paper, was calculated by measuring the distance between the first footprint and the projection of the second footprint. SF, which indicates the rate of stride per second, was obtained by formula 2, where $CT$ is the contact time in ms, $FT$ is the flight time in ms, and 1,000 is the constant in meters. The average of all SL and SF for the period of the maximum part in 100-m sprint was used for the statistical analysis.

$$SF = 1000 \cdot (CT + FT)^{-1} \tag{2}$$

Vertical Jumps
Vertical jump procedures were carried out over 2 sessions, the first of which included SJ, CMJ, and DJ for assessing the overall lower-body neuromuscular performance. In the second session, RJ was performed in 60-second continuous explosive jumping on the switching mat. To provide standardization during vertical jump tests, the sprinter performed the jumps with the hands kept on the hips on the switching mat area of 0.60-m width and 1.0-m length. To prevent possible positional differences in each vertical jump test, the subjects were instructed to take off from and land on the switching mat in the same position and place.

CT and FT were measured with PTS during vertical jump tests. Formulas 3 and 4 of Bosco et al. (10) were used to obtain jump height and mechanical power.

$$h = g \cdot t_f^2 \cdot 8^{-1} \cdot 100 \tag{3}$$

$$p = (g^2 \cdot t_f \cdot t_c) \cdot (4 \cdot t_c)^{-1} \tag{4}$$

Where $h$ = jump height (cm); $g$ = gravitational acceleration (9.80665m s$^{-2}$); $t_f$ = flight time
(second); \( P = \) mechanical power of one jump (W\( \cdot \)kg\(^{-1} \)); \( t_c \) = contact time of 1 jump (second); and \( t_{\text{t}} \) = total time of 1 jump (second).

The sprinters flexed the knees until they felt a comfortable starting position; semi-squatting position occurred normally at a knee angle of about 85 degrees when performing SJ (7). The subjects maintained their posture at least 2 to 3 seconds, which prevented the prestretching of muscles from any preliminary downward movement before jumping. The sprinters performed 2 maximum vertical jumps from the starting position and landed on switching mat with the legs kept straight with a 1-minute rest period. FT was recorded to calculate SJ height, which was used for the statistical analysis.

CMJ, where the muscles were prestretched before shortening in the desired direction, made use of the stretch–shorten cycle. The sprinters performed maximum vertical jump with hands kept on the hips, started from an upright standing position following a preliminary downward movement by flexing the knee approximately to the same knee angle as the starting position in SJ during CMJ. FT was recorded to calculate the CMJ height of 2 attempts, which were used for the statistical analysis.

In DJ, sprinters were instructed to step to space from the DJ stair and perform a maximum effort vertical jump immediately after landing on the switching mat. It was instructed that the sprinters landed on the mat after the vertical jump. The position of the center of mass was almost the same with takeoff and landing; the sprinters were asked to keep their hands on their hips throughout the whole movement. Subjects performed 7 drop jumps from the DJ stair (20, 30, 40, 50, 60, 70, and 80 cm) in a random order and instructed to perform 1 trial in each drop height with a rest period of 5 minutes, which allowed time to recover. CT and FT in each DJ were recorded to calculate the maximum jump height and jump power. Drop height resulted in maximum jump height, which was used as a drop jump height (DJH) for the statistical analysis.

Drop height resulted in maximum jump height, which was the same for any DJH, the jump having the highest power was used.

The sprinters performed continuous rhythmic vertical jumps with hands kept on the hips during RJ on switching mat. The subjects were encouraged to jump with a maximum frequency and height. CT and FT of each jump were recorded to calculate RJ height and mechanical power. RJH, rebound jump mean power (RJP), and rebound jump peak power (Ppeak) were used for the statistical analysis.

### Horizontal Jumps

Horizontal jump procedures including SLJ, STJ, SQJ, and STENJ were performed in 1 session in a random order. Subjects performed 2 trials in each horizontal jump with a 5-minute rest period. As an actual jump distance, the distance between feet points at the start and back trace of sprinters in

<table>
<thead>
<tr>
<th>Table 2. Sprint, vertical and horizontal jump tests; mean and standard deviation (SD).</th>
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<tbody>
<tr>
<td><strong>Sprint</strong></td>
</tr>
<tr>
<td>parameters</td>
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<tr>
<td>Vmax (m.s(^{-1}))</td>
</tr>
<tr>
<td>CT (s)</td>
</tr>
<tr>
<td>FT (s)</td>
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<tr>
<td>SF (Hz)</td>
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<td>SL (cm)</td>
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<th>Table 3. Correlations among the sprint and vertical jump performances.</th>
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<tr>
<td><strong>SJ</strong></td>
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<tr>
<td>100 m</td>
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<tr>
<td>Vmax</td>
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<tr>
<td>CT</td>
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<td>FT</td>
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<td>SF</td>
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<td>SL</td>
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\( *p < 0.05 \).
the long jump area was measured with the meter (Stabila, Germany). The better horizontal distance of 2 trials in each type of jumps was recorded for the statistical analysis. An SLJ test, a forward jump, was started with feet together and from the side of the long jump area and completed with both feet landing into the long jump area. An STJ test, which consisted of 3 dynamic horizontal bounds, was used to assess the rebound stretch–shortening cycle muscular contractions. Each subject started with feet together and completed 3 consecutive bounds using alternate feet. The third contact was completed with feet together landing in a long jump area. SQJ and STENJ were performed with 5 and 10 consecutive bounds, as with STJ.

### Statistical Procedures
Statistical analysis was carried out on SPSS for Windows (Chicago, Illinois, U.S.A.). Pearson correlation coefficients ($r$) were calculated to establish the relationships between sprint parameters and both vertical and horizontal jump parameters. Statistical significance was determined using a probability level of $p \leq 0.05$.

### Results
Mean and standard deviations of sprint and jump parameters were presented in Table 2. Tables 3 and 4 showed the correlation coefficients among the sprint parameters in the Vmax part of the 100-m sprint and the jump parameters.

There were significant relationships between Vmax and the vertical jump parameters ($p < 0.05$). CT was significantly correlated with RJP and Ppeak ($p < 0.05$). FT was significantly correlated with DJH ($p < 0.05$). SL was significantly correlated with SJ, CMJ, RJH, RJP, and Ppeak ($p < 0.05$), whereas there were no relationships between SF and the vertical jump parameters.

Horizontal jumps were significantly correlated with only FT and SF. Although there were significant relationships between FT and all horizontal jumps ($p < 0.05$), SF was significantly related with only STJ, SQJ, and STENJ ($p < 0.05$). No relationships were found among the horizontal jumps, 100-m sprint, Vmax, CT, and SL.

### Discussion
The purpose of this study was to investigate the relationships between both vertical and horizontal jump performances and sprint parameters such as Vmax, contact time, flight time, stride frequency, and stride length in the distance reaching Vmax phase during sprint running.

Some studies indicate relationship between sprint time and double- or single-leg vertical jumps (4,11,20,25,27,30,31, 37,40). Double-leg vertical jumps reflect similar force-time characteristics to single- or dominant-leg concentric movement, which is elicited by training (39). SJ, CMJ, DJ, and RJ with double leg have been the most widely used vertical jump tests in most scientific studies (3,4,6,24,25,31,37,40). SJ that contains only concentric muscle activity is closely related to dynamic and explosive strength and it is also regarded as a general indicator of reactive strength (3,4). CMJ is used to measure the improvement of this reactive strength under the stretch–shortening cycle (3). It is indicated that CMJ elicits more power output in the concentric phase as a result of potential energy stored for the period of eccentric stretching of the leg muscles (6). Moreover, it has also been stated that the amount of strength elicited or energy stored in the concentric phase of the CMJ is greater than the concentric phase of SJ (3,6). Similarly, DJ and RJ movements contain the stretch–shortening cycle and elicit high power output in a short time (37). It is assumed that the foot contact during sprint running shows more physiomechanical similarities to CMJ, DJ, and RJ. Stored extra elastic energy in the series elastic components of the muscle within the stretch–shortening processes helps to increase running velocity and Vmax in the concentric phase (23). Therefore, movements demonstrated in sprint running are also similar to SJ, CMJ, DJ, and RJ movements and require a high level of muscular power. Studies show significant relationships between sprint parameters and both SJ and CMJ (4,11,25, 27,30). Furthermore, Young et al. (40) stated that CMJ is related to Vmax because it contains the stretch–shortening cycle in its movement pattern. Berthoin et al. (4) has stated that Vmax was significantly correlated with SJ ($r = 0.63$) and CMJ ($r = 0.56$). Similarly, the other studies (25,27,30) have reported significant relationships between Vmax and both SJ ($r = 0.62$) and CMJ ($r = 0.48$ to 0.65). Faccioni (18) reported the highest significant correlation between Vmax and CMJ ($r = 0.72$) in elite–subelite sprinters. The present study demonstrated similar relationships between Vmax and both SJ ($r = 0.56$) and CMJ ($r = 0.55$) as given in these studies. Some studies have been concluded that jumping tests including stretch–shortening cycle such as CMJ and DJ are the best anaerobic predictors of Vmax (4,5). However, other studies denoted that DJ and RJ are better predictors of Vmax compared to CMJ (37,40). In the earlier study, Mero et al. (30) reported that Vmax was significantly correlated with

### Table 4. Correlations among the sprint and horizontal jump performances.

<table>
<thead>
<tr>
<th></th>
<th>SLJ</th>
<th>STJ</th>
<th>SQJ</th>
<th>STENJ</th>
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<tbody>
<tr>
<td>Vmax</td>
<td>0.33</td>
<td>0.18</td>
<td>0.25</td>
<td>0.29</td>
</tr>
<tr>
<td>FT</td>
<td>-0.12</td>
<td>-0.16</td>
<td>-0.26</td>
<td>-0.34</td>
</tr>
<tr>
<td>SL</td>
<td>0.52*</td>
<td>0.43*</td>
<td>0.50*</td>
<td>0.43*</td>
</tr>
<tr>
<td>SJ</td>
<td>-0.34</td>
<td>-0.41*</td>
<td>-0.46*</td>
<td>-0.47*</td>
</tr>
<tr>
<td>CMJ</td>
<td>0.26</td>
<td>0.23</td>
<td>0.27</td>
<td>0.24</td>
</tr>
</tbody>
</table>

*p < 0.05.*
More recently, Katja and Coh (25) found that there was a significant and positive relationship between Vmax and DJH ($r = 0.72$). In addition, Miguel and Reis (31) have demonstrated that RJ performance had correlations with sprint time ($r = -0.753$). RJ contains good exhibit eccentric and concentric muscle activity as possible short contact time for power output as the drop jump (37). However, the highest relationship was found between Vmax and DJH in the present study, as reported in the study of Mero et al. (30). Young et al. (40) indicated that better sprinters showed higher contraction forces in a shorter time during the eccentric phase of foot contact. Relatively smaller knee angle in the stretch–shortening cycle type of movements during drop jump brings out shorter contact times like contact times demonstrated during sprint running (40).

In the present study, CT was significantly correlated with both RJP and Ppeak, whereas FT was not significantly related to the vertical jump performances except with DJH. However, SL correlated with the jump parameters except with DJH. However, no significant relationship was found between SF and the vertical jump performances. Mero et al. (30) demonstrated a significant relationship between SF and CMJ ($r = 0.48$). Furthermore, Kale et al. (24) found significant correlations between DJH and CT of 30 to 40 m ($r = -0.505$, $p < 0.05$) and DJH and CT of 50 to 60 m ($r = -0.562$, $p < 0.05$). When the literature was investigated, it showed that more powerful sprinters have shorter foot CT with the ground, more stride frequency (17), and longer SL and FT (18). SL and SF are influenced by body height (36) and leg length, but athletes who have higher Vmax for a given body height demonstrate higher SF. However, athletes who have shorter body height show lower SL and perform higher SF (22). In the Vmax phase of sprint running, each sprint stride including higher SL and SF occurs as a result of decreasing CT and increasing FT. Decreasing of CT and increasing of FT are affected by more standing posture position and shorter horizontal distance between feet (17). The use of the stretch–shortening cycle also augments the concentric phase of leg movement that results in an increase in power (7). The stretch–shortening cycle in both sprinting and vertical jump movements shows similarities to concentric or slow and fast stretch–shortening cycle behavior of different types of muscle function (28).

Horizonal jumps show physiomechanical similarities to vertical jumps and are used for monitoring the high class sprinter’s performance capacity. Dick (16) has given the normative values of horizontal jumps for different levels of sprinters. SLJ, one of the horizontal jumps, provides horizontal direction effort with explosive strength. Muscle mass, tension, the differences of hip and knee joint angles, and segment positions may influence SLJ. Davies et al. (15) have reported that the greater leg mass, the greater distance jumped in SLJ. However, STJ, SQJ, and STENJ combine repetitive forward movement responses and explosive strength is repeated in these jumps. It is thought that horizontal jumps provide significant impulses for shorter amortization recovery phases of the strides. Consecutive horizontal jumps with short amortization phases and maximum efforts are believed to provide repetitive responses. Horita et al. (21) stated that improved horizontal jumping ability increases the range of motion of the lower limbs for the period of the flight phase of the sprint stride. Therefore, there is an increase in horizontal distance jumped in jumping tests. Eccentric contractions including high velocity stimulate the muscle spindles, which produce reflexive movements close to DJ during the horizontal jumps. This type of instantaneous contractions in the muscle increases the muscle activity and the force developed as a result of muscle contraction (7). Serial elastic components of the musculo-tendinous unit are stretched in the eccentric phase of the horizontal jumps and more elastic or potential energy is stored. Immediately following the eccentric phase, this stored energy is released at that moment of concentric contraction of the muscles (9). Muscle activity of the leg shows a similar stretch–shortening cycle activity from the beginning to the end of CT during horizontal jumps and sprinting. Apparently, increased applied force is shortened for the duration of the support phase despite the shortened CT in increased running velocity and Vmax (38). Foot impact is coupled with force and power of the leg by way of contacting the ground and leads to the shortening of CT (1). There is short CT to maintain maximum ratio for horizontal velocity of center of mass in sprinting among repeated FTs (26). However, the amount of vertical strength developed at horizontal jumps is greater than developed in maximum sprinting because of long contact time with the ground (29). Nagona et al. (33) explained that flexor muscles of the leg were recruited to generate greater joint flexion motions during the counter-movement phase in the horizontal jumping and this action had a more effective moving of the body’s center of mass in the forward direction than sprinting. Therefore, this finding can support longer CT of horizontal jumps than sprinting. As a result of long CT, the horizontal jumps did not show any correlation with CT in the Vmax part of sprint running in the present study. The present study showed that Vmax, sprint time, and SL were also not correlated with the horizontal jumps, whereas FT and SF were significantly correlated with STJ, SQJ, and STENJ. Similarly, Hennessy and Kilty (20) have also observed no significant correlation between 100-m running time and SQJ. Although some studies supported the correlation between horizontal jumps such as SLJ, STJ, SQJ, and STENJ and sprint running time (2,18,19,35), there are no studies within our knowledge examining the correlation between sprint parameters during the distance reaching Vmax in sprint running and the horizontal jumps.
In conclusion, the highest relationship between Vmax and DJH suggests that DJH has been demonstrated to be a more effective way to reflect Vmax in sprint running than other vertical jump tests. The results of this study indicated that the vertical and horizontal jump tests could be used for evaluating the sprint parameters at the distance reaching Vmax in sprint running at the beginning of the preparation training phase. Future research also should involve the continual monitoring of the jumping and sprinting performance in different training phases of the sprinters to determine how changes in these parameters would relate to changes in Vmax phase.

**Practical Applications**

Vmax in 100-m sprint running and vertical jump relationships revealed that coaches should consider the drop jump height resulted in the maximum vertical jump height as an indicator of Vmax. Vertical jumps, especially drop jump, should also be considered as a useful training exercise to improve Vmax, which may lead to an improvement in a sprinter’s performance. However, horizontal jumps may not be good indicators of sprint parameters at the distance reaching Vmax because horizontal jumps were just correlated with stride frequency negatively and flight time positively. Furthermore, athletes and coaches should know that the flexor muscles were activated to a higher level in the forward direction of horizontal jump and thus the hip joint was used more vigorously than in sprint running. Such forward cyclic horizontal jumps would develop effective specific strength in extensor muscles of the legs for the drive phase of the sprint stride. Therefore, horizontal jump exercises should be incorporated into a training to improve sprint performance.

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