Relationships between horizontal jump tests and sprint performance

by

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Abstract

Athletic performance assessments are important for identifying physical giftedness, monitoring athlete progress and supporting training recommendations. Sprint performance is a key component in athlete success both in athletics and field-based sports, and talent identification testing batteries often include sprint and jump assessments. Jumping and sprinting share a number of similar characteristics and research has shown that the relationships between sprint and jump tests depend on the recorded segment of the sprinting task, type of jump performed, and the speed and sex of the athlete. The majority of this research has been conducted in small, single sex, similar athlete cohorts and there has yet to be an analysis of a large cohor multi-sport population with both male and female groups. Understanding the relationships between sprint ability and horizontal jump performance, based on large groups of athletes separated by sex can provide great insight into the shared and independent value of sprint and jump performance tests to support athlete testing and development. Therefore, the purpose of this study was to investigate the relationships between horizontal jump tests and sprint performance within different athlete sexes and sprint ability. To the authors' knowledge, this is the first study with a large population sample of multisport athletes, with differing sprint and jump abilities. The associations and relationships between horizontal jump performance in standing broad jump (SBJ) and standing triple jump (STJ) with 0-10m and 30-40m sprint time in a group of athletes participating in a talent identification event were investigated in this study. Correlations and linear regressions were assessed with athletes grouped only by sex (male (n = 742), and female (n = 610)), and then grouped by sex and speed (fast = -0.5 *SD*, slow = +0.5 *SD*) for both 0-10m and 30-40m time separately. When grouped only by sex there were very large and large associations between sprint and jump measures (*r* = -0.533 to -0.717), and linear regression equations explained 37.4% to 55.5% of the variance. When grouped by sex and speed, slow athletes showed stronger associations (*r* = -0.353 to -0.488) than fast athletes (*r* = -0.088 to -0.307). Linear regressions explained 20.3% to 28.5% of the variance in slow athletes, but only up to 12.0% of the variance explained in fast athletes. Linear regressions in slow and fast males all included SBJ as a predictor, but not STJ. Linear regressions in slow and fast females all included STJ as a predictor, but not SBJ. Overall, these results support the use of general sprint and jump tests for slower athletes, the importance of both sprint and jumps tests with higher resolution in faster athletes, as well as the utility of different jump tests to evaluate lower limb performance between sexes.

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Acknowledgments

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Chapter 1

Physical Testing for performance tracking and athlete identification

Physical assessments are of value to sport practitioners in identification of giftedness for performance (42,59), monitoring of athlete progress and guiding training program design (20,35). The physical tests used within various sporting disciplines differs along with the factors required for success, but can include; maximal and submaximal strength testing for upper and lower body, as well as aerobic and anaerobic power and capacity in different forms of locomotion (19,33,58). Of the many physical assessments that are done, sprint testing is common in track events, as well as field-based team sports such as soccer, rugby union, rugby league, and American football. In soccer, rugby union, rugby league, and American football, sprints as short as 5m and as long as 60m are used to inform sport decisions (1,3,4,8,18,43,52,61). Track sprinters are more likely to use longer sprints up to and in excess of 100m and more often collect measures of maximal sprint speed (9,30,46). Other commonly collected physical assessments include vertical and horizontal jumps, often collected alongside sprint assessments as part of a comprehensive physical profile (8,9,12,15–17,24,52,53). There are a variety of jump performances reported in the literature that differentiate between; direction of movement (horizontal vs vertical), use of the lower limbs (unilateral vs bilateral), and continuity of movement (acyclic vs cyclic) (44). Further, the data collected from these jump assessments range from simple kinematics such as horizontal distance and vertical height to more complex kinetics requiring laboratory analysis (44). Field based tests to assess jump performance are simple to perform, highly reliable assessments and a valid proxy for lower limb power (3). Jumps are also considered to be a valuable performance test in differentiating between sprinting abilities (15).

Sprint Contribution to Sport Performance

The ability to rapidly increase and maintain running speed is important to sport performance (36,40,41,45,49). Track events such as the 100m and 200m sprint are the most obvious examples of performance in which success is the result of the athlete's ability to cover a horizontal distance in minimal time (40,41,45). Sprint speed also appears to differentiate between starters and non-starters in rugby league (18), as well as selection to national versus regional representative teams (58). However, within a group of national age grade and senior level rugby athletes, sprint speed does not differentiate level of play but momentum does (3,5). This is likely due to the collision aspect, where sprint speed in conjunction with a high body mass becomes the differentiating factor in high-level collision sports due to the athlete’s ability to win the point of contact. Sprint speed also differentiates between positions in sports such as

American football where there is specificity of positional roles (8,52). While in soccer, linear sprints are the most common occurring action preceding goals (16). In American football, sprint speed measurements taken during the National Football League (NFL) combine were correlated to future success in running backs at the professional level (33). Sprint speed and body fat percentage appear to be important variables in the progression of rugby union players from 15 years old towards national or international level teams by the time they are 21-24 years old (17). The importance of sprint speed in the selection process also appears in rugby league at the U16 and U18 level with selected players exhibiting faster sprint times than their non-selected counterparts (60). Similar results have also been shown in soccer with youth soccer players who are eventually drafted into professional teams displaying superior sprint performance (19). Due to these reasons, sprint testing is a common assessment used to identify potential physical giftedness in athletes and as a part of monitoring protocols. The NFL uses the 40 yard dash collecting splits at 10 and 20 yards as part of their testing battery for players in the NFL combine (33). Field sports such as rugby use a 40m sprint collecting split times at 10m and 30m as part of athlete assessment and talent identification protocols (1,5,6). While elite 100m track sprinters conduct both a 0-30 m sprint from a static start, and a 30-60m sprint after a 30m build up to attain a maximum sprint speed assessment (46). Although it is recognized that there are other factors that contribute to sport success, it appears that sprint speed is linked to performance and future progression in many sports. It is therefore of value to understand the mechanisms and factors that contribute to sprint performance.

The Biomechanics of a sprint

At the simplest kinematic level, sprint speed is the result of stride length and stride frequency (45). Stride length is the distance covered between alternate foot contacts, and is the sum of step distance during the stance phase, and flight distance during the swing phase (22). Stride frequency is the density of alternating foot contacts over a given distance or unit of time, and is the result of ground contact time during stance phase, and flight time during the swing phase per unit of time (22). Both stride length and stride frequency are largely influenced by the vertical and horizontal ground reaction forces that an athlete transmits into the ground during the stance phase of the running stride (26). The amplitude and direction of force produced by the athlete into the ground creates the net propulsive effect over which the performer has the most influence to determine sprint speed (4,31,36,57,62,63,69). Elite rugby players can achieve a maximum velocity of 8.98 m·s-1 (6), while elite sprinters have been shown to reach maximum velocities in excess of 10 m·s-1 (7). Hip extension, and in particular the hamstring muscle group appears to have the greatest contribution to sprint performance (41,62,65). The 100m sprint has three distinct phases; the initial acceleration (0-10m), transition to maximum speed (10-36m), and maintaining maximum speed (36m-100m) (15).

Stride Length and Stride Frequency

Sprint speed is a trade-off between maximizing stride length with greater ground contact forces, and increasing stride frequency with reduced ground contact times during stance phase (26,63). At maximum speed male sprinters display stride lengths of 2.00 - 2.60 m with a stride frequency above 5.00 Hz (45). While male rugby union players show a stride length of 2.06m with a stride frequency of 4.40 Hz (6). Stride frequency and stride length increase linearly as running velocity increases up to 7.00 m·s-1 (45). Stride length is influenced by the strength and power of the leg muscles involved during ground contact of the stance limb (37). In support of this, improving sprint speed in highly trained rugby union players has been linked to improvements in lower limb strength resulting in increased stride length (4). While it has also been noted that leg length can also result in a longer stride length at the expense of stride frequency (26). As sprint speed increases towards maximum velocity, further increases in stride length appear to level off while stride frequency continues to increase (26,40). This appears to be due to a reduction in ground contact time during the stance phase and not a reduction in flight time (26,40,66). In support of this, one of the main determinants of 100 m performance is an athlete's ability to increase step frequency through a greater rate of force development, this allows the athlete to maintain stride length with shorter ground contact time (47).

Stance Phase

Only during the stance phase while the athlete is in contact with the ground can they exert the vertical and horizontal forces that result in sprint performance (62,65). During the acceleration phase of a sprint ground contact times range between 0.12 and 0.20 sec (66), and the athlete assumes a greater forward lean of the body position to allow the propulsive force to be directed horizontally (6,12,43,45,66). In support of this Hunter, 2005, showed that at the 16 m mark of a sprint, the strongest predictor of sprint velocity was horizontal impulse (R^2=0.61, $p<0.001$), with the most favourable vertical impulse being the minimal which facilitates repositioning of the limbs during swing phase (27). Clark, 2015 showed that elite sprinters were able to apply 20% greater propulsive horizontal force than sub-elite sprinters resulting in an average 0.44 $m \cdot s^{-1}$ greater speed out of the starting blocks which translated to a significantly greater 40 m velocity (8.16 $m \cdot s^{-1}$ vs 7.59 $m \cdot s^{-1}$) (14). As sprint speed increases, the net horizontal forces decrease as the sprinter transitions from acceleration towards maximum speed, while peak vertical forces increase resulting in a maintenance of velocity while counteracting the vertical forces on the body due to gravity (66). This increase in peak vertical ground reaction forces is accompanied by a decrease in ground contact time to between 0.09 and 0.12 sec at maximal speed (66). This results in longer stride lengths and greater stride frequencies (4,37,45,47,49,66). Maximizing sprint performance at greater velocities becomes a trade-off between the magnitude of ground reaction force that can be transmitted during minimal ground contact time (63). At maximal sprint speeds, faster athletes are able to apply greater forces into the ground with shorter ground contact times than slower athletes (13,14,40,63,64). This short ground contact time limits the impulse that can be applied to the ground and therefore the rate of force development must increase to reach greater speeds (4,34,57,63). Clark and Weyand, 2014 showed that elite sprinters produce substantially greater forces earlier in the ground contact phase (first 30% of stance phase) than their non-elite counterparts (50% of stance phase) which might be how these athletes continue to increase sprint speed through the strategy they use to apply forces to the ground during very short ground contact times (13). A greater velocity of the stance limb just prior to ground contact and a decreased leg range of motion through creation of muscular stiffness around the ankle, knee, and hip are strategies which may contribute to this observation (40).

Acceleration vs Maximum Speed

The differing kinetics and kinematics in acceleration and maximum speed discussed above have led to them being considered two separate qualities within sprint performance

(6,43,45,52,61). Greater speeds in acceleration performance are correlated to high concentric propulsive forces with a greater forward lean of the body and concomitantly greater horizontal resultant forces (4,8,25,31,36,43,45,57,67,69). In contrast maximum speed performance has a stronger correlation to leg stiffness and the stretch shorten cycle (9,12,43,69). In support of the important role force production plays during initial acceleration, maximal strength appears to have a stronger correlation with 0-10m time ($r = 0.94$) in comparison to 10-30m time ($r = 0.71$) (68). The role of muscular strength in acceleration is supported by research showing that resisted sprint training resulted in improved acceleration ability but not maximum speed (21). Trained elite sprinters have demonstrated that the acceleration phase of a sprint can be extended to between 30-50 m from a static start (32,45), yet most of the studies available on field sport athletes, and non-sprint trained students demonstrate that maximum velocity is achieved within 30 m (6,8,32). Complete sprint performances therefore such as the 0—40m common in field sport athletes will be heavily influenced by acceleration ability, and will not give a good indication of maximum speed ability (25). To attain a valid measure of maximum speed, therefore, researchers use either flying sprints, or collect a split within a given sprint performance (e.g. 30-40m with field sport athletes) where maximum speed is likely to occur (1,5). As success in athletic events can be influenced by both acceleration and maximum speed, testing protocols often facilitate the collection of both sprint measures in a single test.

Shared Characteristics between jumps and sprints

Similarity between the requirements of jumping and sprinting is an important aspect to consider, as the more similar the magnitude and direction of forces and velocities of movements, the greater the potential number of shared attributes (24). Jump and sprint performances both require horizontal and vertical displacement of the athletes centre of mass through forces produced by the lower limb musculature which is transmitted from the foot into the ground (12,24,66). Unilateral horizontal jumps, for example, provide measures of horizontal displacement through rapid unilateral stretch shortening cycle movements, using similar limb mechanics and muscle sequencing as sprint assessments (11). Standing long jumps and sprint accelerations both require higher concentric muscle actions directed horizontally, while maximum speed and drop jumps require greater contribution of eccentric muscle actions directed vertically (66). Due to their similarities, sprint and jump tasks have been used either together or interchangeably to monitor lower limb kinetic athlete attributes. While there are similarities between these tasks, there are also important differences that need to be highlighted and taken into consideration when interpreting the results of both sprint and jump tests.

Magnitude of Force & Maximum Power

Ballistic movements such as jumps, and sprints require the expression of force and velocity of the lower limb musculature. Due to its similarity to sport task demands such as short sprints, tackles, and change of direction, as well as ease of administration, the standing long jump is considered to be one of the best field-based tests to utilize as a proxy for power of the lower limbs (38). The use of jumping tasks as a proxy for lower body power is supported by research showing that vertical counter-movement jumps are highly correlated to maximum power of the lower limbs (r = 0.975, R^2 = 57.3%) (28). Sprint velocity at the end of push-off is similarly influenced by the maximum power the lower limbs can produce and the resulting impulse into the ground (55). However, it is important to note that differences in an athletes force-velocity profile account for a greater share of difference in sprint than in jump performances (24,28). Shorter ground contact times in sprinting as compared to jumping tasks necessitate greater muscular contraction velocity which may be a major differentiator between successful performances in sprinting versus jumping (64). For example, it has been shown that the vertical forces applied during single leg hopping are greater than those applied during forward running, where peak force = 4.20x vs 3.62x of body weight respectively (64). This demonstrates that it is not the maximum values of muscular capacity alone which determine sprint performance but also coordinative and timing factors. To further illustrate this concept, athletes who can express the same maximum power may not have the same sprint time as a result of differences in their force-velocity profile (24), with some athletes better able to coordinate force expression with high velocity contractions.

Direction of Force Application

The direction of applied forces will have a large impact on the resultant horizontal velocity that an athlete can attain in either a jump or a sprint. In support of this, sprint velocity at 16 m is strongly predicted by relative horizontal impulse (27). The similarity in direction of force application towards successful performance in both sprints and jumps has led to some researchers questioning the use of vertical as opposed to horizontal jump assessments when making comparisons to sprint performance (24,44). Due to the differences between acceleration and maximum speed discussed above, however, some researchers have suggested that while horizontal jumps should be used to examine associations with acceleration performance, vertical jumps may be more similar to maximum speed performance (66). There is some support in the research for this as horizontal jumps have shown similar associations with both acceleration and maximum speed (52), while vertical jumps are more strongly associated with only maximum speed (52,66). Further, in research with sprint trained athletes, maximum velocity was only associated with drop jump height when jumps of both vertical and horizontal direction were tested (30).

Force-Velocity Profile

The force-velocity profile for an athlete describes the mechanical capabilities of the lower limbs' neuromuscular system (48). This relationship is influenced at one end of the spectrum by the theoretical maximum velocity an athlete can produce against zero load (force), and at the opposite, the theoretical maximum force that can be expressed at zero velocity (55). The slope of the line between these two variables will be influenced by the maximum power the athlete can express in a movement (55). Therefore, differences in sprint performance that cannot be explained by variation in maximum power capabilities as predicted by jump performance are possibly the resulting influence of differences in an athlete's force-velocity profile (24,28,29,48,55), with some athletes producing greater amounts of force and power at a specific velocity. The capacity of an athlete to express force as well as velocity of muscular contractions will be influenced by the external constraints of load (including body mass), distance, and the time period over which force is applied (48). Further, training to target force-velocity imbalances for jump performance has been shown to improve jump height (29). In comparison to sprints, countermovement jumps have a longer stretch-shorten cycle with greater contribution of eccentric muscle action (28,67). This longer time period allows the neural and mechanical mechanisms of the lower limbs to produce greater amounts of force (28). As discussed previously, the acceleration phase of a sprint displays longer ground contact times, and greater forces directed horizontally compared to the maximum speed phase (66). During accelerations the athlete must overcome inertia and there is a lower velocity of contraction allowing the athlete exert greater forces compared to maximum speed (24,45). As sprint speed increases and ground contact times become shorter, there is a limitation on the ability of the neuromuscular system to exert force due to greater velocities (4,24,66). This is likely due to factors such as the proportion and relative cross-sectional area of type II muscle fibers (2). Within a sprint performance therefore, acceleration requires a force dominant force-velocity profile, while as the sprint speed increases there is an increase in the velocity at which force is produced (24). Horizonal jumps, therefore may display greater associations with acceleration than maximum speed performances (24). Given their ease of administration and commonplace practice in sport settings, utilizing jump and sprint power as well as force-velocity profiling has been suggested in practical applications for targeting training interventions (54).

Ground Contact Time and Rate of Force Development

While jumping and sprinting use similar lower limb mechanics, the shorter ground contact times seen as sprint speed increases differentiates these two performances (66). Ground contact times during unilateral hopping are significantly longer than in forward running (0.160 s vs 0.108 s) facilitating application of greater ground reaction forces (63). It has also been shown that ground contact time during bilateral horizontal jumps is not correlated to ground contact time during maximum sprint running (30). As a result of this disparity, the use of plyometric exercises for sprint improvements potentially has a more limited transfer as sprint speed increases and ground contact time decreases (4,66). Further, at supramaximal speeds in which ground contact time is experimentally decreased, the rate at which force can be developed appears to become the limiting variable to improved sprint speed (63). Therefore, given the short ground contact times, particularly at maximum speeds, it has been suggested that selecting training exercises that focus on a rate of force development in less than 0.10 seconds may be of value in improving speed in already fast athletes (4). At maximum speeds, faster sprinters achieve greater velocities by exerting similar magnitudes of force over a shorter period of time (47).

Stretch Shorten Cycle and Leg Stiffness

Jumps and sprints both employ strategies to make use of the series elastic components in the musculotendinous unit to maximize performance (9,10,42,45,66). Slow stretch-shorten cycle activities such as countermovement jumps appear to have better correlations with sprint accelerations which require greater contributions from the contractile components of the muscle (9,12,42). As sprint speed increases however, the stretch shorten cycle reflex may not be effective in transmitting force as a result of the increasingly short time available for force application (10,12,45,66). In preparation for the short ground contact times that are required at high velocities during a sprint, the stance leg muscles pre-activate to increase leg stiffness prior to touchdown (45). Pre-activation of the stance leg prior to touch down results in decreased displacement at the ankle, knee and hip through the stance phase during maximum speed (66). This leg stiffness corresponds with performance in 30-60m and 60-100m sprint performances but not 0-30m (9). Drop jumps emphasizing a short ground contact time are therefore recommended as an exercise for maximum speed development due to their vertical direction of force, smaller displacements of ankle, knee and hip, and emphasis on short ground contact time (66).

Correlation between jumps and sprints

While it appears evident that there are shared characteristics between sprint and jump abilities, the strength of these correlations vary widely (r = 0.00 to – 0.86) (1,4,50,52,53,56,61,8,9,11,25,30,42,43,46). This is potentially the result of methodological differences between studies such as sprint distance or intervals selected, as well as type of jump (horizontal vs vertical, unilateral vs bilateral contacts, cyclic vs acyclic actions) compared which is likely to impact the correlation between tasks. In studies in which vertical jumps have been correlated to sprint performance, there is a stronger correlation between maximum sprint speed (r =-0.45 to -0.53) (46,52,53,61) than acceleration sprint speed (r = -0.193 to -0.4885) (46,52,53). In studies in which both horizontal and vertical jumps have been correlated with sprint speeds, horizontal jump performance has a greater correlation with acceleration (r = -0.353 to -0.560

compared to r = -0.193 to -0.350) (52,53), while correlations with maximum sprint speed are similar between the vertical and horizontal jump trajectories (*r* = -0.353 to -0.590 for horizontal jumps and *r* = -0.452 to -0.520 for vertical jumps) (52,53). Furthermore, in studies in which alternate bounding or single leg unilateral jump performance have been correlated to sprint speed, there is a higher correlational association with both measures of sprint speed than either vertical or horizontal bilateral jumps (*r* = -0.370 to -0.860) (11,25,42,46,50,56). Finally, performance in cyclic jumps appears to have a higher correlation to all sprint speeds than acyclic jumps (1,4,9,51). As discussed above, the association between horizontal jumping and sprinting performances may be limited by the chosen task constraints. It is also apparent from the research that there appears to be a point of diminishing associations between jump ability and sprint speed (1,4). Therefore, it is important to understand the association between sprint speed and jump ability in faster and slower athletes as they may differ.

How sprint speed impacts correlations between jump/sprint

In field sport athletes such as rugby union, American football, and soccer the associations between sprint and jump performance appear to be similar to those of non-sprint trained physical education students (1,4,11,43,51–53,56,61). In highly sprint trained athletes such as 100 m track sprinters however, the strength of these correlations appears to decrease with increasing sprint speed (30,46). Even amongst field sport athletes, those with the slower sprint speeds have been shown to have a greater correlation with jump performance than their faster counterparts (1,5). The differences in association between sprint and jump ability is not well established in a large population of multisport athletes of different speeds.

How Sex impacts correlations between sprint/jump

Agar-Newman et al, 2015 showed that STJ was a better predictor of both acceleration and maximum sprint ability than SBJ in a group of elite female rugby athletes. To the authors knowledge there are is no study that has examined if SBJ or STJ can better predict sprint performance in males. It is possible that males and females utilize different strategies to achieve a sprint performance such as reliance on passive tissues in the stretch shorten cycle, or active muscular contractions. Previous research on the higher prevalence of anterior cruciate ligament injuries in female versus male athletes has shown that females use different movement patterns in athletic movements such as sprinting (39). Further it has been shown that males and females experience different forces as a result of these different plyometric movement strategies (23). It is possible therefore that males and females utilize different strategies to achieve sprint and jump performances which could further influence the associations and relationships between these two performances.

Given the importance of sprint ability in various sporting contexts, the collection of sprint and jump measures is commonly seen in athlete identification, and monitoring programs.

Therefore, there is value in understanding shared characteristics between these two tests to better inform sport decisions. Currently, there is a lack of research investigating how or if these associations and relationships change with increasing sprint speed. It appears likely that the shared characteristics between jump and sprint performance decrease with increasing speed due to a decrease in ground contact time in faster athletes. There is also a lack of research that investigates the differences between sexes and how this impacts the association and relationship between sprint and jump ability. It is possible that males and females use different mechanisms to produce similar performances, and therefore require different jump tests to predict sprint performance. The aim of this study is to investigate the impact of sprint speed and sex on the associations and relationships between the 40m sprint and horizontal jumps (SBJ and STJ). This study is the first to report on a large population of multisport athletes with differing sprint abilities.

Chapter 2

Relationships between horizontal jump tests and sprint performance within different athlete sexes and sprint abilities.

ABSTRACT

Sprint ability contributes to success in many sport performances. Athlete assessments often conduct both sprint and jump testing to guide athlete selection and training intervention. However, there is disagreement about the association between these similar yet distinct abilities. The majority of research has been conducted in single sex, single sport athlete cohorts and there has yet to be an analysis of a large multi-sport population. Therefore, the purpose of this study was to investigate the relationships between horizontal jump tests and sprint performance by sex and sprint ability in a multi-sport population. One thousand three hundred fifty-two athletes (males $n = 742$, females $n = 610$) participated in this study and performed 40m sprints, standing broad jumps (SBJ) and standing triple jumps (STJ). Correlations and linear regressions between sprints, SBJ and STJ were assessed with subjects grouped by sex and then grouped by sex and speed. When grouped by sex there were very large and large associations between sprint and jump measures (r = -0.533 to -0.717), and linear regressions explained 37.4% to 55.5% of the variance. When grouped by sex and speed, slow athletes showed stronger associations (r = -0.353 to -0.488) than fast athletes (r = -0.088 to -0.307). Linear regressions explained 20.3% to 28.5% of the variance in slow athletes, but only up to 12.0% of the variance in fast athletes. Linear regressions in slow and fast males all included SBJ as a predictor whereas slow and fast females all included STJ as a predictor. These results support the use of general sprint and jump tests for slower athletes, however when examining athletes of different performance levels and sex, specific tests or tests with higher resolution may be necessary to evaluate lower limb performance.

Key Words: Talent Identification, Standing Broad Jump, Standing Triple Jump, Acceleration, Maximum Speed

INTRODUCTION

Physical performance assessments are important for the purpose of identifying physical giftedness (42,59), monitoring athlete progress and guiding training decisions (20,35). Performance assessments can include; maximal and submaximal strength testing for upper and lower body, as well as aerobic and anaerobic power and capacity in different forms of locomotion (19,33,58). Numerous sports such as athletics, rugby, football, and soccer (36,40,41,45,49) where competitive success is impacted by the athlete's ability to cover a horizontal distance in minimal time (40,41,45) utilize sprint testing as part of their test battery to help assess an athletes lower limb power. This type of assessment has been useful at differentiating between starters and non-starters in rugby league (18), as well as future success in rugby union and American football (17,33).

For the purpose of identifying physical giftedness sprint tests are often examined for two separate qualities, acceleration and maximum speed. This is due to kinetic and kinematic differences present while accelerating or holding maximum speed (6,43,45,52,61). In the acceleration phase athletes exhibit a greater forward lean to direct larger forces horizontally with longer ground contact times, while at maximum speeds forces are directed more vertically with high rates of force development and very short ground contact times (4,8,25,31,36,43,45,57,67,69). Acceleration ability is collected from a static start whereas measures of maximum speed are collected using either flying sprints in which the athlete is given a distance (usually 30m) to build up to maximum velocity, or a split within a given sprint performance (e.g. 30-40m with field sport athletes) where maximum speed is likely to occur (1,5). Examples of this include elite track sprinters collecting a 0-30m time from a static start to assess acceleration, and a 30m flying sprint time to assess maximum speed (46), whereas a field sport such as rugby union, may collect a 40m sprint with splits at 10m to assess acceleration and 30m-40m to assess maximum speed (1,5,6).

Sprint speed assessments are often collected in tandem with horizontal jumps to add to a comprehensive physical profile (1,5,8,11,30,43,46,52,56). Field-based tests to assess jump performance are simple to perform, highly reliable, a valid proxy for lower limb power, and often compared to sprint testing results (35). Jumping and sprinting share a number of similar characteristics such as the magnitude and direction of force application and the velocity of movement (24). It is suggested that horizontal jump performance can provide similar, yet unique insight into physical performance when compared to sprint tests (44). For example, there are significant associations between horizontal jumping ability and acceleration (r = -0.353 to -0.560) and maximum speed (r = -0.353 to -0.590) (52,53) and the associations between sprint and jump ability appears to be similar to those of non-sprint trained physical education students to many field sport athletes (1,4,11,43,51–53,56,61). Interestingly, slower field-based athletes display stronger correlations to jump performance than their faster teammates (1,3). This is consistent with findings that, in highly sprint trained athletes such as 100m track sprinters, the strength of the associations between sprint and jump performance appears to deteriorate with increasing sprinting ability (30,46). Therefore, there appears to be differences in the association between jump ability and sprint speed as velocity increases (1,4). Further, this may also suggest that at the highest speeds, sprint and jump performance may provide unique, and possibly different, performance insights. While the majority of this research has been conducted in small samples of similar athlete cohorts, there has yet to be an analysis of a large cohort multi-sport population. Further, comparisons have not been done in both male and female populations. Understanding the relationships between sprint ability and horizontal jump performance, based on large groups of athletes separated by sex can provide great insight into the shared and independent value of sprint and jump performance tests to support athlete testing and development. Further, an analysis using a large group of multisport athletes will likely reflect the characteristics of a wider population, and increase the generalizability of the research. Therefore, the purpose of this research was to investigate the relationship between horizontal jump distance and sprinting time from a large group of multi-sport athletes separated by sex and sprint speed.

METHODS

Approach to the Problem

A cross-sectional study design was used to examine the relationship between horizontal jumping ability and sprinting ability. To answer the questions of how jump distance relates to sprint ability, sprint time (time over 0-10m and 30-40m) was used as the dependant measure while horizontal jump distance from standing broad jump (SBJ) or standing triple jump (STJ) was the independent measure. Participants were separated by sex and categorized as fast or slow using ± 0.5 *SD* in 0-10m or 30-40m split time as the grouping variable. Sprint ability was chosen as the dependent variable as sport performance is more often linked with this measure of physical performance.

Subjects

One thousand, three hundred and fifty-seven participants, were purposefully sampled from national talent identification events between 2016 – 2019. Seven hundred and forty-two subjects were male (age = 19.08 ± 2.93 years, height = 180.78 ± 8.08 cm, bodyweight = 77.40 ± 12.49 kg), and 615 were female (age = 18.21 ± 3.13 years, height = 168.60 ± 7.81 cm, bodyweight = 63.80 ± 10.61 kg). All participants were selected based on performance on physical field-based tests (vertical jump, 0-30m sprint, 22m shuttle run, isometric mid-thigh pull) in regional qualifier events. The event gave their informed consent to utilize secondary anonymized data and ethical approval for the study was obtained from the University of Victoria's Human Research Ethics Board and complied with the principles outlined in the Declaration of Helsinki

Procedures

Tests were done in the same order all on the same day (in the order reported below) and indoors to limit the impact of environmental factors. Height was collected using a Seca stadiometer (Hamburg, Germany) recorded to the nearest 0.1 cm. Body weight was collected using a calibrated scale to the nearest 0.01 kg with athletes unshod and in athletic clothing. SBJ was tested first followed by STJ, and then a 40m sprint with splits at 10m and 30m. Participants were given the option of following a warm-up prescribed by a National Strength & Conditioning Association Certified Strength & Conditioning Specialist or an individual warm-up to maximize their performance. Subjects wore athletic clothing and running shoes, no track spikes were permitted. The running surface was a hard, rubberized surface in all testing locations.

Horizontal Jump Assessment. Jump distance was collected for SBJ and STJ. For both jumps the subjects were required to start with toes behind the 0.00m mark of the measuring tape (Lufkin, Apex Tool Group, USA). If the subjects were unable to land a jump without falling backwards, or their feet shifting position they were given no score for that jump. Each jump could be attempted a maximum of 3 times. Distance jumped was measured from the 0.00 m mark to the closest heel and measured to the nearest centimeter. During the STJ subjects were instructed to maintain forward momentum and jump with continuity through the first two of the three jumps. The best of the attempted jumps was recorded and used for analysis. Research by Barr et al. (2014) has shown typical error of measurement (TEM) and coefficient of variation (CV) of 0.04 m and 7% for the SBJ and 0.12 m and 7% for the STJ.

Sprint Speed Assessment. Sprint time was assessed using a 40m sprint with splits recorded at 10m and 30m. Sprint times were collected using the Brower Timing TC-System (Draper, UT, USA). Subjects started using a two-point stance with the middle of their front foot placed 0.75m behind the first set of timing gates. The first set of timing gates were set to 0.50 m in height, while the gates at 10 m, 30 m, and 40 m were set to 1.00 m. Subjects were given a maximum of 3 attempts with full recovery between trials. The best 0-40 m time was recorded and used for analysis with corresponding 0-10 m and 30-40 m splits. Research by Barr et al. (2014) has shown 0-10 m and 30-40 m times collected with Brower Timing Gates to be reliable with an intra-class correlation of 0.91 and 0.94 respectively

Statistical Analysis

Data sets with missing or incorrectly completed jump or sprint time were removed prior to the analysis. The data was then divided by sex and checked for normalcy. Participants separated by sex were grouped as fast (average time < –0.5 *SD*) or slow (average time > + 0.5 *SD*) for both 0-10m time and 30-40 m time. Correlations and linear regressions were then run (α set at 0.05).

To determine the associations between sprint time and jump distance in fast versus slow athletes, Pearson's correlations were calculated for all members of the group's male and female first, and then for fast and slow groups for 0-10 m time as well as 30-40 m time within each sex group. Hopkins scale of magnitudes was used for interpreting and comparing correlations (Hopkins, WG. A scale of magnitudes for effect statistics. A New View Stat, 2002).

Finally, to determine whether horizontal jumping distance was able to predict sprint time a multiple regression was conducted. This model contained the independent variables of body weight, standing height, SBJ, and STJ to predict either 0-10 m time or 30-40 m time within groups of sexes, and then groups of sexes as well as fast and slow groups respectively. All statistical analysis was conducted using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, New York, USA).

RESULTS

Descriptive statistics of sex groups and sex and speed groups is presented in Tables 1-4.

Correlations between all sprint times and jump metrics performed on data grouped by sex were large to very large for all variables in both sexes (Tables 5 and 6). When grouped by sex and speed, slow athletes in both groups had moderate correlations between all sprint time and jump metrics. For fast athletes separated by sex, there were small to moderate correlations between jump metrics and 30-40 m sprint time and insignificant correlations between jump metrics and 0-10 m sprint time.

When separated by sex (female, male) significant regression equations accounted for 37.5% to 41.4% for 0-10m times and 52.9% to 55.5% for 30-40m time. When sex groups were separated by speed, significant regression equations accounted for 20.3% to 22.6% for 0-10 times and 22.6% to 28.5% for 30-40 m time for slow athletes (female, male). For fast athletes, females had a non-significant 0-10m time equation and males had a significant equation with 4.4% of the variance accounted for. For fast athletes 30-40m time, females and males had significant equations with 8.8% and 12.0% of the variance accounted for respectively.

When grouped by sex, not separated by speed, all significant equations included SBJ and STJ. For both male and female slow athletes significant equations included SBJ and STJ for 30-40 m time. For female slow 0-10 m time and fast 30-40 m time significant equations only included STJ. For male slow and fast 0-10 m time and fast 30-40 m time significant equations only included SBJ.

For all females 0-10m sprint time, a significant multiple regression equation explained 37.4% of the variance ($F(4,605)=90.40$, $p<0.000$):

$$0-10m(s) = 2.115 - 0.150\,(SBJ(cm)) - 0.037(STJ(cm)) + 0.002(Bodymass(kg)) + 0.001(Height(cm)) \tag{1}$$

For all males 0-10m sprint time, a significant multiple regression equation explained 41.4% of the variance (F(4,737)=130.142, p<0.000):

$$0 - 10m(s) = 2.013 - 0.057\big(SBJ(cm)\big) - 0.052\big(STJ(cm)\big) + 0.002\big(Bodyweight(kg)\big) + 0.001(Height(cm)) \tag{2}$$

For all females 30-40m sprint time, a significant multiple regression equation explained 52.9% of the variance (F(3,606)=226.467, p<0.000):

$$30 - 40m(s) = 1.997 + 0.002\big(Bodweight(kg)\big) - 0.078\big(STJ(m)\big) - 0.128(SBJ(m)) \tag{3}$$

For all males 30-40m sprint time, a significant multiple regression equation explained 55.5% of the variance (F(4,737)=229.393, p<0.000):

$$30 - 40m(s) = 1.511 + 0.001(Height(cm) + 0.001\big(Bodymass(kg)\big) - 0.047\big(STJ(cm)\big) - 0.096(SBJ(cm)) \tag{4}$$

For slow females 0-10m sprint time, a significant multiple regression equation explained 22.6% of the variance (F(2,174)=25.400, p<0.000):

$$0 - 10m(s) = 2.241 + 0.001(Bodyweight(kg)) - 0.047(STJ(cm)) \tag{5}$$

For fast males 0-10m sprint time, a significant multiple regression equation explained 4.4% of the variance (F(2,226)=5.185, p<0.006):

$$0 - 10m(s) = 1.648 + 0.001\big(Bodyweight(kg)\big) - 0.031\big(SBJ(m)\big) \tag{6}$$

For slow males 0-10m sprint time, a significant multiple regression equation explained 20.3% of the variance (F(2,215)=27.441, p<0.000):

$$0 - 10m(s) = 2.015 + 0.001(Bodyweight(kg) - 0.94(SBJ(cm)) \tag{7}$$

For fast female 30-40m sprint time, a significant multiple regression equation explained 8.8% of the variance (F(1,196)=18.878, p<0.000):

$$30 - 40m(s) = 1.404 - 0.026\big(STJ(cm)\big) \tag{8}$$

For slow female 30-40m sprint time, a significant multiple regression equation explained 22.6% of the variance (F(3,170)=16.523, p<0.000):

$$30 - 40m(s) = 1.856 + 0.001\big(Bodyweight(kg)\big) - 0.038\big(STJ(cm)\big) - 0.097\big(SBJ(cm)\big) \quad (9)$$

For fast male 30-40m sprint time, a significant regression equation explained 12.0% of the variance (F(2,267)=18.196, p<0.000):

$$30 - 40m(s) = 1.214 + 0.001(Bodyweight(kg) - 0.068(SBJ(cm)) \quad (10)$$

For slow male 30-40m sprint time, a significant regression equation explained 28.5% of the variance (F(3,188)=25.015, p<0.000):

$$30 - 40m(s) = 1.441 + 0.001(Height(cm) - 0.024(STJ(cm)) - 0.080(SBJ(cm)) \quad (11)$$

There was no regression equation that would predict fast females 0-10m time that was significant.

DISCUSSION

This is the first study to assess the relationships between horizontal jump and sprint metrics for a large population of male and female multi-sport athletes across a wide spectrum of sprinting and jumping abilities. When grouped by sex, there were significant correlations between all horizontal jump and sprint metrics. However, when each sex was separated by speed, the associations and relationships between sprinting and jumping ability became small and moderate for all jump and sprint metrics for the slow cohorts and non-significant for the 0-10m time and small to moderate for the 30-40m time for the fast cohorts. This supports a differential relationship between jump and sprint metrics based on the speed of the athlete. Further, when examining the multiple regression results between sexes there were differential jump test predictors of sprint ability. Overall, these results support the use of general sprint and jump tests for slower athletes, the importance of both sprint and jumps tests with higher resolution in faster athletes, as well as the utility of different jump tests to evaluate lower limb performance between sexes.

In the present study, there were significant correlations between all horizontal jump and sprint metrics when athletes were separated by sex. This is similar to what is found in the literature, with significant associations between horizontal jumping ability and acceleration (r=-0.353 to -0.56) and maximum speed (r= -0.353 to -0.59) (27,28). This relationship has also been shown to apply to large segments of the population including non-sprint trained physical education students and field sport athletes (1,2,6,21,26–29,32). Similarities in the direction of motion, lower limb inter and intra-muscle coordination, and ballistic muscle action have been given as rationale for this observed association between jump and sprint ability (6,7,12). This suggest that both horizontal jump tests (SBJ, STJ) and sprint times, in the present study, can be used as proxies for one another when examining general athlete physical performance, and that these relationships remain in both sex cohorts. Thus, for practitioners assessing general athlete capability some sprint and jump tests may be used alone or together when comparing athletes across a broad level of ability and speeds.

While the association between sprint and jump ability appears to remain true for each sex group across a broad speed range, and in the slow cohort, the decrease in associations towards small or insignificant in the fast cohort indicates that other abilities not accounted for in simple horizontal jumps may influence sprint speed in already fast athletes. In studies of elite sprinters the association between sprint and horizontal jumping ability is not significant (30,46). This has implications for the administration and tracking of performance tests based upon the level of athlete and purpose for comparison. In the current analysis, when separated by speed, the associations and relationships between sprinting and jumping ability became unclear in the fast cohort. In a study of elite female rugby athletes Agar Newman et al. 2005 found differential relationships between fast and slow athletes and jump ability. Barr et al. 2014 similarly found differences in the association between sprint and jump abilities when split into fast and slow groups using either initial or maximal sprint velocity. Kale et al. 2009 also showed in a group of sprint trained men that horizontal jumps were negatively associated with stride frequency, positively associated with flight time, and not significantly associated with 100m sprint performance. While both stride rate and stride length increase linearly as an athlete accelerates, at maximal speeds it appears that stride length plateaus while stride frequency continues to contribute to increasing velocity (26,40,45). Stride frequency can be increased through deceasing either the time the athlete is in contact with the ground (stance phase), or the time the athlete has both limbs in the air (swing phase) (64). Research shows that flight times during the swing phase remain relatively constant between athletes, while ground contact time during the stance phase decreases with increasing speed to produce an increase in stride frequency (64,66). As the athletes' speed increases the time available for force application decreases to achieve this greater stride frequency (63). This requires a greater rate of force development early during ground contact and a shorter overall ground contact time (14). Therefore, for faster athletes the ground contact time becomes dissimilar to horizontal jumps and different physical attributes likely increase in importance. For example, while slower athletes could benefit from a general improvement in maximum power or maximum force which positively impacts sprint and jump performance, other, more specific muscular characteristics such as those that sustain a high contraction velocity may be important to improve sprint performance in already fast athletes. In support of this Hicks et al, 2019 have suggested that athletes with similar maximum power may have differences in sprint time which can be explained by individual muscular force-velocity capabilities. It appears therefore, that a more in-depth analysis between jump and sprint ability should include some understanding of the sprint ability of the athlete to allow meaningful interpretation of the results.

Multiple regression analysis revealed that predictors of sprint performance are different between sexes as well as speed groups. The strength of associations through correlational analyses and the predictive ability through linear regression analyses was greater when athletes were grouped only by sex than when grouped by sex and speed.

Regression equations for slow athletes only explained 20.3-28.5% of the variance compared to 37.4-55.5% when athletes were grouped only by sex. These results highlight the importance of understanding the level of athlete when interpreting statistical results. When separated by sex and speed, of the two jump variables, females 0-10m sprint times were predicted by STJ only whereas males 0-10m sprint times were predicted by SBJ only. In their study of national team female athletes Agar Newman et al, 2015 similarly showed that STJ was a better predictor of both initial sprint speed, and maximal sprint speed. It is possible that males and females employ different strategies in order to achieve a 0-10m sprint performance. Previous research on the higher prevalence of anterior cruciate ligament injuries in female versus male athletes has shown that females use different movement patterns in athletic movements such as sprinting (39). Further it has been shown that males and females experience different forces as a result of these different plyometric movement strategies (23). Therefore, it is possible that males and females utilize different strategies to achieve sprint and jump performances which could further influence the associations and relationships between these two abilities. Male athletes may take advantage of a greater muscle cross sectional area and contractile strength to concentrically drive the limb into the ground. Whereas, females may make use of passive tissues to more efficiently create the forces required in sprint running. While male athletes would likely have a stronger association between sprint performance and maximal strength, females may rely more on the series elastic muscular components which are more evident in a STJ performance. This area requires further research to better understand the mechanisms through which both sprint and jump performances are achieved in athletes of different sex.

Overall, these results support the use of general sprint and jump tests for slower athletes, the importance of both sprint and jumps tests with higher resolution in faster athletes, as well as the utility of different jump tests to evaluate lower limb performance between sexes. In large scale talent identification events where the ability of the attending athletes is not known, either jump or sprint tests can be used interchangeably to differentiate sprint ability. In environments without the space or equipment requirements to conduct a sprint assessment, either a SBJ or STJ assessment provides a useful alternative predictor of sprint time. In choosing a horizontal jumping test to assess sprint performance, STJ may be a better predictor for female athletes, while SBJ may better predict males sprint ability. Further in selecting training exercises to enhance acceleration performance, sport practitioners should consider maximal strength-based interventions for males, and stretch shorten cycle interventions for females. However, this study is not without its limitations. First, only the associations and relationships between bilateral horizontal jumps and sprint ability were assessed. There are likely other jump tests such as unilateral jumps or bounding that could provide more information on sprint ability due to increased movement similarity. Second it is possible that the sprint start is distinct from an athlete's ability to accelerate. As the athletes in this study started slightly behind the first timing gate it is possible that the 0-10m segment did not account for differences in performance due to an athlete's starting ability. Therefore, caution is recommended when generalizing the results of this study to a sprint that includes the starting component.

PRACTICAL APPLICATION

Practitioners can utilize general sprint and jump tests for large groups of athletes or subsets of slower athletes However in faster athletes, lower limb tests with a high level of resolution may be necessary to evaluate lower limb performance. When utilizing horizontal jump tests for the purposes of predicting sprint speed SBJ should be utilized for males or whereas STJ may be a better test for females.

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Appendix

Table 1. *Female 0-10m time grouping*

	N	0-10m Mean (+/-SD)	SBJ Mean (+/-SD)	STJ Mean (+/-SD)
All Acceleration	610	1.91 (+/- 0.11)	2.15 (+/- 0.22)	6.57 (+/- 0.71)
Fast Acceleration	198	1.80 (+/- 0.05)	2.27 (+/- 0.20)	6.95 (+/- 0.63)
Slow Acceleration	177	2.04 (+/- 0.06)	2.00 (+/- 0.20)	6.07 (+/- 0.60)

Table 2. *Male 0-10m time grouping*

	N	0-10m Mean (+/- SD)	SBJ Mean (+/- SD)	STJ Mean (+/- SD)
All Acceleration	742	1.74 (+/- 0.10)	2.66 (+/- 0.27)	8.26 (+/- 0.90)
Fast Acceleration	229	1.64 (+/- 0.05)	2.83 (+/- 0.23)	8.85 (+/- 0.75)
Slow Acceleration	218	1.86 (+/- 0.05)	2.46 (+/- 0.25)	7.58 (+/- 0.79)

Table 3. *Female 30-40m time grouping*

	N	30-40m Mean (+/- SD)	SBJ Mean (+/- SD)	STJ Mean(+/- SD)
All Max Speed	610	1.34 (+/-0.12)	2.15 (+/- 0.22)	6.57 (+/- 0.71)
Fast Max Speed	198	1.22 (+/- 0.05)	2.32 (+/- 0.17)	7.15 (+/- 0.53)
Slow Max Speed	174	1.48 (+/- 0.08)	1.95 (+/- 0.18)	5.93 (+/- 0.54)

Table 4. *Males 30-40m time grouping*

	N	30-40m Mean (+/-SD)	SBJ Mean (+/- SD)	STJ Mean (+/- SD)
All Max Speed	742	1.16 (+/- 0.09)	2.66 (+/- 0.27)	8.26 (+/- 0.90)
Fast Max Speed	270	1.07 (+/- 0.04)	2.86 (+/- 0.19)	8.93 (+/- 0.66)
Slow Max Speed	192	1.27 (+/- 0.06)	2.40 (+/- 0.21)	7.38 (+/- 0.65)

Table 5. *Correlation matrix for females*

Groupings	SBJ	STJ
All Females 0-10m	-0.536**(large)	-0.533**(large)
Fast 0-10m	-0.105	-0.112
Slow 0-10m	-0.411**(moderate)	-0.419**(moderate)
All Females 30-40m	-0.676**(large)	-0.696**(large)
Fast 30-40m	-0.292**(small)	-0.296**(small)
Slow 30-40m	-0.442**(moderate)	-0.447**(moderate)

** = significant at p<0.05; ** = significant at p<0.01*

Table 6. *Correlation matrix for males*

Groupings	SBJ	STJ
All Males 0-10m	-0.555**(large)	-0.577**(large)

Fast 0-10m	-0.088	-0.090
Slow 0-10m	-0.361**(moderate)	-0.353**(moderate)
All Males 30-40m	-0.702**(very large)	-0.717**(very large)
Fast 30-40m	-0.307**(moderate)	-0.299**(small)
Slow 30-40m	-0.488**(moderate)	-0.486**(moderate)

** = significant at p<0.05; ** = significant at p<0.01*