Title: Effect of ball inclusion on jump performance in soccer players: a biomechanical approach

Running title: Soccer-specific vertical jump test

**Abstract**

Objective: In soccer, vertical jump (VJ) means jumping toward a ball. Since no VJ test includes the ball as a reference element, the effect that the ball would have in a VJ test is unknown. The aim of this study was to examine the biomechanical differences between run-up vertical jump measurements without (Run-up Vertical Jump]) and with ball inclusion (Heading Test).

Methods: Twelve semi- and professional soccer players were recruited. Athletes performed both jump tests in a biomechanical laboratory, where kinetic and spatiotemporal variables were collected and compared using a Student's dependent t-test for paired samples.

Results*:* Overall, players performed a different jumping strategy during the heading test compared to the run-up VJ, exhibiting: 1) higher horizontal velocity during initial contact (+45.3%, P ≤ .001), 2) shorter contact time, greater rate of force development, and total impulse during push-off (+27.5%, +53%, and +10.6%, respectively, P ≤ .008), 3) higher CoM horizontal and resultant velocity during take-off (+76.1% and 20.5%, respectively, P ≤ .001), 4) better vertical jump performance (+4.3%, P ≤ .0001, and 5) larger body angle rotation during landing (+63.3%, P = .006), compared to run-up VJ (effect size: 0.78 to 3.7).

Conclusion: In general, soccer players perform better in heading test, which highlights the importance of including an overhead ball during soccer-specific jump tests. Coaches and practitioners are encouraged to assess,and perhaps develop, the jumping ability of soccer players using a suspended ball as a specific target.


**Key words:** Vertical jump, Performance, Strength, Soccer, Testing.

**Introduction**

In soccer, vertical jump (VJ) are performed when jumping toward a ball in an attempt to head the ball for either an attack (scoring / passing) or defensive (clearance / interception) task and is a decisive action during matches. In fact, this skill can be considered an important determinant of the match outcome; for example, at the 2010 South Africa world cup, 19.4% of the goals were scored by headers (Njororai, 2013).

One of the key factors in heading maneuvers is the VJ height. One-foot and two-feet jumping headers have different characteristics but, in both cases, jumping height is critical, depending on well- developed lower-limb intermuscular coordination, elastic energy storage in both muscle and tendon, stretch-shortening cycle, and the strengthening of trunk and hip flexors (Bosco & Komi, 1979; Paoli et al., 2012). A previous study concluded that increase of the "elevation" index (ratio in percentage between vertical height reached by head marker and subjects' height) contributes to improving ball directionality as, at higher heights, players are able to touch the ball under better conditions for passing, shooting, intercepting, or clearing the ball (Marcolin et al., 2007). Despite the importance of VJ height for heading (Marcolin et al., 2007; Paoli et al., 2012), the majority of studies on the topic have focused on other aspects, such as head acceleration (Caccese et al., 2018), kinetic variables (i.e., ground reaction force) (Paoli et al., 2012), and other kinematic variables (i.e., segmental characteristics) (Erkmen, 2009; Kristensen et al., 2004).

Most research and practitioners use standardized VJ assessments such as squat jump (SJ), countermovement jump (CMJ), and, drop jump (DJ) to evaluate the jumping ability and neuromuscular function of soccer players (Slimani et al., 2017; Stojanović et al., 2017).

However, previous authors reported from weak to moderate associations (-0.10 to 0.49) between standardized vertical jumps (e.g., CMJ, DJ) and soccer-specific jump variables (Requena et al., 2014). Although VJ height would be easier to measure if trajectory was purely vertical (e.g., through contact time record), purely vertical displacements are rarely performed during actual soccer competitions as maximal VJs are commonly preceded by horizontal run-up approaches, and are performed in a wide-spectrum of jump types (i.e., one-foot, two-feet parallel, or two-feet sideways) (Sarajärvi et al., 2020) (conditions that are standard during regular jump tests such as CMJ, SJ or DJ). As a consequence, a parabolic trajectory during the flight phase predominates in these jumps (trajectory which describes a parabola or vertical and horizontal velocity are higher than 0m/s).
This indicates that the methods for testing jump ability in soccer should be modified, perhaps focusing on the actual demands and requirements of soccer-specific jumps (i.e., involving a horizontal run-up phase, unrestricted arm movement, and one-leg or two-legs jumps) (Paoli et al., 2012; Requena et al., 2014; Sarajärvi et al., 2020). This is an essential step to create more effective testing approaches, as traditional VJs (e.g., CMJ, SJ, DJ) lack specificity and movement contextualization, and do not reflect the typical features of soccer-specific jumps (Requena et al., 2014).

Although the above-mentioned adjustments (e.g., unrestricted arm movement jumps executed from a run-up) create a more specific testing condition for soccer players (Requena et al., 2014; Young et al., 1999), the presence of the ball (i.e., external target) is perhaps a key element to mimic a real match scenario and improve ecological validity. In this regard, for example, including a specific external target (e.g., a ball suspended in the air) may increase the level of reality experienced by players during jump assessments

(Mok et al., 2017; Wulf & Dufek, 2009), thereby contributing to generate a movement pattern more closely related to actual match demands.

The aim of this study was to determine the biomechanical (spatiotemporal and kinetic) differences between maximal vertical jump tests executed from a run-up with (heading test) or without including a suspended ball as a stationary target (run-up VJ). We hypothesized that heading test would report significant differences in kinetic and spatiotemporal data such as: higher horizontal velocity of the center of mass, shorter ground contact time, and higher rate force of development during push-off which would contribute to higher VJ performance. Also, it was hypothesized that possible inter-subject variations in jumping technique (one-leg *versus* double-legs) during the heading test could increase pelvic rotation in landing phase.

## Materials and methods

### *Participants*

Twelve players (age = 23.9 ± 3.5 years; height = 175.1 ± 5.2 cm; mass = 71.6 ± 3.5 kg) were recruited from a semi-professional (n=10) and a professional (n=2) Spanish soccer teams. All athletes regularly participated in the training and competitive routines of their teams, which included from 5 to 6 technical-tactical training sessions and 1 to 2 matches per week. The players also had extensive experience in strength training (at least 5 years of experience) and were free of injury. The study methodology was approved by the XXXXX Ethics Committee, and was carried out in accordance with the Declaration of Helsinki. All subjects were informed of the risks and benefits of the experiment and signed an informed consent for participation.

### *Design*

This cross-sectional investigation comprised two tests to assess jump performance in soccer players. During the tests, a three-dimensional motion capture system and a force platform collected kinetic and spatiotemporal data throughout the jump trials, from the initial contact during the last step to the contact of the heels during the landing. These tests were previously performed and showed high reliability (Requena et al., 2014; Rodríguez-Rosell et al., 2017; Young et al., 1997).

### *Data collection protocol*

Data were collected during a single session and players performed the tests without training within the 72 hours before the test. A total of six jumps were performed (3 of each test). The measurements occurred at the human movement laboratory of Sport and Health University Research Institute (IMUDS) (Granada, Spain) (image B of figure 1), under the same ambient temperature conditions (18-20 ºC and 50-60 % of relative humidity).

Athletes did not perform a familiarization session to familiarize with jump procedures because the movements mimic a specific soccer task which they commonly perform in their sport.. The test consisted of three trials for each jump, in the following order:  run-up VJ and  heading test with a 60-second rest between trials, and a 2-minute rest between jump types.The warm-up exercises consisted of jogging for 5 minutes at a self-selected pace, followed by a series of dynamic warm-up drills (walking knees to chest, lunge walks, lateral lunge, high knee, butt kicks, and high skips), and three submaximal attempts at each specific jump type.

***Equipment***

Kinetic and spatiotemporal variables were acquired with a 3D motion analysis capture system. Marker trajectories were captured using 8 Oqus motion analysis cameras (Qualisys Inc. Gothenburg, Sweden) sampling at 200 Hz. Ground reaction force was collected using a force platform (Kistler Instruments, Winterthur, Switzerland) sampling at 200 Hz. A soccer ball was attached to a tripod and used as a suspended-ball-system to simulate a specific soccer jump (the "heading test") (fig. 1). Figure 1 shows the laboratory image (image B) where variables were collected, and the possible implementation of the apparatus on the soccer field (image A).

[Figure 1 near here]

***Tests***

*Run-up Vertical Jump (without ball presence).*

These tests were performed with a standardized starting position, with the lead-off foot behind the starting line, which was placed 5.5 meters behind the take-off zone, marked with a delimited square. Athletes completed the run-up (5.5m) and jumped in the square take-off zone (1m x 1m). For this test, we allowed free use of the arms and the jump was performed using both legs (fig. 2). The player was instructed as follows: run to the platform and jump as high as you can. This type of jump was used in previous studies, but with restriction in the steps during run-up and determination of the respective jumping leg (one *versus* double-leg) (Rodríguez-Rosell et al., 2017).

[Figure 2 near here]

*Heading Test (with ball presence).*

An illustration of the heading test is depicted in figure 3. A ball was initially positioned in the air, one meter above the subjects standing height, connected to an apparatus that was attached to the goal post (a tripod was used to simulate the goal post in the laboratory). The player self-selected the distance of the ball from the platform. A simulation of the test was executed to adjust the ball-platform horizontal distance and ensure that subjects performed the push-off within force platforms. After a test simulation, ball height was individually adjusted so that participants felt they could reach the ball during the heading test, although the players would never touch the ball. A specific height (~1m) for the ball was agreed to ensure the players' maximal effort in their jumps. All trials started from the area perimeter and were performed with a 5.5 meters run-up at a self-selected speed and number of strides. The only instructions were: start the jump out of the run-up testing area (5.5m from the ball), and perform a maximal run-up jump with the objective of heading the ball at the highest height possible, using a technique that you consider mimics actual playing (Requena et al., 2014).

The only difference between the run-up VJ and heading test was the reference point. The reference point for the take-off in the run-up VJ was a delimited square (force platform), while in the heading test the reference point was the ball. The rest of the conditions were repeated in both jumps (i.e., run-up approach, free-movement (freely take-off technique: one- vs. two- legs), jump as high as possible, instructions).

[Figure 3 near here]

***Data analyses***

After completing the warm-up, a total of 74 anatomical markers (44 markers and 8 clusters [6 clusters with 4 markers and 2 clusters with 3 markers]) were attached to the participant's body using a full-body model. No markers were attached to the participants' hands. After the static calibration trials, 10 markers were removed. The marker trajectories and ground reaction forces were low-pass filtered at 6Hz and 50Hz, respectively, using Visual 3D software (C-Motion, Bethesda, Maryland) before being used to calculate the three-dimensional spatiotemporal and kinetics of the lower extremity (Butler et al., 2014) (segmental inertial parameters used were those proposed by Dempster et al. (Dempster, 1955) and Hanavan et al. (Hanavan, 1964)). If markers were lost, gaps ≤20 were interpolated using a cubic polynomial interpolation. All data events were calculated after filtering GRF. For the different variables calculated, several events were created according to the jump movement using Visual 3D software. The Centre of Mass (CoM) was calculated as the CoM of the 13 segments included in the full-body model, following the segment inertial parameters proposed by Havanan et al. (1964). The CODA pelvis model was used to define the pelvis (Bell et al., 1989), with markers located in anterior and posterior superior iliac spines, and superior iliac spines as tracking markers. The initial contact or start of the last step were considered when the vertical GRF exceeded 20N (Harry et al., 2017). The take-off was considered when the vertical GRF subsided below 20N. The maximum vertical height reached was considered when the CoM registered its maximal vertical value during the flight phase. The landing was considered when the fifth metatarsal marker from the first foot touching the ground registered its minimal vertical value. The heel contact after landing was considered when the heel marker of the foot that landed later registered its minimal vertical value, representing the heels touching the ground. The stance phase was considered the phase comprised between initial contact and take-off. Furthermore, the stance phase was divided into deceleration and acceleration phases; the latter corresponding to the time event lasting from the moment at which the CoM velocity becomes positive to the take-off. Likewise, the deceleration phase corresponded to the event comprised between initial contact and the moment when the CoM's velocity becomes positive. Acceleration was defined as the phase in which CoM was accelerating in their vertical component. Deceleration was defined as the phase in which CoM was decelerating in their vertical component (i.e., until the CoM velocity (z) becomes positive). The resultant of the GRF was used for the calculation of the impulse. The variables of interest were CoM velocity (m/s) at both initial contact and take-off; total, deceleration and acceleration impulse (calculated from the first integration of the forces measured by the force plate, through the use of the derivate's pipeline in Visual 3D; N·s), rate of force development (RFD) ($N \cdot s^{-1}$) (RFD was calculated as time-interval RFD [change in force divided by time], which is calculated at two time-intervals (high reliability) during accelerative force (0-0.03 and 0.03-0.06s) (Haff et al., 2011) and contact time (s) during stance phase; head and CoM height (m), and cranium angle (cranium angle was always converted into its positive values because the direction to which the rotation was performed was out of the scope of the analysis) at maximum height reached; and pelvis torsion (º) (pelvis rotation angle was calculated as the rotation of the pelvis [using the inertial parameters used for the Coda pelvis calculation] in the Z-axis, considering 0 degrees as the position in which pelvis was perpendicular to the direction of movement) at heel contact after landing. All the variables were obtained using Visual 3D software.

***Statistical Procedures***

The statistical analysis was performed using SPSS 21.0 (IBM Corp., Armonk, NY). Descriptive statistics are expressed as means ± standard deviations (SD), with 95%

confidence limits (95% CL). The normality of the data distribution were checked using the Shapiro-Wilk test. Kinetic and kinematic data were compared between run-up VJ and heading test using the Student's dependent t-test for paired samples (average of heading test vs. run-up VJ). Cohen's *d* effect sizes (ES) were calculated and interpreted as follows: ≤0.2 trivial, >0.2–0.6 small, >0.6–1.2 moderate, >1.2–2.0 large, and >2.0–4.0 very large (Batterham & Hopkins, 2006). Differences were reported at the $p < 0.05$ level.

**Results**

The mechanical outputs for both run-up VJ and heading test are presented in table 1 with the main statements shown in figure 4. Action data were divided into distinct parts, as follows: a) initial contact, b) last foot contact (LFC), c) take-off, d) maximum height reached, and e) landing.

The CoM horizontal velocity was higher during heading test than run-up VJ (fig. 5) in initial contact. There were significant differences in contact time during LFC prior to take-off between both jumps. Run-up VJ exhibited significantly longer contact times (table 1).

During LFC, deceleration impulse was very largely greater in run-up VJ (207.02 ± 44.33 N·s) than heading test (103.72 ± 48.54 N·s) ($p < 0.001$; ES = 2.22) and acceleration impulse was similar in heading test (357.19 ± 51.23 N·s) and run-up VJ (356.51 ± 55.38 N·s) with trivial differences. Therefore, total impulse, was moderately lower in heading test, with significant differences. Significant differences in RFD between tests were registered, and RFD was higher in heading test (table 1).

Heading test registered higher horizontal and resultant velocity in the take-off phase (table 1) (fig. 5).

The vertical height was largely higher in heading test. The cranium angle in relation to the Z-axis was largely greater ($p < 0.001$; ES = 1.69) in heading test (27.77 ± 10.06 º) than run-up VJ (0.98 ± 21.69 º).

During the landing phase, the pelvis torsion angle in relation to the run-up trajectory was greater in heading test (table 1).

[Figure 4 near here]

[Figure 5 near here]

[Table 1 near here]

**Discussion and implications**

We analyzed the biomechanical differences between a run-up vertical jump without and with ball overhead (run-up VJ and heading test, respectively). The main findings of this study showed that with ball presence (heading test): a) CoM horizontal velocity during initial contact was higher, b) LFC time prior to take-off was lower, c) lower braking and total impulse were generated, d) greater RFD was produced, e) horizontal and resultant velocity during take-off was higher, f) higher jump height was achieved, g) cranium angle during the flight phase was higher, and h) more body rotation during the flight phase in relation to the run-up trajectory was reported.

Data showed that during the heading test the CoM horizontal velocity was higher than the run-up VJ CoM velocity (+45.3%) during initial contact, which could be explained by the reference point (ball vs. force platform). This led to higher horizontal and resultant velocity during the take-off in heading test (fig. 5).

During the run-up VJ the reference point was the force platform, on which the player jumped, before subsequently landing in a free mode and free area, without any constraint. This means that the horizontal approach of the run-up is converted into a vertically-oriented movement (fig. 2) with high production of eccentric forces (braking force) tolerated by leg extensor muscles to produce the movement (Young et al., 1997). In contrast, during the heading test, the reference point was the ball, which caused the take-off to be performed before the reference point (ball) increasing the horizontal and resultant velocity and causing a parabolic movement (figs. 3 and 4). In fact, a 76.1% difference in horizontal velocity during the take-off was found between jump types (table 1).

Previous studies found parabolic trajectories in jumps under specific conditions and suggested that jumping preceded by run-ups is, in fact, a typical competitive situation which causes a non-purely vertical displacement during the flight phase (Requena et al., 2014; Wagner et al., 2009; Zahálka et al., 2017). In this regard, the inclusion of the ball as a reference element allows the player to perform the take-off or push-off freely, contributing to reflect a more match-specific situation. These findings suggest the need to create and implement more specific jump training and testing sessions for soccer players, which should include, for example, the ball as an additional stimulus for players' performance.

The contact time was 27.5% lower in heading test compared to the run-up VJ. When players see a ball overhead (i.e., external target), they tend to simulate an actual heading maneuver and the time to jump is reduced, as a consequence of different contextual variables (e.g., overcoming an opponent in a one-on-one situation) (Sarajärvi et al., 2020). This scenario causes a critical difference able to affect (and likely enhance) the stretch-shortening cycle (SSC). Indeed, SSC was faster in heading test than run-up VJ, which involves a shorter contact time and smaller displacements of CoM during LFC (Butler et al., 2014; Requena et al., 2014).

Previous authors showed a "weak" association between the reactive strength index in slow and fast SSC tasks (Flanagan, 2007), suggesting that, in accordance with the principle of specificity, there may be limited transfer of training adaptation between slow and fast SSC training. Depending on the duration of the SSC (RFD is manifested during the SSC), exercises are classified as either slow-SSC (≥ 250ms) or fast-SSC (≤250ms) movements (Turner & Jeffreys, 2010). Accordingly, slow and fast SSCs have been found to have independent qualities (Ham et al., 2007). In this study, the heading test recorded 240±4ms (fast SSC), and on the contrary, the run-up VJ recorded 350±9ms (slow SSC). This finding indicates that a ball overhead contributes to generating a specific LFC strategy, which will directly affect the ability to produce force onto the ground and, thus, provide different training stimulus.

Young et al. (Young et al., 1999) described that pure concentric muscular actions are more related to standing VJ than run-up VJ, and reactive strength is mostly related to run-up VJ. These authors suggested that VJ and run-up VJ, based on kinetic variables, rely on different performance factors. In this sense, this inference may also be extrapolated to run-up VJ and heading test, since the latter seems to be more "reactive dependent".

Regarding negative impulse (braking force), heading test recorded lower braking (49.9% difference) and similar acceleration (0.2%) to run-up VJ. Despite obtaining less contact time in heading test than run-up VJ, the total impulse was greater in run-up VJ (10.6%). Therefore, higher RFD data were obtained during heading test than run-up VJ (59.7% difference), which, among other mechanical factors, elicited better performances during heading test. In fact, higher RFDs have been directly related to better jump performances (McLellan et al., 2011). These data can be explained by the availability of time to apply force in each jump type. In this sense, these kinetic results show that a single element (ball overhead) produces meaningful changes with "very large" magnitude during the LFC, as a consequence of perception-action processes coupled to a "real jump" simulation (i.e., short time to jump, take-off anytime and anywhere, target overhead, and free execution technique).

Our results showed a meaningful difference of 4.3% in jump height between jumping types, with better performance in heading test. In this line, a previous study reported a 5.8% increase in height when the athletes aimed for an overhead target (Mok et al., 2017). Research that analyzed the different attention focuses (external vs. internal), confirmed that subjects jumped higher by producing greater forces when they adopted an external (and specific) stimulus (Wulf et al., 2007; Wulf & Dufek, 2009).

Cranium angle was analyzed in relation to transverse axis angle (Z axis) at maximum height reached, showing a higher angle in the heading test than run-up VJ (96.5%

difference). This result is justified, again, by the presence of the ball, which meant the players kept their eyes on it. A previous study (Shewchenko et al., 2005) reported a positive head angle during different heading scenarios. In that study, the average head angle was inclined downwards (- 4°to - 33°) for all heading scenarios where there was ball contact. Thus, a greater downward angle was noted for heading types involving redirection of the ball while a more horizontal trajectory was noted for the clearing scenarios. In contrast, a light upward orientation was noted for the non-impact scenario likely caused by the difficulty in judging the relative position of the head and body in relation to an imaginary ball(Shewchenko et al., 2005). Furthermore, it was previously reported that clearing scenarios result in shallower ball–head angles (8° – 45°) whereas those involving greater redirection have greater angles (58° – 76°).

Frame sequences during both tasks can be observed in figures 2 and 3. Specifically, in the heel contact event, heading test resulted in greater pelvic rotation than run-up VJ (63.35% difference) in relation to the run-up trajectory (table 1). This rotation could be a consequence of tracking the ball with the eyes during most of the flight phase, and executing the push-off asymmetrically (1-foot or 2-feet sideways), only performed by some players during heading test, probably to mimic authentic VJ (Sarajärvi et al., 2020). In this sense, it would be difficult to execute a real jump trial with external focuses such as force platforms or other measurement instruments (e.g., optical measurement system) placed on the ground.

Soccer-specific scenarios during matches, where attention is directed to a contextual-specific informational variable (i.e., teammates or opponent positions, ball trajectory, or the environment itself), contribute to generate multi-planar displacement (frontal and transverse plane) (DiCesare et al., 2011; Erkmen, 2009) and not only in the sagittal plane, typically used in standardized VJ tests. This difference shows that run-up VJ and heading test generate independent and different movement strategies, from the initial approaching technique to the last jumping event. This emphasizes the need for implementation of more specific jump measurements in soccer, which involve actual external stimulus (e.g., a ball) and allow the use of free and multi-planar movement strategies during their execution.

The main limitation of this study was not to categorize the kinetic and spatiotemporal variables taking into account the player positions and heading purposes (i.e., clear, shoot, pass). In addition, despite performing an adequate warm-up prior to tests, we did not perform the jumps in a randomize order; therefore, there could potentially be slight effects of post-activation potentiation enhancement which could have influenced contributed to performance difference between both tasks. In terms of equipment, this platform allows data to be obtained at a frequency of 200 Hz, which could be considered low compared to other studies. However, up to 200 Hz, the ground reaction force varies less than 2% compared to a 500-Hz platform (Hori et al., 2009), so the sampling frequency at 200 Hz was acceptable. Future studies should analyze vertical jumps with the ball present in different player positions and with different objectives (i.e. clear, pass, shoot, interception).

**Practical applications**

As the ball overhead contributes to the use of a more specific jump strategy and increases jump performance compared to jumping without the ball, practitioners and sport scientists are encouraged to assess (and perhaps develop) jumping ability with ball inclusion in soccer players. It is also important that these measurements comprise free movement strategies and previous run-up actions before jump attempts. This is necessary to allow players to improve their power-related performance within the "real game context". In addition, this could provide coaches and technical staff with more accurate information regarding actual player performance.

## References

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50–57. https://doi.org/10.1123/ijspp.1.1.50

Bell, A. L., Brand, R. A., & Pedersen, D. R. (1989). Prediction of hip joint centre location from external landmarks. *Human Movement Science*, *8*(1), 3–16. https://doi.org/10.1016/0167-9457(89)90020-1

Bosco, C., & Komi, P. V. (1979). Mechanical characteristics and fiber composition of human leg extensor muscles. *European Journal of Applied Physiology and Occupational Physiology*, *41*(4), 275–284. https://doi.org/10.1007/BF00429744

Butler, R. J., Russell, M. E., & Queen, R. (2014). Effect of soccer footwear on landing mechanics. *Scandinavian Journal of Medicine and Science in Sports*, *24*(1), 129–135. https://doi.org/10.1111/j.1600-0838.2012.01468.x

Caccese, J. B., Buckley, T. A., Tierney, R. T., Rose, W. C., Glutting, J. J., & Kaminski, T. W. (2018). Sex and age differences in head acceleration during purposeful soccer heading. *Research in Sports Medicine (Print)*, *26*(1), 64–74. https://doi.org/10.1080/15438627.2017.1393756

Dempster. (1955). Space Requirements of the Seated Operator. (Technical Report WADC-TR-55-159). In *Wright-Patterson Air Force Base, OH: Aerospace Medical*

*Research Laboratory*. https://doi.org/citeulike-article-id:437004

DiCesare, C. A., Kiefer, A. W., Bonnette, S. H., & Myer, G. D. (2011). Realistic Soccer-Specific Virtual Environment Exposes High-Risk Lower Extremity Biomechanics. *Journal of Sport Rehabilitation*, *13*, 1–7.

Erkmen, N. (2009). Evaluating the Heading in Professional Soccer Players by Playing Positions. *Journal of Strength & Conditioning Research*, *23*(6), 1723–1728.

Flanagan, E. P. (2007). an Examination of the Slow and Fast Stretch Shortening Cycle in. *Symposium A Quarterly Journal In Modern Foreign Literatures*, *November*, 51–54.

Haff, G., Ruben, R., Lider, J., Twine, C., & Cormie, P. (2011). A Comparison of Methods for Determining the Rate of Force Development During Isometric Midthigh Clean Pulls. *Journal of Strength & Conditioning Research*, *29*(2), 386–385.

Ham, D. J., Knez, W. L., & Young, W. B. (2007). A Deterministic Model of the Vertical Jump: Implications for Training. *Journal of Strength & Conditioning Research*, *21*(3), 967–972.

Hanavan, E. P. (1964). *A mathematical model of the human body* (Wright-Pat).

Harry, J. R., Barker, L. A., Mercer, J. A., & Dufek, J. S. (2017). Vertical and Horizontal Impact Force Comparison during Jump Landings with and Without Rotation in NCAA Division i Male Soccer Players. *Journal of Strength and Conditioning Research*, *31*(7), 1780–1786. https://doi.org/10.1519/JSC.0000000000001650

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Kraemer, W. J., & Nosaka, K. (2009). Reliability of Performance Measurements Derived From Ground Reaction Force Data During Countermovement Jump and the Influence of Sampling Frequency. *Journal of Strength and Conditioning Research*, *23*(3), 874–882. https://doi.org/10.1519/JSC.0b013e3181a00ca2

Kristensen, L. B., Andersen, T. B., & Sørensen, H. (2004). Soccer: Optimizing segmental movement in the jumping header in soccer. *Sports Biomechanics*, *3*(2), 195–208. https://doi.org/10.1080/14763140408522840

Marcolin, Giuseppe, & Petrone, N. (2007). A method for the performance evaluation of jumping headers in soccer. *ISBS Conference Proceedings*, *July*, 10–13.

McLellan, C., Lovell, D. I., & Gass, G. (2011). The Role of Rate of Force Development on Vertical Jump Performance. *Journal of Strength & Conditioning Research*, *25*(2), 379–385.

Mok, K. M., Bahr, R., & Krosshaug, T. (2017). The effect of overhead target on the lower limb biomechanics during a vertical drop jump test in elite female athletes. *Scandinavian Journal of Medicine and Science in Sports*, *27*(2), 161–166. https://doi.org/10.1111/sms.12640

Njororai, W. W. S. (2013). Analysis of goals scored in the 2010 world cup soccer tournament held in South Africa. *Journal of Physical Education and Sport*, *13*(1), 6–13. https://doi.org/10.7752/jpes.2013.01002

Paoli, A., Bianco, A., Palma, A., & Marcolin, G. (2012). Training the vertical jump to head the ball in soccer. *Strength and Conditioning Journal*, *34*(3), 80–85. https://doi.org/10.1519/SSC.0b013e3182474b3a

Requena, B., Garcia, I., Requena, F., Bressel, E., Saez-Saez de Villarreal, E., & Cronin, J. (2014). Association between traditional standing vertical jumps and a soccer-specific vertical jump. *European Journal of Sport Science*, *14*, 37–41. https://doi.org/10.1080/17461391.2012.708790

Rodríguez-Rosell, D., Mora-Custodio, R., Franco-Márquez, F., Yáñez-García, J. M., & González-Badillo, J. J. (2017). Traditional vs. Sport-Specific Vertical Jump Tests. *Journal of Strength and Conditioning Research*, *31*(1), 196–206. https://doi.org/10.1519/JSC.0000000000001476

Sarajärvi, J., Volossovitch, A., & Almeida, C. H. (2020). Analysis of headers in high-performance football: evidence from the English Premier League. *International Journal of Performance Analysis in Sport*, *00*(00), 1–17. https://doi.org/10.1080/24748668.2020.1736409

Shewchenko, N., Withnall, C., Keown, M., Gittens, R., & Dvorak, J. (2005). Heading in football. Part 1: Development of biomechanical methods to investigate head response. *British Journal of Sports Medicine*, *39*(SUPPL. 1), 10–26. https://doi.org/10.1136/bjsm.2005.019034

Slimani, M., Paravlić, A., & Bragazzi, N. L. (2017). Data concerning the effect of plyometric training on jump performance in soccer players: A meta-analysis. *Data in Brief*, *15*, 324–334. https://doi.org/10.1016/j.dib.2017.09.054

Stojanović, E., Ristić, V., McMaster, D. T., & Milanović, Z. (2017). Effect of Plyometric Training on Vertical Jump Performance in Female Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine*, *47*(5), 975–986. https://doi.org/10.1007/s40279-016-0634-6

Turner, A. N., & Jeffreys, I. (2010). The stretch-shortening cycle: Proposed mechanisms and methods for enhancement. *Strength and Conditioning Journal*, *32*(4), 87–99. https://doi.org/10.1519/SSC.0b013e3181e928f9

Wagner, H., Tilp, M., Von Duvillard, S. P. V., & Mueller, E. (2009). Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine*, *30*(10), 760–765. https://doi.org/10.1055/s-0029-1224177

Wulf, G., & Dufek, J. (2009). Increased jump height with an external focus due to enhanced lower extremity joint kinetics. *Journal of Motor Behavior*, *41*(5), 401–409. https://doi.org/10.1080/00222890903228421

Wulf, G., Zachry, T., Granados, C., & Dufek, J. S. (2007). Increases in Jump-and-Reach

Height through an External Focus of Attention. *International Journal of Sports Science & Coaching*, *2*(3), 275–284. https://doi.org/10.1260/174795407782233182

Young, W., Macdonald, C., Heggen, T., & Fitzpatrick, J. (1997). An evaluation of the specificity, validity and reliability of jumping tests. *Journal of Sports Medicine and Physical Fitness*, *37*(4), 240–245.

Young, W., Wilson, G., & Byrne, C. (1999). Relationship between strength qualities and performance in standing and run-up-vertical jumps. *Journal of Sports Medicine and Physical Fitness*, *39*(4), 285–293.

Zahálka, F., Malý, T., Malá, L., Ejem, M., & Zawartka, M. (2017). Kinematic Analysis of Volleyball Attack in the Net Center with Various Types of Take-Off. *Journal of Human Kinetics*, *58*(1), 261–271. https://doi.org/10.1515/hukin-2017-0115

Table I. — *Mean ± standard deviation (SD) and confidence limit (95%) data of some biomechanics variables obtained during initial contact, LFC, take-off phase, maximum height, and landing phases.*

| Variable | Initial contact | LFC | | | Take-off | | Maximum height | Landing |
|---|---|---|---|---|---|---|---|---|
| | CoM Horizontal vel. (m/s) | Contact time (s) | Total impulse (N·s) | RFD (N·s$^{-1}$) | CoM H Vel (m/s) | CoM R Vel (m/s) | Head height (m) | Pelvic torsion (º) |
| **RUVJ** | 1.96 ± 0.34 | 0.35 ± 0.09 | 368.0 ± 50.16 | 4432.4 ± 2231.68 | 0.52 ± 0.24 | 3.01 ± 0.17 | 2.21 ± 0.06 | 15.66 ± 14.72 |
| **HT** | 3.58 ± 0.65† | 0.24 ± 0.04† | 328.9 ± 49.92† | 9452.55 ± 5093.08† | 2.15 ± 0.64† | 3.79 ± 0.32† | 2.31 ± 0.08† | 42.71 ± 24.0† |
| **Difference (95%CL)** | 1.62 (1.03-2.21) | 0.097 (0.02-0.17) | 39.1 (56.84- 13.34) | 5020.15 (1614.07-8426.23) | 1.64 (1.10-2.18) | 0.71 (0.96-0.41) | 0.10 (-0.4-0.52) | 27.05 (0.06-0.14) |
| **ES** | 3.28 (*Very large*) | 1.41 (*Large*) | 0.78 (*Moderate*) | 1.37 (*Large*) | 3.7 (*Very large*) | 3.16 (Very *large*) | 1.43 (*Large*) | 1.4 (*Large*) |

† p ≤ 0.01 compared heading test with run-up vertical jump values. CL: Confidence Limits; CoM H Vel: Centre of Mass Horizontal Velocity; CoM R Vel: Centre of Mass Resultant Velocity; ES: Effect size; LFC: Last foot contact; RFD: rate of force development; RUVJ: Run-up vertical jump; HT: Heading test.

**Figure Captions**

Figure 1. Suspended-ball-system to simulate a soccer-specific jump (“A” in the field; “B” in the laboratory).

Figure 2. Run-up vertical jump graphical representation.

Figure 3. Heading test graphical representation.

Figure 4. Representation of frame-by-frame differences promoted by ball inclusion.

Figure 5. Vertical, horizontal, and resultant velocities during different phases of both measurements (“A” run-up vertical jump; “B” heading test).

**Note:** The authors report no conflict of interest