A Narrative Review of Limb Dominance: Task-Specificity and the Importance of Fitness Testing

Abstract

Preferential limb function must be sustained through repetitious asymmetrical activities for continuous athletic development and ultimately, optimal athletic performance. As such, the prevalence of limb dominance and between-limb differences are common in athletes. Severe between-limb differences have been associated with reductions in athletic performance and increased injury risk in athletes. However, in the current literature, the terms limb preference and limb dominance have been used inter-changeably. Together, these terms include a limb which is subjectively preferred and one that is objectively dominant in one or more performance measures from a variety of athletic tasks. In this review, we 1) discuss reported correspondence between task-specific limb preference and limb dominance outcomes in athletes, 2) provide greater context and distinction between the terms *limb preference* and *limb dominance*, and 3) to offer pragmatic strategies for practitioners to assess context-specific limb dominance. A limb which is subjectively preferred is not necessarily objectively dominant in one or more athletic qualities or sport-specific tasks. Further to this, a limb which is objectively superior in one task may not exhibit such superiority in a separate task. Thus, limb preference and limb dominance are both task-specific. As such, we propose that practitioners intentionally select tasks for limb dominance assessment which resemble the most relevant demands of sport. Because limb dominance profiles are inconsistent, we suggest that practitioners increase assessment frequency by integrating limb dominance testing into standard training activities. This will allow practitioners to better understand when changes reflect sport-specific adaptation versus potential performance or injury ramifications.

Key Words: Limb preference; consistency; between-limb differences; fitness testing

Introduction

Human limb preference appears to manifest itself during infancy, but the development of limb preference is highly malleable (47, 151). Repeated motor task exposure impacts the degree of limb preference; a range of motor tasks, both complex and simple, involving tools and other objects (e.g., unilateral teeth-brushing, shooting a basketball or throwing a baseball) can contribute to limb preferences (151). Consequently, it is not uncommon for limb preference to differ by body segment. For example, approximately 90% of people exhibit a well-defined right-hand preference, whilst only 25-45% demonstrate right leg preference in lower extremity actions (52). Furthermore, limb preference is evidently task-specific (76, 178). Velotta et al. (178) asked healthy college-aged individuals about limb preference when performing different tasks; 90% of the cohort preferred the right limb to kick a ball, but only 40% preferred the right limb for single-leg standing (178). Thus, it seems important to make the distinction between subjectively preferred and objectively better-performing limbs. Historically, a “dominant” limb has been used in both contexts (e.g., a subjectively preferred limb and an objectively better-performing limb) (168, 175). Further to this, it is not uncommon to see these terms used in study design and analyses without reporting how the “limb dominance” or “limb preference” was determined (73, 74, 118, 180). Choosing to analyze between-limb differences by a subjectively preferred limb (e.g., limb preference) can result in a completely different interpretation than by objective performance (e.g., limb dominance). For example, Kuki et al. (108) found no inter-limb difference in peak force generation when limb performance was defined by preference, but one limb generated significantly greater peak force than the other when limb performance was segregated by dominance (108). The ramifications of not having a clear, well-recognized distinction between limb preference and dominance are clear: researchers cannot accurately consolidate findings relating to asymmetry and limb preference-dominance interactions, and clinicians cannot effectively interpret and use findings in practice. In this review, *limb preference* indicates the subjectively preferred limb for completing a task, whereas *limb dominance* indicates the limb which objectively outperforms the other in a particular task. A relationship can exist between these two constructs — the subjectively preferred limb may also produce better objective performance abilities (3) — but, this is not always the case (103).

Compared with the general population, the interaction between limb preference and limb dominance is more complex in athletes. Sporting tasks oftentimes encompass a tapestry of orchestrated movements, which can be impacted by numerous factors, including sport-specific environmental constraints, spatial orientation of the body, fatigue, and injury (42, 49, 81, 83, 116, 128, 153). In many sports, sustained preferential function through repetitious asymmetrical activities may be required for continuous athletic development and ultimate success (41, 94-97, 101, 152, 161). Athletes may also develop limb preference for sport-specific tasks (115, 131, 164), which may differ from the preferred limb in everyday activity (89, 115). Through asymmetric task-specific repetition, task-specific limb dominance can emerge, or preceding limb dominance can become more pronounced. Associations between limb dominance and reductions in physical performance (6, 11, 21, 23, 32, 36, 95, 114, 119, 120, 122, 123, 150) and increased injury risk (10, 50, 58, 82, 98, 144, 157, 162, 173) have been identified in athlete populations. For example, greater isometric midthigh pull (IMTP) peak force asymmetry was associated with reduced vertical jump height during squat jump and countermovement jump tasks, in collegiate athletes (6). In National Hockey League (NHL) players, preseason hip strength was compared with subsequent in-season adductor strain probabilities (173). Players who sustained adductor strains during the season had lower hip adduction-to-abduction strength ratios in the injured limb compared with the non-injured limb during preseason testing (173). However, there are also investigations where associations between limb dominance and performance or injury risk are not observed (33, 43, 58, 113). Thus, because limb dominance can have potential physical performance and injury implications, its quantification and systematic assessment is likely to be of interest to both practitioners and athletes.

In sport, limb dominance is task-dependent (22, 119, 125, 176). Referring to a limb as being holistically “dominant” from performance in one task is an over-simplification and lacks necessary context. For example, Dos’Santos et al. (59) found that the limb that performed best during horizontal jumping did not correspond with the better-performing limb during change-of-direction (CODS) tasks, in collegiate athletes (59). In soccer, the limb that is used to strike the ball is generally considered dominant (29, 92, 144), but this notion fails to appreciate that the kicking motion is complex and requires the integration of multiple skills (24). Specifically, the limb used to strike a ball may be capable of producing more force or achieve faster movement velocity, but the standing (e.g., non-kicking) limb may be considered dominant when performing stability or supporting actions (8, 45, 130, 150, 161). Not only should test selection for limb dominance profile assessment reflect the most frequent and relevant demands of sport, but also, test results should be contextualized. Because limb dominance profiles can also change throughout a season of sport participation (18), it is also important to understand when changes in these tasks reflect sport-specific adaptation versus potential performance or injury ramifications.

Therefore, the primary aim of this review is to discuss reported correspondence between task-specific limb preference and limb dominance outcomes in athletes. Secondary aims include: 1) to provide greater context and distinction between the terms *limb preference* and *limb dominance* so as to offer practitioners with a more consistent approach in their understanding and analysis, and 2) to offer pragmatic strategies for coaches and practitioners to assess context-specific limb dominance.

Limb Preference vs. Limb Dominance: A Need for Terminology Clarification

In the current literature, many tasks have been used to determine limb preference in athletes, including the preferred kicking or jumping leg (12, 27, 70, 85, 99, 129, 132, 137, 152), writing, throwing, or serving hand (4, 44, 68, 91, 176), and other various multi-component assessments (e.g., the Lateral Preference Inventory and Waterloo Footedness Questionnaire) (14, 71, 78, 89, 171, 174). The heterogeneity and generalized methodology used to quantify limb preference in athletes is confusing and like limb dominance, limb preference in one task cannot be inferred from its preference in another (178). The Lateral Preference Inventory (LPI) is a questionnaire frequently used to categorize limb preference (48). In the LPI, people are asked about which leg they would prefer to use during bilateral mobilizing tasks (e.g., tasks involving both legs), including: 1) “With which foot would you kick a ball to hit a target?”, 2) “Which foot would you use to step on a bug?” and, 3) “If you had to step up onto a chair, which foot would you place on the chair first?” (48). In each of these tasks, the non-participating limb maintains contact with the ground (e.g., when stepping onto a chair, one foot is planted on the ground to support the body while the other foot steps onto the chair). Hart and Gabbard (77) categorized limb preference of 100 university students using the LPI (77). Students were also asked to identify the limb preferred to perform a single-leg balance task whereby the other limb was not in contact with the ground. More than half of students (62%) who had right limb preference via LPI categorization (e.g., bilateral context) preferred the left limb for performing the static single-leg balance task (e.g., unilateral context). Almost half of students (44%) who had left limb preference on the LPI also switched limb preference for the static single-leg balance task (77). In other words, the task used in limb preference assessment influenced the choice of limb preferred. While "With which foot would you kick a ball to hit a target?" is on the LPI and has contextual appropriateness for a soccer player, it would be an unsuitable question to infer unilateral jumping preference for a basketball or volleyball athlete (71, 133, 160). Thus, in order to gain meaningful insights from limb preference assessment in athletic performance contexts, the task in which the limb is preferred must be carefully considered. An array of tasks and metrics have also been used to quantify limb dominance, including medial knee displacement during bilateral jumping (130), muscle strength (104, 166, 169), balance (27, 110, 182), unilateral jumping (105, 132, 152), and change-of-direction performance (97), among various other assessments (42, 55, 122). This review will focus on interactions between limb preference and limb dominance for balance, muscle strength, unilateral jumping, and change-of-direction task performances because they are often assessed in literature and demonstrate contextual application for many sports.

Understanding Sport-specific Tasks

Athletic success in sport oftentimes requires repetitious high-level performance of specific biomechanical patterns. For actionable limb preference and dominance appraisal, performing a needs analysis for the sport in question is necessary and will provide practitioners with the information they need to choose assessments that align with the sport-specific biomechanical demands. To categorize motor tasks in sport, Maloney (122) suggests using the motor task groupings presented by Guiard (90): (Group 1) unilateral (e.g., throwing a baseball), (Group 2) bilateral asymmetric (e.g., hockey shot), (Group 3) out-of-phase bilateral symmetric (e.g., sprinting or cycling), and (Group 4) in-phase bilateral symmetric (e.g., bilateral jump or weightlifting). Because sport can encompass a wide array of motor tasks, holistic sport categorization is difficult, and it is arguably more relevant to categorize the primary tasks required in the sport of interest. For example, batting in baseball (127) requires bimanual asymmetric high-velocity actions (Group 2), whereas throwing (69) requires unimanual high-velocity actions (Group 1). Batting in cricket (28) or using the stick in ice hockey (140) represent other bimanual asymmetric high-velocity actions, whereas throwing in handball, shot put (111), or hammer represent other unimanual high-velocity actions. As such, because a repetitious unimanual movement is required to throw a baseball, limb dominance of high magnitude in a throwing arm should be expected for this action, and the benefit of limb dominance appraisal may not outweigh the time, resource, and energy costs to routinely assess its presence. For example, unimanual overhead athletes oftentimes present with relatively greater internal rotation strength than external rotation strength (2, 54, 56, 65, 67, 148, 179) in the preferred (e.g., throwing or serving) shoulder, compared with the non-preferred shoulder. Thus, it may not be important or realistic for an athlete to spend time aiming to restore this between-limb imbalance.

The range of motor tasks and associated groupings that warrant assessment are sport-dependent; each sport sits on a continuum in respect to both relevance and frequency of motor task and motor task group requirement. Most sports, such as soccer and basketball, rely on frequent high-level performance of Group 2 and Group 3 tasks. Although other task groups are relevant (e.g., layups: Group 1; bilateral jumping: Group 4), kicking, approach jumping, and changing direction (Group 2), as well as sprinting (Group 3), are particularly relevant in these sports. Because soccer and basketball rely on frequent high-level performance of tasks in Group 2 and Group 3 categories, two-sided proficiency is likely required to enhance athletic success probability (7, 34, 39, 88, 164, 165). Through frame-by-frame video analysis, Carey et al. (40) analyzed foot use patterns in a sample of 236 soccer players from 16 teams in the 1998 World by comparing passing, first touch, dribble and tackle success rates between preferred and non-preferred limbs (40). Players demonstrated bias towards preferred foot use during games, but the skill levels (e.g., success rates) between preferred and non-preferred limbs were similar (40). Players recognize the significance of limb dominance as it pertains to skill acquisition. When asked about what it takes to be a skilled soccer player, 400 amateur soccer players determined that “two-footedness” (e.g., being equally skilled with both feet) was a very important quality (39). Stöckel and Vater (164, 165) reported similar results in professional, semiprofessional, and amateur basketball players. Frame-by-frame video analysis of 14 games revealed a bias towards using the preferred hand for all assessed skills (dribbling, passing, catching, and throwing) (165). A negative linear relationship (r = - 0.39) between preferred hand use and level of competitive play was reported; the frequency of ball contacts with the preferred hand decreased from 59.2% in amateurs to 49.6% in semi-professionals to 48.8% in professional players (165). Like soccer players, elite basketball players recognize the importance of equal skill acquisition across limbs; when questioned about hand preference for performing basketball-specific tasks, nearly all players (n=176) reported that being equally skilled with both hands was necessary for basketball success (164).

As described above, whether limb preference and dominance presence will benefit athletic performance depends on many variables, including the sport, task, and context. Because some sports require bimanual and bipedal task-specific proficiency for success (e.g., dribbling in soccer and basketball), devoting substantial efforts toward enhancing abilities of the non-preferred or non-dominant limb may be advantageous, but such efforts may not be warranted in other sports or tasks. Understanding the demands of the sport and its most relevant tasks through a needs analysis is a prerequisite for contextually suitable limb preference and limb dominance profiling. If assessed strategically, longitudinal profiling can potentially enhance athletic performance through improved training prescription and a better understanding of limb dominance underpinnings.

Limb Preference and Limb Dominance: Do they Correspond?

Balance, various muscle strength measurements, unilateral jumping and change-of-direction performance appear to be the most common tasks used for limb dominance assessments in literature, and thus, will form the focus of this review. Just because a limb is preferred does not infer that it will objectively outperform the non-preferred limb in balance (76), strength (108), unilateral jumping (131), or change-of-direction tasks (72). In the following sections, the correspondence between limb preference and limb dominance for these tasks will be discussed in detail.

Balance Tasks

Bressel et al. (27) assessed static and dynamic balance performances using the Balance Error Scoring System (BESS) (145) and the Star Excursion Balance Test (SEBT) (87), respectively, in a group of 34 National Collegiate Athletic Association (NCAA) Division I female athletes (soccer, n = 11; basketball, n = 11; gymnastics, n = 12), (27). There were no meaningful differences in the SEBT or BESS performances between the non-preferred and preferred (e.g., preferred limb to kick a ball) limbs, in any of the sport groups (27). The modified SEBT is also termed the Lower Quarter Y Balance Test (YBT-LQ) and includes three reaching directions: anterior, posteromedial, and posterolateral. In an investigation of YBT-LQ performance, Fort-Vanmeerhaeghe et al. (72) quantified limb preference in elite youth female basketball players by asking players to identify which limb was preferred to: 1) kick a ball, 2) initiate stair climbing, and 3) regain balance following a slight, unexpected perturbation, with the limb chosen in two or more of the scenarios considered as the preferred limb. There was little consistency between limb preference and dominance; only 45%, 48% and 41% players demonstrated better objective YBT-LQ performance on the preferred limb in the anterior, posteromedial, and posterolateral directions, respectively (72).

Comparable limb preference and dominance discrepancies are also observed in rugby athletes. Brown et al. (31) reported inconsistent limb preference-dominance results in male rugby union athletes during a dynamic evaluated dynamic single leg balance task during more stable and less stable conditions, using a Biodex Balance SD system (31). The Biodex Balance SD system measures the degree of tilt about each axis, and it is from this assessment that anterior-posterior, medial-lateral, and overall stability indices were quantified and used to determine balance performance (31). Limb preference was defined by the preferred kicking leg. Rugby union backs performed moderately worse on the non-preferred limb for medial-lateral and overall stability indices in the more stable (Biodex Balance Level 8) condition, but there were no differences between non-preferred and preferred limbs in the anterior-posterior stability index or any of the less stable (Biodex Balance Level 2) stability indices (31). In addition, there were no differences between non-preferred and preferred limbs in any of the stability indices for the forwards (31). Static and dynamic balance performances were assessed in 37 elite Australian Footballers using force plate excursion metrics and the results were similar; there were no differences between non-preferred and preferred (e.g., preferred to kick a ball) limbs in static or dynamic balance performances (102). In contrast, limb preference coincided with limb dominance in a large cohort of skiers. Steidl-Müller et al. (159) investigated balance performances in 285 high-level competitive ski athletes (125 females, 160 males) from three different age categories: 95 youth (aged 10–14 years), 107 adolescent (aged 15–19 years), and 83 elite athletes (aged 20–34 years) (159). Athletes were asked to balance on an MFT® Challenge Disc for 20 seconds on each limb, with the level of stability (e.g., stability index) recorded based on the position of the body's center of gravity within the circle. Youth, adolescent, and elite skiers attained 10.9 ± 9.5%, 11.3 ± 7.7%, and 9.6 ± 6.8% worse stability index scores on the non-preferred limb, compared with the preferred (e.g., preferred to accept body weight upon being instructed to “fall forward”) limb (159).

Using the Upper Quarter Y Balance Test (YBT-UQ), Borms et al. (26) found no differences in YBT-UQ performance between non-preferred and preferred (e.g., preferred to throw a ball) limbs in 29 overhead athletes (26). Ludwig et al. (117) reported larger dynamic knee valgus angle during single-leg drop landing down from a box in the preferred (e.g., preferred to kick a ball) limb, in 114 amateur and elite youth soccer players (117). Further to this, elite players had larger between-limb differences than their amateur counterparts. The kinematic differences between limbs reflect the different motor requirements of the supporting and the kicking leg in soccer. The kinematic differences between cohorts reflect a potential impact of sport-specific adaptation on limb preference-dominance relationships.

The cohorts assessed along with limb preference and limb dominance determination methods in the balance literature are heterogeneous. With this consideration, the available body of evidence suggests that the preferred limb rarely coincides with a performance advantage in static or dynamic balance tasks. There are many potential reasons as to why these discrepancies exist. For example, the method used for limb preference determination may have been unsuitable in that it did not include similar biomechanical demands to the tasks used for limb dominance assessment. The limb preference criteria often included mobilizing tasks (e.g., limb used to kick a ball or initiate stair climbing) while the limb dominance task assessed was static balance. The disparate speed and force of movement between preferred and dominance criteria may also be a factor (e.g., kicking a ball is a forceful action requiring high velocity of movement, while SEBT or YBT-LQ reaching is a low-force and low-velocity activity). Further to this, kicking a soccer ball is a bipedal activity (one foot kicks the ball while the other supports the body), while many of the outcome measures required unilateral stance. Peters (138) sums up this notion by stating that “in the design of [lower extremity limb] controls, the preferred limb should perform the actions that are more directly related to the goal of movement,” (138). To make relevant comparisons between limb preference and dominance outcomes, motor task group categories and important biomechanical patterns should be similar between limb preference and dominance assessments. Interactions between cohort demographics, including injury history, age, training age, access to training and recovery resources, and sport-specific adaptations, among various other factors, will also likely influence these limb preference-dominance relationships.

Muscle Strength Tasks

Isokinetic dynamometry is the most common muscle strength assessment in limb preference literature to date. Although relatively novel in the literature, functional field test assessments using force plate and motion capture technology is becoming more prevalent in practice. Thus, these two methods of muscle strength assessment will be the focus of the literature discussed below.

Rahnama et al. (141) investigated differences between non-preferred and preferred (e.g., preferred to kick a ball) limbs in concentric and eccentric isokinetic knee flexion and extension strength (peak torque) at varying speeds (1.05, 2.09, and 5.23 rad/s) in 41 elite and sub-elite English male soccer players aged 23.4 ± 3.8 years (141). No differences were found in any of the muscle strength measures between the non-preferred and preferred limbs except for the knee flexors at 2.09 rad/s during concentric muscle actions, where the non-preferred limb demonstrated greater strength than the preferred limb (119 ± 22 vs. 126 ± 24 Nm) (141). Daneshjoo et al. (53) reported similar findings in a slightly younger cohort of 36 male professional soccer players, aged 18.9 ± 1.4 years. There were no differences in isokinetic knee flexion peak torque, knee extension peak torque, or hamstring:quadricep (H:Q) peak torque ratios at varying speeds (60, 180, and 300 deg/s) between non-preferred and preferred (e.g., preferred to kick a ball) limbs (53). In 17 female national team soccer players (aged 24.2 ± 3.7 years), Maly et al. (124) also found no differences between non-preferred and preferred (e.g., preferred to kick a ball) limbs in H:Q peak torque ratios at varying speeds, including 60, 120, 180, 240, and 300 deg/s (124). Similar to older cohorts, Maly et al. (125) also found no differences between non-preferred and preferred (e.g., preferred to kick a ball) limbs in isokinetic H:Q peak torque ratios at 60, 120, 180, 240, or 300 deg/s in 41 male under-16 national team soccer players (125). More successful soccer players demonstrate a high H:Q peak torque ratio, particularly at high isokinetic velocity. The H:Q ratio tends to increase in both limbs as velocity increases (124), and this phenomenon is thought to occur due to greater antagonistic activation of the hamstring muscles with increasing isokinetic velocity, leading to a subsequent increase of the H:Q ratio (167). In elite soccer players, the H:Q ratio may increase more for the non-preferred limb than the preferred limb (168). This notion has also been reported in world-class tennis and squash athletes. Read et al. (142) reported no difference between non-preferred and preferred (e.g., the leg ipsilateral to the racket arm) limbs for isokinetic H:Q peak torque ratio at 90 deg/s, but at faster speeds (180 deg/s, 240 deg/s, and 300 deg/s), greater H:Q ratios for the non-preferred limb were reported (142). However, a disproportional increase in H:Q ratio for the non-preferred limb with increasing velocity is not always observed (66) The notion that the hamstrings produce more force compared to the quadriceps as speed of movement increases, particularly in the non-preferred leg (9, 142, 147, 170), indicates that a complex relationship exists between lower limb musculature and single joint movement velocity, which may be influenced by many factors, including: neural demands, muscle architecture, and mechanical advantage. According to a limited quantity of research in basketball players, relationships between the preferred limb and isokinetic dynamometry metrics seem to echo those of the aforementioned cohorts. No significant differences were evident between non-preferred and preferred (e.g., preferred to kick a ball) limbs in isokinetic knee flexion or knee extension peak (60 and 180 deg/s) in 12 professional basketball players (167).

In contrast, other studies compare outputs between dominant (e.g., objectively better-performing) and non-dominant (e.g., objectively worse-performing) limbs (59, 104, 105, 109), and this is an important distinction when interpreting between-limb differences (108). Kuki et al. (108) investigated bilateral and unilateral isometric midthigh pull (IMTP) capabilities in 15 male collegiate football players and sprinters. There were no differences between the non-preferred and preferred (e.g., preferred to kick a ball) limbs in bilateral or unilateral IMTP peak force generation (108). Interestingly, more than half of athletes performed better with the non-preferred limb; during bilateral and unilateral IMTP tasks, 10/15 (67%) and 8/15 (53%) athletes, respectively, generated greater peak force with the non-preferred limb compared with the preferred limb (108). Furthermore, when peak force was compared between non-dominant (e.g., less peak force) and dominant (e.g., greater peak force) limbs, statistically significant inter-limb differences were observed during both bilateral ($p < 0.05$; Cohen's $d = 1.12$) and unilateral ($p < 0.05$; Cohen's $d = 0.56$) IMTP tasks (108). During the bilateral IMTP, muscle activity (mean EMG as a percentage of unilateral muscle activity) for the gluteus maximus, gluteus minimus, semitendinosus, biceps femoris, rectus femoris, and vastus lateralis muscles were also collected. There were no differences in muscle activity for any muscle groups between non-preferred and preferred limbs, but when segregated by limb dominance (e.g., the limb with higher EMG values compared to the limb with lower EMG values), the dominant limb had significantly higher vastus lateralis muscle activity than the non-dominant limb (108). In another study by Kuki et al. (109), between-limb comparisons for unilateral IMTP, countermovement jump, and drop jump performances were assessed in 20 male collegiate football players (109). Six performance metrics were assessed (IMTP absolute peak force, IMTP relative peak force, IMTP absolute peak force at 100ms, IMTP relative peak force at 100ms, countermovement jump height, and reactive strength index), and the non-preferred limb was outperformed by the preferred (e.g., preferred to kick a ball) limb in only one of the metrics: IMTP relative peak force (109). Gleason (79) assessed between-limb bilateral IMTP peak force in 17 NCAA Division I male soccer players. Significant differences between non-preferred and preferred (e.g., preferred to kick a ball) limbs were evident, and only 9/17 (53%) of athletes produced greater peak force with the preferred limb (79). Kobayashi et al. (106) investigated inter-limb ground reaction force differences in male long jumpers while performing the back squat exercise with loads of 50, 70, and 90% of their three-repetition maximum (106). There were no differences in peak vertical and horizontal ground reaction forces between non-preferred and preferred (e.g., leg used for long jump takeoff) limbs in any loading condition. However, bilateral kinematic differences, particularly at the hip joint, were reported (106). While athletes may not present with preference-related strength imbalances, limb preference may influence the adoption of asymmetric movement strategies to achieve bilaterally equivalent strength levels.

Isokinetic and IMTP muscle strength limb dominance cannot be inferred from identifying the limb that is subjectively preferred using traditional limb preference assessment methods. When considered relevant for athletic success, practitioners are encouraged to assess muscle strength limb dominance directly. Kinematic analyses may provide additional value to identify disparate movement strategies across limbs, particularly when kinetic outcomes are similar. Regardless of the sport-specific demands of the athletic cohort assessed, limb preference was quantified as the limb that was preferred to kick a ball (in most studies), which may have influenced limb preference-dominance correspondence outcomes. Strength assessment was constrained to mostly non-functional tasks by way of isokinetic dynamometry; isokinetic assessments typically have poor relationships with functional athletic performance tasks, such as sprinting and jumping (51, 135). More research investigating limb preference-dominance interactions in muscle strength tasks is warranted. Future research should investigate correspondence between functional field tests and limb preference for performance of a similar motor task in order to better understand how limb preference practically relates to limb dominance in sport.

Jump, Change-of-Direction Speed (CODS), and Sprint Tasks

Many sports require high-level proficiency in a tapestry of specific power movements. As such, these movements are arguably the most sought-after quality in sport and are frequently tested as physical performance measures (60, 62, 63, 155). Because jumping, CODS, and sprinting are common to most sports and are the most studied power-related tasks in the limb preference literature, limb preference-dominance relationships for these tasks will be discussed below.

Vaisman et al. (174) studied limb preference-dominance interactions in 27 professional soccer players (174). To determine limb preference, players were instructed to: 1) kick a soccer ball, 2) extinguish a simulated fire, and 3) draw figures on the ground; the limb that was mobilized in two or more of the three tasks was determined to be preferred. There were no differences in unilateral vertical jump height or power between preferred and non-preferred limbs (174). Samadi et al. (149)

conducted a study comparing limb preference and unilateral single-leg horizontal triple jump performance in one-legged athletes (e.g., long and high jumpers) and two-legged athletes (no description given). There were no differences in jumping performances between non-preferred and preferred (e.g., preferred to kick a ball) limbs, in either group (149). Mulrey et al. (132) examined relationships between limb preferences and unilateral vertical and horizontal jumping performances in 40 adolescent (aged 15.5 ± 1.2 years) female basketball players (132). Limb preference was categorized into kicking and jumping preferences. Players were asked to respond to two different questions: 1) “What limb would you use to kick a ball as far as possible?” and, 2) “What limb would you use to jump as high as possible?”, determining kicking and jumping limb preference, respectively. The preferred limb for jumping did not outperform the non-preferred jumping limb in the unilateral vertical (single-leg countermovement jump) or horizontal (single-leg triple hop jump for distance) jumping tasks. The preferred limb for kicking performed better than the non-preferred kicking limb in the single-leg triple hop for distance task, but not the single-leg countermovement jump task (132). Fort-Vanmeerhaeghe et al. (71) assessed unilateral countermovement jump performance to examine limb preference-dominance correspondence in 79 volleyball and basketball athletes (41 males, 38 females) (72). To determine limb preference, athletes were asked to identify the preferred limb with which to: 1) kick a ball, 2) initiate stair climbing and, 3) regain balance following a slight and unexpected perturbation. The limb that was identified in two or more of the three responses was determined to be preferred. Less than half (40.5%) of athletes achieved greater countermovement jump height when jumping with the preferred limb (71). Using the same limb preference criteria as the previous study, Fort-Vanmeerhaeghe et al. (72) assessed inter-limb differences in multidirectional unilateral jumping (vertical, horizontal, and lateral directions) and change of direction speed ([CODS]; 10 meter total distance with a 180˚ turn at 5 meters) performances in 29 elite youth female basketball players (72). Similar to previous findings, less than half of players demonstrated objectively better unilateral jumping performance on the preferred limb; only 48%, 48% and 35% of players performed better with the preferred limb during unilateral vertical, horizontal, and lateral jump tasks, respectively. On the CODS task, roughly half of players (52%) achieved faster times when the preferred limb was also the plant limb for the 180˚ turn (72). Greska et al. (85) reported no between-limb differences when evaluating hip and knee biomechanics between non-preferred and preferred (e.g., preferred to kick a ball) limbs during an unanticipated side-cutting task in 20 collegiate female soccer athletes (85). Joint angles, internal moments, vertical ground reaction forces at initial contact, peak knee adductor moment and peak stance periods did not differ between limbs upon planting, despite equivalent approach velocities. Additionally, there were no differences in muscle activity (peak EMG as a percentage of maximal voluntary isometric contraction) at any of the time points assessed for any of the measured muscles, including the gluteus medius, biceps femoris, semitendinosus, rectus femoris, vastus lateralis, and vastus medialis (85).

Brown et al. (30) investigated force and power outputs during initial acceleration and maximal velocity sprinting in 30 male academy-level rugby union players (30). The forwards produced lower peak relative vertical force, peak relative horizontal force, and maximal relative power with the non-preferred limb than the preferred (e.g., the “front” leg during sprint setup) limb during acceleration (effect size [ES] = -0.32, -0.58 and -0.67, respectively) and maximal velocity sprinting (ES = -0.50, -0.65 and -0.60, respectively). During acceleration, the backs produced similar between-limb vertical forces (ES = 0.02) with unclear differences in horizontal forces and maximal power. The backs also produced similar vertical forces (ES = 0.10) between limbs during maximal sprinting, alongside an unclear between-limb difference in maximal power and greater horizontal force (ES = 0.54) with the non-preferred limb (30). Korhonen et al. (107) investigated between-limb force outputs during sprinting in 18 younger (age 23 ± 4 years) and 25 older (aged 70 ± 4 years) high-level sprinters and found no differences in mean force outputs between the non-preferred and preferred (e.g., preferred to perform a single-leg jump) limbs (107).

When considering the available evidence, there does not appear to be a consistent correspondence between the limb which is subjectively preferred and the limb which is objectively dominant for jumping, CODS, and sprinting performances in athletes. Although correspondence between limb preference and limb dominance during balance, muscle strength, and power performance tasks may exist in athletes, evidence dissemination is obstructed by a host of difficulties: 1) few studies on the topic, 2) heterogeneity in methods and cohorts assessed, 3) heterogeneity in limb preference quantification criteria, and 4) lack of limb preference criteria specificity as it relates to the task performance of interest.

Limb Dominance: A Comparison Between Sports-specific Tasks

Because sporting success requires high-level performance of complex motor actions that include varying combinations of kinematic, biomechanical, and kinetic properties, it is not uncommon for a limb to objectively outperform the other in one sporting action, but not another. For example, a limb that is dominant in strength tasks may not be dominant in jumping or CODS tasks. Dos'Santos et al. (59) investigated correspondence between horizontal jumping and CODS abilities in 22 male collegiate team sport athletes (soccer, n =10; rugby, n = 6; cricket, n = 6) and found that the better-performing (e.g., dominant) limb for horizontal jumping did not correspond to the plant limb which produced faster times for 180˚ and 90˚ turns during CODS (59). In another study by Dos'Santos et al. (57), unilateral IMTP force-time characteristics, including relative peak force and impulse at 200 and 300ms, were compared with between-direction CODS performance in 20 male collegiate athletes (soccer: n=8, rugby: n=6, and cricket: n=6) (57). The dominant limb for IMTP metrics was rarely dominant for CODS performance (via the 505 test); nearly half of athletes (9/20) had significant between-limb IMTP relative peak force differences, and of the nine athletes who had significant strength asymmetry, only one (11%) produced faster times when the stronger limb was also the plant limb for 180˚ turns during CODS. Similarly, 6/20 and 7/20 athletes had significant between-limb IMTP impulse differences at 200 and 300ms, respectively, but only one athlete had a significantly faster CODS time when planting on the limb that also had greater IMTP impulse values (57). Gleason (79) compared IMTP strength with CODS times and ground foot contact times in 17 NCAA Division I soccer athletes; unilateral IMTP limb strength was determined through bilateral IMTP performance on dual force plates and the 505 test was used to quantify CODS performance (79). The limb which was considered dominant for peak force during the IMTP task was not the same limb which was considered to be dominant in the 505 CODS task (79).

When comparing performances between two different jumping tasks, a limb that is dominant in one task may not also demonstrate dominance in the other. Using a portable force platform, Bishop et al. (16) compared unilateral isometric squat (peak force), countermovement jump (peak force, concentric impulse, and eccentric impulse), and broad jump (peak force, concentric impulse, and eccentric impulse) performances in 28 recreational sport athletes (16) and reported task-dependent limb dominance (16). Calculating a Kappa coefficient is an approach used to assess the consistency of a between-limb difference (e.g., limb dominance) for a common metric across two tasks and describes the proportion of agreement between two methods after any agreement by chance has been removed (16, 46). When assessing limb dominance consistency in peak force, Kappa values ranged from poor to slight (-0.34 to 0.05); limb dominance peak force consistency was slight between the unilateral isometric squat and countermovement jumps (Kappa = 0.04), poor between the isometric squat and broad jumps (Kappa = -0.34), and slight between the countermovement and broad jumps (Kappa = 0.05) (16). Five of the six descriptive levels of agreement between the dominant and non-dominant limbs for eccentric and concentric impulse metrics during the two jumping tasks ranged from poor to fair (Kappa = < 0.01 to 0.32), with only concentric impulse between unilateral countermovement and broad jumps showing substantial levels of agreement (Kappa = 0.79) (16). In a separate study, Bishop et al. (17) investigated limb dominance profiles of under-17 elite female soccer players, again using a portable force platform (17). Players performed unilateral squat jumps, countermovement jumps, and drop jumps; jump height, peak force, concentric impulse, and peak power were reported as common metrics across tasks. Again, inconsistent limb dominance was present across tasks. Kappa coefficients revealed fair to substantial levels of agreement for direction of limb dominance between the unilateral squat and countermovement jump tasks (Kappa = 0.35 to 0.61), but only poor to fair levels of agreement between the squat jump and drop jump (Kappa = -0.26 to 0.18) and countermovement and drop jump tasks (Kappa = -0.13 to 0.26) (17). During a mid-season fitness test battery inclusive of unilateral countermovement, lateral, and broad jump tasks, Madruga-Parera et al. (120) evaluated between-limb differences in 42 elite youth handball athletes (120). Similar to findings of Bishop et al. (17, 22), the limb that was dominant in one task was rarely dominant in another, as demonstrated by Kappa coefficients ranging from poor to slight (-0.05 to 0.15) (120); differences between unilateral countermovement and lateral jumps (Kappa = 0.15), countermovement and broad jumps (Kappa = -

0.05), and lateral and broad jumps (Kappa = 0.00), were slight, poor, and poor agreements, respectively (120).

Limb dominance for one task or athletic quality (e.g., strength, power, and agility) cannot be used to infer limb dominance in another. An athlete that achieves greater peak force with one limb during IMTP may not be more agile when pivoting on that limb during a CODS task or achieve greater height with that limb during vertical jumping. Even when tasks have many similar qualities (e.g., unilateral vertical, horizontal, and lateral jumping), it cannot be inferred that a better-performing limb in one task will perform better in the other, similar tasks. The task-specific nature of limb dominance is important for practitioners to understand when assessing inter-limb qualities to make more informed decisions for athlete care and development. It is suggested that practitioners consider the athletic qualities of the task being assessed when applying data in practice from limb dominance and asymmetry evaluation.

Limb Dominance: A Task-specific Concept

The notion that limb dominance is task-specific is well-recognized throughout the literature (8, 22, 45, 72, 79, 95, 120, 141, 156) and can be further articulated by understanding specific movement patterns that occur in sport. To better contextualize this, we provide an example of the interaction between offensive and defensive actions required in the sport of basketball.

When a player has to perform a skill when interacting with other players (e.g., in games and team practices) or under high pressure circumstances, the most proficient limb in the given situation will be most often used to perform the skill (163). Using data on 3,647 National Basketball Association (NBA) players from 1946 through 2009, Lawler et al. (112) discovered that the vast majority of NBA players prefer to shoot with the right hand; the overall prevalence of right-hand preference (e.g., preferred hand to shoot the ball) of NBA players was 94.9% (112). Thus, during NBA competition, most players will use the right hand for layup attempts. A right-handed layup attempt includes a 2-step approach sequence whereby the left leg ultimately propels the athlete into the air, creating the required vertical displacement to perform the action successfully (158). Within the layup skill itself, the two-step sequence involves a horizontal displacement focus during the first step to create separation from the defender, and a vertical displacement on the second step to bring the athlete closer to the basket for increased scoring success (92). Sensibly, the repetitious favoring of one side in a unilateral task, such as a layup, is thought to increase the likelihood of an athlete developing a lower-body muscular imbalance (158), because one lower limb is consistently tasked with facilitating maximal center of mass displacement in the horizontal direction while the other limb is tasked with doing the same, but vertically. Therefore, right-hand layup preference may facilitate horizontal and vertical displacement dominance development for the left and right lower limbs, respectively. A general NBA right-hand favoritism for offensive actions, including layups, may also have an impact on limb dominance development in NBA players on the defensive side of the ball. In response to right-hand offensive preference, defenders are required to repetitiously perform actions that may develop lateral horizontal displacement dominance in the right lower limb. On defense, a basketball player must consistently perform explosive lateral movements while facing the offensive player in attempt to prohibit the offensive player from getting close to the basket with the ball (126). In fact, defensive shuffling makes up the largest proportion of high-intensity activity during elite basketball competition (3.1%), followed by sprinting (2.8%), striding (2.4%), sideways running (1.9%), and jumping (1.3%) (1). The defensive player is tasked with prohibiting the offensive player from doing what he or she prefers, which includes using the right side for performing common offensive skills, including dribbling and accelerating towards the basket for a layup opportunity. To prevent the offensive player from executing skills with the preferred (e.g., right) side, the defensive player must perform more frequent and explosive lateral horizontal displacement actions with the right lower limb. A basketball player who performs a higher proportion of layup attempts from the right side on offense (requiring vertical center of mass displacement facilitated by the left limb), and a higher explosive lateral horizontal actions with the right lower limb on defense to prevent their right-handed counterparts from utilizing the preferred limb, may create a task-specific limb dominance profile whereby the left and right lower limbs exhibit vertical and lateral horizontal jump dominance, respectively. Using the aforementioned example, the prevalence of task-specific limb dominance should be expected in basketball athletes. Monitoring task-specific limb dominance changes over time would allow for practitioners to better understand the relevance of such changes and whether they are due to sport-specific adaptations. Given that inconsistencies in limb dominance over repeated test sessions and time points appears to be evident (18,19) repeated testing seems warranted in order to build a consistent picture of limb dominance characteristics, before such data can be used to inform decision-making.

Limb Dominance: Importance of Longitudinal Monitoring

Limb dominance testing using tasks which reflect the demands of an athlete's sport is of high importance. First, the requirements of the athlete to tolerate the demands of his or her position in sport must be determined by conducting a needs analysis. There is a substantial body of literature covering the demands of various sports (5, 15, 61, 136, 143, 172); however, it is imperative that a current needs analysis is conducted due to the time-sensitive changes in participating athletic populations, equipment, and sport rules, that take place. Once the kinetic, kinematic, and physiological qualities required for successful sport performance are well understood, the practitioner has the knowledge to develop tests which resemble the athletic qualities of interest. It is through the informed selection of tests, each intentionally chosen to provide insight into a specific feature of successful sport performance, that relevant task-specific limb dominance appraisal can occur.

The timing and frequency of limb dominance testing, as well as the method applied to calculate the metrics used for determining limb performance, are important considerations. Because directional limb dominance between test sessions can be inconsistent (20), frequent limb dominance profile assessment is likely necessary to differentiate between consistent limb dominance and fluctuations in natural performance variability. Using a portable force plate, Bishop et al. (20) assessed agreement between unilateral isometric squat (peak force and impulse), countermovement jump (peak force and jump height), and drop jump (reactive strength index [RSI] and jump height) performances across two testing sessions separated by three days, in 28 recreational soccer and rugby athletes (20). Between-session consistency of limb dominance direction for the unilateral isometric squat, countermovement jump, and drop jump, were fair to substantial (Kappa = 0.29 to 0.64), substantial (Kappa = 0.64 to 0.66), and fair to moderate (Kappa = 0.36 to 0.56), respectively (20). This data indicates that the direction of asymmetry can be highly variable. Further to this, levels of agreement were higher for tests with greater reliability; the unilateral countermovement jump test had the lowest coefficient of variation (CV) for both within and between test sessions (CV ≤ 6.3%), and also had the highest levels of agreement (Kappa = 0.64 to 0.66) (20). Using the average of testing trials as the metric to calculate inter-limb differences was more consistent across sessions than using the data from the best trial; thus, calculating the average of trials, as opposed to using the best trial for each limb, might be considered more appropriate for assessing inter-limb differences (20). In another study, Bishop et al. (19) assessed athletic performance in 18 elite male under-23 male academy soccer players at three times points over the course of a competitive season: at pre-season, mid-season, and end-season (19). Unilateral countermovement jump (jump height and concentric impulse) and drop jump (jump height and RSI) performances were measured, and magnitude and direction of limb dominance were assessed independently. Limb dominance magnitude changed in a trivial-to-small, nonlinear fashion throughout the season for both unilateral countermovement jump (ES range = -0.43 to 0.05) and drop jump (ES range = -0.18 to 0.41) performances, providing the impression of consistent asymmetry scores over time. However, limb dominance direction was extremely variable. Levels of agreement ranged from poor to substantial for both the unilateral countermovement jump (Kappa = -0.06 to 0.77) and drop jump (Kappa = -0.10 to 0.78) measures. Substantial levels of agreement were only shown for jump height when comparing mid-season with end-season (Kappa = 0.68) and RSI when comparing pre-season with mid-season (Kappa = 0.78); all other time points showed poor to fair levels of agreement for the direction of limb dominance (19). As such, this highlights the need to: 1) test over repeated sessions to identify any consistencies in limb dominance characteristics (or lack thereof), and 2) consider the direction and magnitude independently when interpreting limb dominance outcomes.

Given that levels of agreement for limb dominance appears highly variable, practitioners are encouraged to adopt regular and longitudinal testing protocols to establish an athlete’s limb dominance characteristics more accurately. Further to this, frequent limb dominance assessment will allow practitioners to make a distinction between whether inherent changes over time are merely a consequence of natural fluctuations in performance variability, caused by sport-specific adaptation, or illuminate an underpinning injury or performance concern. When testing limb dominance, conducting multiple trials per test, and using average metric values (rather than peak or “best” values) are recommended for limb dominance calculations.

Practical Applications

Limb dominance in one test does not infer dominance in another. Therefore, when selecting performance tests for limb dominance assessment, practitioners should carefully consider the demands of sport and positional requirements to ensure test and sport demands are similar (100, 168). From a practitioner’s perspective, functional field tests (e.g., jumps, IMTP, CODS) are recommended because they can be more easily integrated into training environments compared with more laboratory-based assessments (e.g., isokinetic dynamometry), which also typically have poor relationships with athletic performance tasks (51, 135).

***** INSERT TABLE 1 ABOUT HERE *****

Although coincidence between limb preference and dominance during balance tasks was discussed, balance is not included as a primary limb dominance assessment parameter because it is rarely considered a key physical testing parameter for athlete populations. When surveyed, an overwhelming proportion of strength coaches working in Major League Baseball (MLB) (64), the National Football League (NFL) (62), NHL (63), and NBA (155) reported testing strength, power, and agility qualities as part of physical testing; with the exception of a few strength coaches in the NHL. However, no strength coaches reported testing balance.

Infrequent limb dominance testing during a competitive season may cause mis-interpretation of limb dominance testing results, owing to the frequent fluctuations seen in limb dominance characteristics (18-20). Making important decisions based off a single data point is inherently risky, particularly when the data lacks consistency and agreement. Therefore, more frequent testing (e.g., weekly to monthly) is suggested so that practitioners can better identify trends in limb dominance profiles and prescribe appropriate training, accordingly. By increasing testing frequency, and thus, the number of testing data points, practitioners will be better able to detect true changes in athletic performance and limb dominance if and when they exist (13).

In sport training environments, and in field testing, there are many factors that can confound results, which may affect their interpretation, and ultimately, effective implementation of longitudinal performance monitoring (84). For example, differing warm-up protocols, prior training load exposures, testing times, and nutrition practices between testing sessions may influence observed performance changes. Thus, it is of utmost importance that practitioners try to control for as many potential confounding variables as possible to facilitate the capture of contextually valid and reliable results. As such, adopting a standardized testing protocol is suggested. Components of this standardized protocol may include a specific warmup sequence prior to testing, instructions given during testing, technologies used (if any), and footwear selection. Other potential contextual performance moderators, including test timing, are important to consider. Selecting a specific day within the training schedule (e.g., morning of game day or the day following a game day-off day sequence), and time of day to implement testing will reduce the factors that could contribute to performance variability, and thus, increase confidence in observed results. There are differences in resistance training performances between morning and evening times, but habitually training at the same time of day is likely to mitigate these differences (25, 86). An additional benefit of selecting a consistent day and time for repeated testing is that it allows for athletes and staffs to develop a routine.

Standardized repeated testing is suggested. However, we recognize that testing standardization that resembles the strict controls of a lab setting may not always be entirely feasible in some sporting environments due to a host of challenges, such as, chaotic training environments, limited staff support, dynamic competition schedules, and limited training time. These real-world challenges make it difficult to routinely collect valid and reliable data. Given this reality, we will discuss strategies that attempt to minimize confounding influence on results that can be pragmatically applied in sport settings with high frequency: 1) using data outputs from technologies already implemented in structured training with sport coaches (e.g., global position system [GPS] and inertial measurement units [IMUs]), and 2) integrating testing as a normal part of the training routine. Effective execution of either of these strategies require considerable forethought; similar to conducting a research experiment, a plan that is ecologically feasible and well-controlled must be in place prior to implementation.

Collaboration between practitioners, and coaches is advised to enhance sport-specific performance (35, 38, 139). When players are instrumented with a GPS unit or IMUs on each limb during training with coaches (e.g., practice), sport-specific limb dominance data is available. However, collaboration with sport coaches is necessary to foster a recurring controlled environment that will allow for meaningful application data outputs as they relate to limb dominance. To gain longitudinal insights, we suggest developing a consistent testing framework around the coaches' practice philosophies and drill tendencies. For example, the coaches may prefer to run "Drill X" following days off from training. For example, the practitioner and coaches might collectively decide that once per month that "Drill X" is prescribed for five minutes in duration as the second drill in the drill sequence for that day. Spatio-temporal gait metrics can be used to quantify limb dominance, which can be derived from a single GPS unit worn during training (80, 134, 181). When interpreting results, it is important to appreciate the validity and reliability of the metrics and technology, particularly for GPS devices (93, 121, 154, 177). Although a natural consequence of technology evolution, validity, and reliability within and across devices can impact longitudinal limb dominance data interpretation. Another means of limb dominance quantification during sport-specific training may include between-limb IMU ground reaction force comparisons (37, 146). To our knowledge, limb dominance between sport-specific training using GPS or IMUs and functional field tests has not yet been investigated. Because limb dominance is task-specific (8, 22, 45, 95, 156), observations during sport-specific training may not coincide with observations from performances in functional field tests.

Typically, practitioners have greater control over how activities are structured in their training environment. Thus, functional field testing in this environment is an ideal place for practitioners to facilitate testing in an organized and consistent manner, even if standardized warmups and direct practitioner-led testing are infeasible. Prescribing sets of complex training (e.g., a set of loaded exercise followed by a set of plyometric exercise) (75) within a session as part of the program design, may facilitate more frequent limb dominance data collection, assuming that athletes are able to record performance of the plyometric movement. For example, five sets of a loaded lower body exercise with 3-5 unilateral vertical jumps in between sets would be an example of an exercise pairing using complex training. When training groups are large and technology is used for data collection, athletes may be instructed to only track jumping performance for one of the five sets, allowing for collection of 3-5 data points per athlete without the burden of waiting for technology to become available. During a consistently programmed unilateral loaded exercise, recording weight lifted alongside rating of perceived exertion or repetitions in reserve per limb is a simple, technology-free means for collecting information that could provide limb dominance data from the training environment.

The examples above are not suggested implementations. Rather, they should be viewed as ideas that facilitate critical thinking for how to strategically apply more frequent limb dominance testing in a practical manner that is minimally burdensome to practitioners, coaches, and athletes. With forethought and strategic implementation, more frequent limb dominance testing is possible in many sport training environments. If strategies that can be pragmatically applied with high frequency in real-world sport settings do not exist, effective longitudinal limb dominance assessment in these settings cannot occur. Infrequent limb dominance testing, which is known to provide inconsistent results (18-20), would be the alternative approach. Despite the strategies offered lacking the full scientific rigor of standard experiments, high-frequency testing that minimizes burden to athletes coaches using semi-standardized protocols (using as much standardization as possible) will enable practitioners to better understand limb dominance profiles over time, fostering more informed monitoring and program design decisions for athletes.

Conclusion

A limb which is subjectively preferred in one task is not always the same limb which is preferred for a separate task. Furthermore, a subjectively preferred limb does not always exhibit superiority in objective athletic performance, including balance, strength, jumping, or sprinting-based tasks. Not only are there discrepancies between subjectively preferred and objectively dominant limbs within individuals, but also, a limb that is objectively superior in one task may also be objectively inferior in a separate task. In other words, similar to limb preference, limb dominance is task-specific.

Given the task-specific nature of limb dominance, testing tasks which reflect the demands of an athlete's sport is of critical importance for practitioners.

An athlete's direction of limb dominance appears to be inconsistent when assessed infrequently over the course of a competitive season (e.g., pre-season, mid-season, and end-season). Due to the intra-individual specificity of magnitude and direction of limb dominance, inter-limb relationships, whether it be between test metrics or changes over time (i.e. longitudinal), should occur on the individual level. In order to determine whether limb dominance is consistent or merely fluctuations in performance variability, more frequent limb dominance testing is suggested. Incorporating semi-standardized testing within the training environment or using information collected during sport-specific training that occurs under supervision of the sport coaches are strategies that may allow for increased testing with minimal burden to athletes and coaches. In this review, we assigned the preferred limb label to the limb that is subjectively preferred whereas the dominant limb referred to the limb that is objectively dominant in a given task. Future research should aim to clarify distinctions between limb preference and dominance.

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Table 1. Example physical qualities with proposed tests, metrics and technologies that may be considered for limb dominance assessment in sport.

Physical Quality	**Possible Tests**	**Metrics**	**Technologies**
Strength	Unilateral isometric mid-thigh pull or squat	Peak force, time to peak force, force at different time points	Force plate
Power	Unilateral jumps: drop jump (UDJ), countermovement jump (UCJ), horizontal jump (UHJ)	UDJ: jump height, reactive strength UCMJ: jump height, peak/mean force*, impulse*, reactive strength-modified* UHJ: jump distance, peak/mean force*, resultant force*	Force plate, OptoJump, jump mat or My Jump app
Change of Direction Speed (CODS)	Change-of-direction tasks (CODS): 505, 505-modified	Total time, change of direction deficit	Dual beam electronic timing gates
* indicates that metric can only be computed if a force plate is available.			