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# Specific adaptations in performance and muscle architecture after weighted jump-squat vs body mass squat jump training in recreational soccer players.

Running head: Weighted vs body mass jump-squat training

The study was conducted at the Department of Neurological, Biomedical and Movement Sciences, University of Verona, Italy.

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## ABSTRACT

The aim of the present study was to compare the effects of weighted **jump squat** (WJST) vs **body mass squat jump training (BMSJT)** on quadriceps muscle architecture, **lower-limb** lean-mass (LM) and muscle strength, performance in change of direction (COD), sprint and jump in recreational soccer-players. Forty-eight healthy soccer-players participated in an off-season randomized controlled-trial. Before and after an eight-week training intervention, *vastus lateralis* pennation angle, fascicle length, muscle thickness, LM, squat 1-RM, quadriceps and hamstrings isokinetic peak-torque, agility T-test, 10 and 30m sprint and squat-jump (SJ) were measured. Although similar increases in muscle thickness, fascicle length increased more in WJST (ES=1.18, 0.82-1.54) than in **BMSJT** (ES=0.54, 0.40-0.68) and pennation angle only increased in **BMSJT** (ES=1.03, 0.78-1.29). Greater increases in LM were observed in WJST (ES=0.44, 0.29-0.59) than in **BMSJT** (ES=0.21, 0.07-0.37). Agility T-test (ES=2.95, 2.72-3.18), 10m (ES=0.52, 0.22-0.82) and 30m-sprint (ES=0.52, 0.23-0.81) improved only in WJST, while SJ improved in **BMSJT** (ES=0.89, 0.43-1.35) more than in WJST (ES=0.30, 0.03-0.58). Similar increases in **squat 1-RM** and peak-torque occurred in both groups. The greater inertia accumulated within the landing-phase in WJST vs **BMSJT** has increased the eccentric workload, leading to specific eccentric-like adaptations in muscle architecture. The selective improvements in COD in WJST may be related to the increased braking ability generated by the enhanced eccentric workload.

**Key-words:** Change of direction; sprint; fascicle length; isokinetic; ballistic training; pennation angle

## INTRODUCTION

Ballistic training is often used to improve skeletal muscle function and athletic performance (15). In ballistic exercise, the athletes has to exert the highest strength in the shortest time to maximally accelerate **their** body mass (e.g., jumping) or an object (e.g., kicking or throwing a ball). Jump-squat **is** among the most used ballistic exercise to enhance mechanical power in lower-limb muscles (15,25,30). **Jump-squat has been shown to improve jump height** (17,25,38), as well as sprint performance (15,16,38). However, since the increased role of change of direction (COD) in soccer (8), the effects of jump-squat training on COD were only recently investigated, reporting improvements in COD after **jump-squat** training **only (26,27), or jump-squat added to a traditional strength training program** (23). **Importantly, jump-squat training was shown to improve physical ability in soccer players in pre-season** (27) **and to counteract the decrease in speed and power performance due to the high endurance training load the players undergo before the season begins** (28)**. Additionally, jump-squat training was effectively added to traditional soccer training to elicit power in-season** (35)**. Finally, in order to get meaningful adaptations, jump-squat training was carried out for six weeks or more** (15,16,23,26,27,35)**.**

Muscle architecture, encompassing muscle thickness, pennation angle and fascicle length, is a strong determinant of muscle force generating capacity (5). Muscles with longer fascicles **can** develop force at a higher rate, while muscles with wider thickness and pennation angle have a larger physiological cross-sectional area, thus enhancing the maximal force **produced** (5). Muscle thickness, pennation angle and fascicle length are known to increase after traditional resistance training (3,11,20,32). However, little is known about the effects of jump-squat training on muscle architecture. Previous studies have examined the effects of jump-squat training using quadriceps muscle as the target muscle because of its **influential** role in jumping tasks (19).

However, inconsistent results, such as increases in pennation angle but not in muscle thickness **in *vastus lateralis*** (15) or increases in muscle thickness after a combined strength and jump-squat training in ***rectus femoris*** (35), have been recently reported. **Such a discrepancy could have derived from the different targeted muscles, and from the different protocols used. Indeed, given that some Olympic-lift exercises were included in the latter** (35)**, the larger knee-range of movement compared to the self-selected depth used in jump-squat training may have resulted in a greater work completed**. Moreover, no change in fascicle length after combined strength/jump training (36) nor after combined jump/sprint training was observed (4).

Jump-squat training has been shown to improve **lower-limb** isometric muscle strength (15), **as well as to** increase squat 1-RM (16,25,30). Given the important contribution of the quadriceps and hamstrings during both take-off and landing in jump-squat (19), **training using jump-squat** may have specific effects on the maximal strength of these muscle groups. A previous surface electromyographic study highlighted **that a** higher hamstrings activity **in both concentric and eccentric phase occurred when jumps are performed without a stretch-shortening cycle** (31)**. Since jump-squat does not include a fast countermovement or a plyometric action, the repetitive jumps may result in a noteworthy** specific strength adaptation in **the** hamstrings. **Interestingly, it was shown that quadriceps muscle activation was not affected by** the **load** (21) **leading to hypothesize that** specific adaptations in the hamstrings-to-quadriceps strength ratio, an index to estimate hamstring injury risk (9), **may be derived from jump-squat training. Interestingly, greater fatigue was shown in the hamstrings compared with the quadriceps after a standardized task** (10) **or after a soccer match simulation** (9)**. Therefore, jump-squat training may be used to increase hamstrings strength, consequently increasing the hamstrings-to-quadriceps strength ratio** (9,10)**, therefore decreasing the hamstrings strain injury risk.**

Several previous studies have investigated the effect of jump-squat training using the external load that maximized the power output (15–17,38). However, measuring such a load appropriately requires devices (i.e. force plates and linear transducers) that are often unavailable in the field **setting.** Notwithstanding, it was reported that the maximal power output usually ranges from 0% to 30% of the squat 1-RM (14,18,30), **and also shown in a direct optimum load vs body mass comparison** (29). Jump-squat training is characterized by repetitive explosive concentric take-offs followed by repetitive eccentric landings. Both work and force developed during these phases are accounted for the external load used during the jump-squat. Particularly, **compared to body mass squat jump, a greater inertia accumulated during a weighted jump** results in a greater eccentric work completed, which was shown to be a key-factor for inducing improvements in muscle performance (17). **Previous studies have shown that irrespective of the exercise**, an accentuated eccentric phase induced specific adaptations in muscle architecture **after isokinetic or isoload knee-extension training** (11) or greater hypertrophic stimuli **after a six-week bench press training.** (13). Finally, the repeated excessive braking-load during landing could result in greater improvements in COD, which similarly requires the athletes to repetitively brake the inertia of their body mass and subsequently accelerate.

Therefore, the aim of the present study was to evaluate the effects of weighted (with 30% of squat 1-RM) jump-squat training (WJST) or **body mass squat-jump training (BMSJT)** on quadriceps muscle architecture and **lower-limb** lean mass (LM) in recreational soccer players. COD, sprint and jump performance were also evaluated. Lastly, both **changes in** hamstrings and quadriceps peak torque were measured **as well as the** changes in functional $H_{ecc}$:$Q_{conc}$ ratio was **calculated**.

## METHODS

### Experimental approach to the problem

The present investigation was designed as a pre-post, parallel three-groups, randomized-controlled trial. Using a restricted-blocks randomization (computer-generated sequence), the participants were randomly allocated into **BMSJT** or WJST or control group (CON). The allocation and the randomization were completed by one of the researchers without any contact or knowledge of the participants. Therefore, no allocation concealment-mechanisms were necessary. To calculate the sample size, a statistical software (GPower, Dusseldorf, Germany) was used. Given the study design (3 groups, 2 repeated measures), the effect size = 0.25 (medium), α-error < 0.05, the non-sphericity correction € = 1, the correlation between the repeated measures = 0.5 and a desired power (1-ß error) = 0.8, the total sample size resulted in 42 participants. To prevent **the effect of any possible drop-out on the statistical power**, 48 participants were included.

### Participants

Forty-eight male recreational soccer players (age: 21 ± 3 years, **age ranged from 18 to 25 years**; body-mass: 73 ± 4 Kg; height: 1.78 ± 0.10 m) volunteered to participate in the present investigation. The participants joined two Italian recreational soccer teams, which competed in a recreational soccer championship. **The participants had a soccer history of at least five consecutive years in young or recreational soccer teams. Within the previous season, their typical training volume consisted of three training sessions (about 2 hours per session) plus one match per week, from September to May. Lower-limb** muscular or joint injuries in the previous 12 months, as well as cardio-pulmonary diseases, smoking or drugs use, were listed as exclusion criteria. The present investigation was approved by the local Ethical Committee and was in line with the Declaration of Helsinki (1975 and further updates) concerning the ethical standards in studies involving human subjects. Finally, the participants were carefully informed about any possible risks due to the investigation's procedures, and they signed a written informed consent.

**Procedures**

To evaluate the **lower-limb** muscle strength, squat 1-RM, isokinetic concentric, eccentric and isometric quadriceps peak-torque and eccentric hamstrings peak-torque were measured. To evaluate the quadriceps muscle architecture, muscle thickness, fascicle length and pennation angle were measured on *vastus lateralis* muscle. To evaluate the **lower-limb** (LM), dual-energy X-ray absorptiometry (DXA) scans were used. Finally, to evaluate their soccer abilities, change of direction (COD), sprinting- and jumping-ability were measured.

The present investigation lasted 10 weeks and was carried out in the off-season (from May to July). The participants were instructed to avoid any other form of resistance training for the entire duration of the present investigation. In the first week, the participants were involved in three testing-sessions. In the first session, the participants were familiarized with the squat technique, isokinetic strength testing procedures, COD, sprinting- and jumping-ability testing-procedures. Within the second session, muscle architecture, LM and squat 1-RM were measured, and the participants familiarized with the training protocols. Within the third session, isokinetic strength, COD, sprinting- and jumping-ability was measured. The intervention lasted eight weeks. Finally, the post-training testing measurements were assessed the week after the end of the intervention and **they were** conducted over two sessions. In the first one, muscle architecture, LM, squat 1-RM and isokinetic strength were measured. In the second session, COD, sprinting and jumping abilities were measured. **Each assessment was performed by the same experienced operators and interspersed by 30 min of passive recovery. COD, sprints and jumps were measured indoor, on a concrete surface.**

### Squat 1-RM

The back squat 1-RM was measured using an Olympic bar. After a standardized warm-up, consisting of 30 weight-free squats, the 1-RM attempts started from 80% of the body mass. Thereafter, additional 5% was added until failure. Each set was separated by 3 min of passive recovery. A standard time under tension (2 s for the concentric and eccentric phase, 1s for the isometric phase) was used and the participants had to lower the bar until the thighs were parallel to the ground. Strong standardized encouragements were provided to the participants to maximally perform each trial. Squat 1-RM / body mass was calculated and inserted into the data analysis. Lastly, the 30% of squat 1-RM was used as overload for WJST.

### Isokinetic measurements

An isokinetic dynamometer (Cybex Norm, Lumex, Ronkonkoma, USA) was used to measure quadriceps' and hamstrings' strength. The procedures followed previous recommendations (11). Briefly, the device was calibrated according to the manufacturer's procedures and the centre of rotation was aligned with the tested knee. The participants were seated on the dynamometer's chair, with their trunks slightly reclined backwards and a hip angle of 95°. Two seatbelts secured the trunk and one strap secured the tested limb, while the untested limb was secured by an additional lever. The strength measurements were preceded by a standardized warm-up, consisting of three sets x 10 repetitions of weight-free squats. Quadriceps peak-torque was measured in concentric ($1.05 \text{ rad} \cdot \text{s}^{-1}$) and eccentric ($-1.05 \text{ rad} \cdot \text{s}^{-1}$) modalities (12). Hamstrings peak-torque was measured in eccentric ($-1.05 \text{ rad} \cdot \text{s}^{-1}$) modality. Each testing-modality consisted of three maximal trials and was separated by 2 min of passive recovery. Strong standardized encouragements were provided to the participants to maximally perform each trial.

The peak-torque was then calculated and inserted into the data analysis. Finally, the hamstrings-to-quadriceps strength ratio, defined as the ratio between eccentric hamstrings-to-concentric quadriceps peak torque (i.e., functional $H_{ecc}$-$Q_{conc}$ ratio) (9) was also calculated. ***Excellent* test-retest reliability was found for all the isokinetic measurements (from α = 0.915 to α = 0.963).**

## Muscle architecture

*Vastus lateralis* muscle architecture was measured using an ultrasound device (Acuson P50, Siemens, Germany) at the 39% of the distal length of the thigh (12). The participants laid supine and the 4 cm ultrasound transducer was oriented perpendicularly to the skin surface of the *vastus lateralis* and longitudinally to the muscle's fascicles. Two images were scanned and then analysed using a free imaging analysis software (ImageJ, NIH, Maryland, USA). Images were obtained at 50% of the muscle width defined as the midpoint between the fascia separating the *vastus lateralis* and *rectus femoris*, and fascia separating the *vastus lateralis* and *biceps femoris* muscles. Muscle thickness was defined as the distance between the superficial and deep aponeurosis. Pennation angle was defined as the angle between the fascicles and the aponeurosis. Finally, fascicle length was calculated according to the formula (5):

$$FL = \mathrm{syn}(y+90°) * MT/\mathrm{syn}[180°-(y+180°-PA)]$$

where y is the angle between the superficial and the deeper aponeurosis, PA is the pennation angle, and MT is the muscle thickness. The same experienced operator performed the data collection, and data analysis and the operator was blinded to the participants' allocation. ***Excellent* reliability was found for muscle thickness (α = 0.917) and pennation angle (α = 0.902) and *good* reliability for fascicle length (α = 0.876).**

### Lower-limb lean-mass

Total body and regional composition were evaluated using DXA, a total body scanner (QDR Explorer W, Hologic, MA, USA; fan-bean technology, software for Windows XP version 12.6.1), according to the manufacturer's procedures. The DXA body composition approach assumes that the body consists of three components that are distinguishable by their X-ray attenuation properties: fat mass, LM and bone mineral (34). The scanner was calibrated daily against the standard supplied by the manufacturer to avoid possible baseline drift. Whole-body scanning time was about seven min. Data were analysed using standard body region markers: upper and lower extremities, head, and trunk (pelvic triangle plus chest or abdomen). All scanning and analyses were performed by the same operator to ensure consistency. The whole **lower-limb** LM amount was reported in data analysis.

### Squat jump and counter-movement jump

The peak heights of squat jump (SJ) and counter-movement jump (CMJ) were investigated using an infrared device (OptoJump, Microgate, Italy). In the SJ, the participants were instructed to stand, flex the knees to approximately 90° and jump. The participants had to avoid as much as possible any countermovement, and they were instructed to stop for 2 s at each phase. In the CMJ, the participants were instructed to stand, lower themselves to a self-selected knee flexion and immediately jump. Arms were placed on the hips in both SJ and CMJ tests. The participants were instructed to avoid any knee-flexion before the landing in both SJ and CMJ, and the operator visually checked for it. Three attempts were performed for each jump, and the peak-height was inserted into the data analysis. Two min of passive rest separated each jump. **A *good* reliability was found for SJ (α = 0.876), CMJ (α = 0.861)**

### Sprint and COD

The time-trials of 10 m and 30 m dash and agility T-test (7) were separately investigated using an infrared device (Polifemo, Microgate, Italy). The participants were placed 30 cm behind the starting line, with the preferred foot in forward position and autonomously started each trial. **An *excellent* reliability was found for 10 m and 30m sprint (α = 0.945 and α = 0.921, respectively).**
Agility T-test was performed turning right or left as first, and the sum of the two trials was inserted in the data analysis. Four cones were arranged in a T-shape, with a cone placed 9.14 m from the starting cone (photocell gates 2 m apart) and two further cones placed 4.57 m on either side of the second cone. The participants had to sprint forward 9.14 m from the start line to the first cone and touch the cone with their right hand, shuffle 4.57 m left to the second cone and touch it with their left hand, then shuffle 9.14 m right to the third cone and touch it with their right hand, and shuffle 4.57 m back left to the middle cone and touch it with their left hand before finally back pedalling to the start line. The trials were not considered if participants failed to touch a designated cone or failed to face forward at all times. Only one timing gate placed on the start-finish line was used for timing the T-test. Each test was repeated three times, and the best performance was calculated and inserted into the data analysis. Two min of passive rest separated each trial. **Agility t-test showed a *good* reliability (α = 0.818).**

### Intervention

Both **BMSJT** and WJST sessions involved a warm-up consisting of 5 min of cycling followed by 20 weight-free squats. **Training volume load was calculated as a number of repetitions * load, assuming a similar time under tension and distance covered (13). Particularly, load referred to body mass, resulting in 1 A.U. (= body mass only) in BMSJT and 1.2 A.U. in WJST (as shown in table 3). To equalize the training volume over the whole intervention, BMSJT performed five sets * 10 repetitions (n = 50), and WJST initially performed four sets * 10 repetitions (n = 40).**

**After four weeks, in WJST only, the load was increased to 1.25 A.U. and WJST performed two sets * 10 and two sets * 11 repetitions (n = 42). The sets were separated by three min of passive recovery**. Both groups were instructed to maximally jump and finish the landing phase of each jump at a knee-angle corresponding approximately to 90°. **BMSJT** were instructed to keep their hands on their hips for the full duration of each jump. In WJST, the overload consisted of a bar grasped on the shoulder in a back-squat position for the whole duration of each jump. The weight used as the external load in WJST was tailored according to the individual squat 1-RM results. The participants received strong standardized encouragements to maximally perform each jump. The intervention lasted eight weeks, two sessions per week, separated by at least two days, during which CON did not perform any training.

## Statistical analysis

Statistical analysis was performed using statistical software (SPSS 22, IBM, USA). The normality of the distribution was checked using Shapiro–Wilk's test. The sphericity assumption was calculated using the Mauchly's test. The test–retest reliability was measured using an intraclass correlation coefficient (ICC, Cronbach-α) and interpreted as follows: $\alpha \geq 0.9$ = *excellent*; $0.9 > \alpha \geq 0.8$ = *good*; $0.8 > \alpha \geq 0.7$ = *acceptable*; $0.7 > \alpha \geq 0.6$ = *questionable*; $0.6 > \alpha \geq 0.5$ = *poor* (37). The variations of the dependent parameters were analysed by separate mixed-factors ANOVA (time × group) for repeated measurements. Additionally, data were log-transformed and analysed using an ANCOVA, considering baseline values as covariate. Post-hoc analysis using Bonferroni's correction was then performed to calculate the main effect for group (three levels: **BMSJT**, WJST, and CON) and time (two levels: pre- and post-training). Significance was set at $\alpha < 0.05$. Data are reported as mean with standard deviation (SD). Changes are reported as %change with 95% of confidence intervals (CI95%) and effect-size (ES) with CI95%. ES was interpreted following the Hopkins's recommendations (24): 0.0 to 0.2 = *trivial*; 0.2 to 0.6 = *small*; 0.6 to 1.2 = *moderate*; 1.2 to 2.0 = *large*; >2.0 *very large*.

## RESULTS

**The compliance rate for BMSJT and WJST was 94% and 96%, for a total of 16 and 11 missed training sessions, respectively. No injury occurred during the intervention period.**

Time x group interactions were found for muscle thickness (p = 0.013), pennation angle (p = 0.023) and fascicle length (p = 0.003). However, despite the similar increases in muscle thickness (**BMSJT** = *moderate* and WJST = *small*), pennation angle *moderately* increased only in **BMSJT**, while greater increases in fascicle length were found in WJST compared to **BMSJT** (+8%, CI95% 2 to 15). Finally time x group interaction was found for **lower-limb** LM (p < 0.001) and greater increases in LM were found in WJST compared to **BMSJT** (+7%, CI95% 5 to 10). CON did not show any change. (Table 1)

Please insert table 1 here

Significant time x group interaction was found for agility T-test (p < 0.001). *Very large* decreases in agility T-test time were observed in WJST, while no change occurred in **BMSJT**. Significant time x group interactions were found for 10 m (p = 0.001) and 30 m (p = 0.012) performance. *Moderate* decreases in 10 m and 30 m sprint time occurred in WJST and not in **BMSJT**. Significant time x group interactions were found for SJ (p = 0.003) and CMJ (p = 0.001). Although both **BMSJT** and WJST increased SJ and CMJ height, greater increases occurred in **BMSJT** than WJST in SJ (+5%, CI95% 2 to 8) and in CMJ (+6%, CI95% 1 to 11). CON did not show any change. (Table 2)

Please insert table 2 here

Time x group interactions were found for squat 1-RM (p = 0.021), concentric (p < 0.001), eccentric (p < 0.001) peak-torque and hamstrings' eccentric peak-torque (p < 0.001). Both **BMSJT** and WJST similarly increased quadriceps' and hamstrings' muscle strength over time. Similarly, time x group interaction was found for functional $H_{ecc}$ to $Q_{conc}$ ratio (p < 0.001). Only **BMSJT** *moderately* increased it. CON did not show any change (Table 3).

Please insert table 3 here

## DISCUSSION

The present investigation highlighted that: i) despite the similar increments in *vastus lateralis* muscle thickness, pennation angle widened only after **BMSJT**, while fascicle length increased more after WJST than in **BMSJT**; this was accompanied by greater increases in **lower-limb** LM in WJST compared to **BMSJT**; ii) only WJST improved COD and sprint performance, while **BMSJT** improved jumping ability more than WJST; and iii) similar increases in hamstrings and quadriceps muscle strength occurred in both **BMSJT** and WJST, even if the functional $H_{ecc}$ to $Q_{conc}$ ratio increased in **BMSJT** but not in WJST.

The specific WJST *vs* **BMSJT** training-induced adaptations in *vastus lateralis* muscle architecture is introduced here for the first time. The greater increases in fascicle length after WJST than in **BMSJT** may derive from the enhanced eccentric phase due to the greater external load used in WJST. Such a hypothesis is in agreement with the studies that have reported eccentric-only (11,20) or enhanced eccentric training-induced (32) fascicle elongations. Indeed, as debated in the literature, it seems that eccentric exercise selectively affects fascicle length (1,11,20). Increments in fascicle length are reflective of serial sarcomere addition, which facilitates fastening in muscle contraction and larger range of movements (5). Consistently, combined jump/sprint training was able to induce *vastus lateralis* fascicle elongation, **in both distal and proximal sites by a *large* extent** (4). On the other hand, increases in pennation angle do not seem to be induced after enhanced eccentric training. The present data highlighted that only **BMSJT increased pennation angle, indicating that a greater eccentric work does not usually affect the in-parallel sarcomere number and consequent increases in pennation angle** (1,11,20). Similarly to the present study, increases in pennation angle were reported after **body mass jump** training (15).

On the contrary decreases in pennation angle occurred after combined jump/sprint training (4). Since inhomogeneous changes in *vastus lateralis* muscle architecture were reported (4,18), the lack of changes in WJST may have derived from the different sites on which the ultrasound scans were placed. Lastly, adaptations in muscle thickness can depend on adaptations in pennation angle, fascicle length, or both. The *small* and *moderate* increases (for WJST and **BMSJT**, respectively) in *vastus lateralis* muscle thickness are in contrast with previous studies that failed to show changes in muscle thickness after a **jump-squat training performed at the load that elicited optimum power (15)** or combined **body mass** jump/sprint training (4). One possible explanation for such an inconsistency may be the different populations involved. Both the above-mentioned studies recruited competitive athletes (4) or resistance-trained men (15), while the present population consisted of recreational soccer players. Given the greater training-induced effectiveness in structural muscle adaptations in untrained *vs* trained populations (22), it may be hypothesized that the current participants were more prone to muscle enlargements. **However, since the current increases in muscle thickness had *small* or *moderate* extent, it should be acknowledged that the traditional strength training could be more effective, as previously reported** (4,15). Aside, greater increases in **lower-limb** LM were found in WJST than in **BMSJT**, although both increments were *small*. Increases in muscle size were previously reported (4), and they were shown to be specifically related to type-IIx fibres (40). The present results agree with a previous study that reported greater hypertrophy after eccentric *vs* traditional training (13). On the contrary, no change in LM occurred in resistance-trained males (15), suggesting that the different initial fitness level may have led to different adaptations.

*Very large* improvements in agility T-test time occurred only in WJST, with no changes recorded in **BMSJT**. The present results are in line with a previous study reporting improvements in COD after jump-squat training with the optimum power load (27). Consistently, jump-squat training added to traditional strength training resulted in gains in COD, as previously reported (23).

COD requires the athletes to rapidly brake and immediately accelerate their body in different directions. The greater external load in WJST than in **BMSJT** may have conditioned the participants to effectively perform both decelerations and accelerations required by the intervention (27). The increased capacity to rapidly accelerate the body mass is a key-feature for sprint performance (39). The present results confirmed the effectiveness of WJST in improving sprint performance (15,39), as well as combined jump/sprint training (4) or strength/jump training (23). **Unloaded jumps** resulted in greater force at a given velocity within the force/velocity relationship (16). This may lead to argue that training with no external load may reduce transfer in power from training to performance. Such a transfer depends on the training intensity, frequency as well as specificity, as previously reported (15). In addition, it may be expected that recreational soccer players may be accustomed to both sprint and CODs (8). Therefore, the absence of further improvements in **BMSJT** may be explained by the insufficient stimuli received during the training. Lastly, the greater eccentric load that WJST underwent may have greatly accounted for the increases in concentric/eccentric tasks as **demanded in** COD and sprints, as previously shown (17). Notwithstanding the greater external load in WJST, greater increases in SJ and CMJ were recorded in **BMSJT**. The increases in jump height after **jump** training have been largely reported (4,15–17,30,39). However, the training-testing specificity may have played a key-role in the greater improvements in **BMSJT**, since both training and testing were performed without any external load**. In line with the current result, adding an eccentric overload exercise did not lead to any difference in jump height gained compared to traditional training in handball players** (33). In addition, it may be argued that **BMSJT** could have accustomed the participants to higher velocities developed during the vertical jumps, resulting in greater specific jumping adaptations (27).

To the best of the authors' knowledge, another novel aspect of the present investigation is the selective increment in functional $H_{ecc}$ to $Q_{conc}$ ratio in **BMSJT** but not in WJST.

The functional $H_{ecc}$ to $Q_{conc}$ ratio can be used to evaluate the hamstrings strain-injury risk, as the lower the ratio, the higher the risk (9). The different outcomes shown in **BMSJT** *vs* WJST are mainly due to the greater, albeit not different, increases in quadriceps concentric peak-torque in WJST than in **BMSJT**, with very similar increases in hamstrings eccentric peak-torque. It could be speculated that the loaded jumps led to greater trunk flexion in order to maximize the jump height (2). Thus, higher forwarded load may have differently stimulated **the** forward *vs* backward **lower-limb** muscles. The increases in squat 1-RM and quadriceps and hamstrings peak-torque come with previous inconsistent literature. Indeed, no improvement in squat 1-RM (15) or quadriceps concentric peak-torque (4) was observed after jump-squat training. Conversely, increases in half squat 1-RM (40) or in isometric maximal force (38) were previously reported. It can be argued that the current unaccustomed participants may have resulted in ***small*** **but significant** strength gains. Aside, the similar between-group adaptations in lower-limb muscles strength may derive from the similar total training load volume, as already shown (11,13). **Particularly, WJST resulted in overall greater but not significant increases in quadriceps strength, irrespective of the testing modality. In line with the present results, it was shown that volume-matched eccentric isoload vs isokinetic training resulted in similar knee-extensors strength gains (11). Interestingly, volume-matched but different training modalities resulted in similar increases in bench press 1-RM (13).**

The present investigation comes with some acknowledged limitations and some interesting perspectives. Firstly, the unaccustomed population may have been sensitive to the training-induced adaptations. Therefore, further accustomed populations should be included for a more comprehensive evaluation of the jump-squat training-induced adaptations. Secondly, the present investigation has been conducted off-season. This may permit to isolate its training-induced adaptations, but it should be tailored to the weekly training load when performed pre- or in-season.

Thirdly, only the traditional lower and upper bounds of the external load that maximizes power were here examined. Therefore, further loads in between could provide more insights on this topic. Lastly, power output was not measured during the training or during the SJ and CMJ. **The lack of the power measurement did not allow the correct use of the training load that elicits the maximum power.** However, the present investigation was designed to have a strong practical impact, **since the device necessary to measure power output is often unavailable in the field practice.**

In conclusion, specific training-induced adaptations were observed after **BMSJT** or WJST. Despite similar increases in *vastus lateralis* muscle thickness, greater increases in fascicle length occurred in WJST, while increases in pennation angle occurred only in **BMSJT**. In addition, greater increases in LM were shown in WJST than in **BMSJT**. Specific load-dependent performance improvements were shown, as COD and sprint performance improved only in WJST, while greater increases in jump height were observed in **BMSJT.** Such adaptations were accompanied by similar increases in quadriceps and hamstrings strength and by increases in functional $H_{ecc}$ to $Q_{conc}$ ratio in **BMSJT** but not in WJST.

## PRACTICAL APPLICATIONS

The present findings suggest that different external loads should be used to selectively improve COD, sprint or jump performance in recreational soccer players. Since the increased role of COD in soccer (8), trainers and conditioners may use WJST to improve such an ability. Similarly, the same training method may be recommended to improve sprints, while weight-free jump-squats should be proposed to improve jumping ability.

The functional $H_{ecc}$ to $Q_{conc}$ ratio is often monitored to reduce the hamstrings strain injury risk. Since it was seen to decrease with the advancement of a soccer match (9), specific training sessions should be dedicated to **reinforce hamstrings eccentric strength**.

Although specific exercises have been proposed (e.g., Nordic hamstrings) (6), it can be suggested here **that BMSJT could be included into a weekly routine, possible coupled with specific hamstrings lengthening exercises, since the *small* effect here reported.**

## REFERENCES

1. Baroni, BM, Geremia, JM, Rodrigues, R, De Azevedo Franke, R, Karamanidis, K, and Vaz, MA. Muscle architecture adaptations to knee extensor eccentric training: rectus femoris vs. vastus lateralis. *Muscle Nerve* 48: 498–506, 2013.
2. Blache, Y and Monteil, K. Effects of spine flexion and erector spinae maximal force on vertical squat jump height: a computational simulation study. *Sport Biomech* 14: 81–94, 2015.
3. Blazevich, AJ, Cannavan, D, Coleman, DR, and Horne, S. Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. *J Appl Physiol* 103: 1565–75, 2007.
4. Blazevich, AJ, Gill, ND, Bronks, R, and Newton, RU. Training-specific muscle architecture adaptation after 5-wk training in athletes. *Med Sci Sports Exerc* 35: 2013–22, 2003.
5. Blazevich, AJ, Gill, ND, and Zhou, S. Intra- and intermuscular variation in human quadriceps femoris architecture assessed in vivo. *J Anat* 209: 289–310, 2006.
6. Breno de A. R. Alvares, J, Marques, VB, Vaz, MA, and Baroni, BM. Four weeks of Nordic hamstring exercise reduce muscle injury risk factors in young adults. *J Strength Cond Res* 1, 2017.
7. Chaouachi, A, Manzi, V, Chaalali, A, Wong, DP, Chamari, K, and Castagna, C. Determinants analysis of change-of-direction ability in elite soccer players. *J Strength Cond Res* 26: 2667–76, 2012.
8. Coratella, G, Beato, M, and Schena, F. The specificity of the Loughborough Intermittent Shuttle Test for recreational soccer players is independent of their intermittent running

ability. *Res Sport Med* 24: 363–74, 2016.

9. Coratella, G, Bellin, G, Beato, M, and Schena, F. Fatigue affects peak joint torque angle in hamstrings but not in quadriceps. *J Sports Sci* 33: 1276–82, 2015.

10. Coratella, G, Bellini, V, and Schena, F. Shift of optimum angle after concentric-only exercise performed at long vs. short muscle length. *Sport Sci Health* 12: 85–90, 2016.

11. Coratella, G, Milanese, C, and Schena, F. Unilateral eccentric resistance training: a direct comparison between isokinetic and dynamic constant external resistance modalities. *Eur J Sport Sci* 15: 720–6, 2015.

12. Coratella, G, Milanese, C, and Schena, F. Cross-education effect after unilateral eccentric-only isokinetic vs dynamic constant external resistance training. *Sport Sci Health* 11: 329–335, 2015.

13. Coratella, G and Schena, F. Eccentric resistance training increases and retains maximal strength, muscle endurance and hypertrophy in trained men. *Appl Physiol Nutr Metab* 41: 1184–89, 2016.

14. Cormie, P, McCaulley, GO, and McBride, JM. Power versus strength-power jump squat training: influence on the load-power relationship. *Med Sci Sports Exerc* 39: 996–1003, 2007.

15. Cormie, P, McGuigan, MR, and Newton, RU. Adaptations in Athletic Performance after Ballistic Power versus Strength Training. *Med Sci Sport Exerc* 42: 1582–1598, 2010.

16. Cormie, P, McGuigan, MR, and Newton, RU. Influence of Strength on Magnitude and Mechanisms of Adaptation to Power Training. *Med Sci Sport Exerc* 42: 1566–1581, 2010.

17. Cormie, P, McGuigan, MR, and Newton, RU. Changes in the Eccentric Phase Contribute to Improved Stretch-Shorten Cycle Performance after Training. *Med Sci Sport Exerc* 42: 1731–1744, 2010.

18. Earp, JE, Newton, RU, Cormie, P, and Blazevich, AJ. Inhomogeneous quadriceps femoris hypertrophy in response to strength and power training. *Med Sci Sports Exerc* , 2015.

19. Finni, T, Komi, P V., and Lepola, V. In vivo human triceps surae and quadriceps femoris muscle function in a squat jump and counter movement jump. *Eur J Appl Physiol* 83: 416–426, 2000.

20. Franchi, M V, Atherton, PJ, Reeves, ND, Flück, M, Williams, J, Mitchell, WK, et al. Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. *Acta Physiol (Oxf)* 210: 642–54, 2014.

21. Giroux, C, Guilhem, G, Couturier, A, Chollet, D, and Rabita, G. Is muscle coordination affected by loading condition in ballistic movements? *J Electromyogr Kinesiol* 25: 69–76, 2015.

22. Häkkinen, K, Komi, P V, Alén, M, and Kauhanen, H. EMG, muscle fibre and force production characteristics during a 1 year training period in elite weight-lifters. *Eur J Appl Physiol Occup Physiol* 56: 419–27, 1987.

23. Hammami, M, Negra, Y, Shephard, RJ, and Chelly, MS. The effect of standard strength vs contrast strengt training on the development of sprint, agility repeated change of direction and jump in junior male soccer players. *J Strength Cond Res* 31: 901–912, 2017.

24. Hopkins, WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. *Sportscience* 11: 16–20, 2007.

25. Lamas, L, Ugrinowitsch, C, Rodacki, A, Pereira, G, Mattos, ECT, Kohn, AF, et al. Effects of Strength and Power Training on Neuromuscular Adaptations and Jumping Movement Pattern and Performance. *J Strength Cond Res* 26: 3335–3344, 2012.

26. Loturco, I, Nakamura, FY, Kobal, R, Gil, S, Pivetti, B, Pereira, LA, et al. Traditional Periodization versus Optimum Training Load Applied to Soccer Players: Effects on Neuromuscular Abilities. *Int J Sports Med* 37: 1051–1059, 2016.

27. Loturco, I, Pereira, LA, Kobal, R, Maldonado, T, Piazzi, AF, Bottino, A, et al. Improving sprint performance in soccer: Effectiveness of jump squat and olympic push press exercises. *PLoS One* 11: 1–12, 2016.

28. Loturco, I, Pereira, LA, Kobal, R, Zanetti, V, Gil, S, Kitamura, K, et al. Half-squat or jump squat training under optimum power load conditions to counteract power and speed decrements in Brazilian elite soccer players during the preseason. *J Sports Sci* 33: 1283–1292, 2015.

29. Loturco, I, Pereira, LA, Zanetti, V, Kitamura, K, Cal Abad, CC, Kobal, R, et al. Mechanical differences between barbell and body optimum power loads in the jump squat exercise. *J Hum Kinet* 54: 153–162, 2016.

30. McBride, JM, Triplett-McBride, T, Davie, A, and Newton, RU. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res* 16: 75–82, 2002.

31. Padulo, J, Tiloca, A, Powell, D, Granatelli, G, Bianco, A, and Paoli, A. EMG amplitude of the biceps femoris during jumping compared to landing movements. *Springerplus* 2: 520, 2013.

32. Reeves, ND, Maganaris, CN, Longo, S, and Narici, M V. Differential adaptations to eccentric versus conventional resistance training in older humans. *Exp Physiol* 94: 825–33, 2009.

33. Sabido, R, Hernández-Davó, JL, Botella, J, Navarro, A, and Tous-Fajardo, J. Effects of adding a weekly eccentric-overload training session on strength and athletic performance in team-handball players. *Eur J Sport Sci* 17: 530–538, 2017.

34. Skalsky, AJ, Han, JJ, Abresch, RT, Shin, CS, and McDonald, CM. Assessment of regional body composition with dual-energy X-ray absorptiometry in Duchenne muscular dystrophy: correlation of regional lean mass and quantitative strength. *Muscle Nerve* 39: 647–51, 2009.

35. Spineti, J, Figueiredo, T, Bastos DE Oliveira, V, Assis, M, Fernandes DE Oliveira, L, Miranda, H, et al. Comparison between traditional strength training and complex contrast training on repeated sprint ability and muscle architecture in elite soccer players. *J Sports Med Phys Fitness* 56: 1269–1278, 2016.

36. Stasinaki, A, Gloumis, G, Spengos, K, Blazevich, A, Zaras, N, Georgiadis, G, et al. Muscle Strength,Power, and Morphologic Adaptations After 6Weeks of Compound Vs. Complex Training in Healthy Men. *J Strength Cond Res* 29: 2559–2569, 2015.

37. Tavakol, M and Dennick, R. Making sense of Cronbach's alpha. *Int J Med Educ* 2: 53–55, 2011.

38. Vanderka, M, Longova, K, Olasz, O, Krčmár, M, and Walker, M. Improved Maximum Strength, Vertical Jump and Sprint Performance after 8 Weeks of Jump Squat Training with Individualized Loads. *J Sports Sci Med* 15: 492–500, 2016.

39. Wilson, GJ, Newton, RU, Murphy, AJ, and Humpries, BJ. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 25: 1279–1286, 1993.

40. Zaras, N, Spengos, K, Methenitis, S, Papadopoulos, C, Karampatsos, G, Georgiadis, G, et al. Effects of strength vs. Ballistic-power training on throwing performance. *J Sport Sci Med* 12: 130–137, 2013.

Table 1: Mean values (SD) of quadriceps' muscle architecture and lower-limbs fat-free mass pre- and post- training are shown. Changes (%) and effect size are reported with confidence interval (CI95%).

| | **Pre: Mean (SD)** | **Post: Mean (SD)** | **Change (%) (CI95%)** | **Effect size (CI95%)** |
|---|---|---|---|---|
| **Muscle thickness (mm)** | | | | |
| **BMSJT** | 24.9(3.4) | 28.0(3.6) | 12 (7 to 18) | 0.89 (0.53 to 1.25) |
| WJST | 23.7(3.8) | 25.6(2.6) | 8 (3 to 14) | 0.45 (0.12 to 0.79) |
| CON | 25.5(3.2) | 26.1(3.8) | 2 (-5 to 7) | 0.14 (-0.02 to 0.26) |
| **Pennation angle (°)** | | | | |
| **BMSJT** | 14.5(2.7) | 17.7(3.5) | 18 (10 to 26) # | 1.03 (0.78 to 1.29) |
| WJST | 15.2(3.3) | 16.1(3.5) | 6 (-2 to 14) | 0.26 (-0.10 to 0.62) |
| CON | 14.1(2.2) | 14.3(3.6) | 1 (-7 to 9) | 0.06 (-0.25 to 0.37) |
| **Fascicle length (mm)** | | | | |
| **BMSJT** | 94(10) | 100(12) | 6 (1 to 11) | 0.54 (0.40 to 0.68) |
| WJST | 95(12) | 108(10) | 10 (4 to 16) * | 1.18 (0.82 to 1.54) |
| CON | 98(15) | 100(14) | 2 (-5 to 9) | 0.14 (-0.10 to 0.34) |
| **Fat-free mass (Kg)** | | | | |
| **BMSJT** | 21.6(2.2) | 22.1(2.1) | 2 (4 to 6) | 0.21 (0.07 to 0.37) |
| WJST | 21.1(2.3) | 22.2(2.3) | 5 (3 to 7) * | 0.44 (0.29 to 0.59) |
| CON | 22.2(2.2) | 22.1(2.0) | 0 (-2 to 2) | -0.01 (-0.10 to 0.10) |

**BMSJT**: body mass squat jump training; WJST: weighted jump-squat training.
* : greater than **BMSJT**; # : greater than WJST

Table 2: Mean values (SD) of performances in COD, sprinting and jumping pre- and post-training are shown. Changes (%) and effect size are reported with confidence interval (CI95%).

| | **Pre: Mean (SD)** | **Post: Mean (SD)** | **Change (%) (CI95%)** | **Effect size (CI95%)** |
|---|---|---|---|---|
| **Agility T-test (s)** | | | | |
| **BMSJT** | 15.2(0.9) | 15.2(0.8) | 0 (-2 to 2) | -0.04 (-0.28 to 0.20) |
| WJST | 15.4(0.5) | 13.9(0.5) | -10 (-12 to -7) * | -2.95 (-3.18 to -2.72) |
| CON | 15.4(0.9) | 15.5(0.6) | 1 (-1 to 3) | 0.16 (-0.09 to 0.41) |
| **10 m sprint (s)** | | | | |
| **BMSJT** | 1.9(0.1) | 1.9(0.1) | 0 (-3 to 3) | 0.10 (-0.30 to 0.40) |
| WJST | 2.0(0.2) | 1.8(0.2) | -5 (-8 to -2) * | -0.52 (-0.82 to 0.22) |
| CON | 1.8(0.1) | 1.9(0.1) | 2 (-1 to 5) | 0.04 (-0.30 to 0.39) |
| **30 m sprint (s)** | | | | |
| **BMSJT** | 4.4(0.2) | 4.4(0.2) | -2 (-10 to 8) | -0.06 (-0.33 to 0.43) |
| WJST | 4.6(0.2) | 4.4(0.2) | -6 (-9 to -3) * | -0.52 (-0.81 to -0.23) |
| CON | 4.5(0.2) | 4.5(0.2) | -1 (-8 to 6) | -0.04 (-0.30 to 0.39) |
| **SJ (cm)** | | | | |
| **BMSJT** | 38.8(3.3) | 41.8(5.0) | 8 (4 to 13) # | 0.89 (0.43 to 1.35) |
| WJST | 38.6(5.7) | 40.4(4.9) | 5 (0 to 9) | 0.30 (0.03 to 0.58) |
| CON | 39.2(5.6) | 39.5(5.0) | 0 (-4 to 5) | 0.02 (-0.27 to 0.31) |
| **CMJ (cm)** | | | | |
| **BMSJT** | 40.8(6.9) | 44.6(6.2) | 10 (6 to 14) # | 0.55 (0.37 to 0.73) |
| WJST | 40.4(6.4) | 42.2(6.6) | 5 (1 to 9) | 0.28 (0.08 to 0.48) |
| CON | 40.5(4.7) | 41.1(5.1) | 1 (-2 to 5) | 0.10 (-0.18 to 0.38) |

**BMSJT**: body mass squat jump training; WJST: weighted jump-squat training.
SJ: Squat jump; CMJ: counter-movement jump.
* : greater than **BMSJT**; # : greater than WJST

Table 3: Mean values (SD) of quadriceps’ and hamstrings’ strength pre- and post-training are shown. Changes (%) and effect size are reported with confidence interval (CI95%).

| | **Pre: Mean (SD)** | **Post: Mean (SD)** | **Change (%) (CI95%)** | **Effect size (CI95%)** |
|---|---|---|---|---|
| **Squat 1-RM (Kg·BM$^{1}$)** | | | | |
| **BMSJT** | 1.21(0.20) | 1.30(0.22) | 7 (2 to 12) | 0.40 (0.15 to 0.75) |
| WJST | 1.18(0.14) | 1.33(0.21) | 13 (6 to 20) | 0.73 (0.34 to 1.07) |
| CON | 1.19(0.23) | 1.21(0.23) | 1 (-10 to 12) | 0.05 (-0.20 to 0.30) |
| **Quadriceps CPT (N·m)** | | | | |
| **BMSJT** | 226(39) | 249(41) | 10 (5 to 15) | 0.58(0.30 to 0.85) |
| WJST | 214(34) | 248(37) | 16 (10 to 22) | 0.97(0.65 to 1.29) |
| CON | 223(40) | 222(41) | 0 (-9 to 10) | -0.01(-0.13 to 0.12) |
| **Quadriceps EPT (N·m)** | | | | |
| **BMSJT** | 284(45) | 324(41) | 15 (9 to 21) | 0.88 (0.49 to 1.26) |
| WJST | 274(46) | 341(65) | 24 (18 to 31) | 1.46 (1.07 to 1.89) |
| CON | 295(60) | 300(67) | 2 (-11 to 13) | 0.05 (-0.15 to 0.25) |
| **Hamstrings EPT (N·m)** | | | | |
| **BMSJT** | 195(35) | 230(46) | 17 (10 to 24) | 0.98 (0.65 to 1.31) |
| WJST | 190(29) | 220(34) | 15 (9 to 21) | 0.94 (0.60 to 1.28) |
| CON | 199(38) | 204(43) | 2 (-4 to 8) | 0.08 (-0.10 to 0.26) |
| **Functional Ratio (A.U.)** | | | | |
| **BMSJT** | 0.86(0.12) | 0.92(0.14) | 7 (4 to 10) # | 0.51 (0.32 to 0.70) |
| WJST | 0.88(0.13) | 0.88(0.15) | 1 (-5 to 7) | 0.08 (-0.43 to 0.64) |
| CON | 0.89(0.12) | 0.91(0.14) | 3 (-6 to 11) | 0.24 (-0.10 to 0.48) |

**BMSJT**: body mass squat jump training; WJST: weighted jump-squat training.
BM: body mass; CPT: concentric peak-torque; EPT: eccentric peak-torque.
#: greater than WJST